Fig. 1. Sister F_2 plants from the cross 81-1 (resistant) × NK6604 (susceptible) showing highly susceptible segregate (left) and resistant segregate (right), in the field. Picture shows cumulative ozone damage after several episodes of high pollution and high temperature.

in resistant 'Bonanza'. Both acute and chronic leaf injury were visible in 'Monarch Advance'.

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Response of Mung Bean [*Vigna radiata* (L.) Wilczek Var. *radiata*] and Soybean [*Glycine max* (L.) Merr.] to Increasing Plant Density[1, 2]

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Abstract. The performance of the mung bean cultivar Thai Green Oil was compared with the soybean cutivar Hsih-Hsih over a range of 12 plant densities from 10,000 to 800,000 plants/ha. Increasing plant density was positively related to yield and plant height and negatively related with significant reductions in flowering, yield per plant and plant branching. The higher yield potential of soybeans at high plant densities, relative to mung bean, was attributed to differences in the production of the number of flowers per plant and, subsequently, the number of pods per plant. This relationship can be applied to breeding and selecting improved mung bean cultivars.

The Asian Vegetable Research and Development Center has initiated a mung bean (*Vigna radiata* (L.) Wilczek var. *radiata*) improvement program with the specific objective of elevating the yield potential of this nutritionally important Asian crop. One approach considered is to increase yield by increasing plant density.

It has long been known that the response of the soybean (*Glycine max* (L.) Merr.) to plant density varies among cultivars (3, 4). The application of this relationship has been hindered by crop management restrictions which require interrow tillage for weed control. Donovan et al. (1), recognizing the application of newly available chemical weed control methods, investigated this application, and reported increased soybean yield from closely drilled soybean stands.

In general, commercial yield levels of most bean species in Southeastern Asia are low and rarely exceed one metric ton/ha. Commercial soybean yields in Southern Taiwan are distinctly higher, commonly exceeding 2 and sometimes even 2.5 metric tons/ha. This difference is attributed to the development of an intense crop management system for soybeans following lowland paddy rice. One striking aspect of this crop management system is the relatively higher soybean seeding rates, ranging from 320,000 to 640,000 seeds/ha.

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These seeding rates produce plant densities 2 to 4 times those common for other bean crops. Such greatly increased plant densities are feasible because of low weed populations existing after the paddy rice is harvested.

Sawing et al. (2) reported poor yield response to increased mung bean plant density. However, it is not known how such differences, relative to soybean, might be expressed. Our objective was to determine how the mung bean responds to increased plant density relative to the soybean. A better understanding of the responses of both crops to population stress would be helpful in establishing the plant breeding criteria necessary to identify mung bean selections that are better able to withstand increased plant density.

Materials and Methods

The soybean cv. Hsih-Hsih and mung bean cv. Thai Green Oil selected for study are widely used and well-adapted commercial cultivars in Southern Taiwan. A randomized complete block design replicated 6 times was planted on a plot of uniform soil type. Prior to hand seeding, the selected area was fertilized at the rate of 40 N, 60 P_2O_5 and 40 K_2O kg/ha. and turned under with compost applied at a rate of 20 tons/ha. By intention, seeding densities exceeded the desired plant densities and stands were thinned to obtain plant densities of 1, 2, 3, 4, 6, 8, 12, 21, 30, 40, 60, and 80 plants per square meter (Table 1). Each treatment plot measured 3 x 1 m and plots were contiguous within blocks. The blocks were separated by 1-m walkways to provide access for note taking and weed control. The entire experimental area was uniformly irrigated by sprinklers on 4 occasions during development of the crop. Weeds were controlled manually as required. Potential disease and insect problems were controlled with 1 application each of benomyl, malathion, and diazinon applied at recommended rates just before flowering.

Data were collected on the frequency of open flowers for both species at all 12 plant densities. Yield component estimates (mean seed wt, mean number of seeds per pod, and mean number of pods per plant) were obtained from samples taken from the first square meter of each 3-meter plot. The second (or center) square meter was harvested for total grain yield. The third square meter was reserved for snap bean and green-shell bean production data. Replications 1, 2, and 3 were continuously harvested at the snap bean stage. Replications 4, 5, and 6 were continuously harvested at the green shell bean stage. The mung beans and soybeans were treated identically. Additional notes on plant height and branching were obtained from the center square meter of each plot during dry bean harvest. Protein quantities were determined by the orange dye binding method (Udy) standardized with the micro-kjeldahl method. Soybean oil quantities were measured by the Soxhlet method.

