ALLOMETRY, DRY MATTER ALLOCATION, AND YIELD IN MUNGBEAN : EFFECTS OF POPULATION DENSITY AND PLANTING CONFIGURATION

Md. Sarwar Jahan

Registration No. 95-08-376

Certificate of Approval :

(Dr. Jalal Uddin Ahmed)
Member
Advisory Committee

(Dr. Abdul Hamid)
Major Professor
and Chairman
Advisory Committee

(Dr. M. Moynul Haque)
Member
Advisory Committee

THESIS ABSTRACT

ALLOMETRY, DRY MATTER ALLOCATION, AND YIELD IN MUNGBEAN : EFFECTS OF POPULATION DENSITY AND PLANTING CONFIGURATION

By

Md. Sarwar Jahan

A field experiment was conducted to determine the influence of population density and planting configuration on allometry, dry matter allocation and yield performance of mungbean. The experiment was conducted with six levels of planting 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 was also developed. At maturity, grain yield and yield contributing characters were recorded.

Population density decreased plant size, but the effect was offset when converted to per unit area basis. Leaf area per plant increased over time almost parabolically regardless of planting density or configuration. On land area basis, however, leaf area index (LAI) increased progressively with increasing planting density. Specific leaf mass (SLM) decreased with increasing population density while planting configuration exerted no significant influence on SLM. Stem

materials per unit leaf weight increased over the growth stages. Reproduction enhanced dry matter allocation into stem per unit leaf weight. Planting configuration had little effect on the allometric relationship. Reproductive effort decreased linearly with increase in population density.

Seed yield per plant decreased progressively with the increase in planting density. Significant variation in the number of pods per plant and seeds per pod due to differences in population density caused the variation in seed yield. Planting at higher rectangularity (1:5) outyielded other planting configurations. Planting density and configuration caused similar effect on harvest index.

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Summer, 1998 **The Author**

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CHAPTER I

INTRODUCTION

Mungbean (*Vigna radiata* (L.) Wilczek) is an important grain legume in Bangladesh. It is rich in proteins and minerals. The crop is grown widely and the dry seeds are consumed as soup or *dahl*. Mungbean sprouts can be used as substitute of vegetables. The mungbean sprouts are rich in iron, vitamins etc.

The productivity of mungbean being low, it often cannot compete with high yielding cereals and high valued vegetable crops. There have been considerable efforts towards increasing yield of mungbean at national and regional levels; but the yield remains low. Old varieties/ land races degenerated and new varieties have been released. For the newer varieties package of practices have been evolved. However, the experimental evidence of agronomic requirements for higher yield in mungbean is rather inadequate. Among the agronomic practices that influence crop growth and seed yield, plant population stands prominent. Yield is the function of total dry matter production and its favorable partition into seeds. Radiation intercepted by the leaf surface and the efficiency of its use in developing biomass govern the total dry matter production. While leaf area development, more particularly the speed of leaf area development, depends on varietal characteristics, the efficiency of light energy conversion into biomass is related with both biological and physical factors.

The proportion of intercepted radiation is determined by plant architecture which is genetically determined, and by the rate at which the canopy closes. The rate of canopy development is affected by management practices. Studies carried out at the International Rice Research Institute (1988) suggests that in order to hasten canopy closure and increase radiation interception planting geometry and density has a large bearing. Agronomic management that promotes vegetative growth ensuring early canopy closure helps maximize radiation interception. Consequently, yield is very sensitive to plant density. Under ideal growing conditions, optimum plant density is that which allows full light interception to be achieved prior to pod production, but that which avoids excessive vegetative growth. It has been shown that optimal planting density for higher seed yield should be around 50-60 plants m^{-2} (IRRI, 1988). However optimum plant density varies with cultivar and growing season (Lawn *et al.*, 1977; Carter and Boerma, 1979).

Although the yield of mungbean is generally lower than other grain legumes (Rachie and Roberts, 1974), a fairly high yield potential has been reported (Lawn and Ahn, 1985, Ali *et al.*, 1997). Yields more than 3t ha^{-1} have been reported in many trials (Beech and Wood, 1978; Lawn, 1978) but in Bangladesh the average yield is about 540kg ha^{-1} (BBS, 1995). Much of the improved yield potential of modern mungbean cultivars has come from increasing the portion of total growth that a crop partitions to seed i.e. harvest index. High mungbean yield is thus

determined by larger TDM as well as high harvest index (Kuo, 1998). In grain legumes, the vegetative, reproductive and ripening phases overlap each other. Dry matter partitioning between vegetative and fruiting structures of indeterminate plants may be regulated either by competition between vegetative and fruiting structure or simply by the dominance of developing pods. In many crops, the pattern of proportional dry matter distribution correlates strongly with the developmental stage of the crop (Penning de Vries and Van Laar, 1982).

As growth proceeds progressively, the plant changes form and shape. Such changes are often coordinated and related with the quantitative relationships among the organs of the plants. The most commonly used mathematical model to describe the relationship is a simple power function known as allometry. Analysis of allometric relationships may help estimate the allocation of resources to reproduction, mechanical and other functions (Jolliffe *et al.*, 1988; Niklas, 1993). However, information on allometric relationships in crop plants are either lacking or highly inadequate.

Dry matter partitioning, and more particularly its consequence on yield, is often assessed by determining the reproductive effort (Reekie and Bazzaz, 1987). However, the use of reproductive effort in crop plants is rather uncommon. Since planting density and configuration are reported to have influence on the size structure and developmental biology of plants (Bonnan, 1991), it is conceivable that these management factors may influence the reproductive effort in mungbean plants.

CHAPTER II

REVIEW OF LITERATURE

Food legumes are the major source of vegetable proteins in the diets of most Bangladesh people. Among the food legumes grown in Bangladesh mungbean ranks fifth in terms of area and production (BBS, 1995). However, the yield of the crop is comparatively low compared to that of cereals and some other pulses. During the past two decades, there have been considerable research on the varietal development and yield improvement in mungbean (Islam and Rahman, 1991). Pulses in general are considered to be slow runner because of their inherent low yielding capacity. Kuo *et al.* (1978), Hamid *et al.* (1991), and Lawn and Ahn (1985) provided comprehensive treatment of physiological and agronomic aspects of yield constraints in mungbean. Recently Sinha (1994) postulated that genetically pulses are comparable or even more productive than many cereal crops.

The low yield of mungbean is attributable to its short growth duration, particularly the slow rate of dry matter accumulation prior to flowering, unfavorable canopy structure (Hamid *et al.*, 1990), non-responsive to applied inputs and management conditions (Chainuvati and Charnnarongkul 1991; Chotechuen and Egawa, 1996) etc. Seed yield is related with the total dry matter accumulation which in turn depends almost wholly on the canopy photosynthesis.

Physiological analysis of mungbean indicated that lower photosynthetic rate and consequential lower amount of dry matter accumulation during the pre-flowering phase restricts higher yield (Kuo *et al.*, 1978). Subsequent studies by many researchers revealed that the mungbean yield is source limited (Clifford, 1979; Chowdhury *et al.*, 1982; Hamid *et al.*, 1991).

Plant density regulates the shape of the canopy (Hashem and Hamid, 1996). To obtain high yield, plant densities must be high. However, as plant population increases per unit area, a point is reached at which each plant begins to compete for essential growth resources: nutrients, light and water. The effect of increasing competition is similar to decreasing availability of growth resources. Works on yield density relationships and on plant competition in the community abound in literature (e.g. Shinozaki and Kira, 1956; de Wit, 1960; Willey and Heath, 1969; Trenbath, 1974, Bonnan, 1991; Hassan, 1992). Assessment of yield density relationship is of practical importance because, for example, it determines the minimum plant population needed to achieve a maximum yield.

Population density and planting arrangement influence yield greatly (Rowden *et al.*, 1981; Hamid, 1989) through modification of plant's microclimate and better exploitation of growth resources. While overcrowding depresses biological yield potential, sparse population utilizes growth resources inefficiently resulting in poor yield.

The response of plants to increased densities in monocultures has been well documented. Shinozaki and Kira (1956) found a linear relationship between the reciprocal of mean plant weight and density. Plant to plant variation in weight and height generally increases, and frequency distribution become positively skewed with increased density. Empirical data indicate that plants grown at high densities usually have greater size variability than plants grown at low densities (Weiner, 1985; Geber, 1989). Bonnan (1991) studied the density effect on size structures of annual plant populations. Plants were grown at ten densities (7, 19, 37, 61, 127, 181, 233, 291 and 355 plants) under situations in which neighborhood competition could create the variability in growth rates required to form size hierarchies. At each density plants were grown in a random and a hexagonal planting spatial pattern. Mean plant mass decreased with higher stand densities.

Field experiments were carried out for two consecutive growing seasons to evaluate the competition effect on the growth and yield of mungbean at population densities ranging from 3.7 to 363 plants m^{-2} (Hamid, 1996). Plants grown at densities greater than 156 plants m^{-2} failed to produce seed yield because of high rate of mortality. Dry matter yield per plant decreased progressively with increasing density. When accounted for unit area basis, yields showed an asymptotic curve at densities between 3.7 and 156 plants m^{-2}. Seed yield per plant decreased at a diminishing rate with increasing density but the yield-density function based on grain yield per unit area followed a quadratic relationship.

Similar observation was made by Rahman *et al.* (1995). They noted that mungbean plants sown at low density produced significantly higher dry matter and yield per plant. In contrast, Muchow and Charles- Edwards (1982) found that the seed yield of mungbean remained relatively unresponsive to a wide range of plant densities from 10 to 50 plants m^{-2}.

