

## Agro-physiological Studies on the Yield Performance of Mungbean

### II. Cultivars differences in dry matter production, partitioning and yield components, and their relationships with earliness in flowering\*

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**Abstract:** The relationships among dry matter production and partitioning, yield components, earliness in flowering and seed yield in 24 cultivars of mungbean, *Vigna radiata* (L.) Wilczek, were studied in field experiments in 1987 and 1988 to examine the agro-physiological basis of yield. Total dry matter (TDM) production and partitioning significantly differed among cultivars (cvs.), but cv. performance were similar across years. Early flowering cvs. produced less TDM and vegetative DM, but had higher seed-stem ratio, harvest index (HI) and yield than later flowering ones. Since stem DM was negatively correlated with seed-stem ratio and HI, reduced stem DM may increase yield. Seed yield was correlated with TDM only in cultivars with low TDM. Cvs. with high TDM were separated into 2 groups, one with higher HI and higher yield, and another with lower HI and lower yield. Seed yield was mainly determined by the number of pods/plant while the number of seeds/pod, 100 seed weight, and pod length tended to compensate for reduced pod number. It was suggested that earlier flowering, higher TDM but lower percentage of stem DM, higher HI, and more and longer pods with more and bigger seeds, which were shown by the top-yielding cv. KUS in both years, characterize the mungbean "Ideo-type" for warm temperate environments.

**Key words:** Dry matter partitioning, Dry matter production, Harvest index, Ideo-type, Mungbean, Seed-stem ratio, Seed yield, *Vigna radiata* (L.) Wilczek, Yield components.

リョクトウの収量成立に関する栽培生理学的研究 第2報 乾物生産、分配及び収量構成要素の品種間差異とそれらの開花の早晩性との関係：フランシスコ、P. B., Jr.・前田和美〔愛媛大学大学院連合農学研究科・(高知大学農学部)〕

**要 旨：**インド（1品種）とアジア各地域産の弱感光性の計24品種を用い、乾物生産とその器官別分配、収量構成要素、子実収量などと品種の開花の早晩性との関係について圃場条件で2カ年にわたり調べた。収穫時の個体全乾重（TDM）、器官別乾重割合は品種間で有意な差異が見られたが、両年ともほぼ同様の品種の特性が認められた。開花の早い品種では遅い品種よりもTDMと栄養器官乾重が小さく、粒茎比と収穫指数（HI）が大きい傾向が認められた。茎乾重は粒茎比及びHIとは高い負の相関を示し、茎乾重を減らすことにより子実収量が高められる可能性が示唆された。子実収量は、全品種ではTDMとの相関が見られなかったが、TDMの小さい品種では正の相関を示した。TDMが大きい品種は高収量・高HIと低収量・低HIの2群に分かれた。子実収量の主支配要因は1株莢数で、1莢粒数、100粒重及び莢長は莢数減少に対して補償的關係にあった。2カ年とも最高収量を示した品種KUSに代表される、開花が早く、TDMは大きい茎乾重割合が小さく、そしてHIが大で、莢数が多い、莢が長い、1莢粒数が多い、より大粒などの特性は温暖な温帯地域に適したリョクトウの“Ideo-type”の特性を示唆するものと考えられる。

**キーワード：**Ideo-type, 乾物生産, 乾物分配, 子実収量, 収穫指数, 収量構成要素, 粒茎比, リョクトウ。

The authors described in a previous paper<sup>6)</sup> that early flowering mungbean cultivars had a limited vegetative growth and development but produced higher seed yield than later flowering ones. High yielding cultivars also exhibited earlier initiation of pod maturation and longer reproductive growth

duration.

The total amount of plant dry matter accumulated (biological yield) is one of the factors that determine yield. However, in crop species where the seeds are of economic importance, the capacity and efficiency of dry matter partitioning to the seeds appear to be more critical in determining yield. Increase in yield of improved cultivars of many grain legume crop species like peanut<sup>4)</sup>, and

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soybeans<sup>7,8)</sup> have been associated with increase in dry matter partitioning to the seeds rather than with increase in total biomass. In mungbean, seed yield was also found to be more related with harvest index than with biomass<sup>1,14)</sup>.

Both biological yield and harvest index were found to be strongly correlated with the number of days to maturity, i.e., 95% of pods are brown, in soybeans<sup>1)</sup>, and in mungbean, adzuki bean and rice beans<sup>14)</sup>. Mungbean yield is primarily determined by the number of pods, while the number of seeds/pod and seed weight seem to have lesser influence<sup>1,2,6,10,21)</sup>.