Table 1. Planting scheme used to achieve the desired number of plants per unit area.

Plants per square meter[z]	Number of rows	Distance (in cm) between	
		rows	plants
1	1	100	100
2	1	100	50
3	1	100	33
4	2	50	50
6	2	50	33
8	2	50	25
12	3	33	25
21	3	33	14
30	3	33	10
40	5	20	12
60	5	20	8
80	5	20	6

[z] To convert to the number of plants per hectare, multiply by 10,000 or to the number plants per acre by 4049.

Results

Flowering. Increased plant density depressed the total number of flowers per plant that opened throughout the crop's duration for both species (Fig. 1). This effect was more apparent for mung bean than for soybean. Moreover, the pattern of flowering intensity was dissimilar. The primary effect of increased plant density on the soybean cultivar was observed to be a decrease in the frequency of flowering subsequent to the first flush (Fig. 2). Mung bean flowering was depressed throughout the entire flowering period (Fig. 3) by increasing plant density.

Yield. The total dry wt production harvested at the snap bean stage for soybean and mung bean were dissimilar in response to increasing plant density (Fig. 4). Soybean production plateaued at significantly higher plant densities than did mung bean. Similar results were obtained for soybean and mung bean production of dry wt harvested at the green-shell and dry bean stages (Figs. 5, 6).

We concluded from multiple regression analyses of the relationship of the combined effects of seed wt and number of pods per plant on yield that, as plant density increased, the preponderance of the response of the plant was expressed by the number of pods per plant. The relative importance of these 2 yield components to yield can also be estimated from Figs. 7, 8, and 9. The striking similarities between the mung bean and soybean yield per pod suggest that the fourfold differences in yield per unit area for sobean *vs.* mung beans shown in Fig. 6 can only be ascribed to differences in the production of pods per plant.

The proportion of open flowers that set mature pods was independ-

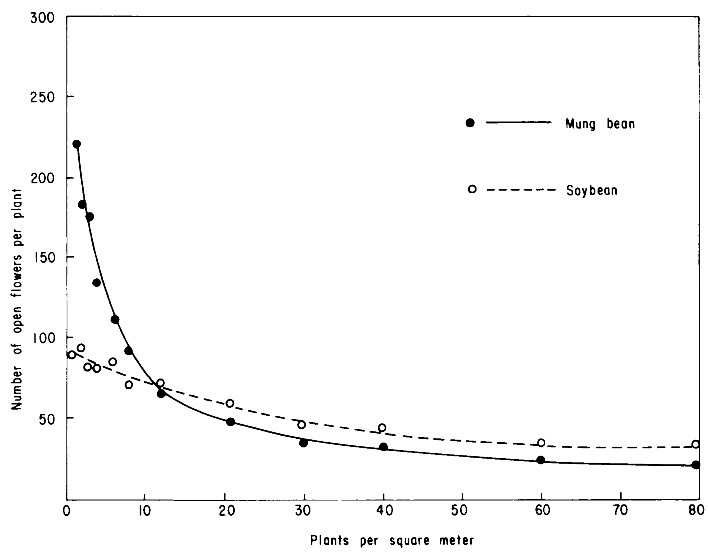

Fig. 1. Effect of plant density on the number of flowers per plant.

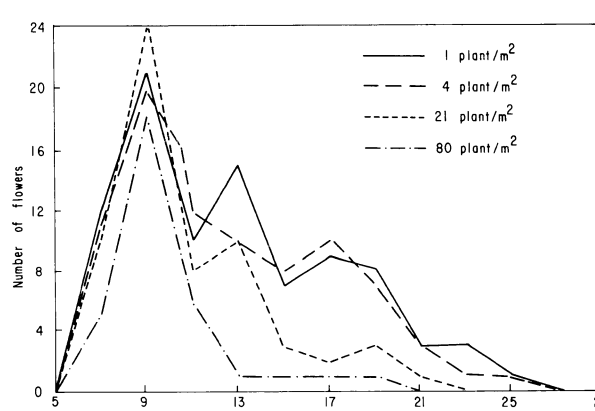

Fig. 2. Effect of plant density on the intensity and duration of soybean flowering. For simplicity of presentation, selected plant densities from the range studied are given.