Singh and Singh (1988) demonstrated that planting patterns 1:2 and 1:4 gave the significantly higher pods per plant, seeds per pod and grain yield than 1:1 planting pattern but seed size did not vary significantly. They concluded that rectangular planting proved better than square planting pattern in mungbean.

The pattern of resource allocation in plants and its regulation is of great practical importance to agriculturists and horticulturists. It is generally considered that nutritional and energetic resources are allocated in a strategic manner that maximizes fitness (Harper, 1977; Fitter, 1986; Bazzaz *et al.*, 1987). The investment of resources to one set of functions seems likely to lead to decrease in allocation to other types of organs or functions, implying, for example, that reproductive growth and development must occur at the expense of vegetative growth and development.

Biomass distribution provides a general approach for allocation studies, but it is important that equivalent comparisons are made, e.g. in relation to the inclusion of flower parts and supporting structures as well as seeds and fruits. Thomson and Stewart (1981) proposed that the term reproductive effort (RE)

should be used to cover investment in all reproductive structures. The distribution of biomass between various parts of a plant represents the balance between the total partitioning of assimilate from source leaves to sinks throughout development and its consumption by respiration in sink tissues.

In *Plantago coronopus*, an annual, Waite and Hutchings (1982) showed that reproductive allocation significantly decreased with increasing density (from 47 to 31%). Similarly, in temperate cereals the harvest index per unit crop area declines as density increases (Donald and Hamblin, 1976).

The allocation of resources to reproductive growth and development is of fundamental importance in determining the yield potential of seed crops. In temperate cereals and legumes it appears that the very large increase (of the order of 60%) in seed yield of modern cultivars compared with their ancestors and very early varieties is more or less entirely due to an improved harvest index, as the total above ground biomass production is very similar (Austin *et al.*, 1986; Gifford *et al.*, 1984; Austin *et al.*, 1980). In mungbean there is enough dry matter accumulation if the duration of crop growth is considered. The plants become indeterminate and the extra photosynthates find their way to vegetative parts and not to the seeds. This results in a low harvest index (Tickoo *et al.*, 1996). So the objective should be to channel more of this dry matter in favour of seeds and increase in harvest index per unit area of land.

Harries and Lovell (1980) studied the growth and reproductive strategy in *Veronica* species. The three species with the lowest aboveground dry weight expended a relatively greater proportion of their dry weight on seed production than the two larger species. The level of seed production is related to growth form, and seed number and seed weight are determined largely by the number of seeds per capsule. This remains constant under different environmental conditions

Seed yield per unit area is a function of number of pods plant^{-1}, number of seeds pods^{-1}, seed size and number of plants per unit area. Akhtaruzzaman (1998) demonstrated the interrelationships among yield parameters. He showed that grain yield in mungbean was strongly associated with biomass produced, as well as pods per plant, seeds per pod, and 1000 seed weight. Grain yield of mungbean is the product of pods plant^{-1}, seeds pod^{-1} and 1000 seed weight. Among the three primary yield components, pods per plant was found positively correlated with grain yield. Hassan *et al.* (1995) and Chowdhury (1996) also reported that mungbean seed yields were strongly associated with pods per plant.

The growth and development of organisms ordinarily involves progressive changes in form. 'Allometry'-the quantitative relationship exists among different features of an organism as growth proceeds. It is often considered in terms of a growth relationship which exists between one part of an organism and the whole. The evaluation of allometry can help understand structural and functional relationships between different levels of organization (Jolliffe *et al.*, 1988). Many

experimental treatments are known to affect plant form, and some studies have specifically examined allometric responses to treatments (e.g. Stanhill, 1977a, b).

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 (Niklas, 1993). General allometric relationships for this purpose are available for tree species (e.g. Whittaker and Woodwell, 1968; Peters *et al.*, 1988; Shipley and Peters, 1990; Kohyma and Hotta, 1990) but comparable descriptions for crop plants are lacking or scant.

Various mathematical expressions are used for the interpretation of allometric relationships. The most commonly used mathematical model to describe an allometric relationship is a simple power function. Such a function has wide biological applicability (Causton and Venus, 1981). Many agronomic and physical factors are reported to have influence on plant form. However, experimental evidences of such effect on the allometric relationships are rare (Stanhill, 1977a,b). 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. Allometric relationship is expressed in a power form

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

or alternatively $\log_e y = \log_e \alpha + \beta \log_e x$.

Unless data are sufficiently extensive and/or of low variability, a log-log plot of them will scarcely show definite trends away from linearity. Causton and Venus (1981) have discussed the limitations of using allometric relationships providing the mathematical nature of and the statistical problems associated with allometry *vis-a-vis* the physiological implications in connection with dry matter partitioning within the plant.

CHAPTER III

MATERIALS AND METHODS

A field experiment was conducted at the *IPSA* 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 about 6.5 (Haider *et al.*, 1991). The experimental site is characterized by hot-humid subtropical climate with abundant rainfall during monsoon extending from May through September while during the remaining part of the year evaporative demand exceeds rainfall (Monalo, 1978). 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 : 31.5 x 31.5 cm (1:1)
- D_1C_2 : 20 x 50 cm (1:2.5)
- D_1C_3 : 15 x 66.7 cm (1:5)

D_2 : 20 plants m^{-2} i.e. 500 cm^2 $plant^{-1}$

D_2C_1 : 22.5 x 22.5 cm (1:1)

D_2C_2 : 14.0 x 35.5 cm (1:2.5)

D_2C_3 : 10 x 50 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 28.50 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 x 25 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 : 22.22 x 9.00 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 : 20.87 x 8.00 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 3 replications. Unit plot size was 4m x 3m. Seeds were sown on March 21, 1996 in rows as per treatment. Seeds were pre-soaked for 3 hours 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. The parentage of the line is VC 2768B x NM 36.

Seedlings emerged by March 25 and gap filling was done using even aged seedlings on March 26. At first trifoliate stage seedlings were carefully thinned to retain one seedling per hill. Soil mulching and hand weedings were done twice-at 13 and 21 days after sowing (DAS). Irrigation was applied twice-at 15 and 25 days after sowing. 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.

Recording of Data

Sampling for Dry Matter Partitioning

Plant samples were taken at a weekly interval beginning 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 and 60 plants m^{-2} were sampled. Plants were cut at the base, put into polythene bag to prevent desiccation of leaves and were brought to the laboratory.

Leaf area : Leaf area of each plant was measured at each sampling date with an automatic leaf area meter (Model AAM-7, Hayashi Dehnco Co. Ltd. Tokyo, Japan) and the mean leaf area per plant was calculated.

Dry matter accumulation : Plant parts were separated into stem, petiole, leaf and reproductive organs and oven dried at 70° C for 72 hours. Weights of individual components were recorded.

Using the data on the leaf area and dry matter, the following growth parameters were derived :

Leaf area index, LAI = L_A/G_A

Specific leaf mass, SLM = L_W/L_A

Where,

L_A = Leaf area

G_A = Ground area

L_W = Leaf weight

Harvest data : At maturity plants were harvested on May 19, 1996 by picking the pods. The variety being nearly a determinate one (Hashem *et al.* 1996) the picking was done only once. For recording yield data an area of 1 m^2 from the center of the plot was harvested. From beyond the harvest area, 5 plant samples were uprooted from each plot at maturity to record yield parameters viz. Pods per plant, pod length, seeds per pod, 1,000 seed weight. Total biomass of 5 plant sample was determined following standard procedure and harvest index (HI) was calculated as follows :

HI = (Seed yield)/(Total biomass) x 100

Analysis of data

Data on plant characters, yield and yield parameters were subjected to analysis of variance (ANOVA). Means were compared by Least significance

difference (LSD) test. Standard regressions were used to describe allometric patterns. The fact that plant form variables covary (King, 1990) 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 regression were obtained. Functional relationships between yield parameters and growth characters were determined using simple correlation and regression analysis.

CHAPTER IV

RESULTS AND DISCUSSION

Mungbean plants were grown during kharif I (March 21-May 14'1996) season and the general growth condition of the crop was good. However, previous studies (e.g. Biswas, 1988) 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 (Appendix I) were generally favourable 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.

