

# Effects of Solar Radiation Regimes on Growth and N<sub>2</sub> Fixation of Soybean, Cowpea, and Bushbean<sup>1</sup>

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## ABSTRACT

Legumes are commonly grown in the tropics under reduced solar radiation due to dense cloud cover and shading from plantation or tall intercrops. This paper examines the growth and N<sub>2</sub> fixation of several grain legumes common to the tropics on an Oxidic Haplustoll in Hawaii. Plantings were made in April (warm season) and November (cool season) of soybean (*Glycine max* L. Merr.) 'Kahala'; Cowpea (*Vigna unguiculata* Walp.) 'TVu 1190' (April) and 'TVu 4557' (Nov.); and bushbean (*Phaseolus vulgaris* L.) 'Burpee Tenderpod'. Polypropylene netting was used to obtain 27, 45, 70, and 100% of the incoming solar radiation through the entire crop cycle. Consistent shading effects were with the three legumes during both warm and cool seasons even though absolute yields were lower in the cool season due to daylength and temperature sensitivity in soybean and cowpea. Nitrogen fixation parameters generally followed dry matter (DM) and seed yields. Total nodule activity (TNA) was very low in all the legumes at 27% sun. With the exception of bushbean at 27% sun, shading caused a 34% average reduction in DM and grain yields, vs a 50% reduction in TNA, and a 76% reduction in nodule mass. Soybean TNA peaked 3 to 4 weeks after flowering, Cowpea (cool season) TNA peaked at flowering, and bushbean TNA peaked slightly before or at flowering. There was a tendency for a delay ( $\approx$  2 weeks) at 70, 45, and 27% sun in the final stages of TNA, for summer and cool-season soybean and bushbean. These delays were not noted for cowpea or cool-season bushbean. Of the three legumes, cowpea was the least shade tolerant. It produced more DM at full sun than either soybean or bushbean, but at 27% sun, DM yields were similar for all three crops. The response of soybean to shade was intermediate with no reduction in DM and grain yield at 70% sun. Bushbean was the least affected by shading; in fact, maximum yields were obtained at 70% sun. At full sun, their leaves were yellow and seed weight was low; this problem could be corrected by N fertilization.

**Additional index words.** Shading, Nitrogen yield, Dry matter yield, Grain yield, Nodule weight, Acetylene reduction, *Glycine max*, *Phaseolus vulgaris*, *Vigna unguiculata*.

THE dependence of plant growth on photosynthesis (and hence sunlight) is well established (Evans, 1972). Most plants adapt to changes in radiation regimes through both morphological and physiological changes. Shading of legumes generally causes elongated growth, reduced specific leaf weight (SLW), and increased leaf area per unit of plant weight (LAR) (Beuerlein and Pendleton, 1971; Bowes et al., 1972). Although shading affects growth and yield, only a few studies have been made on the effect of shading on N<sub>2</sub> fixation. Chu and Robertson (1974) found that shading reduced both nodule number and size on white clover (*Trifolium repens* L.) and similar results have been reported for Cowpea (*Vigna unguiculata* Walp.) (Dart and Mercer, 1965), lupin (*Lupinus arboreus*) (Sprent, 1973), soybean [*Glycine max* (L.) Merrill]

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(Yoshida, 1973; Lawn and Brun, 1974; Wahua and Miller, 1978; Trang and Giddens, 1980), and faba beans (*Vicia faba* L.) (Antoniw and Sprent, 1978).

The assessment of biological N<sub>2</sub> fixation in the field by the acetylene-reduction technique (Hardy et al., 1973) has proved useful for measuring the effects of stress. Sprent (1973) found that shading of lupin decreased the N<sub>2</sub>-fixation activity of the plant in proportion to the logarithm of relative irradiance. This was largely due to reduced nodule mass under shade, while the specific nodule activity was only slightly reduced. Sprent and Bradford (1977) found that shading of faba beans prolonged total (TNA) nodule activity and delayed nodule senescence due in part to delayed senescence of the leaves in shaded plants.

Several studies have shown that symbiotic N<sub>2</sub> fixation is dependent upon a daily continuous supply of photosynthesis (Virtanen et al., 1955; Lawn and Brun, 1974). Seasonal and diurnal variations in N<sub>2</sub> fixation indicate that the process is quite sensitive to the supply of photosynthetic assimilates (Bergersen, 1970; Mague and Burris, 1972; Sloger et al., 1975).

Total plant acetylene-reduction activity of most legumes usually increases with plant age until the start of pod filling and then decreases markedly. However, differences among species and varieties have been reported (e.g., Hardy et al., 1968; Harper and Hageman, 1972; Lawn and Brun, 1974; Sloger et al., 1975; Sprent and Bradford, 1977; Graham and Rosas, 1977). The decrease in N<sub>2</sub> fixation during pod filling has been reported to result from an inadequate supply of assimilates from the shoot due to the sink strength of the developing pods (Lawn and Brun, 1974; Lawrie and Wheeler, 1975).