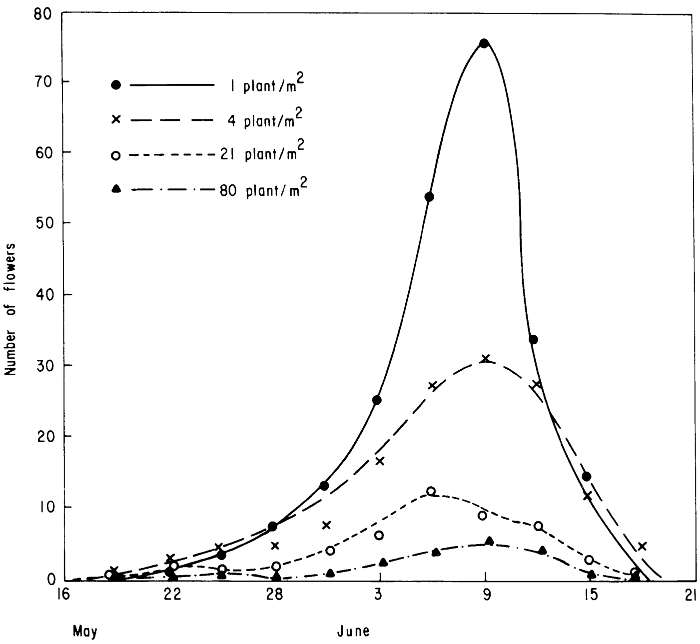

Fig. 3. Effect of plant density on intensity and duration of mung bean flowering. For simplicity of presentation, selected plant densities from the range studied are given.

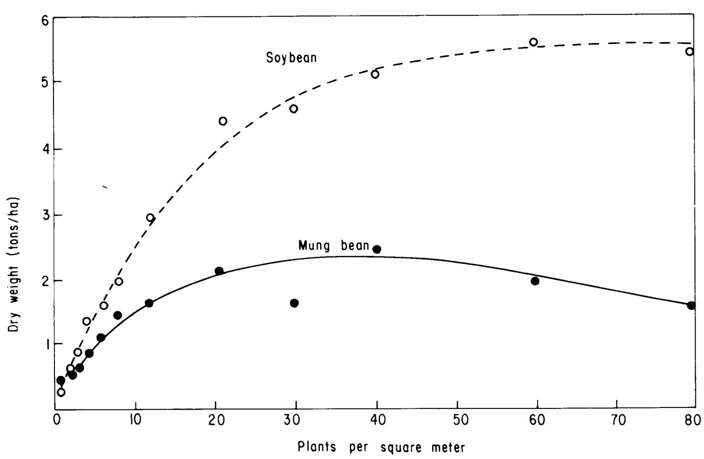

Fig. 4. Effect of plant density on the yield of snap beans.

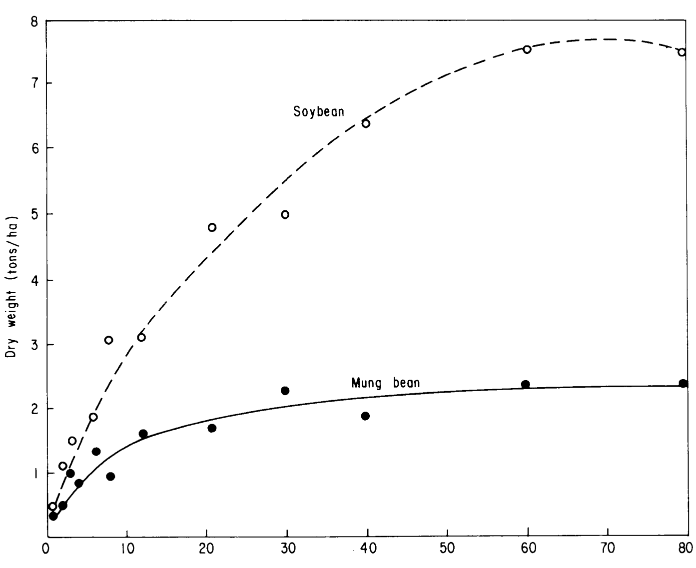

Fig. 5. Effect of plant density on yield of green-shell beans.

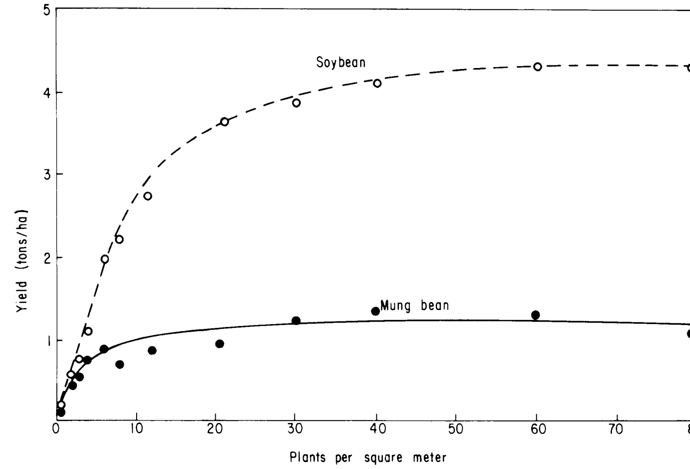

Fig. 6. Effect of plant density on yield of dry beans.