Seasonal changes in the mean biomass of mungbean as influenced by planting density and configuration are presented in Fig. 1. Biomass increased progressively and the variation due to population density treatments was not apparent until second sampling i.e., 19 DAE. From 26 DAE onwards, population density exerted significant influence on plant size and that persisted throughout the

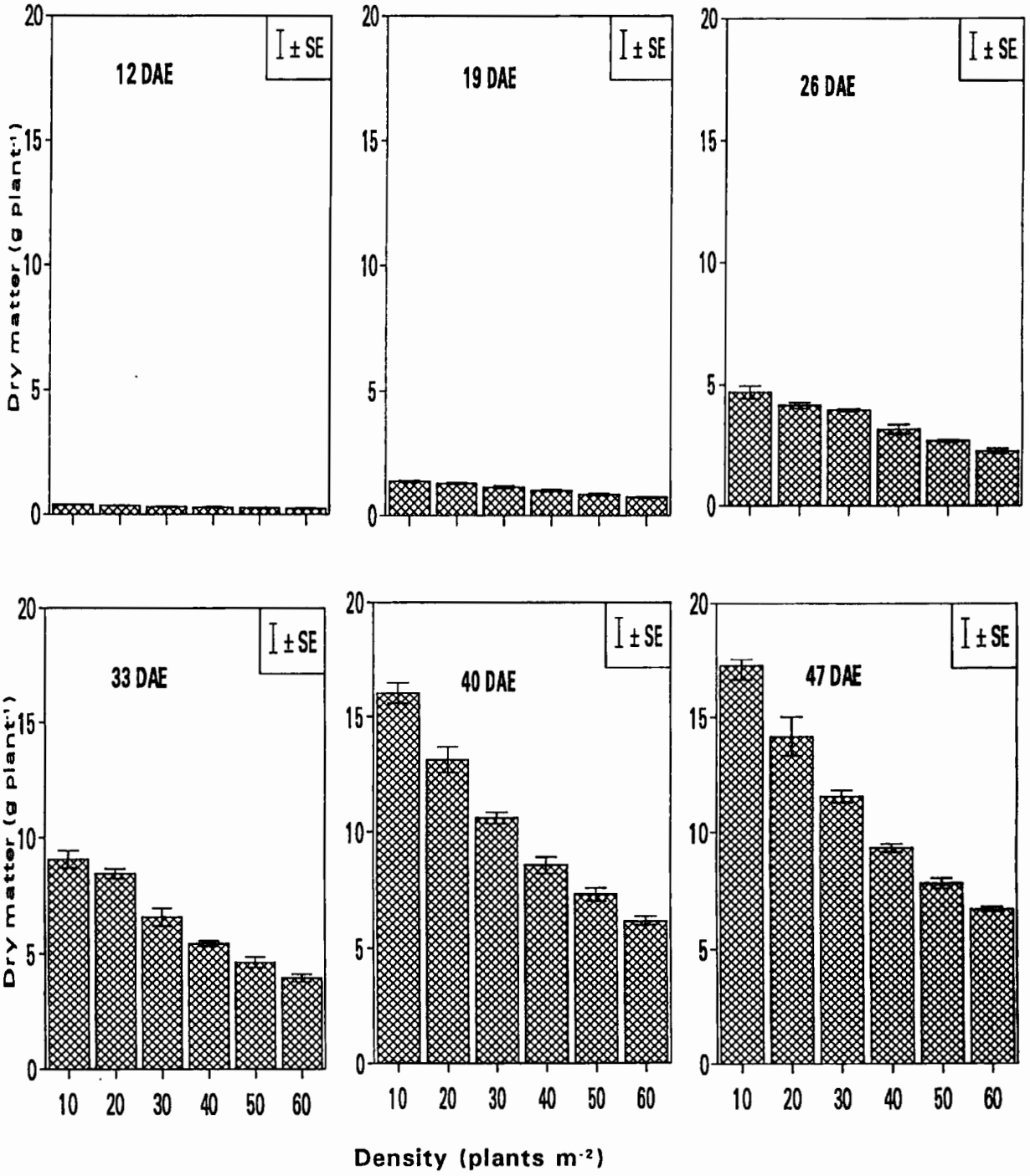

Fig. 1. Seasonal changes of biomass (g dry wt. plant^{-1}) of mungbean as influenced by population density.

growth period. Generally, higher the planting density, smaller was the plant. In other words, the larger the area per plant greater was the resources available per plant that eventually resulted in higher biomass accumulation.

Leaf Growth

Dry matter production of a crop plant depends almost wholly on the amount and pattern of photoactive radiation (PhAR) intercepted and absorbed by the crop and the efficiency of the crop to use the absorbed radiation. The interception of PhAR by a crop surface is the function of leaf area and the posture of the leaves on the plant (i.e. canopy structure).

Leaf area per plant increased over time almost parabolically regardless of planting density or configuration (Fig. 2). From Fig. 2 it is evident that increasing population density tended to depress leaf area per plant right from the early vegetative stage. Reduction in leaf area per plant was due to interplant competition within the community. The competition intensified during reproductive and early pod fill stage (i.e., 28 and 33 DAE). The trend persisted during the remaining part of the growing season.

When the leaf area is viewed as leaf area index (LAI), multiplying per plant area and unit ground area, the scenario changes abruptly (Table 1 and Table 2). Leaf area index increased linearly with increasing population density, although from 26 DAE onwards density greater than 50 plants m^{-2} (D_5) resulted no appreciable increase in leaf area index.

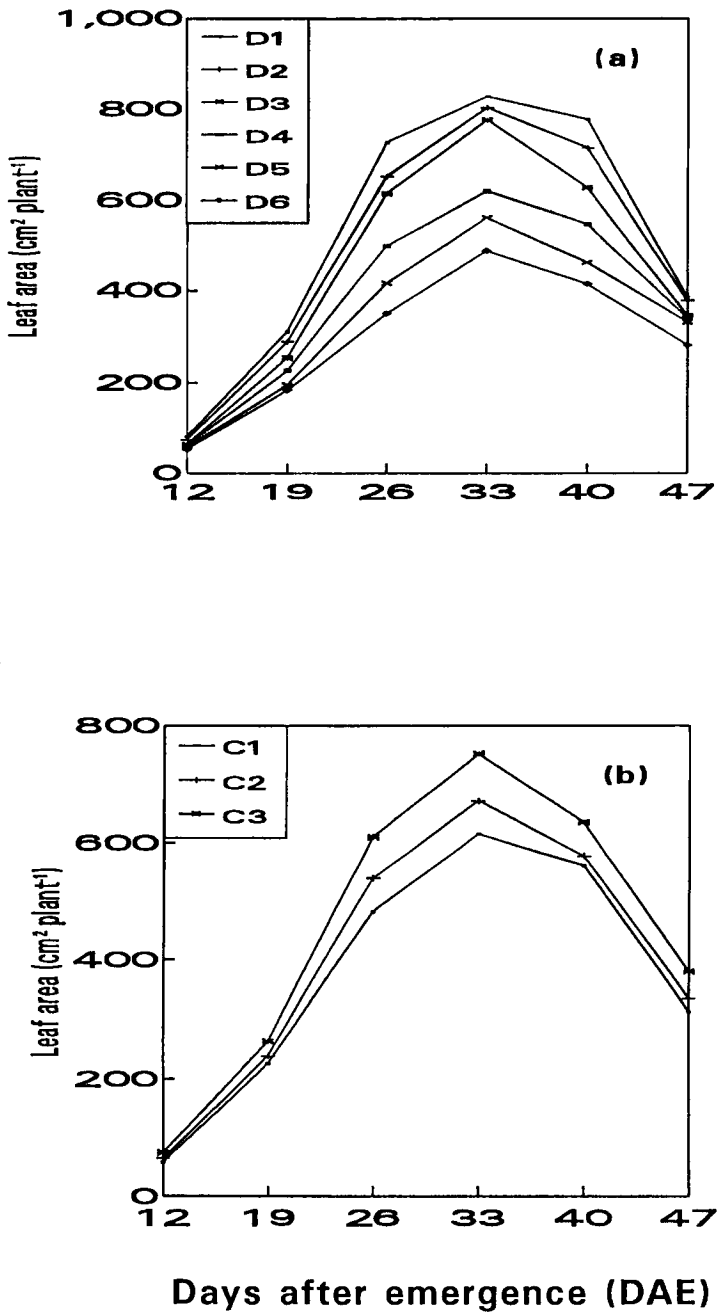

Fig. 2. Leaf area (cm^2 $plant^{-1}$) as influenced by population density (a) and planting configuration (b)

Table 1. Leaf area index (LAI) of mungbean as influenced by population density

Density (plants m^{-2})	12 DAE	19 DAE	26 DAE	33 DAE	40 DAE	47 DAE
10	0.08	0.31	0.73	0.83	0.78	0.39
20	0.15	0.58	1.31	1.61	1.43	0.75
30	0.19	0.76	1.84	2.33	1.88	1.03
40	0.25	0.90	2.00	2.48	2.19	1.36
50	0.29	0.97	2.08	2.81	2.31	1.65
60	0.31	1.10	2.09	2.93	2.48	1.68
CV(%)	11.56	15.83	8.57	13.06	15.08	16.95
$LSD_{0.05}$	0.030	0.117	0.139	0.271	0.268	0.187

Table 2. Leaf area index (LAI) of mungbean as influenced by planting configuration

Configuration	12 DAE	19 DAE	26 DAE	33 DAE	40 DAE	47 DAE
1:1	0.18	0.71	1.51	2.00	1.75	1.06
1:2.5	0.21	0.75	1.67	2.15	1.81	1.13
1:5	0.24	0.84	1.84	2.34	1.98	1.24
CV(%)	11.56	15.83	8.57	13.06	15.08	16.95
$LSD_{0.05}$	0.021	0.083	0.098	0.192	0.189	0.132

Specific leaf mass (SLM)

It indicates the photosynthetic rate of a crop through RuDPCase activity (Kuo *et al.*, 1980). Seasonal changes is specific leaf mass (SLM) due to planting systems are presented in Table 3. Specific leaf mass declined markedly at the second sampling, and from third sampling (26 DAE) it continued increasing reaching the highest at 47 DAE. Almost similar specific leaf mass in mungbean genotypes were recorded at AVRDC (Kuo *et al.*, 1980). The decline in SLM at second sampling might be due to the fact that the sampling corresponded to late vegetative phase when demand for photosynthates was more in triggering from vegetative to reproduction. Except in first sampling, SLM decreased with increasing population density although the difference between D_1 and D_2 was not appreciably great. Planting configuration exerted no significant influence on SLM (Table 4).