We studied the effect of various radiation regimes on the performance of several grain legumes in the field during the warm and cool seasons with respect to growth patterns (including yield and N<sub>2</sub> fixation) in order to determine the relationship between these two characteristics under shaded conditions.

## MATERIALS AND METHODS

Three grain legumes were planted in April (summer) and November (cool season) on an Oxidic Haplustoll near Paia, Hawaii, approximately 20°55'N156°22'W at about 100-m elevation. Phosphorus and K were applied 9 months prior to the April planting at a rate of 50 kg ha<sup>-1</sup> of P as treble superphosphate, and 180 kg ha<sup>-1</sup> of K as muriate of potash. Lime was applied at 3400 kg ha<sup>-1</sup> to increase the pH to 6.3.

Bushbean 'Burpee Tenderpod' (*Phaseolus vulgaris* L.), soybean 'Kahala', and cowpea selection TVu 1190 were planted 9 Apr. 1976 (summer). These varieties were planted again 4 Nov. 1976 (cool season) except that cowpea TVu 1190 was replaced by TVu 4557. Four different solar shortwave radiation regimes were established with polypropylene screening to provide 100, 70, 45, and 27% of full sun. The screening was stretched over the plots 1.9 m aboveground to allow air circulation and easy passage underneath. The sides facing east and west slanted down at a 45° angle to 1

m above the ground to shade the plants from morning and evening sun. Each shaded block measured 12.2 X 13.4 m. Three replicates of a split-plot arrangement in a completely randomized block were used, with radiation regimes as whole plots and species as subplots. Each subplot consisted of six rows 2.9 m long and spaced 0.42 m apart. Plant populations of 365 000, 260 000, 180 000, and 130 400 plants ha<sup>-1</sup> were established with intrarow spacings of 65, 92, 132, and 183 mm for soybean, bushbean, cowpea TVu 1190, and cowpea TVu 4557, respectively. Prior to planting, seeds were scarified and inoculated with commercial Rhizobium cultures (Nitragin Co., Milwaukee, Wis.). The plots were watered as needed with impulse sprinklers. Each block was watered separately to compensate for less water use under reduced radiation.

Three plants were sampled at random from each plot at weekly intervals from 3 weeks after seeding to maturity for the April planting and at 1 to 3 week intervals for the November planting. Plant height, acetylene-reduction activity, number and dry weight of nodules, and dry weights of roots, stems, leaves, and pods were determined at each sampling. Acetylene-reduction activity was determined by excavating three plants and gently shaking the roots free of soil. Each root system was cut from the tops and immediately placed in a 1000 ml plastic container with minimal agitation to avoid dislodging the nodules from the roots. Acetylene (10% by volume) was introduced within 10 min of sampling. After incubation for 1.5 h, ethylene production was determined by gas chromatography. The roots, nodules, and top portions of each plant were dried at 55°C and individually weighed. The three plant samples were then combined for total N determination.

At maturity, the 3 m<sup>2</sup> (including four of center rows of the six planted) were harvested, dried at 55°C, and total DM, total grain (seed) yield, number of pods per plant, number of seeds per pod, and weight per seed were recorded. The N content of seeds at maturity, and combined (three replications) root, nodule, and top samples at each sampling date were determined by Kjeldahl digestion (using CuSO<sub>4</sub> and selenized Hengar granular catalyst) followed by measurement of NH<sub>4</sub> by the diffusion process (modified Conway dishes) or an automatic NH<sub>4</sub> analyzer.

A separate experiment was conducted in March 1977 to evaluate the N response of bush bean at 100 and 70% full sun. There were three replications, two radiation regimes (whole-plots), and two N levels (split-plots). Thirty kilograms ha<sup>-1</sup> of N as urea was applied to the plus-N treatments at planting and 40 kg ha<sup>-1</sup> 6 weeks later. All other management practices were the same as in the first experiment. At 4 weeks, specific leaf weight and leaf area ratio were measured. At maturity, seed yield and components of yield were determined.

## RESULTS AND DISCUSSION

### General Observations

The average irradiance during the summer period was 26.8 MJ m<sup>-2</sup> day<sup>-1</sup>, and during the cool season 17.6 MJ m<sup>-2</sup> day<sup>-1</sup>. For the summer crop the average daily soil temperature at 50 mm depth in full sun increased linearly from 23.5°C at time of planting to 28°C at time of harvesting. For the cool-season crop the average soil temperature was 22°C for the duration of the experiment. The soil temperature under 27% of full sun was between 0.8°C (cool season) and 2.0°C (summer) lower than at full sun, with intermediate values for 70 and 45% full sun. Hereafter, radiation regimes will be designated as 100, 70, 45, and 27% sun.

### Plant Growth Characteristics

The typical morphological changes associated with shading were observed; larger and thinner leaves, longer internodes, and a greater leaf area ratio. Shading did not affect plant heights of cowpea and bushbean except for some petiole elongation in bushbean. Soybean plant height increased linearly for the first 9 weeks after emergence for the summer crop, with the tallest plants occurring at 45% (600 mm) followed by 70 (560 mm), 27 (500 mm), and 100% (450 mm). During the cool season, the tallest plants were at 27% sun followed by 70, 45, and 100% sun. Heights were, respectively, 310, 270, 250, and 240 mm.

