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# Influence of plant spacing on potato (*Solanum tuberosum* L.) morphology, growth and yield under two contrasting environments

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## Summary

In experiments at a temperate (43 °N) and a tropical (14 °N) location, closer plant spacing decreased stem branching, root growth, and mean tuber size but increased tuber yields per ha. Closer spacing increased plant height at the temperate site but decreased it at the tropical site where canopy cover did not reach 100 %. The increased branching at the wider spacing did not compensate for fewer plants/m$^2$. Total and tuber weight per plant increased with wider spacing and was much greater under temperate than tropical conditions. Tuber yield/stem also increased with lower stem densities. Although these results provide initial data for modelling, the contrast between the two environments and interactions between spacing and cultivar suggest that further experiments need to be done with a range of cultivars at intermediate locations.

## Introduction

Many experiments have demonstrated the influence of plant spacing on potato (*Solanum tuberosum* L.) tuber yield and size (Allen, 1978; Vander Zaag & Demagante, 1987), but little information is available on how spacing affects growth, and how plants compensate when grown close together or wide apart (Sieczka et al., 1986). The simulation model 'POTATO' (Ng & Loomis, 1984) responds incorrectly to changes in plant spacing, and closer spacing tends to increase predicted biomass production per plant (Ewing et al., 1989). To improve the simulation of the effects of plant population density in crop models, it was decided to obtain information on the effects of population density on morphological development at regular intervals during the growing season using plants grown at different spacings in two contrasting environments.

## Materials and methods

The trials were sited at Freeville, New York (43 °N latitude) with a growing season from June 2 to September 4, 1987, and at Canlubang, Philippines (14 °N latitude) with a growing season from January 5 to March 30, 1988. Growing conditions are given in Table 1. The cultivar Katahdin was grown at both sites and also cvs Cosima (late maturing) and Berolina (early maturing) were grown at Canlubang. Within-row spacing was

Table 1. Mean monthly temperature, rainfall (RF), solar radiation (SR) and daylength (DL) during the growing season.

| Location | Month | Temp. (°C) | | RF (mm) | SR ($MJ/m^2/day$) | DL (h) |
|---|---|---|---|---|---|---|
| | | min. | max. | | | |
| Freeville | June | 12.9 | 25.2 | 82 | 19.3 | 15.2 |
| | July | 15.6 | 27.8 | 126 | 20.0 | 14.9 |
| | August | 13.0 | 24.6 | 78 | 17.1 | 13.9 |
| Canlubang | January | 21.5 | 28.3 | 126 | 15.7 | 11.4 |
| | February | 21.5 | 29.8 | 29 | 17.0 | 11.7 |
| | March | 21.5 | 31.8 | 5 | 21.4 | 12.0 |

15, 22.5 or 45 cm and between-row spacing was 85 cm at Freeville, and 90 cm on one side and 30 cm on the other using double row beds at Canlubang. Previous research at Canlubang indicated no statistically significant differences in growth and yield between double row beds and single rows at the same plant population (Vander Zaag & Demagante, 1987). Plots were 9.3 m×5.95 m in a Randomized Complete Block Design (RCBD) at Freeville and 6.0 m×2.4 m in a split plot RCBD at Canlubang. Agronomic management (fertilization, pest and disease control) was standard at both locations. At Freeville, plots were twice overhead irrigated in late June, and at Canlubang, 20 mm water was applied by overhead irrigation at 4 to 5 day intervals.

On successive dates, five plants, surrounded by guard plants, were sampled for each plot and records were made of plant height; numbers of stems, branches (>2 cm), nodes, and main stems. The crop canopy was estimated using a grid and intercepted solar radiation calculated (Demagante & Vander Zaag, 1988b). Dry weights of main stems, main stem leaves, branch stems, and branch stem leaves were recorded and also fresh weight of tubers, tuber dry matter concentration, and tuber yield and size. Roots were recovered to a depth of 30 cm, the length of the longest root was measured and the number of roots with a diameter >1 mm were counted. Root branching was scored visually on a scale of 0 to 5 (0 = no branching, 5 = highly branched). Roots were washed and oven dried. Relative water content (RWC) of plants was determined before irrigating at Canlubang by sampling the first fully mature leaves from three plants (Vos, 1986). Terminal leaflets were immediately weighed (FW) and immersed in distilled water and after 8 hours saturated weight (SW) was determined. Leaflets were then oven dried for 2 days and dry weights (DW) recorded. RWC was calculated as (FW-DW)/(SW-DW)×100. Final tuber yield at Freeville was assessed from 9 m of row 94 days after planting (DAP) and at Canlubang 84 days after planting. Data analysis was by location. It was not possible to statistically compare the two locations.