Specific leaf mass correlated well with total dry matter and seed yield. SLM at 40 DAE gave a best fit simple linear regression with total dry matter (TDM) and yield suggesting that as SLM increased, TDM also increased linearly (Fig. 3). Over 90% of the variation in TDM or yield could be explained from the variation in SLM at 40 DAE.

Total Dry Matter Production

Accumulation of total dry matter increased progressively over time attaining the highest amount at physiological maturity (Fig. 4). The rate of increase, however, varied depending on the growth stage.

Table 3. Specific leaf mass (SLM) (mg cm^{-2}) of mungbean as influenced by density treatments

Density (plants m^{-2})	12 DAE	19 DAE	26 DAE	33 DAE	40 DAE	47 DAE
10	3.29	3.03	3.91	4.99	6.86	8.02
20	3.26	3.02	3.86	4.99	6.68	7.92
30	3.23	2.95	3.78	3.99	6.05	7.61
40	3.22	2.92	3.67	3.87	5.70	7.13
50	3.18	2.78	3.66	3.81	5.52	6.75
60	3.17	2.58	3.63	3.67	5.44	5.60
CV(%)	5.76	4.54	3.38	4.74	3.26	3.08
$LSD_{0.05}$	NS	0.125	0.121	0.120	0.189	0.212

Table 4. Specific leaf mass (SLM) (mg cm^{-2}) of mungbean as influenced by planting configuration

Configuration	12DAE	19DAE	26DAE	33DAE	40DAE	47DAE
1:1	3.20	2.87	3.75	4.21	6.07	7.18
1:2.5	3.22	2.88	3.75	4.22	6.02	7.17
1:5	3.26	2.89	3.76	4.23	6.04	7.17
CV(%)	5.76	4.54	3.38	4.74	3.26	3.08
$LSD_{0.05}$	NS	NS	NS	NS	NS	NS

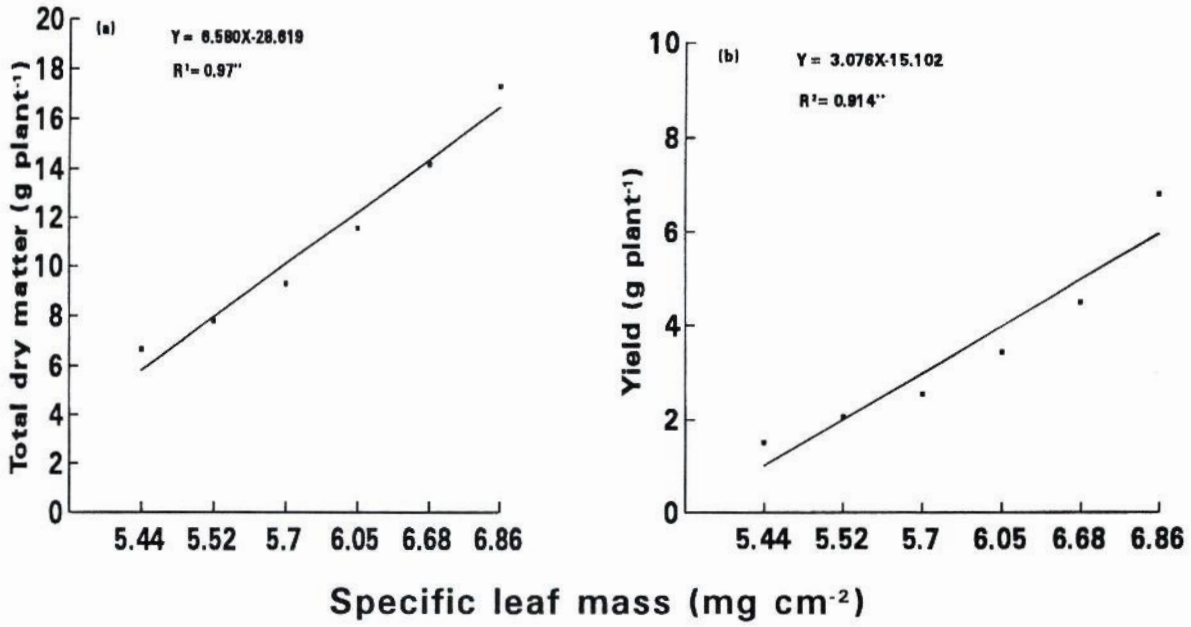

Fig.3. Functional relationship between specific leaf mass (SLM) and total dry matter (a) and seed yield (b) of mungbean

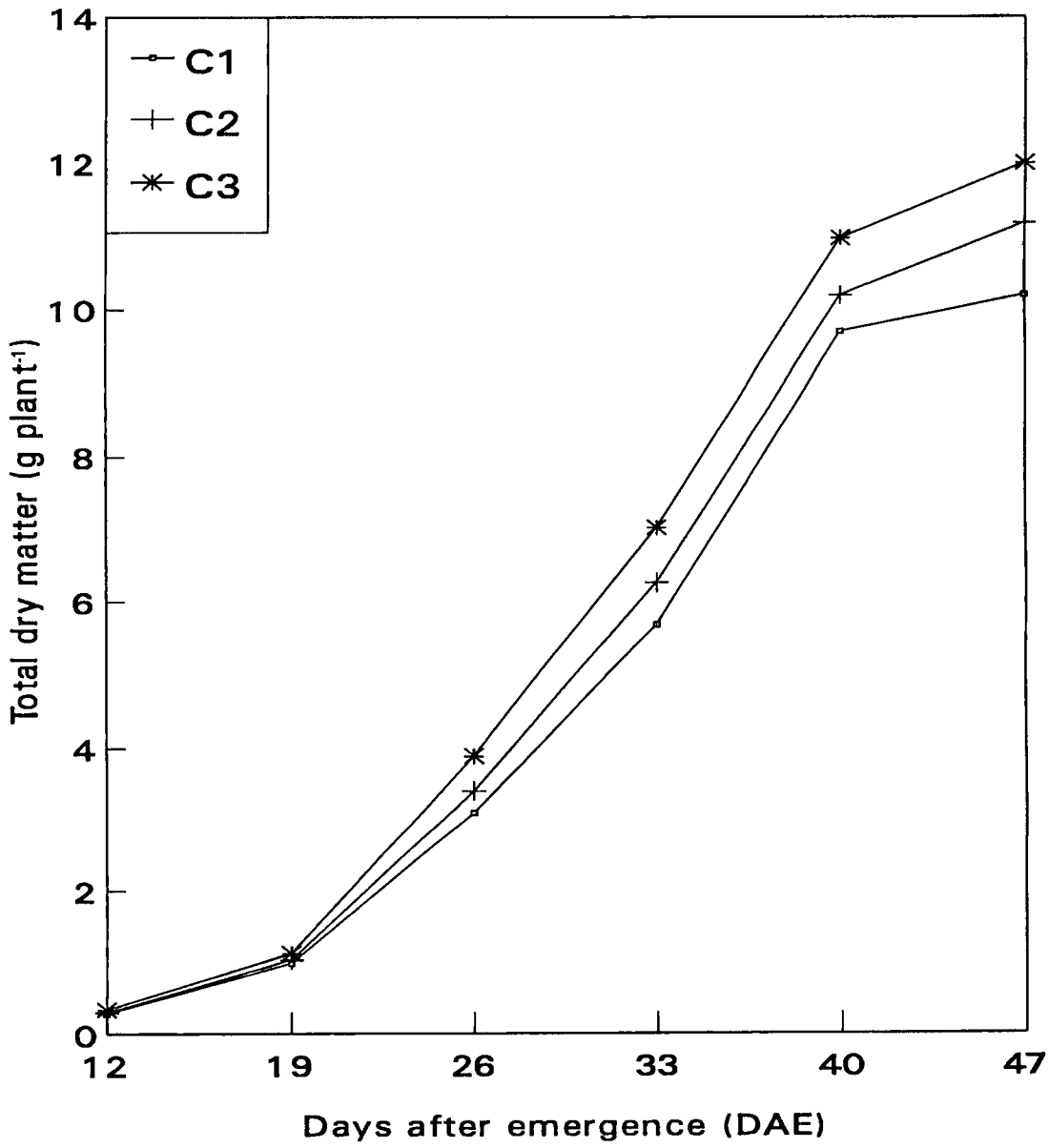

Fig. 4 . Influence of planting configuration on the total dry matter production (g plant^{-1}) of mungbean

There were significant variations in TDM accumulation among the density treatments except at early vegetative stage. The influence of population density was first apparent at around flowering stage (i.e. between 28 and 33 days after emergence, DAE) and the differences among the treatments persisted throughout the growth period. It appears that until the plants attained about 3 leaf stage, and within the range of planting densities, the intra-specific competition was not expressed, for the plants were too small to exhibit competition for growth resources. From 26 DAE onward, the size of plants decreased progressively with the progressive increase in planting densities. As expected the sparsely populated plants had accumulated more dry matter than the densely planted ones. The magnitude of difference between the highest and the lowest total dry matter (TDM) was, however, less than the differences in population densities. The results indicated that although per plant dry matter decreased with the increase in planting density (Fig. 4) the TDM per unit area continued to increase with the increasing population density; and within the population densities used, the dry matter yield per unit area did not decline or plateaued (Fig. 5). Our results compare favourably with those of Muchow and Charles-Edwards (1982) who observed significant, positive linear trends of dry matter production in three varieties of mungbean to increasing density.