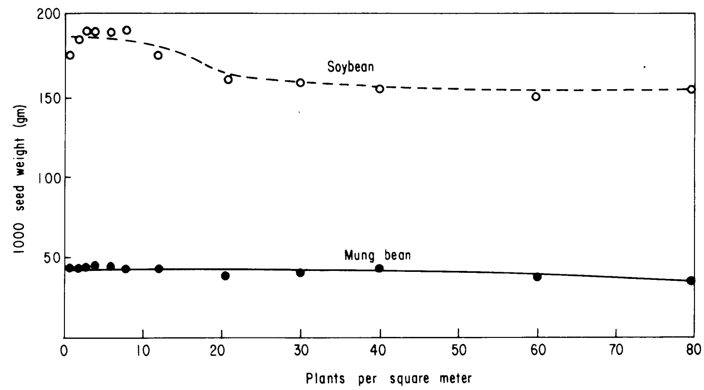

Fig. 7. Effect of plant density on wt of 1000 seeds.

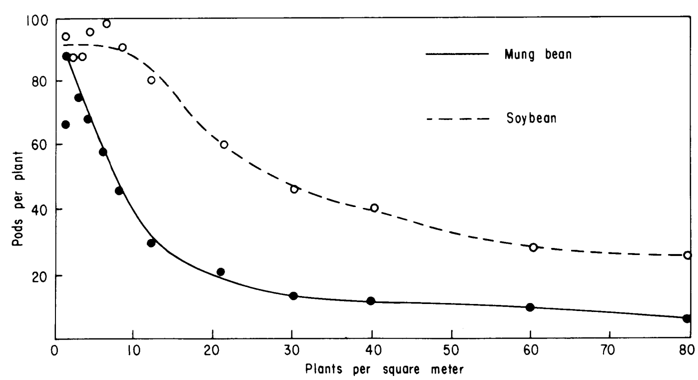

Fig. 8. Effect of plant density on number of pods per plant.

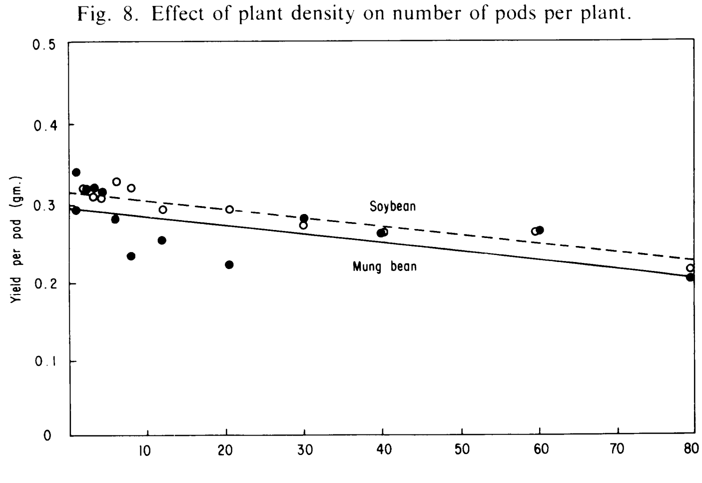

Fig. 9. Effect of plant density on yield of dry beans per pod.

