Air and Soil Temperature Effects on Growth Response of Peas to Phosphorus Fertilization[1]

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Abstract. The effects of 4 air and soil temperature regimes on plant growth and pea yield responses to applied P were investigated in controlled environments. The plants were grown in a low-P (4 ppm) Monroe silt loam, and harvested at 4 predefined stages of plant development. At the 6th node stage applied P increased vine (leaf and stem) weight only at the 21°/13°/18°C day/night/soil temperature regime. At the 10th node and full bloom stages P increased vine weight at all temperature regimes. Increases due to P were greater at the high soil temperature of 18° than at 10°. The increase due to P at the high soil temperature was greater at the cool air temperature of 21°/13° than at 30°/21°. At estimated marketable maturity of peas, P increased the dry weights of the root, vine, pod and pea seed at all temperature regimes, but the magnitude of such increases depended on the tissue and the temperature regime. Efficiency of P in promoting pea yield was greater at the high soil temperature, particularly at cool air temperature. The nearest optimum temperatures were a day/night air temperature of 21°/13° and a soil temperature of 18°. The nearest optimum P rate was 50 kg/ha.

Many experiments have been carried out to establish the effects of air or soil temperature on the growth of peas. However, the combined effects of air and soil temperatures, together with the response to P fertilization as an interacting factor have had little investigation. Also, much of the work reported hitherto did not include observations at different stages of plant development and has generally not been carried to crop maturity. Possible differential effects on various parts of the plant have not received adequate attention.

Went (14) found that the germination of peas at a high temperature of 26°C was faster but the plants were less uniform than when germinated at 23 or 20°. The optimal temperature for stem elongation and plant weight decreased in the course of development. Highkin (5) showed that a lack of day/night temperature fluctuation was inhibitory for growth of the pea plant. Wang and Bryson (13) pointed out that the response of peas to temperature varies with the stage of development. Studies by Fletcher et al. (4) indicated that yield variations due to locations and planting dates were related to temperature differences, and found that the optimum mean temperature for pea yield under field conditions was about 21–22°. In controlled environment studies, Stanfield et al. (12) reported that yield of peas decreased as temperature increased above 16°/10° day/night. The effect of soil temperature on pea growth was studied by Mack et al. (6) in a greenhouse experiment with fluctuating air temperature. They found that dry weights at early bloom were usually highest at soil temperatures of 17 and 21°.

The objective of the present study was to determine the effects of air and soil temperatures and phosphorus fertilization on growth characteristics and yield of peas at 3 pre-fruiting stages and at estimated marketable maturity of peas, and to find out if phosphorus could be applied to offset some of the deleterious effects of cold soils.

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Materials and Methods

A growth chamber with 4 cabinets as described by Ormrod (10) was used. Soil temperature in each cabinet was regulated by the use of controlled temperature water baths in which pots were immersed. The system was similar to that employed by Willis et al. (15). Two air and 2 soil temperatures were combined into 4 air and soil temperature regimes. These were day/night/soil temperatures of 21°/13°/10°, 21°/13°/18°, 30°/21°/10° and 30°/21°/18°C. The 21°/13° and 30°/21° day/night air temperatures are referred to as "cool" and "warm", while the 10° and 18° soil temperatures are referred to as "low" and "high" respectively.

Light was provided by a combination of cool-white fluorescent and tungsten lamps. The light panels were 70 cm above plant container level, and provided a light intensity of about 1600 foot-candles (measured with a Weston Model 756 illumination meter without cosine filter) at 50 cm below the light panels.

The photoperiod, controlled by an "Intermatic" time switch, was 16 hr in a 24-hr cycle. Relative humidity varied between 60 and 65% in the light period, and was about 73% in the dark period.

A low-P Monroe silt loam from the Lower Fraser Valley of British Columbia was used. Chemical analyses indicated the following composition: pH (water), 6.1; N, 0.24%; available P, 4 ppm; exchangeable K, 0.3 me/100 g; exchangeable Ca, 10.8 me/100 g; exchangeable Mg, 1.6 me/100 g; total exchangeable bases, 18.4 me/100 g. Six kg of air dry soil was placed in each 4 liter plastic pot. Commercial superphosphate fertilizer (20% P_2O_5) was used as the P source. Each pot received 0.8 g KCl (185 kg/ha). P was applied at the rates of 1.4 and 5.6 g per pot (50 and 200 kg P/ha respectively). These P levels were chosen on the basis of the results of a greenhouse study (1) in which the response of pea plants to 5 levels of P was determined. The 50 kg level was chosen on the basis of maximum efficiency (pea yield per unit of applied P), and the 200 kg level was chosen to represent a high P rate. The K fertilizer was mixed uniformly with the soil while the P fertilizer was applied as a band.