The TVu 1190 selection of cowpea had a viney habit, and did not flower during the summer. The TVu 4557 selection of cowpea was grown during the cool season only. It had a bushy habit in full sun, but at 70 and 45% sun about one-third of the plants were viney. At 27% sun growth was very retarded with no tendency toward viney growth.

### Nodulation and N<sub>2</sub> fixation

During the summer maximum nodulation for bushbean was reached 3 weeks after emergence, but the maximum for soybean and cowpea occurred 6 to 9 weeks after emergence. Radiation regimes significantly influenced nodule dry weight (DW) in the summer crop of soybean, cowpea, and bushbean (Fig. 1). In soybean the effect of shading on nodule DW was similar during both seasons, although nodule DW in the cool season was only one-fourth of the summer values. Bushbean was less affected by season than soybean presumably because it was better adapted to cool weather. Our results are generally in agreement with others who have reported reductions in nodule mass due to shading of soybean (Sampaio and Dobereiner, 1980; Bergersen, 1970; Yoshida, 1973; Lawn and Brutl, 1974; Kry, 1976; Wahua and Miller, 1978; Trang and Giddens, 1980), faba beans (Antoniw and Sprent, 1978), and cowpea (Dart and Mercer, 1975).

Total nodule activity at different growth stages varied greatly between the three species tested (Fig. 2). At full sun, soybean TNA peaked at 3 to 4 weeks after flowering, cowpea (cool season only) peaked at flow-

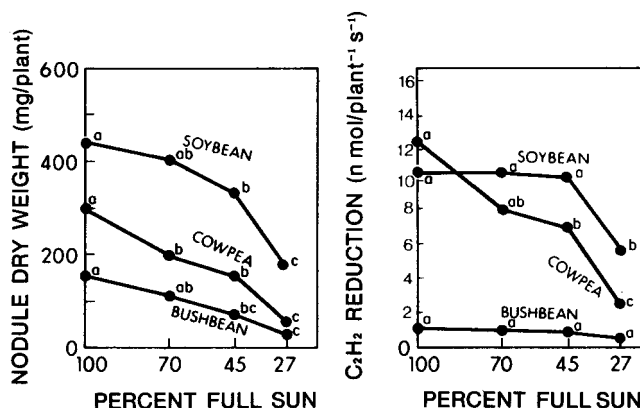


Fig. 1. Integrated values for nodule mass and total nodule activity for summer soybean, cowpea, and bushbean. Letters within lines indicate significance at the 5% level (Bayes LSD).

ering, and bushbean peaked slightly before or at flowering. There was a tendency for a delay of about 2 weeks in the final stages of TNA at 70, 45, and 27% sun in summer soybean and bushbean, and 27% sun in the cool-season soybean. There was little or no effect on cowpea or cool-season bushbean. For the summer, soybean crop integrated values were not significantly affected by the three highest radiation regimes (Fig. 1). The first 5 to 6 weeks after emergence the TNA was

highest at full sun, due to delayed maturity at the other radiation regimes. Accordingly, soybean responded about the same as the faba beans studied by Sprent and Bradford (1977) (maximum  $12.8 \text{ nmol plant}^{-1} \text{ s}^{-1}$ ). Specific nodule activity (SNA) of soybean was not affected by shading at any sampling date. These results are contrary to the data of Wahua and Miller, (1978) who found that shading of soybean accelerated nodule senescence, reducing the SNA from 0.44 to 0.04 nmol