Plotting TDM against planting densities for each sampling stage (Fig. 6) suggests that the rate of dry matter increase with increase in density or the relative

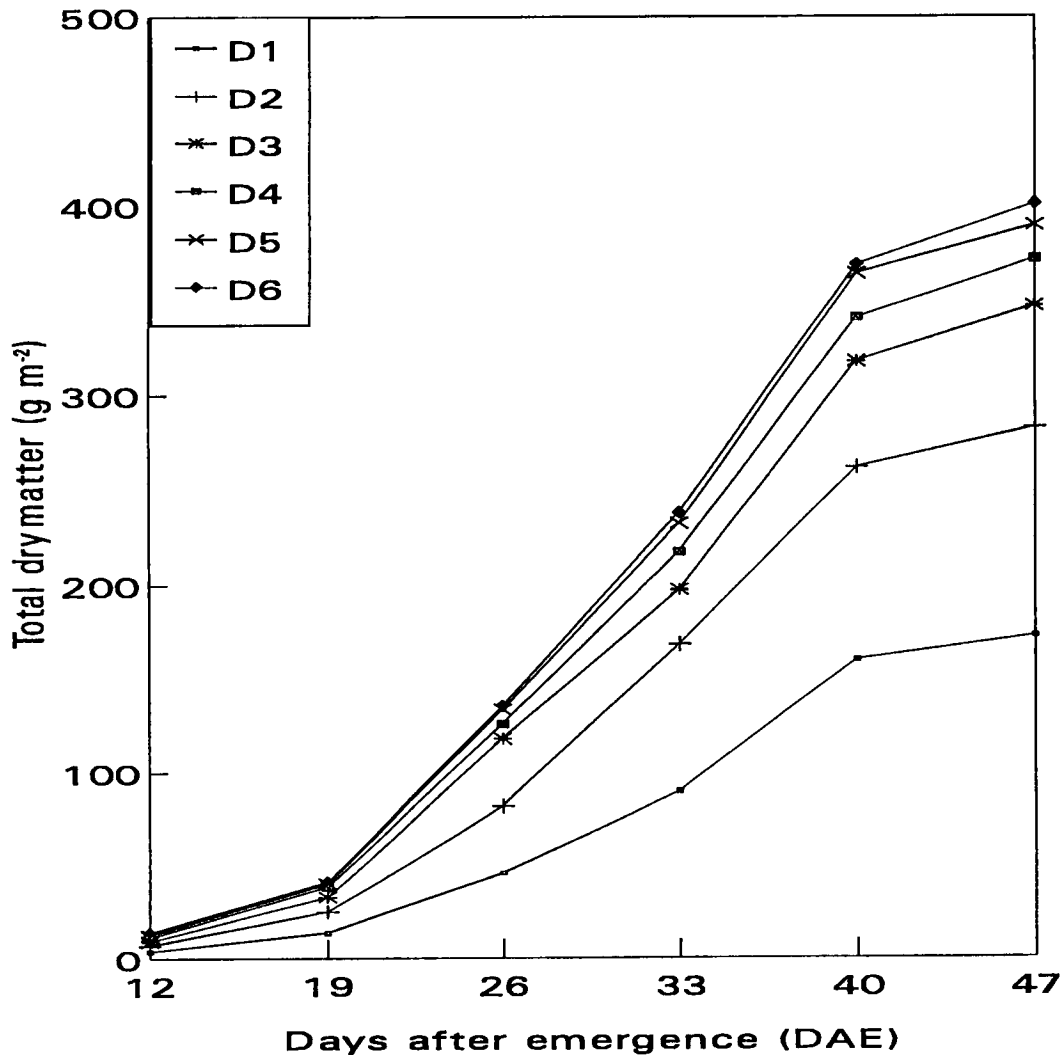

Fig . 5 . Total dry matter production of mungbean (g m^{-2}) as influenced by population density

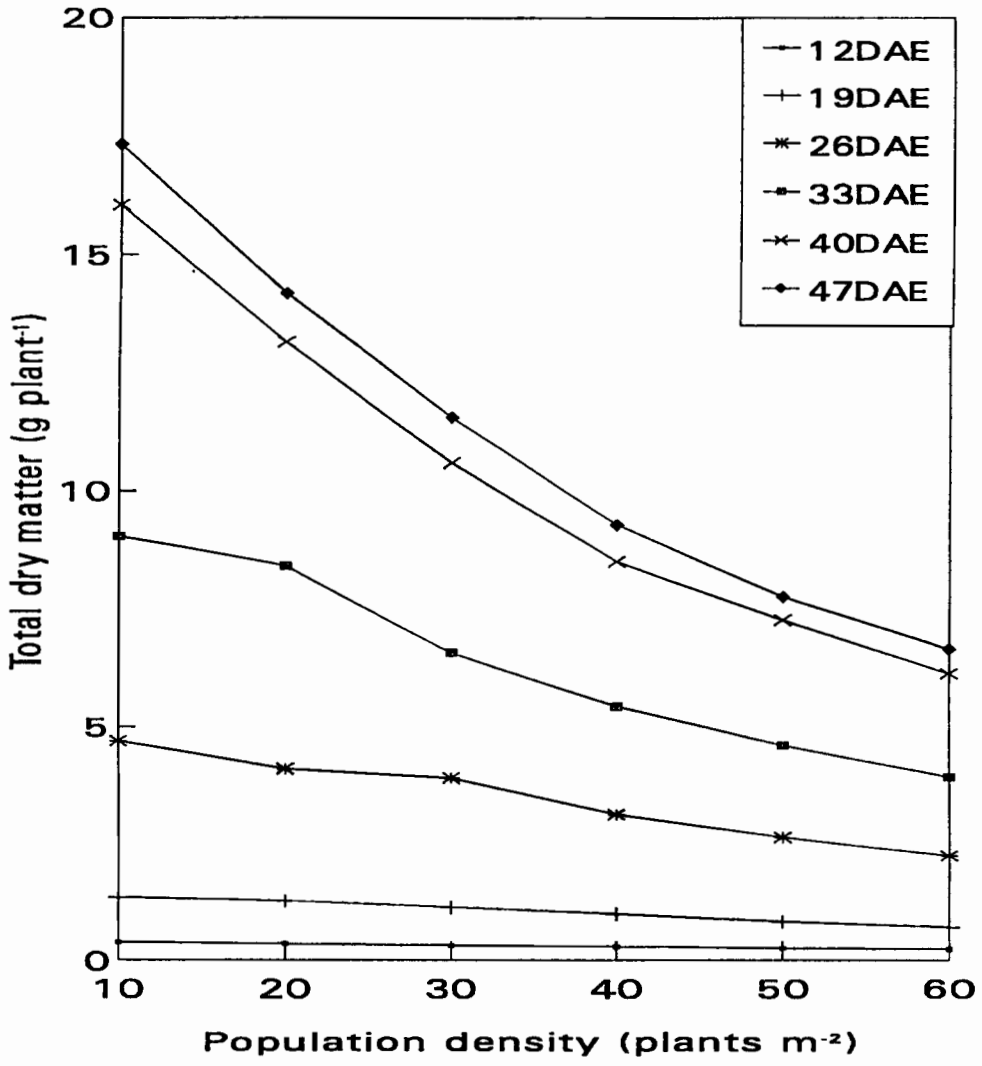

Fig . 6 . Population density effect on dry matter production of mungbean (g plant^{-1}) at different growth stages

growth rate decreased progressively with the advance of plant age. This implies that with time the size of the plants were larger and thus causing plant interference more intense. The variations in competition effect on the plant size in different stages of growth are shown in Fig. 6. From the figure it is apparent that at each stage of growth standard errors ($\pm$SE) were generally larger at higher planting densities. In other words, the crowded plants displayed a greater variability in size. Resources are distributed asymmetrically among competing plants, so that large plants received a disproportionate share of resources relative to their size than small plants competing (Bonnan, 1991).

Table 5 shows the density dependent variation in total dry matter accumulation over time. It seems that plants grown at closer spacings met with intra-specific competition right from the vegetative stage and that persisted throughout the growing season. Regression analysis using dry matter data against density for individual sampling dates indicates that as plant ages the slope values increases sharply (Table 6). Steeper slope toward the sampling dates corresponding to reproductive and pod fill stages is indicative of intense competition. This is rather expected because as the size of the plant increase, competition for growth resources also increases.