Seeds of pea, *Pisum sativum* L. cv. 'Dark Skin Perfection', were treated with "Nitragin" inoculum prior to planting. Six seeds were sown at a depth of 2 cm. A 3 cm layer of peat moss was spread on top of the soil to minimize evaporation. Five hundred ml of water was added to each pot, and the pots transferred to the treatment cabinets. At 2-node stage the seedlings were thinned to 4 per pot. From this stage onward, watering was done according to indicated requirements. Soil moisture was controlled at close to field capacity using gypsum resistance blocks and frequent additions of calibrated amounts of water. Water from a bottle kept in the water bath was used for the pots in that bath, to minimize variations in soil temperature. The difference of soil temperature from bath water temperature was less than 1°.

At the pre-defined growth stages (6th node, 10th node, full bloom and estimated marketable maturity of peas) the plants were cut at soil level. Full bloom was regarded as the stage at 0.5 blossom according to the classification scheme developed by Maurer et al. (8). Marketable maturity of peas was estimated by pod-fill. The root was carefully separated from soil by the flotation method of McKell et al. (9). Fresh weights were taken immediately after harvesting. The tissues were then dried in a forced air oven at 60° for 48 hr and weighed.

The completely randomized design was used within each temperature regime. Each experiment was conducted twice. There were thus 2 runs each of 2 replicates for a total of 4 replicates (pots) for each harvest. In the combined analysis of variance there was a testing term for run, temperature, phosphorus and all possible interactions (Table 1). Significant interactions occurred between temperature and P in the combined analysis of data for main effects at each growth stage (Table 2). Therefore individual analyses were also made for the simple effect of P at each growth stage and each temperature regime. Treatment means were subjected to Duncan's multiple range test (3) for the determination of significant differences among individual means. Means of P rates and of temperature regimes are not presented here because they can be calculated from the tables of simple effects.

Results

Plant height. Applied P had no effect on plant height at the 6th and 10th node stages (Table 3). At full bloom, P at the 50 kg/ha rate increased plant height at all temperature regimes except at the cool air and low soil temperature combination (21°/13°/10° day/night/soil) where P had no significant effect. The influence of P at the 200 kg/ha rate was not significantly different from that at the 50 kg/ha rate. At crop maturity, applied P increased plant height at all temperature regimes except 30°/21°/18° (Table 4).

Dry matter production. At the 6th node stage P had no effect on dry weight at all temperature regimes except 21°/13°/18° where P at the 200 kg/ha rate increased vine weight by 38% (Table 3). At the 10th node and full bloom stages, P increased dry weight at all temperature regimes. Increases due to P were greater at the high soil temperature of 18° than at 10°. Also, the increase due to P at the high soil temperature was greater at the cool day/night air temperature of 21°/13° than at 30°/21°. P effects at the 200 kg/ha rate were not significantly different from those at 50. The magnitude of weight increases due to P were greater at full bloom than at the 10th node stage.

At crop maturity, applied P increased the dry weights of all 4 tissues (root, vine, pod and peas) at all temperature regimes, but the magnitude of such increases depended on the tissue and temperature regime (Table 4). The greatest increases in root weight resulting from P, particularly at the 50 kg rate, were at the high soil temperature. The smallest increase in vine weight due to P was accompanied by the largest increase in pea weight, at 30°/21°/10°. Increases in pea yield due to P resulted largely from increase in pea number and to a lesser extent from pea size and pod number.

The nearest optimal day/night and soil temperature regime for plant growth was the 21°/13° and 18°. The nearest optimal P rate was 50 kg/ha.

Discussion

The deleterious effect of warm air temperature on pea growth increased with plant age. Beyond the 10th node stage the optimal air temperature for pea plant growth was thus indicated to be lower than for preceding stages

Table 1. An example of a combined analysis of variance showing main effects.[a]

Source of variation	df	Sum sq	Mean sq	Testing Term	F	Prob
Run	1	0.00047	0.00047		0.01	0.8779
Temp	3	0.76092	0.25364	R × T (A)	61.09	0.0069
R × T (A)	3	0.01246	0.00415		0.11	0.9502
Phosph	2	0.40887	0.20444	ERR (B)	71.11	0.0001
T × P	6	0.18363	0.03061	ERR (B)	10.65	0.0023
ERR (B)	8	0.02299	0.00287		0.07	0.9994
Error	24	0.92475	0.03853			
Total	47	2.31410				

[a]Variable: Dry weight of plants at the 10th node stage.
Temp: 21°/13°/10°, 21°/13°/18°, 30°/21°/10°, 30°/21°/18° Day/night/soil.
Phosph: 0, 50, 200 kg/ha.