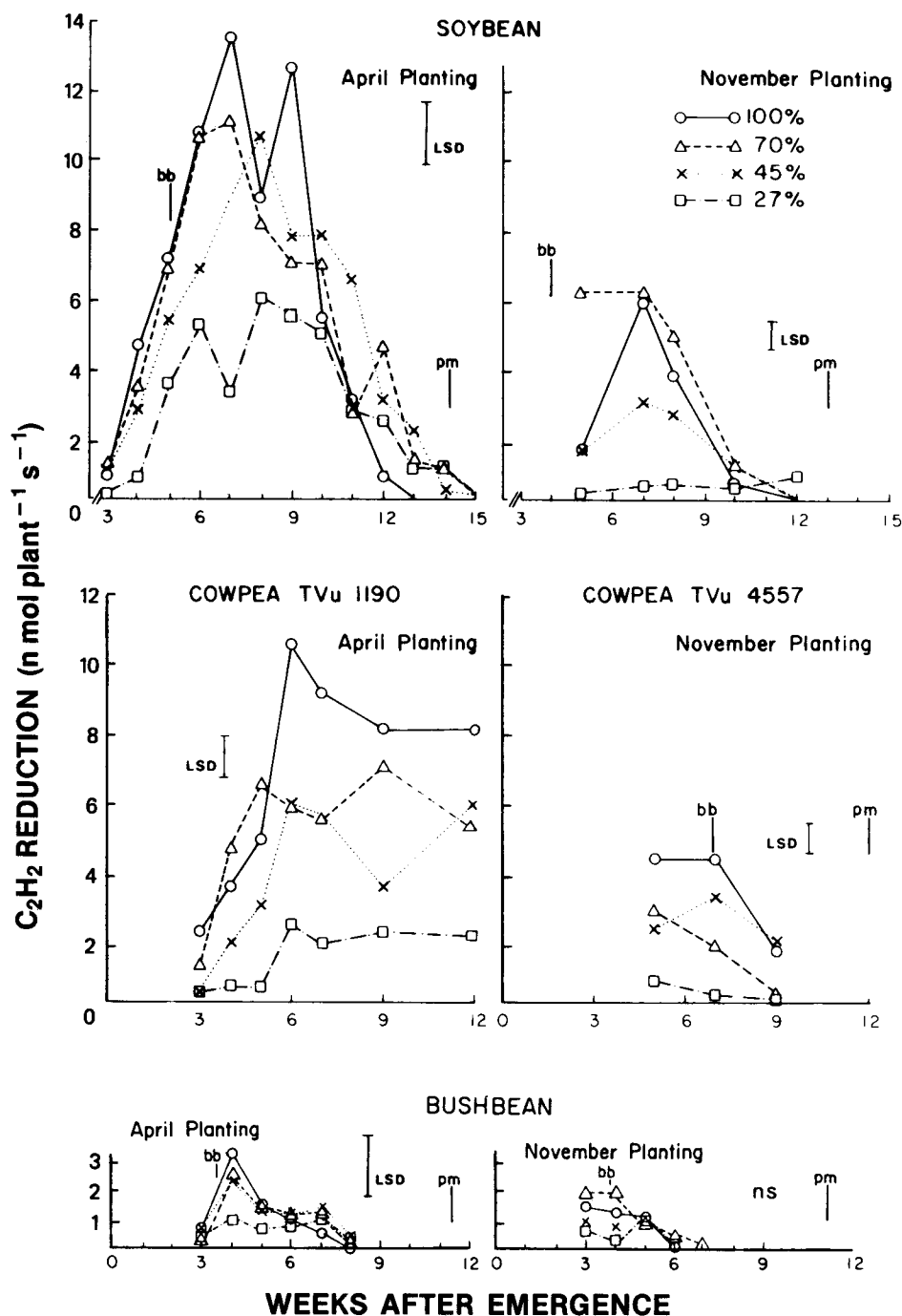


Fig. 2. The effect of radiation regime (100% = full sun) on acetylene reduction of soybean, cowpea, and bushbean grown during two seasons (bb = beginning bloom; pm = physiological maturity).

$C_2H_2$  (g nodule  $DW^{-1}$ )  $s^{-1}$ . However, their plants were first shaded at the fourth trifoliolate leaf stage, while in our experiment the plants were seeded beneath the shading material.

Total nodule activity for both cowpea varieties was highest at full sun for most sampling dates (Fig. 1). Plants grown at 70 and 45% sun had intermediate rates of TNA, and TNA was further reduced at 27% sun. The maximum average SNA of cowpea nodules exceeded 53.9 nmol (g nodule  $DW^{-1}$ )  $s^{-1}$ ; average for soybean was 32 nmol and bushbean was 28.9 nmol (g nodule  $DW^{-1}$ )  $s^{-1}$ .

Bushbean had the lowest TNA (Fig. 2), probably because it peaked at early bloom (only 4 weeks after emergence). By 5 weeks after emergence the activity had dropped to only half of that measured at 4 weeks, due mainly to reduced SNA [from approximately 33.3 to 16.7 nmol (g nodule  $DW^{-1}$ )  $s^{-1}$ ]. The DM yield of bushbean at the time of maximum TNA was only 8% of the total DM yield compared to 50% in soybean. Shading had no significant effect on TNA in bushbean in either season, except for the summer crop at 4 weeks, when full sun resulted in significantly higher than 27% sun.

Our results for bushbean were considerably lower than the maximum TNA of 5.6 to 8.3 nmol  $plant^{-1}$

$s^{-1}$  reported by Graham and Rosas (1977) for bushbean and climbing bean. The fixation period reported by Graham and Rosas was also much longer, reaching a peak at 9 weeks after emergence, compared to 4 weeks in the present experiment. Apparently "Tenderpod" bushbean has been selected under conditions of high N fertilization and has a very poor  $N_2$ -fixation capacity. The data reported here correspond more closely to the 1.7 nmol  $C_2H_2$   $plant^{-1}$   $s^{-1}$  for dark red kidney beans (Janssen and Vitosh, 1974), who showed that TNA per plant was not different at light intensities of 4500 and 7000 lux.

In summer there was very little decrease in TNA for both bushbean and soybean until radiation was reduced below 45% sun, indicating that adequate photosynthates were translocated to the roots to support near maximum  $N_2$  fixation. During the cool season however, irradiance was lower and TNA was reduced when radiation fell below 70%, was reduced more during the cool season than during the warm season (Fig. 2).

