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Allometric Studies in Mungbean (*Vigna radiata* (L.) Wilczek): Effects of Population Density and Planting Configuration

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Abstract: A field experiment was conducted to determine the influence of population density and planting configuration on allometric relationships in Mungbean. The experiment was conducted with six levels of population densities (10, 20, 30, 40, 50 and 60 plants m^{-2}) each at three levels of configuration (1:1, 1:2.5 and 1:5 rectangularity). Accumulation and distribution of dry matter to different components of plants were determined. Allometric relationships between stem weight and leaf weight were developed from their respective dry weights. Stem materials per unit leaf weight increased over growth stages. Reproduction enhanced dry matter allocation into stem per unit leaf weight. The magnitude of increase varied greatly with planting density. The ratio of stem weight per leaf weight and leaf weight were linearly correlated. Planting configuration had little effect on the allometric relationship.

Key words: Mungbean, density, configuration, dry matter, reproduction, allometry

INTRODUCTION

All autotrophic plant species have a requirement for the same set of resources for survival and growth. This includes light, water, carbon dioxide and a range of elements usually obtained from the soil. Despite these fundamental similarities plants show a tremendous diversity in form[1]. Even within each life-form group, such as pulses, there is much variation, not just between species but frequently also between populations of the same species growing under different conditions. The concept of form being governed by a whole series of evolutionary trade-offs between relative allocation of resources to different structures and physiological activities has become widely accepted in recent years[2].

The growth and development of organisms ordinarily involves progressive changes in form. Such changes are often coordinated and related with the quantitative relationships among the organs of the plant. 'Allometry'- the quantitative relationship exists among different features of an organism as growth proceeds. It is often considered in terms of growth relationship which exists between one part of an organism and the whole. The evolution of allometry can help understand structural and functional relationships between different levels of organization[3] and also summarizes the development pattern of a particular population[1]. Many experimental treatments are known to affect plant form and some studies have specifically examined allometric responses to treatments[4-7]. Various mathematical expressions are used for the interpretation of allometric relationship. The most commonly used mathematical model to describe the allometric relationship is a simple power function

$$y = \alpha x^{\beta}$$

or alternatively,

$$\log_e y = \log_e \alpha + \beta \log_e x$$

Many agronomic[8,9] and physical factors[10] are reported to have influence on plant form. However, experimental evidences of such effect on the allometric relationships are rare[4,5]. One probable reason for the absence of the analysis of the influence of management factors on allometric relationships to the usual difficulty in simulating experimental treatments and inadequacy of appropriate method of assessing the allometric relations.

Quantitative descriptions of the relation between biomass and plant size provide useful rules to estimate the allocation of resources to reproduction, mechanical and other functions[11]. General allometric relationships for this purpose are available for tree species[10,12-14] but comparable descriptions for crop plants are lacking or scanty.

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Mungbean (*Vigna radiata* (L.) Wilczek) is an important grain legume in tropical and subtropical countries[15-17]. The mungbean plant is an annual herb[18]. Moreover rapid senescence does not occur in mungbean[19]. Due to its rapid growth, early maturity[20] and lack of senescence mungbean can be an important crop for allometric studies. The present study was designed to examine the effect of population density and planting arrangement on the allometric relationships in mungbean plant.

MATERIALS AND METHODS

A field experiment was conducted at the Bangabandhu Seikh Mujibur Rahman Agricultural University farm during early summer (Kharif I) season. The soil of the experimental plot was silty clay of red brown terrace under Salna series. The pH of the soil was 6.5[21]. The experimental site is characterized by hot-humid subtropical climate with abundant rainfall during monsoon season extending from May through September while the remaining part of the year evaporative demand exceeds rainfall[22]. The mean atmospheric temperature ranges from 11.9°C (January) to 34.4°C (July).

