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Fruit Bearing Behavior of 4 Legumes Cultivated under Shaded Conditions

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Abstract

Fruit bearing behavior of 4 legume crops, soybean, mungbean, cowpea and lima bean, was observed under various light conditions. Response to shading varied among the species. In the 4 legumes, the dry weight of reproductive organs decreased with shading, but the declining pattern and the reproductive allocation varied with the species. In all the species, the dry weight of each sound bean remained almost constant irrespective of light conditions. Throughout the development from flower to fruit, a larger number of flower buds and immature pods underwent abortion under shade conditions than light conditions. Mungbeans and cowpeas, which bear long pods with many ovules, regulated the production of the number of sound beans by reducing the seed set in a pod as well as by reducing the fruit set. On the other hand, soybean and lima bean, which bear short pods with few ovules, responded mostly by reducing the fruit set. The regulating pattern of sound bean production by the suppressed legumes was directly related to the pod structure of the species.

Discipline: Crop production
Additional key words: intercropping, abortion, fruit set, seed set, resource limitation

Introduction

Intercropping is an effective way to utilize strong solar irradiation in tropical environments. However, in suppressed plants, decrease of dry matter production and changes of allocation to reproductive organs[3,8] can often be critical to yield.

We observed that the adaptability of mungbean (*Vigna radiata* L.) to shade conditions was higher than that of maize (*Zea mays* L.) during a previous study in which both species were grown under a stand of shelter trees[5]. When maize was suppressed, material investment to all kernels decreased and sound kernels could not be produced. In contrast, mungbean was able to produce a few sound beans.

It is generally recognized among wild plants that the weight of disseminants increases but the number decreases as they develop from flowers to mature fruits[2,11,13]. Flowers and immature fruits are aborted because of resource limitation[7,11] as well as due to other biotic and abiotic factors[11]. Abortion seems to play a role in the distribution of the limited resources from mother plant to disseminants effectively. We consider that mungbean may exhibit such adaptation to shading in reproduction.

This aspect suggests that the species specificity of reproductive characteristics under shading should

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This paper reports the results obtained in the collaborative studies on the "Rehabilitation of Degraded Forest Lands through the Implementation of Agroforestry Systems" between the Tropical Agriculture Research Center, Japan and the College of Forestry, University of the Philippines at Los Baños, the Philippines, during the period of November 1991 to April 1992.

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be analyzed for each crop to develop intercropping techniques for agroforestry systems. We summarized the issues in raising 2 questions. 1) Is the interspecific variation in reproductive behavior under shading, which is observed between maize and mungbean, recognized among taxonomically close species? 2) How does the reproductive behavior of suppressed crops vary? We grew several legumes under various light conditions to address these issues.

Materials

Four legumes commonly cultivated in the Philippines were used for the experiment: soybean (*Glycine max* (L.) Merrill), mungbean (*Vigna radiata*), cowpea (*Vigna unguiculata* (L.) subsp. *cylindrica* (L.)) and lima bean (*Phaseolus lunata* L. var. *macrocarpus* Benth). Cowpea and lima bean that we used were liana. Soybean and lima bean bear short pods usually with 2 to 3 beans, while others have longer pods which contain more than 10 beans.

Experimental site

The experiment was carried out at Bayog agroforestry experimental site. The site conditions were described in detail in the previous report[5]. We selected 3 blocks at the experimental site for 3 treatments differing in light conditions at ground level. Stand structure of shelter trees and light conditions at ground level are presented in Table 1. Relative light illuminance (RLI) at ground level was measured by using Minolta T-1M illuminance meters. The heavily shaded treatment was the same as that used in the 24.9% RLI treatment described in the previous experiment[5], but the RLI was lower than that measured during the previous study due to the sequential growth of the shelter trees.

Methods

The 4 legume species were hill-seeded in randomly arranged 2 replicated rows in each treatment in November 1991. A compound fertilizer consisting of N, P_2O_5, and K_2O at the rate of 20 kg ha^{-1} was applied to each treatment before sowing. Throughout the experimental period, water sprinkling and weeding were carried out by hand when necessary.

A total of 100 individuals (50 individuals × rows) were selected and tagged for each species in each treatment. In March 1992, after 4 months of sowing, surviving individuals were dug up with their roots carefully. For each individual, stem length and diameter at base were measured, and their components were weighed after oven-drying for 48 h at 80°C.