### Dry Matter and Accumulation

Dry matter accumulation of roots, nodules, stems, leaves, and pods at different radiation regimes were season-dependent and species-dependent. However, the proportions of the different plant parts did not vary with season.

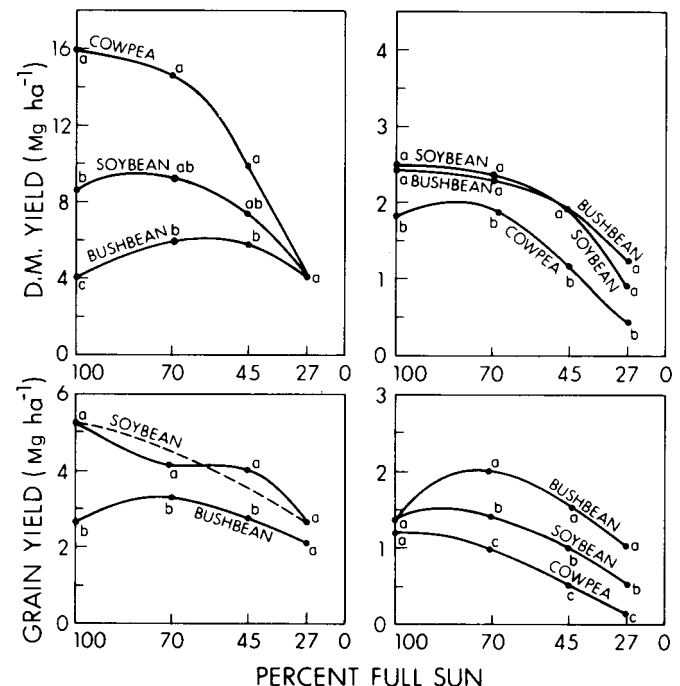
The maximum DM accumulation of soybean during the summer was 9 Mg  $ha^{-1}$  (Table 1, Fig. 3 and 4), but during the cool season the maximum DM yield was only 2.5 Mg  $ha^{-1}$ . The variety used was photoperiod sensitive and began flowering 3.5 weeks after emergence in the cool season 10 days earlier than the summer crop. This restricted the formation of addi-

**Table 1. The effect of radiation regime on the performance of soybean, cowpea TVu 4557, and bushbean. Plant density of 365 000  $ha^{-1}$  for soybean, 130 400  $ha^{-1}$  for cowpea TVu 4557 and 260 000  $ha^{-1}$  for bushbean. Average of three replications.**

| Radiation regime       | To maturity days | Total dry matter $Mg ha^{-1}$ | Pods per plant | Seeds per pod | Weight per seed mg | Seed yield $Mg ha^{-1}$ | Percent N | Seed N $kg ha^{-1}$ |
|------------------------|------------------|-------------------------------|----------------|---------------|--------------------|-------------------------|-----------|---------------------|
| <b>Soybean</b>         |                  |                               |                |               |                    |                         |           |                     |
| <b>Warm season</b>     |                  |                               |                |               |                    |                         |           |                     |
| 100                    | 996a*            | 8.7a                          | 30a            | 2.0a          | 239a               | 5.2a                    | 6.27ab    | 325a                |
| 70                     | 112a             | 9.3a                          | 24a            | 1.9ab         | 253a               | 4.2b                    | 6.44a     | 271ab               |
| 45                     | 107a             | 8.5ab                         | 25a            | 1.8b          | 245a               | 4.1b                    | 6.46a     | 263b                |
| 27                     | 114a             | 4.0b                          | 16b            | 1.9ab         | 233a               | 2.7c                    | 6.20b     | 166c                |
| <b>Cool season</b>     |                  |                               |                |               |                    |                         |           |                     |
| 100                    | 96c*             | 2.50                          | 10.0a          | 1.8a          | 202a               | 1.38a                   | 6.03b     | 83a                 |
| 70                     | 97bc             | 2.35ab                        | 9.3a           | 1.9a          | 210a               | 1.37a                   | 6.09b     | 84a                 |
| 45                     | 88bc             | 1.85b                         | 7.2b           | 1.9a          | 205a               | 1.02b                   | 6.76a     | 70a                 |
| 27                     | 102a             | 0.90c                         | 4.6c           | 1.7b          | 179b               | 0.52c                   | 6.67a     | 34b                 |
| <b>Cowpea TVu 4557</b> |                  |                               |                |               |                    |                         |           |                     |
| <b>Cool season</b>     |                  |                               |                |               |                    |                         |           |                     |
| 100                    | 99c*             | 1.86a                         | 8.9a           | 7.6a          | 138a               | 1.22a                   | 3.50a     | 43a                 |
| 70                     | 100c             | 1.90a                         | 6.7b           | 8.0a          | 139a               | 0.97b                   | 3.59a     | 35b                 |
| 45                     | 102b             | 1.25b                         | 3.4c           | 7.4a          | 133a               | 0.53c                   | 3.65a     | 20c                 |
| 27                     | 105a             | 0.49c                         | 1.0d           | 6.2b          | 134a               | 0.11d                   | 3.66a     | 4d                  |
| <b>Bushbean</b>        |                  |                               |                |               |                    |                         |           |                     |
| <b>Warm season</b>     |                  |                               |                |               |                    |                         |           |                     |
| 100                    | 81c*             | 4.0b                          | 11.5a          | 3.6a          | 247b               | 2.7ab                   | 2.62b     | 71ab                |
| 70                     | 88b              | 5.9a                          | 11.6a          | 3.6a          | 304a               | 3.3a                    | 2.70ab    | 90a                 |
| 45                     | 89b              | 5.8a                          | 10.1b          | 3.4a          | 310a               | 2.8ab                   | 2.79ab    | 77ab                |
| 27                     | 93a              | 3.9b                          | 8.2c           | 3.3a          | 300a               | 2.1b                    | 2.98a     | 63b                 |
| <b>Bushbean</b>        |                  |                               |                |               |                    |                         |           |                     |
| <b>Cool season</b>     |                  |                               |                |               |                    |                         |           |                     |
| 100                    | 83c*†            | 2.40a                         | 6.5a           | 3.0a          | 265b               | 1.37c                   | 3.28a     | 44b                 |
| 70                     | 95b              | 2.30a                         | 6.0b           | 3.6a          | 360a               | 2.30a                   | 2.85b     | 58a                 |
| 45                     | 96b              | 1.85b                         | 5.5c           | 3.2a          | 352a               | 1.60b                   | 3.16a     | 51ab                |
| 27                     | 100a             | 1.20c                         | 3.6d           | 3.2a          | 358a               | 1.01d                   | 3.34a     | 35c                 |