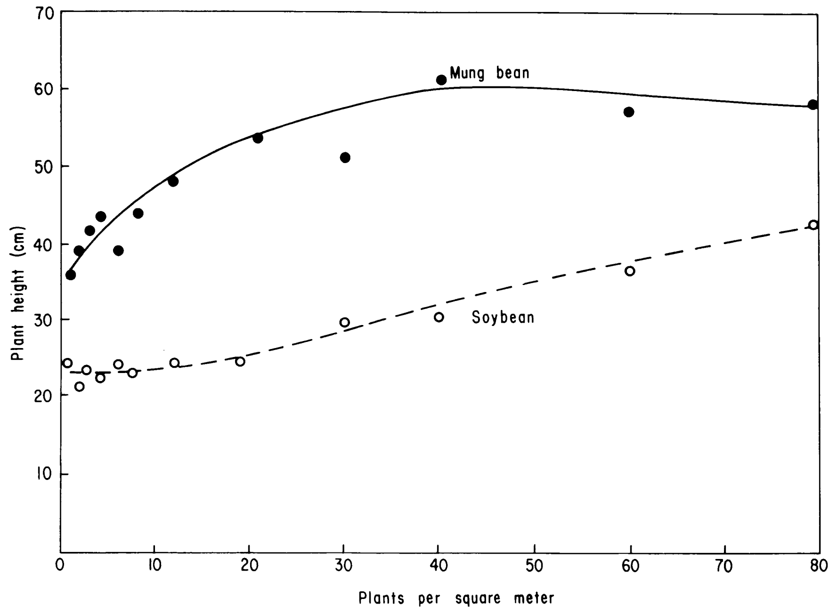

Fig. 10. Effect of plant density on plant height.

Table 2. Protein (by dye binding method) and oil precent of mung bean cv. Thai Green Oil and soybean cv. Hsih-Hsih at 3 stages of maturity harvested from plots of varying plant density.

Plant density/m²	Mung bean			Soybean			Oil in dry bean
	Stage of harvest			Stage of harvest			
	Snap bean	Green-shell	Dry bean	Snap bean	Green-shell	Dry bean	
1	21.7	20.7	22.6	22.9	26.6	42.7	15.0
2	20.5	20.3	23.8	23.6	26.4	42.9	16.4
3	20.6	20.6	23.9	24.5	27.0	42.8	15.7
4	20.3	20.5	25.5	24.4	27.8	43.4	16.4
6	20.6	19.7	24.0	24.1	28.6	43.0	17.0
8	20.4	20.0	23.5	24.8	29.5	42.1	17.1
12	20.3	20.0	24.4	26.0	27.6	40.9	17.7
21	20.3	20.3	23.9	26.3	29.0	41.0	17.6
30	20.1	20.3	24.3	25.9	28.6	41.1	17.7
40	20.4	20.0	24.8	26.7	28.2	38.5	18.1
60	19.9	20.0	24.2	26.6	28.7	39.2	17.7
80	19.9	20.1	23.7	25.4	29.0	39.8	17.9
LSD at 5%	0.81	N.S.*	N.S.*	1.50	1.70	2.11	0.82

* Not Significant.

ent of plant density; approaching 1.0 in the case of soybean and varying around 0.4 for the mung bean. This suggests that the relationship of plant density to yield is involved in the physiology of flowering and fruiting and is expressed as the number of pods per plant.

Plant configuration. Increasing plant density was associated with a significant increase in plant height for both soybean and mung bean (Fig. 10). For the mung bean cultivar this relationship was expressed at much lower plant densities than it was for the soybean cultivar. Plant branching was depressed as plant densities increased for both crops (Fig. 11).

The percent shell-out of mung beans was found to decrease significantly with increasing plant density. Because pod length and the number of seeds per pod were not found to vary significantly with plant density, it is concluded that the reduced percent shell-out of mung beans can be attributed in part to the decrease in 1000-seed wt mentioned previously.

The percent shell-out of soybeans was found to be reduced as soybean plant density was increased. Soybean pod length decreased significantly as plant density increased. This relationship could, at least in part, account for the increased percent shell-out found to be associated with increasing plant density.

Protein production. No significant effect of plant density on the percent protein was observed for the mung bean pods harvested at the green-shell bean stage or harvested as dry beans. At the highest plant density a significant decrease was noted in the percent protein of the mung bean when harvested at the snap bean stage. Soybean protein percent increased with increasing plant density at both the snap-bean stage harvest and at the green-shell bean stage. Conversely, the percent protein in dry soybeans was found to decrease with increasing plant density while percent oil increased with plant density (Table 2).