The survival rate was analyzed by using 2-Way ANOVA and chi-square test. On the other hand, changes in the dry weight and the dry weight allocation within each species were analyzed by 1-Way ANOVA and t-test. To apply 1-Way ANOVA, 10 to 16 individuals were randomly sampled from the survivors among the tagged individuals for each species in each treatment. Additional individuals were sampled from untagged individuals in the same treatment, in case less than 10 individuals of the species survived during the treatment.

Fifteen to 50 sound beans were randomly sampled from mature pods of each species in each treatment for determining the dry weight.

To monitor the dynamics and the development from flower bud to pod, 20 individuals were randomly chosen from each species in each treatment. For those individuals, all the flower buds were marked in November 1991. The survival rate and the development stages were monitored weekly up to March 1992, 4 months after sowing. The survival rate was represented by the ratio of the surviving flower buds, flowers and pods to the number of initially marked buds. The number of sound beans contained in each pod was counted at the end of the monitoring period in March 1992.

Table 1. Site conditions

Treatment	Relative light illuminance (%)	Shelter tree	
		Species	Total basal area (m^2)
Open field	100	–	–
Medium shading	34	*Gmelina arborea*	24.7
Strong shading	14	*Acacia auriculiformis, Pterocarpus indicus, Albizia procera, Eucalyptus camaldulensis*	13.0

Results

1) *Survival, biomass, and allocation under various light conditions*

The survival rate at 4 months after sowing showed a significant difference (P<0.001, ANOVA) among the treatments with various RLIs as well as species (Tables 2 and 3). In mungbeans and cowpeas, the survival rates decreased markedly with shading, while the decrease was less pronounced in soybeans. Lima beans were unaffected.

Table 2. Survival under different light conditions 4 months after sowing

Species	Individuals which survived		
	Open field	Medium shading	Strong shading
Lima bean	94 [a]	95 [a]	91 [a]
Soybean	97 [a]	86 [b]	37 [c]
Mungbean	96 [a]	58 [b]	8 [c]
Cowpea	97 [a]	71 [b]	2 [c]

Values denoted by the same letter are not significantly different from each other at P<0.05 (χ^2-test) within each species. 100 individuals were planted for each species in each treatment.

Table 3. Results of 2-way ANOVA for survival rate of 4 legumes under different light conditions

Source of variation	df	F	P
Species	3	36.35	2.7×10^{-6}
Treatment	2	146.59	3.7×10^{-9}
Species × treatment	6	17.19	3.0×10^{-5}
Error	12		

The individual dry weight at 4 months was significantly different (P<0.001, ANOVA) among the treatments within each species (Tables 4 and 5). In mungbeans and cowpeas, the averaged individual dry weight decreased more than in lima beans and soybeans when they were suppressed. The dry weight of reproductive organs showed a similar tendency to the individual dry weight. Each species showed a significant difference (P≦0.01, ANOVA) among the treatments. In mungbeans and cowpeas, the dry weight of the reproductive organs decreased more than in lima beans and soybeans (Tables 4 and 5).

The reproductive allocation in mungbeans and cowpeas also decreased with shading (Tables 4 and 5). On the other hand, it was constant among the treatments for soybeans and lima beans, whose growth appeared to be relatively indifferent to shading.

In all the species, averaged dry weight of beans retained in the pods up to the harvest, 4 months after sowing, did not vary appreciably throughout the treatments under different light conditions (Table 6).

Table 4. Dry weights and reproductive allocation

Species	Dry weight of individuals (g)			Dry weight of reproductive organs (g)			Reproductive allocation (%)		
	Open field	Medium shading	Strong shading	Open field	Medium shading	Strong shading	Open field	Medium shading	Strong shading
Lima bean	11.53 ± 7.00 [a]	3.21 ± 0.86 [b]	3.63 ± 1.35 [b]	4.19 ± 3.09 [a]	1.89 ± 0.59 [b]	1.92 ± 0.96 [b]	34.5 ± 20.1 [a]	55.9 ± 7.3 [b]	50.9 ± 10.8 [b]
Soybean	2.13 ± 1.56 [a]	0.72 ± 0.34 [b]	0.78 ± 0.36 [b]	1.42 ± 1.10 [a]	0.34 ± 0.26 [b]	0.48 ± 0.22 [b]	62.1 ± 10.7 [a]	44.2 ± 14.7 [b]	62.1 ± 4.9 [a]
Mungbean	3.89 ± 2.74 [a]	0.27 ± 0.14 [b]	0.21 ± 0.11 [b]	1.81 ± 0.14 [a]	0.11 ± 0.12 [b]	0.01 ± 0.03 [c]	44.0 ± 13.5 [a]	31.8 ± 23.8 [a]	4.6 ± 12.2 [b]
Cowpea	12.84 ± 6.90 [a]	1.29 ± 1.06 [b]	0.64 ± 0.24 [b]	7.09 ± 3.07 [a]	0.48 ± 0.64 [b]	0.16 ± 0.15 [b]	58.2 ± 10.4 [a]	31.4 ± 18.3 [b]	23.8 ± 19.3 [b]

Values are M. ± 1 S.D.
Values denoted by the same letter are not significantly different from each other at P<0.05 (t-test) within each species.