The present paper examines the relationships among dry matter production, partitioning, yield and yield components, and earliness in flowering in some mungbean cultivars grown in a warm temperate environment in Japan.

### Materials and Methods

Eighty three and 24 cultivars (cvs.) of different origins were sown in May 7, 1987 and May 9, 1988, respectively, at The Farm of the Faculty of Agriculture, Kochi University, Nankoku, Kochi. Details of the experimental and cultural methods were given in a previous paper<sup>6)</sup>. At maturity, 7 plants in 1 m of the central row of 3 row-plots in 1987, and 14 plants in the two central rows of 4 row-plots in 1988, were cut at ground level. In both years, the harvested plants were separated into leaves, stems+petioles, seeds, and pod walls. In 1988, the branches were separated from the main-stem organs. All plant parts were oven-dried at 80°C for 72 h, then weighed for dry matter production and partitioning studies.

Since fallen leaves and roots were not collected in both years, dry matter partitioning indices were biased for the pods and seeds. Nevertheless, it was believed that the data would give a reasonably reliable indication of the differences among cvs. In chickpea<sup>23)</sup> and soybeans<sup>24)</sup>, apparent harvest index based on standing total dry matter at maturity, was found to adequately reflect the true harvest index based on total biomass.

Mature pods from a 1 m<sup>2</sup> area at the middle of the plots, were harvested and counted daily. After air-drying the pods in the shade for 1 month, 10 pods were randomly picked for the determination of pod length, number of seeds/

pod and 100 seed weight. The rest of the pods were hand-threshed and all the seeds were weighed for the estimation of seed yield.

### Results and Discussion

#### 1. Dry matter production and partitioning at harvest

Total dry matter (TDM) and plant organs DM at harvest varied significantly among cvs. in both years and were lower in 1988 (Table 1). DM reduction in 1988 was highest for the pod due to the decreased number of pods/plant (Table 4). This is reflected by the lower percentage of pod DM in 1988 which consequently increased the percentages of the leaf and stem DM (Table 2). The relative performance of the cultivars were stable in both years for TDM and all organ DM except for stem DM indicating that the latter is the most responsive to the environment. Stem DM had the highest coefficient of variation (CV) in 1988 probably because of the high variability in the number of branches as previously reported<sup>6)</sup>, total branch DM, and all branch organ DM with CVs all exceeding 100% (Table 1).

The number of days to first flower (DFF) was positively correlated with leaf and stem DM and their percentages, but was negatively correlated with pod (reproductive) and seed DM and their percentages (Table 3). These relationships are mainly the consequences of the determinate habit of the cvs. used where vegetative growth effectively ceases at the onset of flowering. Later flowering cvs. therefore accumulated more vegetative than reproductive DM, since the long vegetative growth period was not accompanied by a prolonged reproductive growth as reported earlier<sup>6)</sup>. This is consistent with the observations on mungbean and other grain legume crops<sup>14)</sup>. DFF, however, is not highly correlated with TDM (Table 3, Fig. 1).

Seed yield was not correlated with TDM but was negatively correlated with leaf DM, stem DM, and their percentages to TDM, and was positively correlated with reproductive DM (seed+pod wall) and seed DM weight (Table 3). The absence of correlation between TDM and yield indicates that high TDM does not necessarily guarantee high yield. The data in 1988 when TDM was lower than in 1987 showed that seed yield is positively correlated

Table 1. Cultivara differences in dry matter weight at harvest. Unless otherwise specified, values given are for the whole plant including the organs of the main-stem and the branches (24 cultivars and means of two replicates).

	Total DW <sup>(1)</sup>				Leaf DW				Stem DW				Pod DW				Seed DW				Branch				Total DW <sup>(2)</sup>				Stem DW				Seed DW			
	1987	1988	1987	1988	1987	1988	1987	1988	1987	1988	1987	1988	1987	1988	1987	1988	1987	1988	1987	1988	1987	1988	1987	1988	1987	1988	1987	1988								
Maximum	20.69	18.34	6.63	7.07	12.00	10.75	7.86	6.62	5.24	5.96																										
Minimum	4.76	3.76	0.91	0.61	0.16	1.20	0.60	0.24	0.02	0.12																										
Mean	13.01	10.29	2.98	2.78	5.04	4.58	4.20	2.91	2.78	2.14																										
SD	4.76	4.99	1.80	2.04	3.23	3.54	2.00	1.93	1.47	1.56																										
CV (%)	36.60	48.60	60.40	73.30	20.90	77.30	43.60	66.40	53.00	72.90																										
LSD <sub>0.05</sub>	6.73	5.23	1.81	2.14	3.40	0.45	3.08	1.60	2.07	1.37																										
r between years	0.55**		0.59**		0.24 <sup>ns</sup>		0.83***		0.82***																											