\* means in the same column followed by the same letter are not significantly different at the 5% level (Bayes LSD).

† Based on dry matter yield at 8 weeks after emergence, physiological maturity = 12 weeks.



**Fig. 3. Dry matter and grain yields of soybean, cowpea, and bushbean grown under four radiation regimes and at two different seasons.**

tional photosynthetic surface, thereby decreasing the supply of photosynthates to the nodules as the sink strength of the developing grain became more intense.

The total DM accumulation of both cowpea varieties was significantly reduced at 45 and 27% sun (Table 1, Fig. 3 and 4). The DM yield for both varieties at 27% sun was only one-fourth of the DM yield at 70% sun. This was a much greater yield reduction than that noted for soybean or bushbean. Hence, both varieties proved quite sensitive to shading; similar to the results obtained by Adedipe and Ormrod (1975) and Tarila et al. (1977).

Cool-season DM yields of bushbean averaged about 60% of the summer DM yields. This is about as expected if temperature and daylength were to have no effect since average irradiance in the cool season was 61% of the summer irradiance. Dry matter accumu

lation of bushbean in the summer at 100, 70, and 45% sun increased during the first 8 weeks to about 4 Mg ha<sup>-1</sup> and at 27% sun to about 2.5 Mg ha<sup>-1</sup> (Fig. 3). After about 8 weeks no increase in DM yield took place in full sun and the leaves became yellow and senescent. This coincided with a significantly lower concentration of N in these plants: 2.5% N at 100% sun, 2.8% N at 70% sun, and 3.0% N at 45 and 27% sun. At maturity the total DM yields at full sun and 27% sun were only two-thirds of the yields at 70 and 45% (Fig. 3). The low DM yield in full sun could be due to rapid destruction of chlorophyll which exceeded the rate of chlorophyll regeneration (as postulated for N deficient grasses by Eriksen and Whitney, 1981), and the earlier maturation (by 2 weeks) of plants grown at full sun. Dry matter accumulation of bushbean at full and 70% sun was increased significantly by adding 75 kg N ha<sup>-1</sup>