Table 5. Results of 1-way ANOVA for dry weight and reproductive allocation under different light conditions within each species

Species	Dry weight of individuals			Dry weight of reproductive organs			Reproductive allocation		
	df	F	P	df	F	P	df	F	P
Lima bean	2	20.40	5.0×10^{-7}	2	8.04	1.0×10^{-3}	2	10.49	1.8×10^{-4}
Soybean	2	11.42	9.7×10^{-5}	2	12.44	5.0×10^{-5}	2	14.47	1.4×10^{-5}
Mungbean	2	17.66	1.2×10^{-5}	2	14.66	4.9×10^{-5}	2	13.64	8.0×10^{-5}
Cowpea	2	28.97	1.9×10^{-7}	2	46.75	1.7×10^{-9}	2	12.01	1.8×10^{-4}

Table 6. Dry weight of sound beans

Species	Dry weight of sound beans (g)		
	Open field	Medium shading	Strong shading
Lima bean	0.44 ± 0.05	0.41 ± 0.06	0.42 ± 0.12
Soybean	0.15 ± 0.03	0.14 ± 0.03	0.14 ± 0.04
Mungbean	0.044 ± 0.012	0.044 ± 0.008	0.040 ± 0.010
Cowpea	0.045 ± 0.006	0.042 ± 0.010	0.041 ± 0.011

Values are M. ± 1 S.D. of sample beans.
No significant difference is found among treatments within each species (*t*-test).