Table 2. Variance ratios and significances of temperature, phosphorus and T × P effects. Dry matter, g/plant.

	Pre-fruiting stages			Crop maturity			
	6th node	10th node	full bloom	Root	Vine	Pod	Peas
Temp.	52.0**	61.1**	24.9*	3.5 n.s.	63.9**	70.8**	15.0*
Phos.	18.7**	71.1**	175.3**	106.8**	65.0**	57.2**	61.5**
T × P	7.5*	10.7**	18.7**	4.9*	5.2*	4.9**	2.0 n.s.

Table 3. Growth response of pea plants to P fertilization at 3 pre-fruiting stages of development as influenced by air and soil temperatures. Weights per plant.

Temperature regime day/night/soil °C	P kg/ha	6th node Plant height cm	6th node Dry weight g	10th node Plant height cm	10th node Dry weight g	Full bloom Plant height cm	Full bloom Dry weight g
21/13/10..........	0	11.5a[x]	0.19a	18.8a	0.30b	43.8a	0.65b
	50	12.5a	0.22a	21.0a	0.38a	50.0a	1.35a
	200	12.0a	0.23a	20.0a	0.39a	50.5a	1.82a
21/13/18..........	0	14.3a	0.31b	28.5a	0.42b	49.3b	0.95b
	50	14.0a	0.33b	29.3a	0.75a	69.0a	3.45a
	200	15.5a	0.43a	29.3a	0.88a	66.0a	3.23a
30/21/10..........	0	9.3a	0.18a	18.8a	0.32a	30.3b	0.50b
	50	8.8a	0.18a	19.8a	0.44a	44.8a	1.24a
	200	8.5a	0.16a	17.3a	0.43a	42.0a	1.21a
30/21/18..........	0	9.5a	0.22a	19.0a	0.34b	31.5b	0.53b
	50	9.5a	0.25a	20.3a	0.53a	44.8a	1.43a
	200	10.5a	0.28a	18.3a	0.52a	45.3a	1.46a

[x]Each figure is the mean of 4 replicates. Means followed by the same letter within a particular temperature regime, growth stage and measurement are not significantly different at P = 0.05 according to Duncan's multiple range test.

Table 4. Growth characteristics and yield factors in peas at marketable maturity as influenced by air and soil temperatures and phosphorus fertilization. Weights and numbers per plant.

Temperature regime day/night/soil °C	P kg/ha	Plant height cm	Root dry weight g	Vine[y] dry weight g	Pods Mean no.	Pods Dry weight g	Peas Mean no.	Peas Dry weight g	Total dry matter g
21/13/10.............	0	49.0b[x]	0.24b	0.71b	1.3b	0.24b	2.8b	0.18b	1.37c
	50	65.8a	0.35a	1.91a	2.5a	0.91a	10.0a	0.93a	3.87b
	200	64.8a	0.42a	2.21a	2.8a	1.12a	10.8a	1.31a	5.12a
21/13/18.............	0	54.5b	0.14b	0.75b	1.3b	0.31b	4.0b	0.34b	1.54b
	50	74.0a	0.32a	2.78a	3.8a	1.28a	16.5a	1.74a	6.12a
	200	71.3a	0.28a	2.94a	4.8a	1.46a	16.0a	1.55a	6.23a
30/21/10.............	0	34.5b	0.22b	0.40b	1.0b	0.12b	1.8b	0.08b	0.82b
	50	45.0a	0.33a	0.90a	2.0a	0.45a	7.0a	0.78a	2.46a
	200	50.0a	0.38a	1.07a	1.8a	0.47a	7.8a	0.76a	2.68a
30/21/18.............	0	38.0a	0.14c	0.43b	1.0b	0.12b	2.3b	0.19b	0.88b
	50	46.5a	0.33a	1.17a	2.0a	0.41a	7.8a	0.99a	2.90a
	200	48.0a	0.25b	1.26a	2.0a	0.47a	7.0a	1.03a	3.01a