with TDM only for cvs. with TDM of less than 10 g/plant ( $266 \text{ g m}^{-2}$ ), but not in cvs. with higher TDM (Fig. 1). Apparently, dry matter is a yield-limiting factor where TDM is low but ceases to be so where TDM is relatively high. Yield differences in cvs. with low TDM can therefore be attributed to differences in TDM, but other factors influence yield when TDM is high. The separation of the cvs. with high TDM into high and low yielding groups, and the fact that the medium yielding group had lower TDM than the low yielders, strongly indicate that high TDM is not critical for high seed yield. As will be discussed later, the efficiency of DM partitioning to the seed is more critical than TDM in determining yield.

## 2. Dry matter partitioning indices to the seeds

### (1) Seed-stem ratio

Seed-stem ratio considerably differed among cvs. (Table 2). The average across cvs. was slightly higher in 1988 but the cv. response to environmental factors in both years was similar ( $r=0.90^{***}$ ). Since seed DM was lower in 1988, the higher seed-stem ratio in this year could have been due to the lower stem DM resulting from the lesser branch development as reported earlier<sup>6</sup>). Since stem DM and seed-stem ratio are highly negatively correlated with each other ( $r=-0.87^{***}$ ), high seed-stem ratio could be achieved by reducing stem development, probably through breeding of less branched cvs. or reduction in branch development which may be effected by closer plant spacing. The data obtained in 1988 showed that, averaged across cultivars, branch stem DM accounted for about 13% of the whole plant stem DM but the branches produced only about 6% of the total seed DM (Table 2). It is interesting to note, however, that the branch stem DM of the top-yielding KUS check was only about 10% of the total stem DM but produced about 22% of the total seed weight. The possibility of increasing mungbean seed yield through reduced DM partitioning to the branches deserves some attention. In soybeans, Kokubun et al.<sup>12</sup>) have demonstrated that debranched plants have a higher efficiency of assimilate partitioning to the pods and yielded higher than the control plants. In peanut, Maeda<sup>17,18,19</sup>) found that less branching which decreases dry matter partitioning to the stem system allows greater dry matter partitioning to the fruits and seeds,

resulting to higher harvest index and seed yield.

### (2) Harvest index

Cultivar difference in apparent harvest index (HI) were significant in both years and the average across cvs. was greater in 1988 than in 1987 (Table 2). The generally lower HI in 1987, in spite of the greater seed DM, may be attributed to the greater vegetative development and lodging caused by strong wind and rain at the onset of pod maturation which destroyed some mature pods. The higher HI in 1988 might be attributed to lesser primary branch formation. The negative correlation of stem DM with HI (Table 3) might suggest that the latter, and consequently seed yield, can be improved by decreasing stem development as described above. The significantly negative relationship between percentage of stem DM and HI ( $r=-0.94^{***}$ ) strongly supports this possibility.

The negative correlations of HI with DFF (Table 3) and with days to maturity, i.e. more than 95% of the pods matured ( $r=-0.64^{***}$  and  $-0.17^{ns}$  in 1987 and 1988, respectively), are the consequences of extended vegetative growth duration without an accompanying increase in the reproductive phase, in agreement with the data obtained by Lawn<sup>14</sup>). In soybean cvs., Schapaugh et al.<sup>24</sup>) similarly found a strong negative relationship between HI and maturity.

In contrast to TDM, HI was significantly and positively correlated with seed yield (Table 3). Apparently, the relationship of HI with yield is associated with dry matter production. The data in 1988 showed that the correlation of HI with seed yield was positive and highly significant only for cvs. with TDM of more than 10g/plant (Fig. 2, closed symbols). Seed yield therefore is mainly a function of HI where DM ceases to be a limiting factor. This could reasonably explain the separation of the cvs. with high DM into high and low yielding groups since HI of the cvs. in the former were higher than those in the latter (Figs. 1 and 2). In general, HI seems to be more critical for yield than TDM as further indicated by the observation that the cvs. with low TDM yielded higher than many cvs. with high TDM, because the former have higher HI than the latter. This is consistent with the data obtained for other grain legume crops

Table 3. Correlation coefficient (*r*) values among total plant and organ dry matter (DM), dry matter partitioning indices, days to first flower, and seed yield (*n*=24).