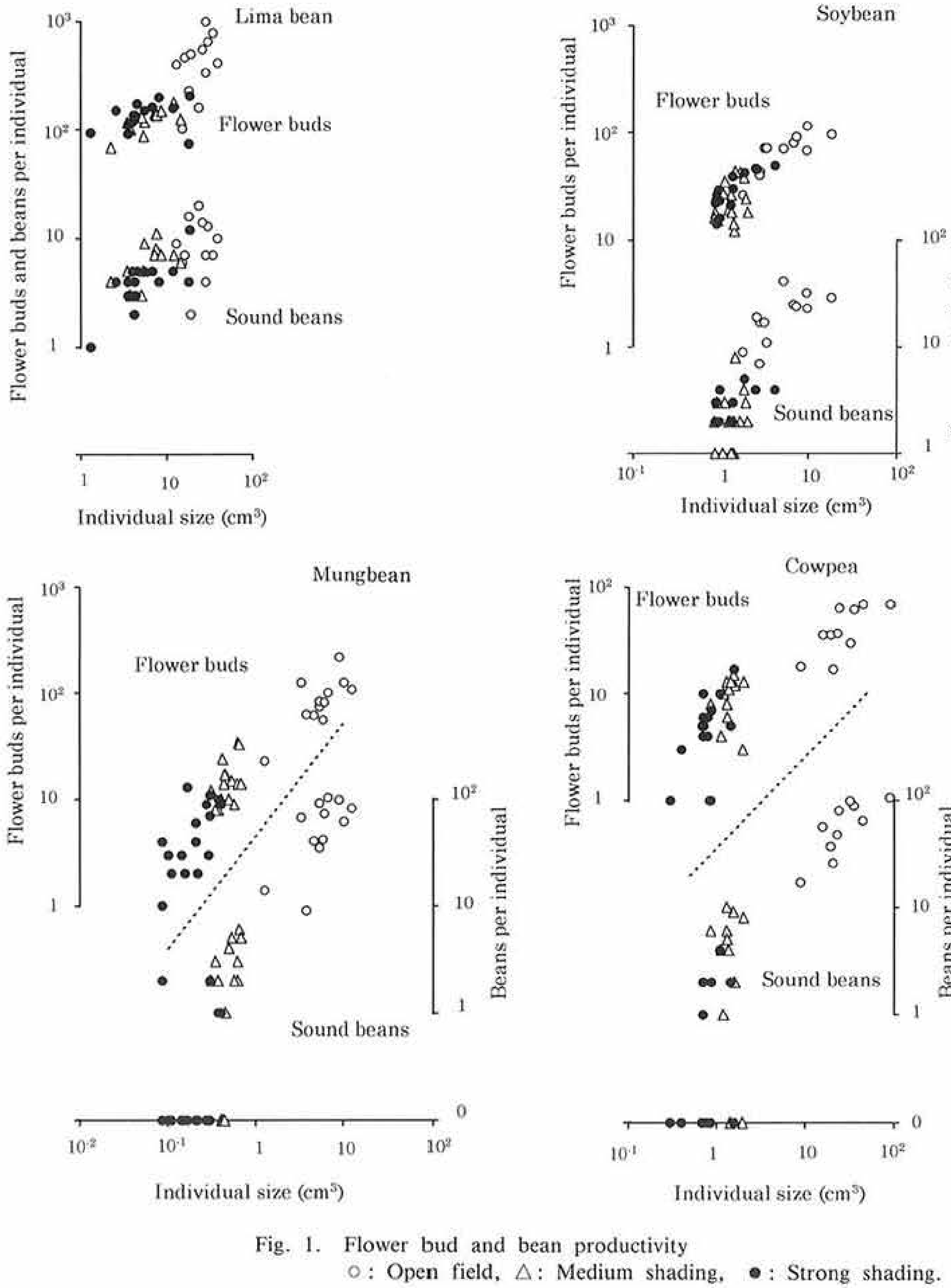

Fig. 1. Flower bud and bean productivity
○: Open field, △: Medium shading, ●: Strong shading.

2) *Flower bud and pod production per individual under various light conditions*

The number of flower buds and mature pods of each individual was compared to the size of the individual to determine whether the individual productivity of reproductive organs changed depending on the treatments (Fig. 1). Individuals which grew in the dark were small and had few flower buds and pods in all species. In each species, the number of flower buds and pods decreased in proportion to the decrease of the individual size, and the relationships did not vary among the treatments.

On a log-log scale, lima beans showed a positive linear relation between the individual size and the number of flower buds or mature pods. On the other hand, for 3 legumes, the relationships between these parameters were not linear, and there was a downward bend for smaller individual size. As the individual size decreased, the number of mature pods decreased more than the number of flower buds. Critical individual size under which no pods were produced was recognized in mungbeans and cowpeas under strong shade conditions.

3) *Flower and pod survival in relation to development*

The survival rates of the flowers and the pods decreased as they developed (Fig. 2). The survival rates markedly decreased at 2 stages in all species; the first occurring in the transition from undeveloped flower bud stage to flower bud initiation stage, and the second in the transition from the flower stage to the pod initiation stage. The decreases preceded