## Results

*Plant growth.* Plant spacing did not influence shoot emergence, which reached 50 % 16 days after planting at Freeville and after 13 days at Canlubang. At Freeville, plant height was initially similar with all treatments but after 72 days the closely-spaced plants were taller (Fig. 1). Differences were significant only at 72 days. By contrast,

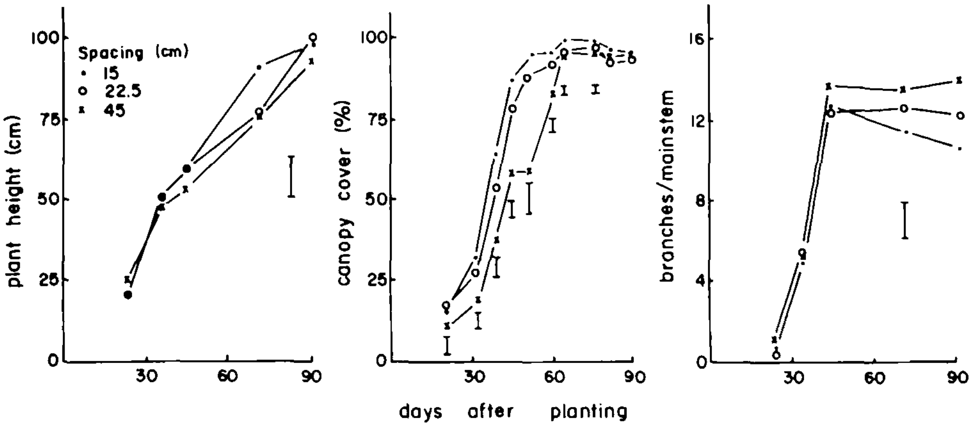


Fig. 1. Plant height, canopy cover and number of branches/mainstem of cv. Katahdin planted at 15, 22.5 and 45 cm spacing, Freeville, NY. Bars indicate least significant differences (LSD) at 5 %.

widely-spaced 'Katahdin' and 'Cosima' plants at Canlubang were tallest (Fig. 2). Plants were only about half the height of those at Freeville.

Canopy cover differed between the two locations and at Freeville the widest spacing gave significantly less cover up to 66 days after planting; in later samples differences were non-significant (Fig. 1). At Canlubang, there was a marked difference in canopy cover between the three plant spacing treatments (Fig. 2) and, in contrast to Freeville, where plants were taller, the widely-spaced treatments did not compensate. Canopy cover did not reach 100 % and plants senesced rapidly after 56 days.

At Freeville, numbers of branches were similar in all treatments up to 50 days, but later the widest spacing gave most (Fig. 1). By contrast, branching increased significantly in all cultivars with wider plant spacing at Canlubang (Fig. 2). With 'Katahdin', the number of branches was similar from the two more widely-spaced treatments at both locations.

Partitioning of foliage dry matter differed between sites. At Freeville, main stems and their leaves tended to reach a plateau by 45 days, after which weights of branch stems and their leaves rapidly increased (Fig. 3). The widest spacing gave the highest dry matter accumulation in branches. At Canlubang, dry weights of 'Katahdin' main stems and their leaves were only about 25 % of these at Freeville, whereas the weight of branches was much less than at Freeville (Fig. 4). In general, the widest spacing resulted in more dry matter in each of the three categories at Canlubang. Maximum dry matter weights of main stems and their leaves were reached 50 days after planting whereas weights of branches increased sharply after 50 days especially with cvs Cosima and Katahdin.

Total dry matter per plant about 10 weeks after planting increased with increasing plant spacing, but when expressed as yield per unit area this only partially compensated for the lower population density (Table 2). At Freeville, total dry matter accumulation was much greater than at Canlubang, where cv. Cosima produced much more total dry matter than cv. Berolina (Table 2).