Parameter	Days to first flower		Seed yield		Harvest index	
	1987	1988	1987	1988	1987	1988
Total dry matter (TDM)	0.26 <sup>ns</sup>	0.42*	-0.02 <sup>ns</sup>	-0.12 <sup>ns</sup>	-0.54**	-0.69***
Vegetative DM	0.44*	0.66***	-0.29 <sup>ns</sup>	-0.23 <sup>ns</sup>	-0.77***	-0.88***
Leaf DM	0.50*	0.67***	-0.39 <sup>ns</sup>	-0.49*	-0.82***	-0.86***
Stem DM	0.39 <sup>ns</sup>	0.64***	-0.23 <sup>ns</sup>	-0.41*	-0.73***	-0.85***
Reproductive DM	-0.70***	-0.79***	0.92***	0.95***	0.64***	0.69***
Seed DM	-0.74***	-0.79***	0.94***	0.95***	0.72***	0.70***
Vegetative DM/TDM(%)	0.78***	0.83***	-0.69***	-0.65***	-0.94***	-0.99***
Leaf DM/TDM(%)	0.77***	0.69***	-0.81***	-0.56***	-0.84***	-0.81***
Stem DM/TDM(%)	0.67***	0.74***	-0.60**	-0.63***	-0.80***	-0.90***
Reproductive DM/TDM(%)	-0.78***	-0.83***	0.69***	0.65***	0.94***	0.99***
Seed/stem DM	-0.76***	-0.83***	0.58**	0.61**	0.87***	0.97***
Harvest index (%)	-0.74***	-0.86***	0.70***	0.70***	—	—

ns, \*, \*\*, \*\*\* : Not significant and significant at 5%, 1% and 0.1%, respectively.

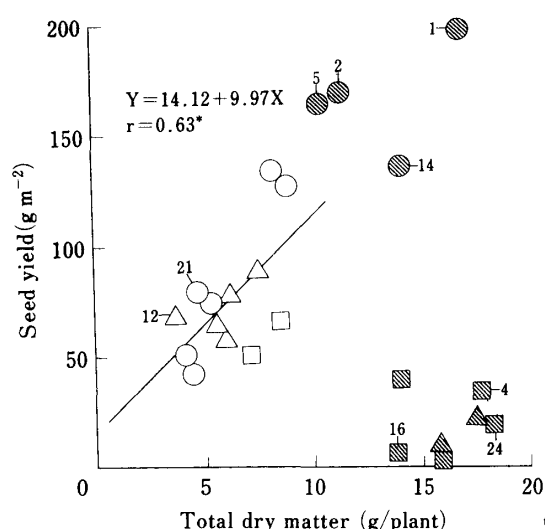


Fig. 1. Relationship between seed yield and total dry matter at harvest in 1988.

Note: Plotted data are means of two replicates. Number for some symbols are cultivar numbers (see text, or Table 2 of Part I<sup>6</sup>).

○, ●: early flowering cultivars (46-50 DAP)

△, ▲: mid flowering cultivars (51-56 DAP)

□, ■: late flowering cultivars (57-64 DAP)

Open and closed symbols represent cultivars with low (less than 10g/plant) and high (more than 10g/plant) total dry matter, respectively.

Correlation equation and coefficient of correlation are for cultivars with low total dry matter only.

like peanut<sup>2,17-19</sup>) and soybeans<sup>7,8,16</sup>). Nevertheless cvs. with high TDM and high HI would undoubtedly produce higher yield.

Since TDM is not a yield-limiting factor in the top-yielding KUS (cv. No.1), its seed yield can be greatly improved by raising its HI level of about 32% to about 41% as exhibited by cv. A 176 (cv. No. 21).

### 3. Yield components

Yield components, i.e., number of pods/plant, number of seeds per pod, and 100 seed weight, and pod length varied significantly among cultivars in both years (Table 4). Coefficients of variation and correlation analyses suggested that yield and its components showed generally similar response for each cv. in both years, and that yearly differences in seed yield were primarily controlled by the number of pods/plant. The KUS (cv. No. 1) check and IPB M82-42-21 (cv. No. 24), consistently produced the most and the least number of pods, respectively. The latter cv. also had the least number of seeds/pod. Cv. V 1387 (cv. No. 2), one of the cvs. with high number of seeds/pod and possessing the heaviest seeds, had the longest pod. Cv. V 2773 (cv. No. 4) had the shortest pod while cv. A 3 (cv. No. 16) had the smallest seeds.