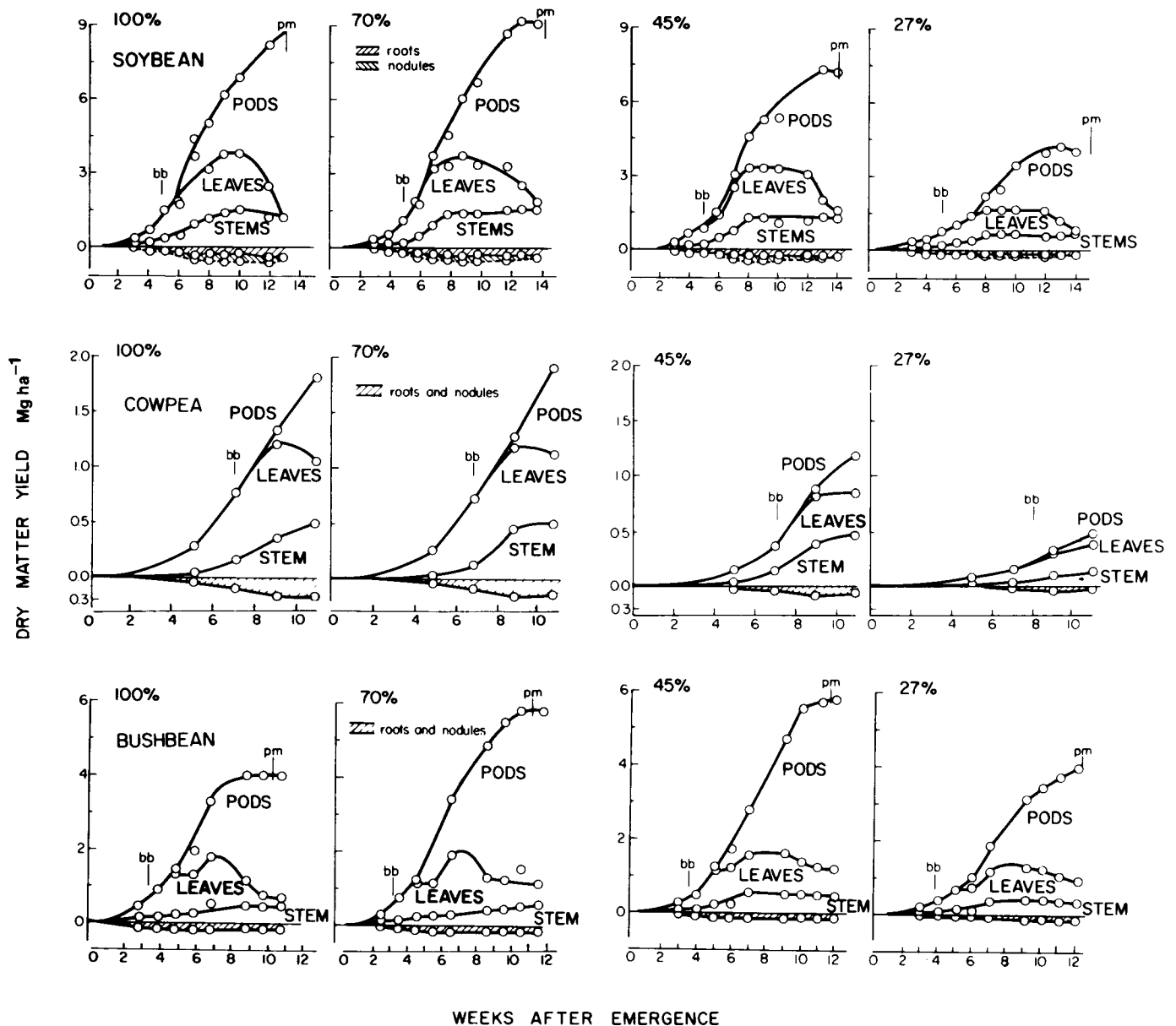


Fig. 4. The effect of radiation regime on the dry matter accumulation of soybean and bushbean grown during the warm season and cowpea TVu 4557 grown during the cool season. (bb = beginning bloom; pm = physiological maturity).

**Table 2. The effect of radiation regime and N fertilizer on yield components of bushbean.**

| Treatment        | Dry matter yield†   | Seed yield | Pods plant <sup>-1</sup> | Seeds pod <sup>-1</sup> | Seed weight |
|------------------|---------------------|------------|--------------------------|-------------------------|-------------|
|                  | Mg ha <sup>-1</sup> |            | no.                      |                         | mg          |
| <b>100% Sun</b>  |                     |            |                          |                         |             |
| 0 N              | 2.14                | 2.05       | 8.8                      | 3.5                     | 260         |
| 75 N             | 2.46                | 3.16       | 10.4                     | 3.6                     | 320         |
| <b>70% Sun</b>   |                     |            |                          |                         |             |
| 0 N              | 1.88                | 2.26       | 8.3                      | 3.5                     | 300         |
| 75 N             | 2.72                | 3.49       | 10.6                     | 3.7                     | 340         |
| <b>ANOVA</b>     |                     |            |                          |                         |             |
| Radiation Regime | NS‡                 | NS         | NS                       | NS                      | **          |
| Nitrogen level   | *                   | *          | *                        | *                       | **          |

\*, \*\* Significant at the 5 and 1% level, respectively.

† At 7 weeks after emergence.

‡ NS = Not significant.

(Table 2), indicating that N was a major limiting factor for growth of bushbean (except when grown in dense shade). Similar yield responses to N fertilizer for bean plants were also reported by Sistachs (1970) and Almeida et al., (1973).

The total growth period for soybean, bushbean, and cowpea during the cool season was about the same, but the proportion of the different plant parts at a given age differed markedly. Cowpea TVu 4557 first started flowering 7 to 8 weeks after emergence at which time 25 to 50% of the total pod DM of soybean and bushbean had already been formed. At maturity (13 to 14 weeks after emergence) about half of the total DM in cowpea TVu 4557 was found in the seeds and pods compared to 85 to 89% for bushbean and soybean. Compared to soybean which had approximately the same yield, cowpea was less efficient in proportioning photosynthate between the grain and other plant parts. Cowpea had the residues N remaining per ha up to 13.8 kg ha<sup>-1</sup> at 70% declining to 10.1 at 45% and 4.7 at 27%. Thus, cowpea may be preferred for low input farming systems where feed for livestock and/or an N benefit to the following crop is an important consideration.