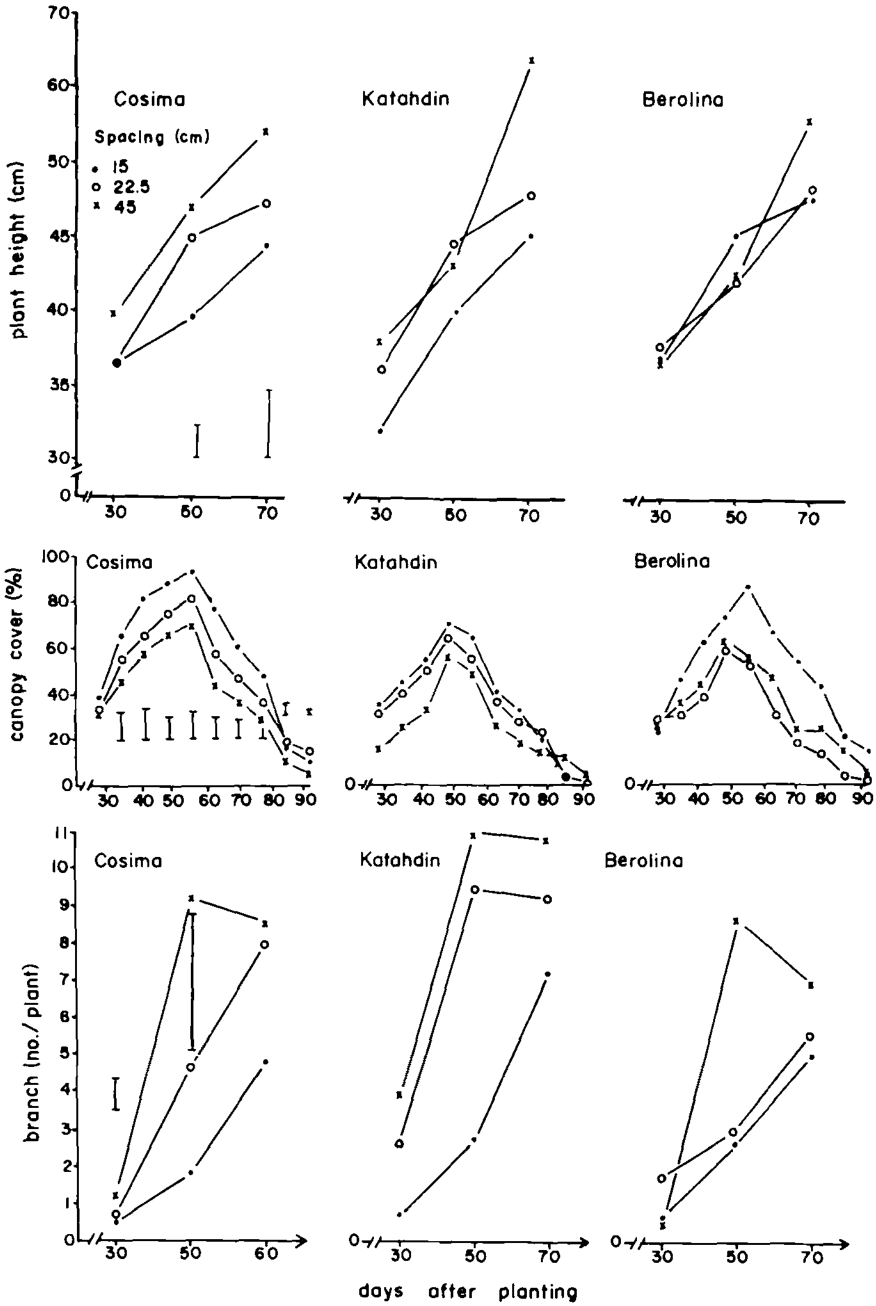


Fig. 2. Plant height, canopy cover and branching of cvs Cosima, Katahdin and Berolina planted at 15, 22.5 and 45 cm spacing, Canlubang, Phil. Bars indicate LSD's at 5 % for spacing treatments.