The changes in dry matter in individual components as influenced by planting density are illustrated in Fig. 7. It is apparent that although the shape of the overall growth curve remained similar for all the planting densities, the

Table 5. The density dependent variation in total dry matter accumulation over time

Density (plants m^{-2})	Total dry matter (g $plant^{-1}$) accumulation on successive dates					
	12 DAE	19 DAE	26 DAE	33 DAE	40 DAE	47 DAE
10	0.37	1.36	4.69	9.05	16.03	17.28
20	0.34	1.27	4.13	8.42	13.14	14.18
30	0.30	1.12	3.94	6.58	10.60	11.57
40	0.28	0.98	3.15	5.44	8.53	9.30
50	0.25	0.82	2.67	4.65	7.29	7.79
60	0.23	0.70	2.26	3.97	6.15	6.68
CV(%)	8.06	9.12	4.56	7.84	10.45	8.80
$LSD_{0.01}$	0.058	0.122	0.203	0.641	1.380	1.261

Table 6. Intercept (α) and slope (β) values of the regression equations giving best fit to TDM accumulation per plant as influenced by population density over the growing season

Sampling at	Intercept (α)	Slope (β)	R^2
12 DAE	0.394	-0.003	0.990
19 DAE	1.521	-0.014	0.995
26 DAE	5.205	-0.050	0.985
33 DAE	10.137	-0.108	0.974
40 DAE	17.192	-0.197	0.967
47 DAE	18.577	-0.213	0.970

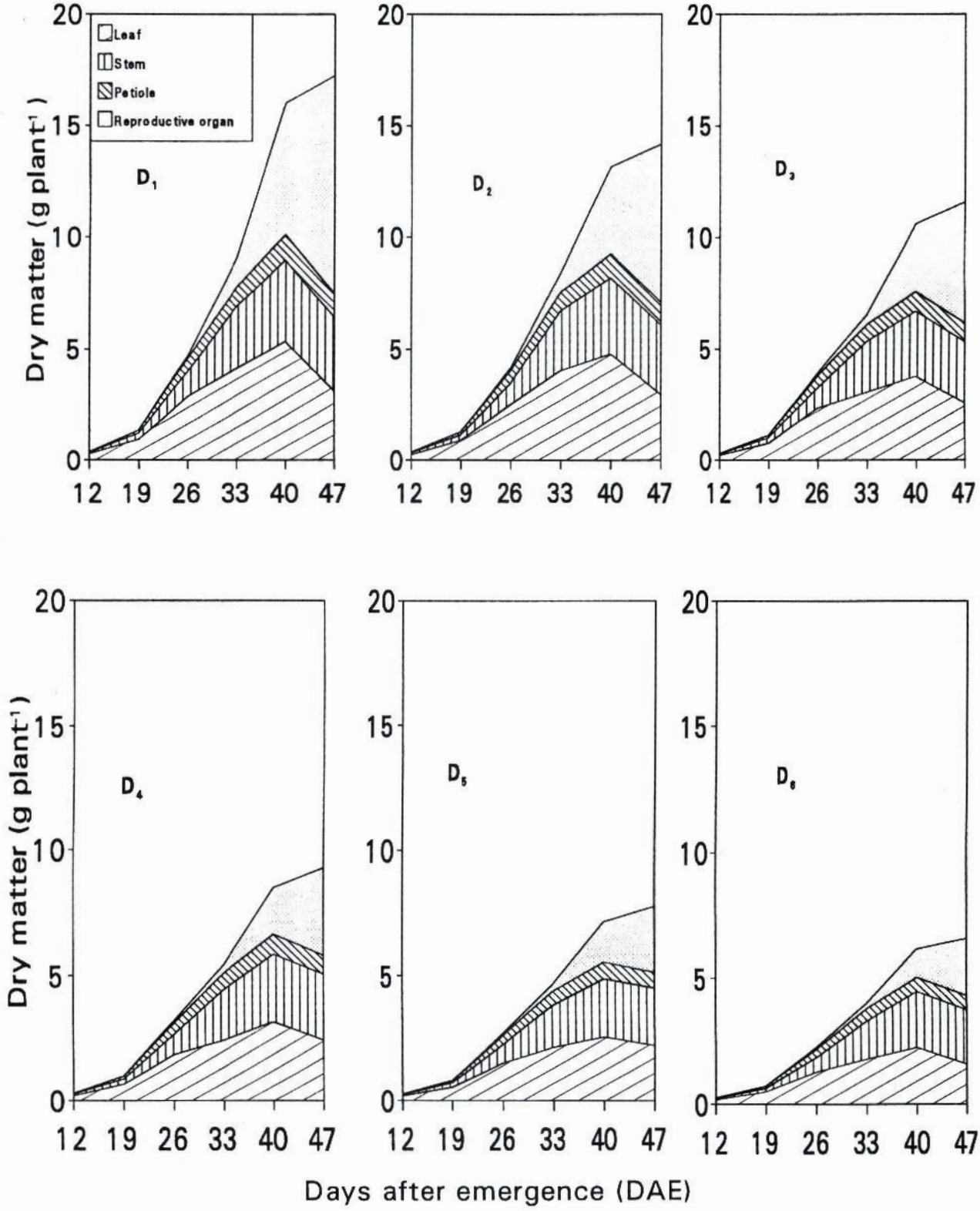

Fig.7 . Accumulation of dry matter in different components in mungbean at varying population densities

changes with time varied appreciably depending on the densities. The differences were also related with phasic changes. The changes across the density treatments was not apparent until the second sampling (i.e. 19 DAE) but at third sampling, which corresponded with reproductive stage, planting density exerted significant influence on dry matter accumulation in different components. Dry matter accumulation in reproductive organ and stem of the sparsely populated plants was relatively more than it was observed for crowded plants. Phasic changes were also somewhat delayed due to plant competition.

Allometric relationships

Allometric analysis provided an insight into the relative distribution of 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 unit leaf weight in all the treatments. The magnitude of the increase varied greatly with planting density (Fig. 8). 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 7. Increase in leaf weight generally favoured the growth of stem weight (Fig. 8).

From the regression analysis it becomes clear that both slope(ß) and intercept (α) values increased with increasing density (Table 7) 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. Poor partitioning of dry matter for reproductive organs with high population could be explained partly by the high rate of reproductive abscission due to high canopy temperature in beans (van Schaik and Probst, 1958). The relationship between the slopes of the allometric equations and planting density can be expressed by an equation of linear form :

$$Y = 1.292 + 0.033X \ (R^2 = 0.575)$$

where X is the population density. This might be an adaptive mechanism of mungbean plant to avoid or endure stress.

The ratio of stem weight per leaf weight and leaf weight were linearly correlated (Fig. 9). Estimates of the values of slopes (α) and intercepts (ß) of the linear relationships are presented in Table 8.

The samplings were done between early vegetative and pod fill stage during which leaf senescence was negligible (Biswas, 1988). 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. 10) indicating that as the population increases the rate and speed of allocation of new dry matter to the stem decreased. This might be due to nearly

Table 7. Intercept (α) and slope (ß) values of the regression equation fitting leaf weight (log g) and stem weight (log g) data for six different densitities

Density (plants m^{-2})	Intercept (α)	Slope (ß)	Coefficient of determination (R^2)
10	0.391	1.387	0.957
20	0.413	1.357	0.954
30	0.485	1.307	0.951
40	0.531	1.392	0.956
50	0.491	1.466	0.962
60	0.628	1.535	0.952

Table 8. Estimates of intercepts (α) and slopes (ß) of the linear relationship of stem weight per leaf weight and leaf weight

Density (plants m^{-2})	Intercepts (α)	Slopes (ß)	Coefficient of correlation (r)
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

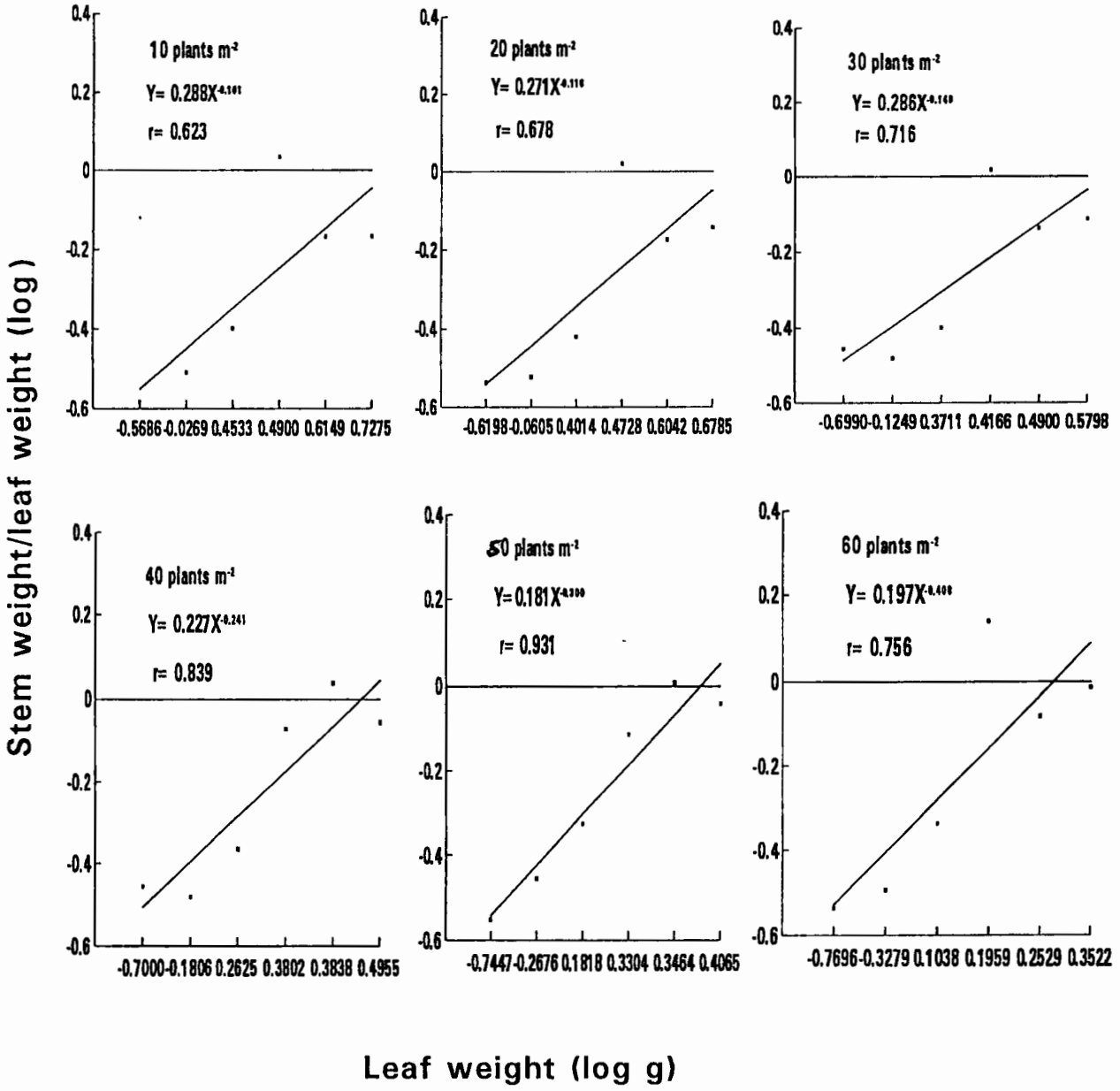

Fig. 9. Functional relationships between the ratio of stem weight /leaf weight and leaf weight at different population densities