The experimental land was ploughed by a tractor and rotovator. A fertilizer dose of 20 kg N, 15 kg P and 20 kg K ha^{-1} as urea, TSP and MP, respectively, was applied basally at final land preparation and incorporated well into the soil. Six levels of planting densities each at three levels of configuration formed the treatment variables. Different configurations were created by varying the rectangularity keeping the density constant. The treatment combinations were arranged as follows:

D_1: 10 plants m^{-2} i.e. 1000 cm^2 $plant^{-1}$
- D_1C_1: 31.50 x 31.50 cm (1:1)
- D_1C_2: 20.00 x 50.00 cm (1:2.5)
- D_1C_3: 15.00 x 66.50 cm (1: 5)

D_2: 20 plants m^{-2} i.e. 500 cm^2 $plant^{-1}$
- D_2C_1: 22.50 x 22.50 cm (1:1)
- D_2C_2: 14.00 x 35.50 cm (1:2.5)
- D_2C_3: 10.00 x 50.00 cm (1: 5)

D_3: 30 plants m^{-2} i.e. 333 cm^2 $plant^{-1}$
- D_3C_1: 18.25 x 18.25 cm (1:1)
- D_3C_2: 11.50 x 28.25 cm (1:2.5)
- D_3C_3: 8.00 x 41.52 cm (1: 5)

D_4: 40 plants m^{-2} i.e. 250 cm^2 $plant^{-1}$
- D_4C_1: 15.81 x 15.81 cm (1:1)
- D_4C_2: 10.00 x 25.00 cm (1:2.5)
- D_4C_3: 7.00 x 35.71 cm (1: 5)

D_5: 50 plants m^{-2} i.e. 200 cm^2 $plant^{-1}$
- D_5C_1: 14.14 x 14.14 cm (1:1)
- D_5C_2: 9.00 x 22.22 cm (1:2.5)
- D_5C_3: 6.25 x 32.00 cm (1: 5)

D_6: 60 plants m^{-2} i.e. 167 cm^2 $plant^{-1}$
- D_6C_1: 12.90 x 12.90 cm (1:1)
- D_6C_2: 8.00 x 20.87 cm (1:2.5)
- D_6C_3: 5.80 x 28.80 cm (1: 5)

The experiment was laid out in a Factorial Randomized Complete Block Design with three replications. Unit plot size was 4x3 m. Seeds were sown in rows as per treatment. Seeds were pre-soaked for 3 h before sowing. Light irrigation was applied one day after sowing. The variety used in this study was NM 92, an advanced line obtained from the Asian Vegetable Research and Development Center (AVRDC), Taiwan. Seedlings emerged by 4 days after sowing and gap filling was done using even aged seedlings on the following day of emergence (DAE). At first trifoliate stage

Table 1: Allometric relationship between leaf dry weight (g) and stem dry weight (g) of mungbean at successive sampling dates for different density treatments

Density (Plants m^{-2})	Sampling at (DAE)	Leaf dry weight (g)	Stem dry weight (g)
10	12	0.27	0.07
	19	0.94	0.29
	26	2.84	1.14
	33	4.12	2.81
	40	5.34	3.63
	47	3.09	3.35
20	12	0.24	0.07
	19	0.87	0.26
	26	2.52	0.95
	33	4.02	2.70
	40	4.77	3.45
	47	2.97	3.14
30	12	0.20	0.07
	19	0.75	0.25
	26	2.35	0.93
	33	3.09	2.25
	40	3.80	2.92
	47	2.61	2.72
40	12	0.20	0.07
	19	0.66	0.22
	26	1.83	0.78
	33	2.40	2.03
	40	3.13	2.74
	47	2.42	2.64
50	12	0.18	0.05
	19	0.54	0.19
	26	1.52	0.72
	33	2.14	1.65
	40	2.55	2.31
	47	2.22	2.27
60	12	0.17	0.05
	19	0.47	0.15
	26	1.27	0.59
	33	1.79	1.49
	40	2.25	2.19
	47	1.57	2.16

seedlings were carefully thinned to retain one seedling per hill. Soil mulching and hand weeding were done twice at 13 and 21 days after sowing (DAS). Irrigation was applied twice at 15 and 25 DAS. Insecticide (Ripcord) was sprayed on four occasions to keep the insect infestation to a minimum. Urea at the rate of 20 kg N ha^{-1} was side dressed at 20 DAS.