The number of pods/plant was lower in 1988 for almost all cvs., but the number of seeds/pod, 100 seed weight, and pod length were higher than in 1987 (Table 4). These might indicate that the other yield components tended to compensate for the reduced

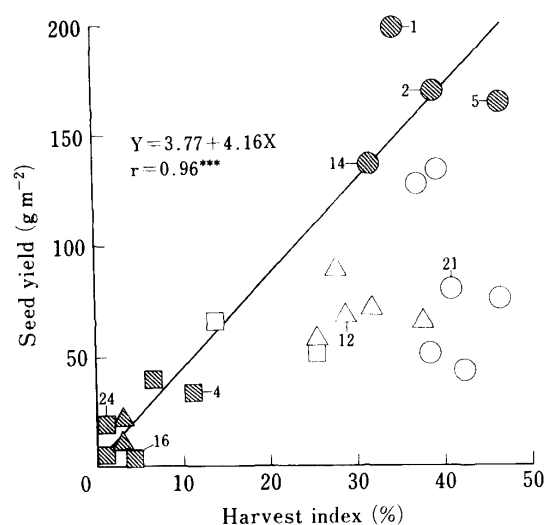


Fig. 2. Relationship between harvest index and seed yield in 1988.

Note: Plotted data are means of two replicates. Correlation equation and coefficient of correlation are for cultivars with high total dry matter only. See Fig. 1 for the legend of the symbols.

pod number. Data obtained by Lawn<sup>15)</sup> on mungbean showed that the number of seeds/pod, but not 100 seed weight, tended to increase as the number of pods/plant decreased in response to high population density. In soybeans, the reduction in pod number by shading treatment at flowering and pod elongation stages induced slight and significant increases in the number of seeds/pod and 100 seed weight, respectively<sup>11)</sup>. Depodding studies in soybeans<sup>5,11,25)</sup> also showed compensatory response of seed number and size, seed to pod wall ratio, and percentage seed abortion.

#### 4. Relationships between yield components with days to first flower and reproductive duration

Except for the number of seeds/pod in both years and pod length in 1987, all yield components were significantly correlated with the number of days to first flower (Table 5). Thus, the variation in the number of seeds/pod among the cvs. differing in earliness is low. This suggests that among the yield components, the number of seeds/pod is relatively the most stable as observed by other researchers on mungbean<sup>13,15)</sup>, and is a genetically-controlled character which is less influenced by the environment. The negative correlations of the yield components with days to first mature pod reflect the decreasing

amount of assimilates partitioned to the pods and seeds as flowering date is delayed<sup>6)</sup>.

Relationship of reproductive duration with yield components was consistently high only with the number of pods/plant while no correlation was observed between reproductive duration and 100 seed weight (Table 5). The strong relationship between reproductive duration and seed yield which was reported previously<sup>6)</sup>, could then be attributed primarily to the increase in the number of pods/plant in cultivars with long reproductive period and their compensatory relationship. Whether or not the long reproductive duration was accompanied by long pod filling period was not examined. Seed weight alone cannot provide a reliable indication for this, since seed weight is determined not only by the length of the pod filling period but by the rate of seed dry matter accumulation and the amount of dry matter partitioned to the seeds<sup>21)</sup> and the inherent differences in seed weight among cultivars.

#### 5. Relationships among seed yield and its components

Seed yield was positively correlated with all yield components, notably the number of pods/plant (Table 5). On a yearly basis, 100 seed weight and pod length seemed to be more associated than the number of seeds/pod with seed yield. When the data for two years were averaged, correlation of seed yield with the yield component was highest for the number of pods/plant ( $r=0.93^{***}$ ) and were also high but similar for the number of seeds/pod, 100 seed weight and pod length at  $0.61^{**}$ ,  $0.62^{**}$  and  $0.62^{**}$ , respectively.

The highly significant association of number of pods/plant with seed yield is consistent with the findings of other workers<sup>1,2,9,10,11,13,22)</sup>. The low correlation of seed yield with 100 seed weight and number of seeds/pod may be due to their lower sensitivity to the environment<sup>13,15)</sup>. This is supported in the present experiment by their low coefficients of variation (Table 4).