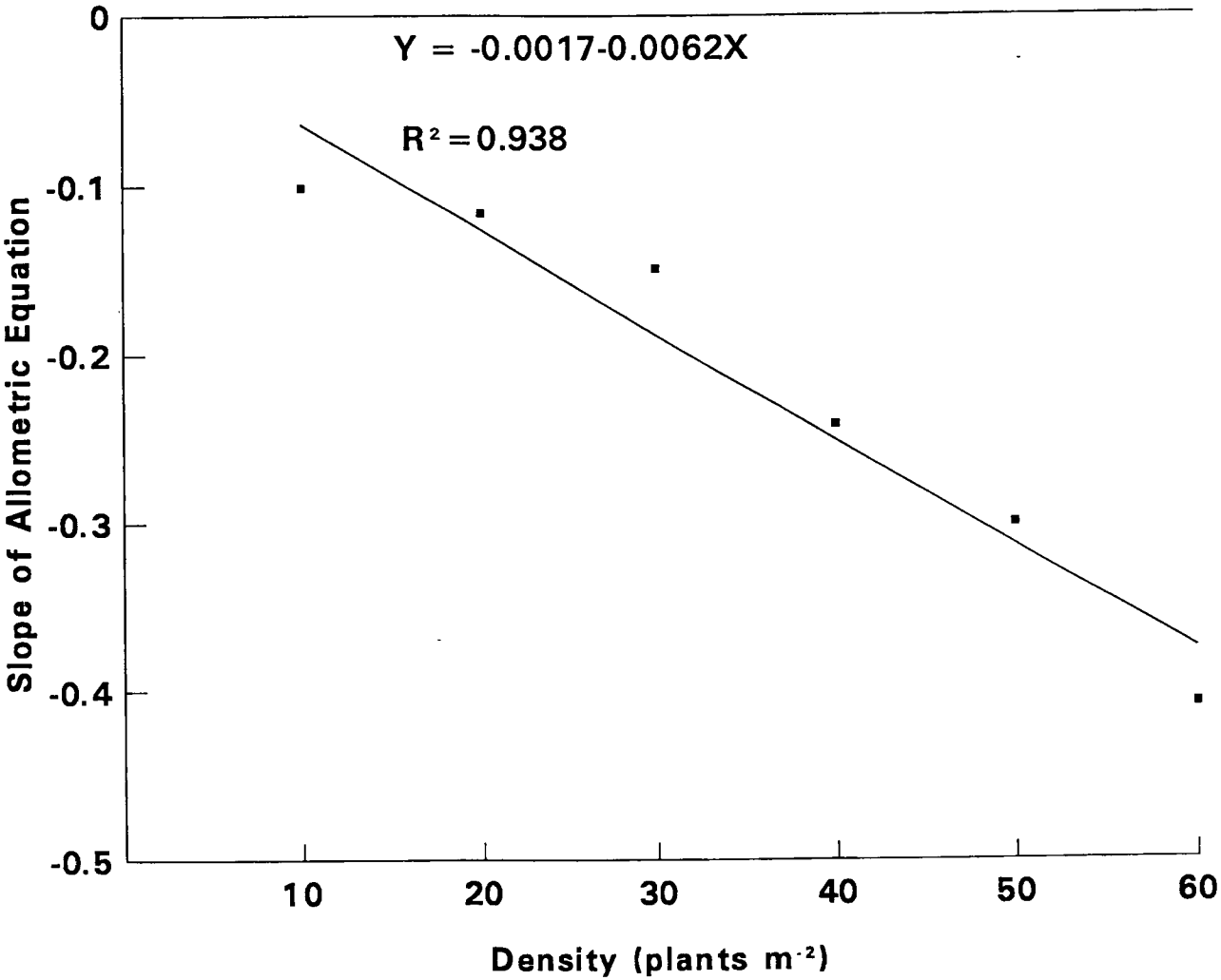

Fig.10. Functional relationship between slope of allometric equation and population density

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 was no indications of non-linearity. Our results are in agreement with Stutzel *et al.* (1988).

Reproductive Efforts

Various theories proposed to explain resource allocation patterns assume that vegetative and reproductive processes compete for a common pool of resources and that an increase in one activity necessarily results in a proportional decrease in the other activity (Harper, 1977). Biomass allocation to reproductive organs, particularly seeds and pods in the case of mungbean, provides a comprehensive measure of reproductive output. Reproductive output is a crucial measure of plant productivity and fitness. In the present study reproductive effort was calculated using aboveground structures alone and assuming that the proportion of biomass aboveground was relatively constant over the comparisons being made among the treatments. Reekie and Bazzaz (1987) observed that for *Agropyron repens* reproductive effort calculated based on the aboveground biomass was a good indicator of the allocation on a total plant basis across a wide range of environments.

Values of reproductive effort plotted against planting density is presented in Fig. 11. It is apparent that RE decreased linearly with increase in population

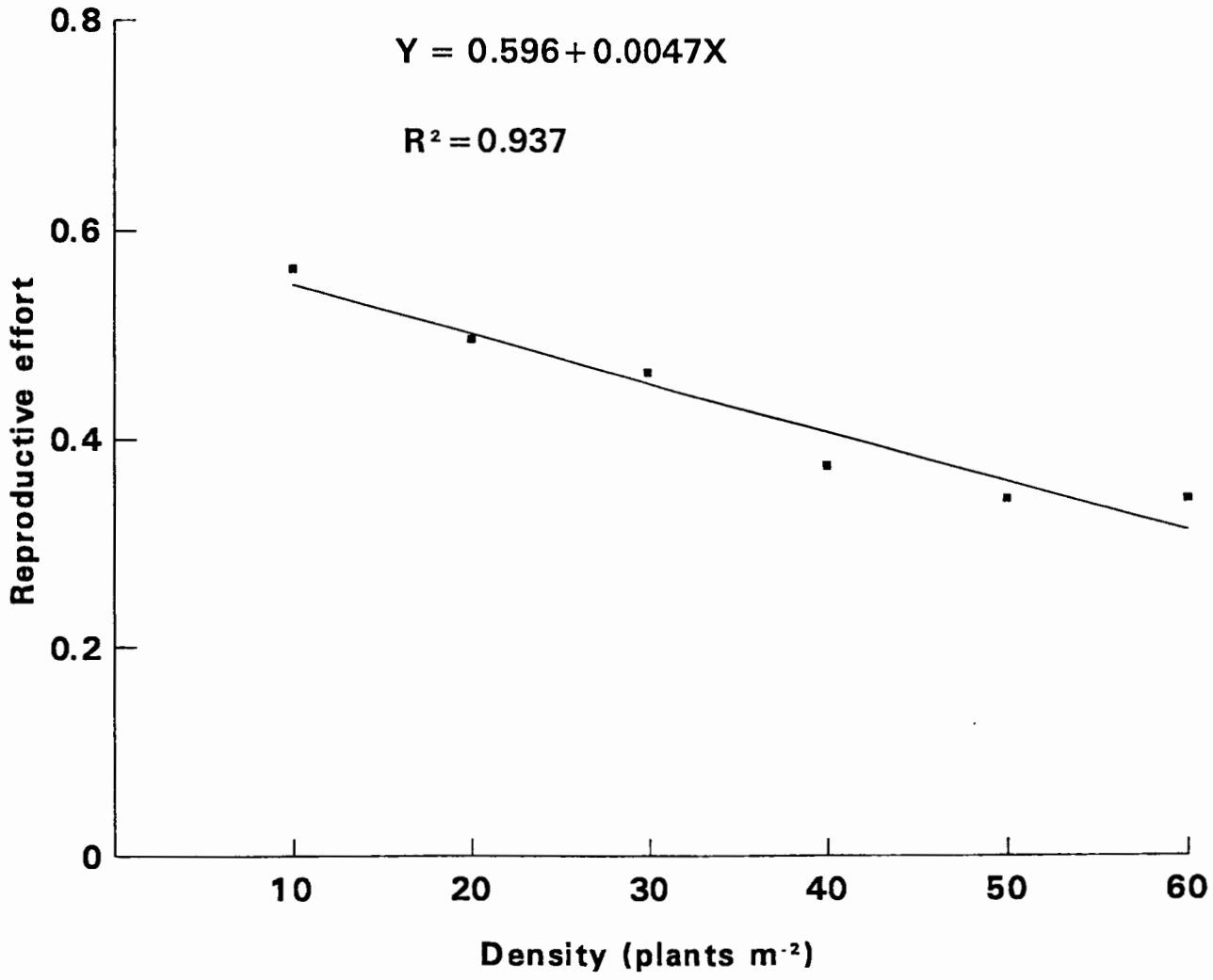

Fig .11 . Functional relationship between reproductive effort and population density

density. The results indicate that as the population density increases the plant competition constrains reproductive allocation, although reproduction did not reduce the overall growth of mungbean (Fig. 7).