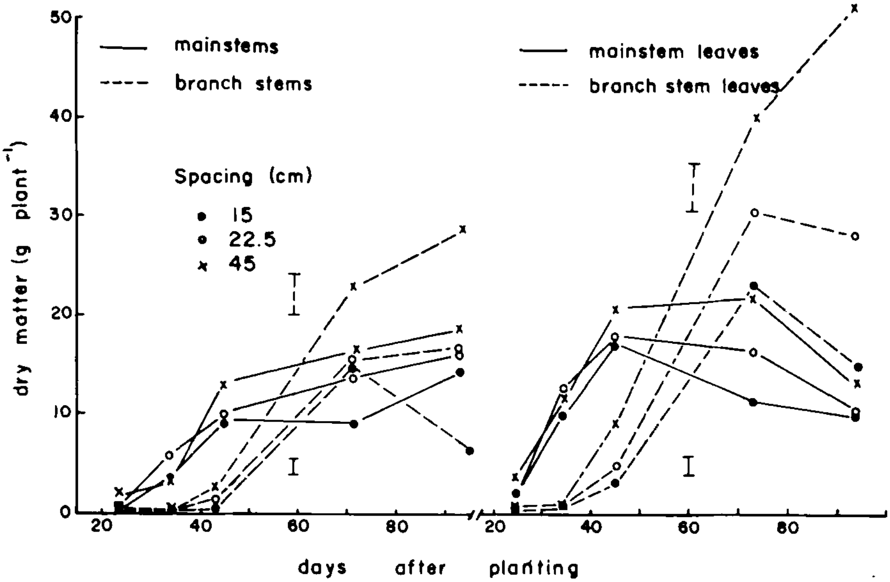


Fig. 3. Dry matter partitioning to the mainstems, branch stems and leaves of cv. Katahdin, Freeville, NY. Bars indicate LSD's at 5 % for spacing over all harvest dates.

The relative water contents were not significantly different on the 4 sampling dates (Table 3) but values were relatively low indicating moisture stress (Van Loon, 1981).

Root growth per plant, expressed as root weight, number and branching, increased significantly as distance between plants increased with cv. Katahdin at Freeville but not at Canlubang (Tables 4 and 5). Similarly, weight of cvs Cosima and Berolina tended to increase as spacing increased (Table 5). At Freeville, root weight was greatest 73 days after planting and at 94 many of the roots were decaying. The shoot:root weight ratio was not influenced by plant spacing, but did decrease with time at Freeville (data not presented) and varied with cultivar at Canlubang (Table 5) where cv. Katahdin had less root dry weight than the other two cultivars (Table 5).

Final tuber yields per stem increased sharply with wider spacing at Freeville. Differences were much smaller at Canlubang (Tables 6 and 7) where the smaller canopy size, did not reach 100 % cover and was always decreased with the wider spacing, with cvs Cosima and Katahdin, the two closely spaced treatments had similar yields per unit area, whereas the widest spacing gave significantly less yield. With the early cultivar Berolina, intermediate spacing caused a yield reduction per unit area (Table 7). Tuber dry matter content at harvest was low at Canlubang ('Katahdin' 11.0 %; 'Cosima' 12.7 % and 'Berolina' 10.8 %) but higher at Freeville ('Katahdin' 17.6 %). No treatment affected dry matter content.

As expected, numbers of main stems per plant were not influenced by spacing. Tuber numbers/stem slightly increased with wider plant spacing at Freeville but the differences were not significant (Table 6). Cvs Cosima and Berolina had more tubers/stem than cv. Katahdin (Table 7). Average tuber size was much greater at Freeville (Table 6)