Sampling for dry matter partitioning: Plant samples were taken at weekly interval beginning at 12 DAE. Three plants from each of the lower density treatments 10, 20 and 30 plants m^{-2} and 5 plants from each of high density treatments 40, 50, 60 plants m^{-2} were sampled. Plants were cut at the base, put in polythene bag to prevent desiccation of leaves and were brought to the laboratory. Plant parts were separated into stem, petiole, leaf and reproductive organs and oven dried at 70°C for 72 h. Weights of individual components were recorded.

Analysis of data: Standard regressions were used to describe allometric relationships. The fact that plant form variables co-vary[23] was, however, ignored. The parameters considered to be least influenced by plant characters were used as independent variables. In all cases variables were log transformed before regressions were obtained.

RESULTS AND DISCUSSION

Mungbean plants were grown during kharif I (March-May) season and the general growth condition of the crop was good. However, previous studies[24] on the seasonal variations in mungbean production suggested that the kharif II (August-October) planting resulted in better crop growth and higher seed yield compared with kharif I season. Weather conditions during the growing season were generally favorable for crop growth except for one occasion in late April when heavy rain coupled with strong wind tended to cause some minor damage to the crop (data not shown).

Statistical analyses revealed that there was a significant density effect for all parameters considered ($p<0.001$). Furthermore, all parameters were significantly affected by sampling date ($p<0.001$). The effect of planting configuration was, however, variable. Therefore, allometric relationships were developed from the density treatments only.

Allometric relationship: Allometric analysis provided an insight into the relative distribution of Total Dry Matter (TDM) in different components as influenced by planting density and arrangement. Stem materials per unit leaf weight increased over the growth stages initially slowly and progressively but reproduction caused a greater surge in dry matter allocation in stem per leaf weight in all the treatments. The magnitude of the increase varied greatly with planting density (Table 1). Planting configuration was found to have little effect on the allometric relationship. The parameter values of the allometric relationship between leaf weight and stem weight are given in Table 2. A good fit was obtained in all cases with R^2 ranging 0.951-0.962. Significant differences

Table 2: Intercept (α) and slope (β) values of the regression equation fitting leaf weight (log g) and stem weight (log g) data for six different densities

Density (Plants m^{-2})	Intercept (α)	Slope (β)	Coefficient of determination (R^2)
10	0.391	1.307	0.957
20	0.413	1.357	0.954
30	0.485	1.367	0.951
40	0.531	1.392	0.956
50	0.491	1.466	0.962
60	0.628	1.535	0.952

Table 3: Allometric relationship between the ratios of stem dry weight per leaf dry weight (log) and leaf dry weight (log g) of mungbean at successive sampling dates for different density treatments

Density (Plants m^{-2})	Sampling date (DAE)	Stem dry weight/leaf dry weight (log)	Leaf dry weight (log g)	Allometric equation
10	12	-0.5850	-0.5686	
	19	-0.5086	-0.0269	
	26	-0.3979	0.4533	$y=0.288x^{0.101}$
	33	0.0334	0.4900	$R^2 = 0.623$
	40	-0.1675	0.6149	
	47	-0.1675	0.7275	
20	12	-0.5376	-0.6198	
	19	-0.5229	-0.0605	
	26	-0.4202	0.4014	$y=0.271x^{0.116}$
	33	0.0212	0.4728	$R^2 = 0.678$
	40	-0.1739	0.6042	
	47	-0.1427	0.6785	
30	12	-0.4559	-0.6990	
	19	-0.4815	-0.1249	
	26	-0.3979	0.3711	$y=0.286x^{0.149}$
	33	0.0170	0.4166	$R^2 = 0.716$
	40	-0.1367	0.4900	
	47	-0.1135	0.5798	
40	12	-0.4559	-0.7000	
	19	-0.4815	-0.1806	
	26	-0.3665	0.2625	$y=0.227x^{0.241}$
	33	-0.0706	0.3802	$R^2 = 0.839$
	40	0.0374	0.3838	
	47	-0.0555	0.4955	
50	12	-0.5528	-0.7447	
	19	-0.4559	-0.2676	
	26	-0.3279	0.1818	$y=0.181x^{0.300}$
	33	-0.1135	0.3304	$R^2 = 0.931$
	40	0.0086	0.3464	
	47	-0.0410	0.4065	
60	12	-0.5376	-0.7696	
	19	-0.4949	-0.3279	
	26	-0.3372	0.1038	$y=0.197x^{0.408}$
	33	0.1399	0.1959	$R^2 = 0.756$
	40	-0.0809	0.2529	
	47	-0.0132	0.3522	

among the density treatments occurred in all the allometric regressions investigated. These differences were largely the result of differences in intercepts as well as the slopes of the allometric equations. Turner *et al.*[1] got similar results in mangrove saplings. Stem dry weight and leaf dry weight showed a linear relationship on a log-log scale at different sampling date for all the density treatments. Increase in leaf weight generally favored the growth of stem weight (Table 1). This result enjoys the support from the work of Clough and Scott[25].