Yield and yield attributes

Data on seed yield and yield attributes as influenced by population density and planting configuration are presented in Table 9 and Table 10. Population density influenced significantly all the yield parameters except seed size. Likewise, planting configuration exerted significant influence on nearly all the attributes. Seed yield is the function of pods per plant, number of seed per pod and seed size. Pod length is usually a varietal character and varies depending on the environmental condition. Pod length by itself does not contribute directly to the yield, but there is often a close relationship between the number of seeds per pod and pod length.

In the present study, the number of pods ranged between 5.3 and 11.2, a two-fold variation, across planting density treatments. Number of pods per plant decreased almost linearly with the increase in density. Similarly, increase in density also decreased pod length. Seeds per pod correlated strongly ($r=0.98$) with pod length. As the size of the pod decreased, the number of seeds per pod also reduced ($r=0.99$). The number of seeds per pod varied from 6.8 to 13.1 across the density.Seed size remained unaltered due to population density. Thus, seed

Table 9. Yield and yield attributes of mungbean as influenced by different density treatments

Density (plants m^{-2})	Pods $plant^{-1}$	Pod length (cm)	Seeds pod^{-1}	Seed size (mg)	Seed yield $plant^{-1}$ (g)	Seed yield ha^{-1} (kg)	Harvest index
10	11.204	8.554	13.120	46.01	6.820	682.00	0.378
20	9.816	7.614	10.023	45.81	4.502	900.22	0.310
30	8.811	7.237	8.603	45.58	3.450	1035.00	0.288
40	7.299	6.638	7.854	45.33	2.561	1024.44	0.260
50	6.632	6.639	6.959	44.81	2.062	1031.11	0.243
60	5.257	6.408	6.781	44.75	1.511	906.67	0.200
CV(%)	7.87	3.53	8.20	2.25	5.60	5.58	3.49
$LSD_{0.01}$	0.827	0.325	0.937	NS	0.251	66.75	0.029

Table 10. Yield and yield attributes of mungbean as influenced by different planting arrangements

Configuration	Pods $plant^{-1}$	Pod lenth (cm)	Seeds pod^{-1}	Seed size (mg)	Seed yield $plant^{-1}$ (g)	Seed yield ha^{-1} (kg)	Harvest index
1:1	7.597	6.968	8.684	44.97	3.139	838.56	0.269
1:2.5	8.076	7.177	8.759	45.40	3.405	913.78	0.278
1:5	8.837	7.399	9.228	45.78	3.909	1037.39	0.294
CV(%)	7.87	3.53	8.20	2.25	5.60	5.58	3.49
$LSD_{0.01}$	0.585	0.230	NS	NS	0.177	47.20	0.020

yield per plant differed greatly depending on planting density. Compared with yield parameters, seed yield was more affected by population density. It varied from 1.511 g to 6.820 g per plant, nearly a five-fold variations. The extent of variation in seed yield paralleled the variation in density.

Harvest index, or the proportion of seeds to total aboveground biomass, was generally low which varied between 0.200 and 0.378. Increase in population density generally tended to decrease harvest index. Planting configuration exerted significant influence on most yield parameters (Table 10). Pods per plant and pod length generally increased linearly with the increase in rectangularity. Seeds per pod and seed size were found non-responsive to planting arrangement. Seed yield per plant varied from 3.139 g to 3.909 g following the trend similar to pods per plant. Rectangularity also influenced harvest index (HI) significantly; greatest rectangularity (1:5) giving the largest HI value (0.294). A simple linear regression analysis using reproductive effort as independent variable and harvest index as dependent variable showed a significantly positive relationship (Fig. 12).

Plotting of yield per plant against harvest index suggested that the seed yield was highly dependent on harvest index and over 96% variation in yield could be explained from the variation in harvest index (Fig. 13).

When the yield per plant is converted into seed yield per unit area, the difference across density is narrowed. It varied from 68.2 g m^{-2} to 103.10 g m^{-2}. Seed yield per unit area tended to increase up to 30 plants m^{-2} and further increase

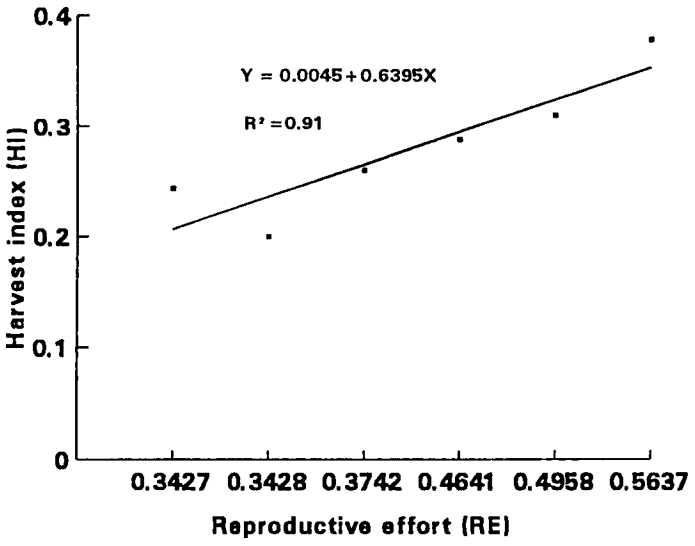

Fig.12. **Functional relationship between harvest index (HI) and reproductive effort (RE) in mungbean**

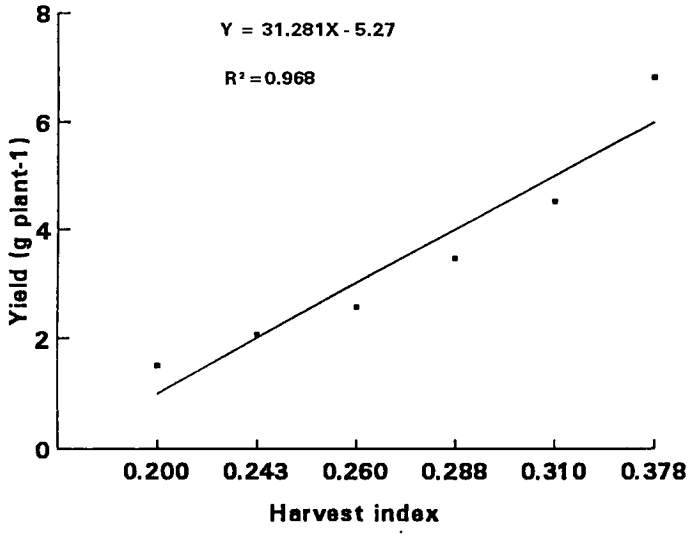

Fig . 13 . Functional relationship between yield (g plant^{-1}) and harvest index in mungbean

in density did not result any further increase in yield per unit area. A density of 60 plants m^{-2} rather tended to decrease seed yield. The relationship between density and seed yield per unit area was thus a curvilinear rather than linear. Our results are in conflict with Muchow and Charles-Edwards (1982) but compare favourably with those of others.

CHAPTER V

SUMMARY AND CONCLUSION

An experiment was carried out at the Institute of Postgraduate Studies in Agriculture (IPSA), Salna, Gazipur farm during kharif I season 1996 to assess the influence of population density and planting configuration on allometry, dry matter allocation and yield of mungbean. Six levels of planting 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) formed the treatment variables. A blanket dose of 40 kg N, 15 kg P and 20 kg K ha^{-1} in the form of urea, TSP and MP was applied. Seeds were sown on March 21, 1996 and the variety used in the study was NM 92. Plant samples were collected at a weekly interval beginning 12 DAE till harvest to determine leaf area (LA) and dry matter accumulation by the plant. At maturity, plants were harvested to record yield parameters. Standard regressions were used to describe allometric patterns.

Total dry matter accumulation of mungbean plant was largely affected by planting density. Effect of planting density was small, except leaf area and leaf weight. Regardless of treatment differences, dry matter accumulation followed a sigmoid growth curve. Initially the accumulation was slow which increased as plant aged reaching peak at reproductive and pod-fill stages. Plant dry matter decreased with increasing population density and the trend persisted throughout the

growing season except at the early vegetative phase. However, total dry matter (TDM) per unit area increased with increasing density.

Plant competition was estimated by regression analysis using total dry matter (TDM) against density for individual sampling dates. Steeper slope toward the sampling dates corresponding to reproductive and pod-fill stages suggested that the density induced plant competition was more critical at those two stages of plant growth. Changes in dry matter accumulation in different components of mungbean were monitored at a regular interval over the growing season. It was observed that the changes in dry matter accumulation in both stem and reproductive organs relative to leaf growth were more susceptible to density included competition. Allometric relationship between the ratio of stem weight per leaf weight and leaf weight (W_S/W_L vs. W_L) suggested that as the plant interference due to crowding increased, mungbean plants tended to allocate more photosynthates to structural organs and invested less in the photosynthesizing or reproductive organs. This might be indicative of plant strategy to endure stress.

Per plant seed yield decreased progressively with increasing population density; but yield per ha increased with increasing density up to 30 plants m^{-2}. Further increase in planting density resulted no increase in yield. Most yield parameters except seed size were influenced by planting density.

Seed yield increased as the rectangularity in planting arrangement increased. Such yield advantage came mainly from the increased number of pods per plant.

The present experiment was conducted for only 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. Against this backdrop, the conclusion drawn from the present study should be taken as tentative and further studies involving wider planting densities and cultivars are to be undertaken.

CHAPTER VI

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