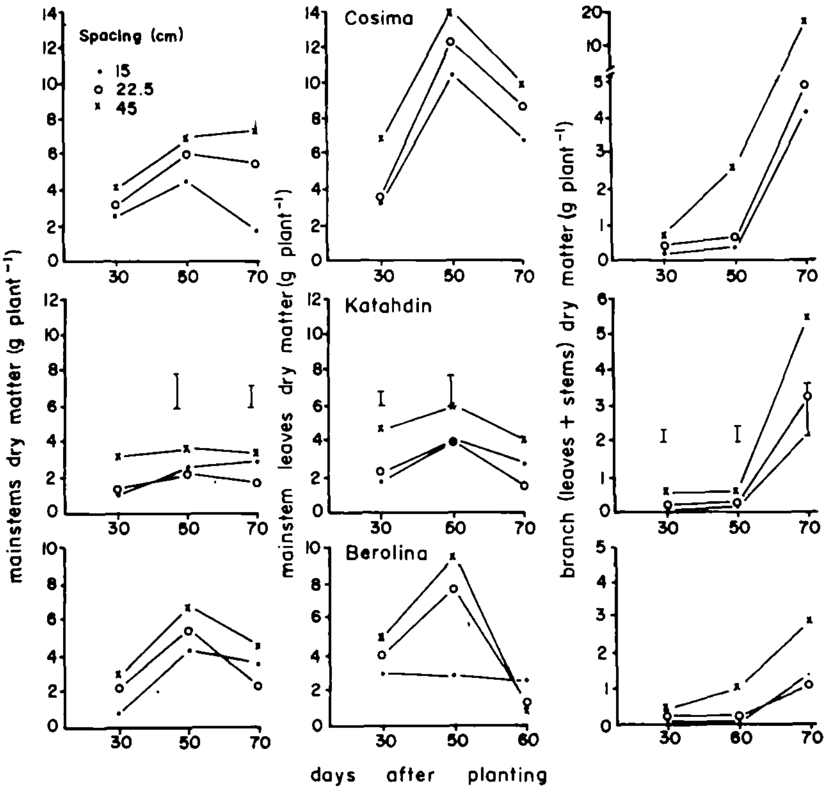


Fig. 4. Dry matter partitioning to the mainstems, leaves and branches of cvs Cosima, Katahdin and Berolina, at Canlubang, Phil. Bars are LSD's at 5 %.

Table 2. Total and tuber dry matter/plant at 73 days after planting at Freeville and at 70 days after planting at Canlubang.

| Spacing (cm) | Freeville | | Canlubang | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Katahdin | | Katahdin | | Cosima | | Berolina | |
| | total (g/plant) | tuber | total | tuber | total | tuber | total | tuber |
| 15 | 132 | 75 | 29 | 21 | 48 | 32 | 37 | 30 |
| 22.5 | 179 | 104 | 39 | 32 | 64 | 45 | 35 | 31 |
| 45 | 215 | 113 | 47 | 35 | 96 | 63 | 46 | 39 |
| LSD (0.05) | 65 | 28 | 11 | 10 | 11 | 10 | 11 | 10 |

Table 3. Relative water content of leaves (mean of three cultivars) as influenced by spacing.

| Spacing (cm) | RWC (%) on days after planting | | | |
|---|---|---|---|---|
| | 35 | 45 | 57 | 69 |
| 15 | 71 | 74 | 67 | 76 |
| 22.5 | 71 | 74 | 70 | 78 |
| 45 | 83 | 76 | 67 | 75 |
| LSD (0.05) | ns | ns | ns | ns |

Table 4. Influence of plant spacing on root weight and branching and the shoot/root weight ratio at Freeville.

| Spacing (cm) | Days after planting | Root weight (g) | Shoot/ root ratio | Roots | |
|---|---|---|---|---|---|
| | | | | branching (score) | >1 mm diam (no.) |
| 15 | 45 | 1.4 | 23 | | |
| | 73 | 2.3 | 25 | | |
| | 94 | 1.4 | 34 | 2.1 | 12 |
| 22.5 | 45 | 1.5 | 24 | | |
| | 73 | 2.5 | 30 | | |
| | 94 | 1.7 | 41 | 2.1 | 15 |
| 45 | 45 | 2.0 | 22 | | |
| | 73 | 3.5 | 29 | | |
| | 94 | 2.5 | 44 | 3.4 | 21 |
| LSD (0.05) | Spacing | 0.4 | ns | 0.9 | 2 |
| | Date | 0.4 | 7 | | |
| | Interaction | * | ns | | |

than at Canlubang (Table 7) and increased with increased spacing. At Freeville at least 90 % of the yield at all spacings was of tubers >50 mm (Table 6), and although the percentage of marketable yield was lower at Canlubang, it increased with wider spacing (Table 7).

Total plant dry matter and fresh tuber yields were highly correlated with intercepted solar radiation (ISR). Although Freeville had the greater ISR, plants at the Canlubang site had efficient conversion of ISR into tuber and plant dry matter (Fig. 5) giving higher tuber yields per unit of ISR.