From the regression analysis it becomes clear that both slope (β) and intercept (α) values increased with increasing density (Table 2) suggesting that as the plant interference due to crowding increased, plants tended to allocate relatively more photosynthates as structural material and invested less in photosynthesizing or reproductive organs. This might be an adaptive mechanism of mungbean plant to avoid or endure drought. Forbes and Watson[26] also reported that an excessively high sowing density causes intense intra-specific competition leading to increased stem growth which eventually lowers the utilizable fraction.

The relationship between the slopes of the allometric equations and planting density can be expressed by an equation of linear form:

$$y = 1.292 + 0.033\,x \quad (R^2 = 0.575)$$

where, x is the population density.

The ratio of stem weight per leaf weight and leaf weight were linearly correlated (Table 3). Estimates of the values of slopes (α) and intercepts (β) of the linear relationships are presented in Table 4. Values for R^2 were more variable and ranged from 0.623-0.931. The samplings were done between early vegetative and pod fill stage during which leaf senescence was negligible[24]. Therefore, the leaf dry weights used represent good estimates. Plotting of the values of slopes of the allometric relationships against population densities yielded a good fit straight line function (Fig. 1) indicating that as population density increases the rate and speed of allocation of new dry matter to the stem decreased. This might be constant rate of photosynthetic productivity and the concentration of labile carbohydrate within the plant declined with time. In the observed relationships between stem weight/leaf weight and leaf weight for mungbean under varying population densities, there were no indications of non-linearity.

The study of growth allometry of individual plants and its consequences for key population traits open new areas for agronomic studies[8]. However, Causton and Venus[27] have discussed the limitations of using allometric relationships providing the mathematical nature of and the statistical problems associated with allometry vis-à-vis the physiological implications in connection with dry matter partitioning within the plant. Unless data are sufficiently extensive and/or of low variability, a log-log plot of them will scarcely show trends away from linearity. The present experiment was conducted only for one season. The range of population density was rather small. Sufficient extensive data with low variability are needed for allometric studies. Also, mathematical relationships often bear no or little physiological or ecological significance. Further works involving wider planting densities and cultivars will provide the opportunities to determine the influence of population density and planting configuration on allometric relationships in Mungbean. But it is becoming increasingly clear that allometric theory is rapidly developing and holds much promise to shed considerable light on virtually every aspect of plant life[7].

Table 4: Estimates of intercepts (α) and slopes (β) of the relationship of stem weight per leaf weight (log) and leaf weight (log g) for six different densities

Density (Plants m^{-2})	Intercept (α)	Slope (β)	Coefficient of determination (R^2)
10	0.288	-0.101	0.623
20	0.271	-0.116	0.678
30	0.286	-0.149	0.716
40	0.227	-0.241	0.839
50	0.181	-0.300	0.931
60	0.197	-0.408	0.756

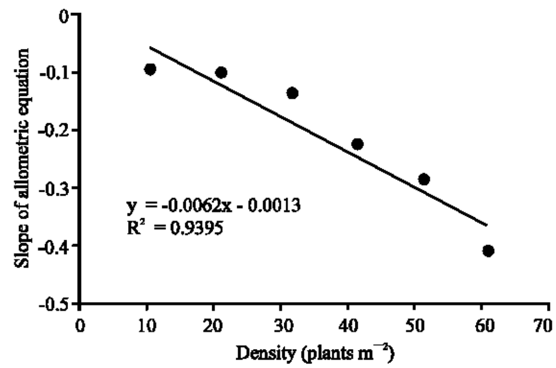

Fig. 1: Functional relationship between slopes of allometric equations and planting density in Mungbean

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