[x]Each figure is the mean of 4 replicates. Figures followed by the same letter within a particular temperature regime and measurement are not significantly different at P = 0.05 according to Duncan's multiple range test.
[y]Total dry weight less roots, pods and peas dry matter.

of growth. This is consistent with the results of Stanfield et al. (12), Wang and Bryson (13) and Went (14). An increase in soil temperature from 10° to 18° generally increased plant weight at the 3 pre-fruiting growth stages. These observations are in general agreement with those of Apple and Butts (2) for pole beans, Singh and Mack (11) for beans, and Mack et al. (6) for peas. However, the response to soil temperature was found in the present studies to also depend on air temperature. For example, although the high soil temperature of 18° increased growth compared with the low soil temperature of 10°, the increases were greater at the cool air temperature of 21°/13° than at the warm air temperature of 30°/21°.

Increased dry matter due to increased P is consistent with the role of P in growth processes such as protein synthesis and cell wall extension (7) but applied P did not measurably offset the growth-limiting effects of warm air temperature or low soil temperature up to about full bloom. This agrees with the results of Mack et al. (6) for snapbeans. After this stage P did offset adverse effects of warm air temperature and low soil temperature on pea yield. While the highest yields were obtained at the high soil temperature, the relative effect of P on final yield was greater at the low soil temperature. At 30°/21°/10°, for example, the increase in pea yield due to applied P was 780% compared to the control. This large increase indicates that the utilization of growth factors by the time of harvest is greatly improved by the application of P at temperatures which adversely affect growth.

Mack et al. (6) found that the dry weight response of pea plants to P fertilizer at about 78 kg/ha was similar at the soil temperatures tested (13° to 25°). Apple and Butts (2) also found no significant effect of soil temperature on response to applied P on the dry weight of pole beans. Their failure to detect significant differences in the magnitude of growth increases at different soil temperatures might have resulted from the native P content of the experimental soil. Relatively high soil P might have led to decreased response to fertilizer P because they used a soil containing 15 to 25 ppm (6) and 312 ppm (2) P while the soil used in the present studies contained only 4 ppm P. There are possible differences in soil test methods which would not make the soil P levels directly comparable.

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Air and Soil Temperature and Phosphorus Effects on Mineral Uptake and Distribution in the Pea Plant[1]

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Abstract. The effects of 4 air and soil temperature regimes and 3 levels of P on the concentrations and total contents of N, P, K, Ca and Mg in pea plant tissues were investigated in controlled environments. There were generally no significant interaction effects between temperature regimes and applied P when contents of these minerals were expressed as per cent of dry matter. When contents were expressed as total uptake into the various tissues there were significant interactions for all 5 minerals.

At the pre-fruiting growth stages, tissue concentration of P generally increased with applied P, particularly at the highest rate. P concentration responses at the 10th node stage were similar to those at the 6th node, but there was a reversal of these effects at full bloom. The warm air temperature of 30°/21°C (day/night) generally increased P concentration but depressed total uptake compared with a temperature of 21°/13°. The increases were largely due to concentration effects resulting from smaller plants. Increases in P concentration at the high soil temperature of 18°, compared with 10°, were absolute because they occurred regardless of plant size. Applied P increased the total uptake of minerals as well as their translocation into the seed.

MINERAL uptake by plants may be influenced by environmental factors, prominent among which are shoot and root temperatures as well as nutrient availability. A number of studies (3, 7) have been carried out to determine the interactive influences of soil temperature and P fertilization on P uptake. However, the influence of air temperature on such responses has not been reported. Also, reports of such responses at various stages of plant development are quite few.

In a greenhouse experiment with peas and beans, Mack et al. (9) maintained soil temperatures of about 13°, 17°, 21° and 25°C with rates of P application ranging from 0 to about 314 kg/ha. Plant P increased with temperature and applied P. Singh and Mack (13) found that P and K contents of snapbean shoots increased with soil temperature up to 24°. In the tomato, Locascio and Warren (8) reported an increase in P content with increase in soil temperature up to 30°. Apple and Butts (3) found that the effect of soil-applied P in increasing the percentage P in pole bean plants was significantly greater at a low than at a high soil temperature.

The present study was carried out to determine the effects of air and soil temperatures and phosphorus fertilization on the uptake of N, P, K, Ca and Mg at 3 prefruiting stages of development, and on their distribution in plant parts at estimated marketable maturity of peas.

MATERIALS AND METHODS

Details of the soil and fertilizer used and method of application, planting, harvesting and statistical analysis

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