## Discussion

Increasing the population density decreased biomass per plant and stem branching, so confirming results of Ifenkwe & Allen (1978). However, plant height was not affected at Freeville. By contrast at Canlubang, the widest spacing gave the tallest plants,

Table 5. Influence of plant spacing on root growth at 50 days after planting per plant at Canlubang.

| Cultivar | Spacing (cm) | Root weight (g) | Shoot/ root ratio | Roots | |
|---|---|---|---|---|---|
| | | | | >1 mm (no.) | length (cm) |
| Cosima | 15 | 0.65 | 22 | 5.4 | 14 |
| | 22.5 | 0.65 | 27 | 5.4 | 14 |
| | 45 | 1.00 | 24 | 6.0 | 15 |
| Katahdin | 15 | 0.25 | 23 | 4.0 | 15 |
| | 22.5 | 0.25 | 21 | 4.6 | 12 |
| | 45 | 0.25 | 25 | 4.0 | 11 |
| Berolina | 15 | 0.40 | 18 | 5.4 | 17 |
| | 22.5 | 0.70 | 19 | 6.0 | 13 |
| | 45 | 0.85 | 19 | 5.8 | 18 |
| LSD (0.05) | Cultivar | 0.1 | 4 | 4 | ns |
| | Spacing | 0.1 | ns | ns | ns |
| | Interaction | * | * | ns | ns |

Table 6. Effects of spacing on final tuber yield with 'Katahdin', 94 days after planting at Freeville.

| Spacing (cm) | Stems/ plant (no.) | Stems/ $m^2$ | Tuber yield/ stem (g) | Tubers/ stem (no.) | Total tuber yield (t/ha) | Average tuber weight (g) | Size (mm) | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | >50 | 30 – 50 |
| | | | | | | | (% of total) | |
| 15 | 2.5 | 19.6 | 194 | 2.3 | 38.0 | 84 | 91 | 8 |
| 22.5 | 2.6 | 13.6 | 257 | 2.5 | 35.0 | 103 | 95 | 4 |
| 45 | 2.9 | 7.6 | 391 | 2.9 | 29.7 | 135 | 95 | 5 |
| LSD (0.05) | ns | 3.0 | 47 | ns | 3.1 | 30 | ns | ns |

and this may have resulted from a greater water stress at higher plant densities early in the season (Table 3). Complete stomatal closure can occur at RWC of 76 – 80 % (Van Loon, 1981) and, as only the wider spaced plants gave a value > 80 %, it suggests that plant growth at low population densities were not interrupted early in the season. Later, RWC values were similar in all treatments. Also the increased root growth at wider spacing probably helped to maintain an adequate RWC and resulted in relatively constant shoot/root ratios between spacing treatments. This ratio increased with time at Freeville and would have placed a greater demand on the root system to provide water for the foliage. Furthermore, the smaller canopy development at Canlubang would not have created strong competition for light even at the highest plant densities. Also, plants tuberized 10 days earlier at Canlubang under relatively short days and this could have decreased plant height.

Table 7. Effect of spacing on final tuber yield, 84 days after planting at Canlubang.

| Cultivar | Spacing (cm) | Stems/ plant (no.) | Stems/ $m^2$ | Tuber yield/ stem (g) | Tubers/ stem (no.) | Total tuber yield (t/ha) | Avg. tuber wt. (g) | Size (mm) >50 (% of total) | Size (mm) 30–50 (% of total) |
|---|---|---|---|---|---|---|---|---|---|
| Cosima | 15 | 3.4 | 37.7 | 74 | 2.1 | 28.0 | 36 | 19 | 73 |
| | 22.5 | 3.8 | 28.1 | 116 | 3.0 | 32.8 | 39 | 19 | 73 |
| | 45 | 3.3 | 12.2 | 137 | 2.5 | 16.7 | 54 | 27 | 69 |
| Katahdin | 15 | 2.5 | 27.8 | 82 | 1.8 | 22.6 | 46 | 14 | 71 |
| | 22.5 | 2.3 | 17.0 | 133 | 2.5 | 22.6 | 54 | 21 | 71 |
| | 45 | 2.4 | 8.9 | 127 | 1.9 | 11.2 | 66 | 31 | 63 |
| Berolina | 15 | 2.3 | 25.5 | 123 | 3.8 | 31.5 | 32 | 16 | 82 |
| | 22.5 | 2.5 | 18.5 | 114 | 3.1 | 21.2 | 37 | 17 | 82 |
| | 45 | 2.4 | 8.9 | 149 | 3.2 | 13.2 | 47 | 38 | 58 |
| LSD (0.05) | | | | | | | | | |
| Cultivar | | .7 | 5.9 | 16 | 0.6 | 3.0 | 6 | ns | 10 |
| Spacing | | ns | 4.2 | 17 | ns | 3.2 | 4 | 9 | 10 |
| Interaction | | ns | ns | * | ns | * | ns | ns | * |