Nitrogen percentages in soybean DM ranged from 3.0 to 3.7 for the summer crop, were slightly higher for the cool-season crop and did not vary significantly with plant maturity or radiation regime. The N percentage of cowpea TVu 4557 (cool season) decreased with increasing maturity from 3.5 to 1.8% at full sun and from 3.5 to 2.7% at 27% sun, but there was no effect for the summer (non-flowering) cowpea TVu 1190. For bushbean the N percentage (excluding fallen leaves) tended to be highest at 70% and lowest at 100%. At 70% average N percentage (over seasons) decreased from 3.8 to 2.4% during the period 3 to 8 weeks after emergence. The summer (non-flowering) crop of cowpea had the highest total N yield: 350 kg N ha<sup>-1</sup>.

The top/root ratio of the three species was not affected by radiation regime. These findings correspond with the findings by Dart and Mercer (1965) for cowpea, but differ from the data of McKee (1962) and Sprent (1973), who reported that shading increased the top/root ratio of lupin and birdsfoot trefoil (*Lotus corniculatus* L.). However the top/root (DM basis) dif

ferred significantly with species and maturity. For soybean the top/root ratio increased linearly from 4.6 at 4 weeks after emergence to 22 at maturity. Similar results were reported by Mayaki et al. (1976) and Sivakumar et al. (1977). The top/root ratio of bushbean increased linearly from 6 at 4 weeks to 30 at 9 weeks, and remained constant thereafter. The top/root ratio of cowpea TVu 1190 (non-flowering) also increased with maturity (from 7 at 4 weeks to 16 at 13 weeks after emergence), but the top/root ratio of cowpea TVu 4557 increased only slightly with maturity. Thus, cowpea again would be preferred for low input situations where an N benefit to the following crop is desired.

### Grain Yield and Yield Components

Grain (seed) yields of the three legumes were significantly depressed at 27% in all cases and at 70 and 45% in the case of both crops of soybeans and coolseason cowpea (Fig. 3 and Table 1). Except for bushbean at 100% sun, the main limiting component of yield was number of pods per plant. Shading decreased pods per plant, especially during the cool season. Wahua and Miller (1978) also found that number of pods per plant was the main component of yield in soybean altered by shading. Number of seeds per pod was unaffected by shading in all three species except during the cool season where 27% caused a significant decrease in number of seeds per pod in cowpea and soybean. Shading had no effect on weight per seed in cowpea (cool-season) and the summer soybean (Table 1). During the cool season, the weight per seed of soybean was significantly lower at 27%. Weight per seed was also generally lower during the cool season probably due to cold temperature stress on the soybean plants and earlier flowering during the cool season. Weight per seed of bushbean at full sun averaged about 80% of the seed weight at 70, 45, and 27% for the summer crop (74% for the cool-season crop).

The low weight per seed and total seed yield of bushbean at full sun was probably due to an inadequate N supply. The bushbean fixed very little N and was therefore almost entirely dependent on soil N. There was early leaf senescence in full sun, probably due also to inadequate N in the leaves. Thus, bushbean responded similarly to N-deficient grasses at full sun (Eriksen and Whitney, 1981).

In the bushbean N-fertilizer experiment it was shown that the low weight per seed and total seed yield in full sun was probably due to N deficiency (Table 2). Weight per seed was increased by 24% at full sun with the addition of 75 kg N ha<sup>-1</sup> but at the 70% level it was increased by only 12%. Weight per seed and the total grain yield were slightly higher at 70% than at 100%, indicating that the 75 kg N ha<sup>-1</sup> was not enough for maximum growth.

Shading reduced the yields of cowpea TVu 4557 more than soybean or bushbean (Table 1). At 27% sun the grain yield for cowpea was only 9% (91% reduction) of the grain yield at 100%. A severe decrease in grain yields of cowpea under shaded conditions was also reported by Ezedinma (1973) and Tarila et al., (1977).

There was no radiation effect on harvest index in the cool-season soybeans. Cool-season cowpea leaves

and stems apparently required an increasing proportion of the N and other assimilates as light became more limiting; thus harvest index was severely reduced with decreased radiation. Bushbean harvest index declined slightly with decreasing radiation at the summer harvest.

Normally, high harvest index is associated with high grain yield. There was a positive correlation with yield in our experiment at 70, 45, and 27% in the cool season; and at 45 and 27% in the warm season. This may be an important consideration in a multiple cropping situation where the legume may be shaded by the associated crop, especially if an N benefit from vegetative residues is desired in addition to the grain yield.

### CONCLUSIONS

The legumes we tested all did poorly at 27% level of shade.

Cowpea was the most shade sensitive, soybean was intermediate, bushbean was least sensitive; seed yields were similar both summer and cool seasons (after adjusting for solar radiation effects).

There were interactions between solar radiation, daylength, and temperature, particularly in soybean and cowpea.

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