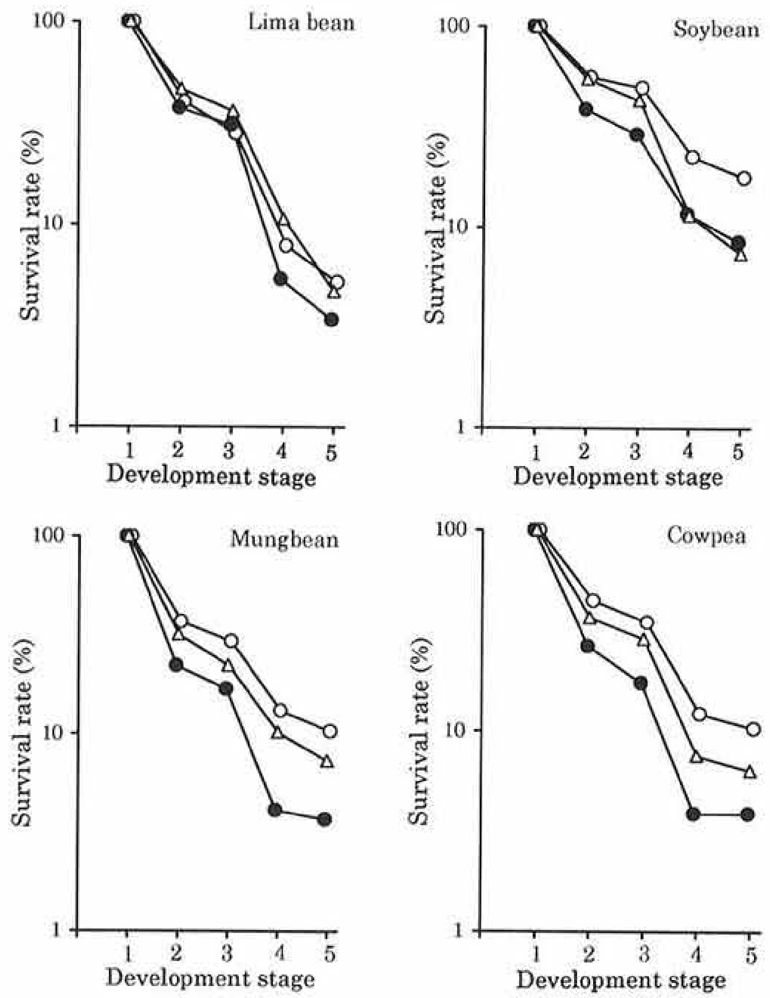

Fig. 2. Flower and pod survival at each development stage
Stage: 1; Dormant buds, 2; Bud initiation stage, 3; Flowering, 4; Pod initiation stage, 5; Mature pods.
○ : Open field, △ : Medium shading, ● : Strong shading.

Table 7. Sound bean number per pod

Species	Number of sound beans per pod		
	Open field	Medium shading	Strong shading
Lima bean	2.0 ± 0.3^{a}	$1.7 \pm 0.4^{a,b}$	1.5 ± 0.4^{b}
Soybean	1.9 ± 0.2^{a}	1.5 ± 0.5^{b}	1.5 ± 0.6^{b}
Mungbean	7.2 ± 1.3^{a}	2.6 ± 1.4^{b}	1.3 ± 0.5^{c}
Cowpea	11.2 ± 2.1^{a}	5.1 ± 2.7^{b}	2.9 ± 2.0^{c}

Values are M. ± 1 S.D.
Values denoted by the same letter are not significantly different from each other at $P<0.05$ (t-test within each species).

material translocation from plants for developing flower buds and pods as described for the fruit development of various species[1,9,14].

Fruit sets generally decreased with shading except for lima beans in which the fruit set was more constant regardless of the light conditions.

4) Seed set in pods under various light conditions

The number of sound beans per pod is shown in Table 7. Seed sets were relatively constant regardless of the treatments for lima beans and soybeans which bear short pods with few, usually 2 or 3, beans. In contrast, seed sets decreased considerably with shading for mungbeans and cowpeas which bear long pods with many beans.

Discussion

1) Fruit bearing behavior of 4 legumes under various light conditions

The 4 legumes we studied showed heterogeneous characteristics not only for vegetative growth but also for reproduction in response to shading. Except for lima beans, the legumes showed a common trend in which they invested less to reproductive organs under suppressed conditions[3,8]. However, the pattern and degree of decrease varied among the species.

Each individual produced fewer seeds when it was suppressed. Furthermore, the number of small-sized sterile individuals increased under strong shading, suggesting the existence of a minimum requirement for irradiation to set seed[6].

Seed production declined more than flower bud production for all 4 legumes indicating the stronger influence of shading during the fruitlet development stage[4]. Numerous pods aborted resulting in a decrease in the fruit set among the suppressed legumes. The low fruit set under shading suggests that limitation in the resources restricts the reproduction.

2) Utilization of limited resources

The 4 legumes appeared to produce few but sound beans in order to maintain their reproductive potential under adverse conditions. In most of the legumes, material investment to reproductive organs decreased under shading, but the weight of each sound bean remained constant under the different light conditions. These findings are in agreement with our previous study on mungbeans[5]. Under shading, the legumes saved their resources by shedding excess flower buds and immature beans, and filled few sound beans. If the limited resources were distributed to all beans, a large number of reproductively imperfect beans would be produced. Moreover, shedding occurred prior to material translocation to flower buds and pods to minimize the waste in investment. We consider that the legumes utilized flower and fruit abortion as an effective measure to secure a regeneration potential with limited resources[7,11].

The adjustment of seed numbers to limited resources occurs at various levels of reproduction depending on the environmental conditions and species[10,12]. Mungbeans and cowpeas, which bear long pods with many ovules, regulated bean production by reducing the seed set in a pod as well as by reducing the fruit set by shedding excess flower buds and pods. On the other hand, soybeans, which bear short pods with few ovules, regulated bean production mostly by limiting the fruit set. The seed regulation pattern of the legumes seems to be related to the specific fruit structure.

Thus, the 4 legumes showed a difference in the reproductive behavior under shading. Therefore, it is necessary to analyze these specific reactions to shading stress, and take them into account for the introduction of crops into agroforestry systems and for obtaining adequate yield.

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