Branching was strongly influenced by growing conditions and at Freeville, branch stems and leaves formed a major part of the total plant dry matter in the more widely spaced treatments (Fig. 3). At Canlubang there was much less branching, because dry matter was rapidly partitioned into the tubers. It has been suggested that photoperiod is more important than temperature in enhancing tuber bulking (Demagante & Vander Zaag, 1988a).

Stem population density varied between treatments but did not greatly influence tuber yields under the long day conditions at Freeville. Similarly, Allen (1979) found that tuber yields were not greatly influenced by stem population densities greater than 12 $m^2$. At Canlubang, densities of less than 18 $m^2$ appeared to be detrimental to yield (Table 7), and also in earlier work we showed that yield was highly correlated to stem density up to 30 $m^2$ (Vander Zaag & Demagante, 1987). Tuber yield per stem decreased with increasing density (Tables 6 and 7), as found by Bremner & Taha (1966), and as tuber numbers/stem were not affected mean tuber weight increased as spacing increased (Bremner & Taha, 1966; Vander Zaag & Demagante, 1987).

Results of these experiments indicate that the response of potato plants to different population densities, is influenced by environment and cultivar. Such information would need to be incorporated into models simulating plant growth. But before this is possible it will be necessary to investigate responses of a range of genotypes under a wide range of environmental conditions. For example, studies could be made at latitudes between 20–30 °, and also with a range of temperatures at a single latitude (Manrique et al., 1989).

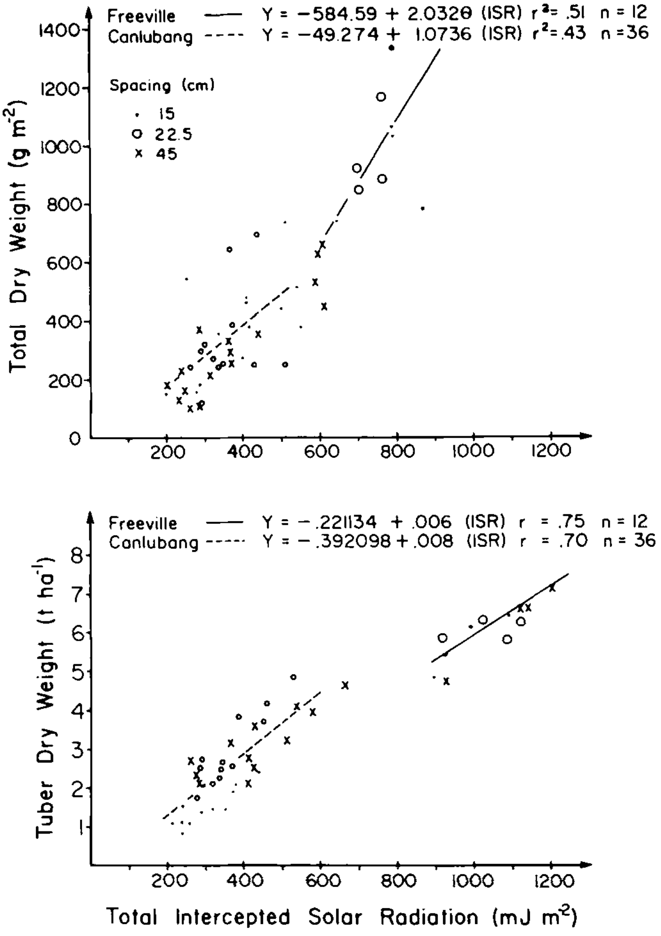


Fig. 5. Total dry matter and tuber dry weight response to intercepted solar radiation with cv. Katahdin at Freeville and three cultivars at Canlubang.

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