Discussion

In terms of developing a breeding strategy for mung bean improvement, the model offered by the soybean permits relatively few alternatives. It is apparent from these results that the advantage of the higher yielding soybean cultivar lies mainly in the relative number of pods per plant when grown at moderate to high plant densities. The mung bean cultivar studied produced only about one fourth the

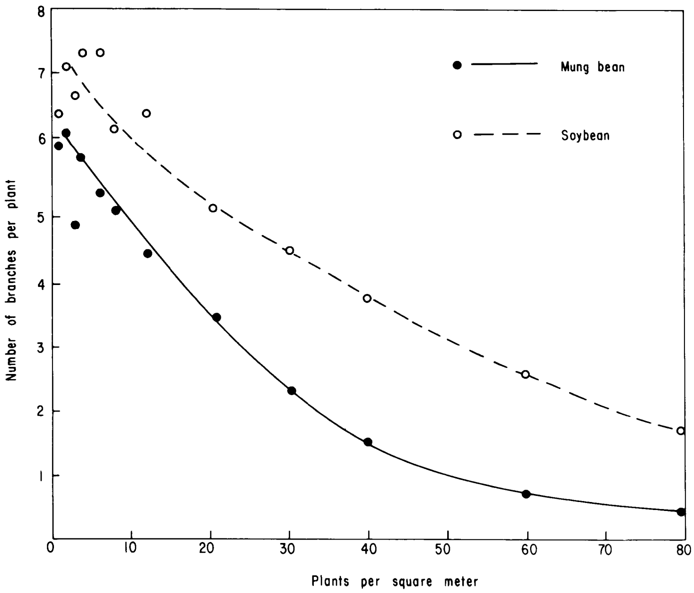

Fig. 11. Effect of plant density on number of branches per plant.

number of pods per plant that the soybean cultivar did when plant densities exceeded 100,000 plants per hectare (10 plants per m^2). Yield per pod did not vary substantially between the 2 species. Hence, yield levels for the mung bean cultivar would be expected, and were found, to be only one fourth those of the soybean.

It appears, based on these results, that there should be little or no detrimental effect of increased plant densities on the other yield components or on most of the other characters studied. In fact, it can be argued that a higher plant densities, plant branching would decrease thereby reducing interplant shading.

An understanding of the response of mung bean and soybean to increased plant density will allow exploration of our mung bean germplasm collection for types which better withstand the stresses of higher plant density. We are hopeful that the genetic resources will be found that will allow mung beans to be bred for more intensive cultivation.

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Diffusible Abscisic Acid and Its Relationship to Leaf Age in Tea Crabapple[1]

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Abstract. Abscisic acid (ABA) and its water soluble glucoside diffused from leaves through petioles and along the axes of seedlings of tea crabapple (*Malus hupehensis*, Rehd.). The apparent mobility of the glucoside was considerably greater than that of free ABA. Concentrations of extractable and diffusible ABA were greatest in growing shoot tips. ABA from mature leaves diffused down the petiole more readily than from younger leaves. The enhanced liberation of inhibitor from older leaves may result in greater quantities of mobile ABA as the season progresses.

Many woody perennials from northern latitudes cease shoot growth and form terminal buds in midsummer. Control mechanisms resulting in development of rest are poorly understood, however, evidence for the involvement of leaves in the cessation of shoot elongation is increasing (9, 12). This influence may be mediated by plant growth inhibitors including ABA (1, 13).

In this report we describe studies involving the contribution of leaves to the level of transportable ABA, and the relative mobility of ABA from leaves of different physiological ages. Analysis of ABA diffusing from leaf tissue may provide insight into source-sink patterns of ABA movement since diffusates will contain only compounds which are transportable and which, therefore, may act at sites remote from regions of production or accumulation.

Materials and Methods

Plant material. Seeds of the tea crabapple, an apomictic crab species, were planted in December, 1973. Seedlings were grown in a glasshouse (24°C day/18°C night) under natural illumination except where noted. Periodically, vigorously growing seedlings, 50 to 100 cm in height, were selected for experimentation.

Effect of defoliation on diffusible ABA. Twelve seedlings were cut off at ground level. Following defoliation of 6 plants, each of the 12 trees was placed vertically in a separate beaker in the dark at 22°C with its cut basal end bathed in 10 ml of 20 mM aqueous EDTA (disodium salt) at pH 7.0 (4). Diffusates, i.e., substances released from the seedlings through the cut were collected over a 6-hr period, the diffusates of each of the 12 seedlings were analyzed separately.

Time course of ABA diffusion. Two greenhouse-grown seedlings were employed to investigate the time course of ABA diffusion over a 24-hr period. Fully expanded leaves were detached from basal, medial, and apical regions of the seedlings. Three leaves per nodal region per seedling were employed. Petioles were recut under water and each 3-leaf sample was placed vertically in a separate vial containing the EDTA solution discribed previously. After the initial 6-hr diffusion period samples were removed to fresh EDTA solution. The process was repeated after the second 6-hr diffusion period. The experiment was terminated 12-hr later.

Diffusible ABA gradients. These were investigated on 3 occasions over a 6-month period. Seedling age and size varied among experi-

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