The consistently high correlation of pod length with yield which is comparable with those of 100 seed weight and number of seed/pod (Table 5), may be due to the tendency of longer pods to have more and heavier seeds than shorter ones, which could be a result of the selection process for high yielding cultivars

Table 4. Yield and yield components of mungbean cultivars (24 cultivars and means of 2 replicates).

	Seed yield (g m <sup>-2</sup> )		Pods/plant		Seeds/pod		100 Seed wt. (g)		Pod length (cm)	
	1987	1988	1987	1988	1987	1988	1987	1988	1987	1988
Maximum	184.31	198.49	15.0	16.6	14.40	15.60	5.92	7.44	10.82	12.63
Minimum	16.32	3.56	3.2	1.2	11.56	12.40	2.79	3.31	7.48	7.30
Mean	95.17	74.74	8.6	6.3	12.77	13.43	4.56	5.47	9.39	9.84
SD	50.12	54.37	3.1	3.6	0.71	0.80	0.91	1.17	0.94	1.24
CV (%)	95.20	72.70	36.4	57.0	5.50	6.00	19.90	21.30	10.00	12.60
LSD <sub>0.05</sub>	48.18	48.28	1.8	2.3	1.01	0.72	0.47	0.47	0.43	0.74
r between years	0.82***		0.79***		0.31 <sup>ns</sup>		0.95***		0.75***	

<sup>ns</sup>, \*\*\* : Not significant and significant at 0.1%, respectively.

Table 5. Correlation coefficient (r) values among number of days to first flower, reproductive duration, seed yield, and yield components.

Parameters	Pods/plant		Seeds/pod		100 Seed weight		Pod length	
	1987	1988	1987	1988	1987	1988	1987	1988
Days to flower	-0.71***	-0.73***	-0.23 <sup>ns</sup>	-0.47*	-0.68***	-0.68***	-0.43*	-0.71***
Reprod. duration <sup>1)</sup>	0.63***	0.79***	0.15 <sup>ns</sup>	0.60*	0.38 <sup>ns</sup>	0.40 <sup>ns</sup>	0.37 <sup>ns</sup>	0.49 <sup>ns</sup>
Seeds/pod	0.36 <sup>ns</sup>	0.62**	—	—	0.28 <sup>ns</sup>	0.39 <sup>ns</sup>	0.53**	0.62**
100 Seed weight	0.40 <sup>ns</sup>	0.31 <sup>ns</sup>	—	—	—	—	0.62**	0.85***
Seed yield	0.90***	0.90***	0.30 <sup>ns</sup>	0.66***	0.66***	0.54**	0.49*	0.62**

1) Number of days from first flowering to full pod maturity. <sup>ns</sup>, \*, \*\*\*, \*\*\*\* : Not significant and significant at 5%, 1% and 0.1% respectively.

in the past. As such, pod length should be considered as an important mungbean yield component.

The number of seeds/pod and 100 seed weight were not significantly associated with each other ( $r=0.41^{ns}$ ). The top-yielding KUS (cv. No. 1) check and V 2984 (cv. No. 5) had high and medium number of seeds/pod, respectively, but both had the lowest 100 seed weight among the 10 top yielders. The 3rd to 8th top yielders had 100 seed weight values between KUS and V 2984, except the 5th yielding V 1387 (cv. No. 2) which was outstanding in possessing the highest values for these two yield components. It is interesting to note that the high yielding cultivars as a group had big and numerous seeds/pod, indicating the close association of these components with seed yield. Nevertheless, since these characters are stable across environments<sup>13,15)</sup>, yield increase can be achieved most likely by increasing pod number using optimum plant

density under moderate water availability. Although we have not yet conducted experiments to examine this possibility, the results obtained by other investigators showed that population density<sup>15)</sup>, irrigation<sup>3)</sup>, and moisture availability<sup>13)</sup> significantly affect the number of pods and seed yield. If the top yielding KUS (cv. No. 1) check in the present experiment would still produce the highest number of pods with these much improved cultural practices, and will not be out-yielded by the big-seeded and long-podded V 1387 (cv. No. 2)—the 2nd top yielder in 1988 and 5th overall, and VC 2768A (cv. No. 14)—the 4th yielder in 1988 and 6th overall, then KUS could be the mungbean “Ideo-type” for warm temperate environments.

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