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THE EFFECT OF DAYTIME TEMPERATURE, PLANTING DENSITY AND INTERCROPPING ON OATS AND PEAS

2013 | KATIE WIGMORE DEGROOT

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THE EFFECT OF DAYTIME TEMPERATURE, PLANTING DENSITY AND INTERCROPPING ON OATS AND PEAS

by

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Dated this 26th day of April, 2013, in Kamloops, British Columbia, Canada

ABSTRACT

Oats and peas are grown throughout Canada and around the world as a nutritious feed for cattle. Commonly, farmers grow oats and peas together in the same field (i.e., intercropped) to produce forage that is higher yielding and more nutritious than individually-grown oats or peas. Given the importance of oats and peas to the cattle industry, investigating and understanding how climatic factors and growing methods affect yields is important.

Previous studies have shown that greatest yields are achieved when daytime temperatures are between 15°C and 20°C, oats and peas are intercropped, and a high planting density is used. However, these three factors have not been investigated together in one experiment before. Therefore in this project, the interacting effect of daytime temperatures, planting densities and cropping methods were studied. Using a climate-controlled greenhouse, oats and peas were grown together and apart at three different planting densities and daytime temperatures.

Contrary to previous studies, I found that temperatures above 20°C positively affected oat and pea yields. However, leaf count and plant height data indicate that these plants were simply maturing earlier.

As expected, planting density positively affected yields in both species. Individual yield data shows that per-plant yields did not vary with density. This indicates that plant growth was not nutrient limited. Thus, increases in yield with planting density are almost wholly attributable to the increased number of plants per area.

Finally, I found that intercropping oats and peas together resulted in yields intermediate to sole-cropped oats and peas. No difference in individual plant weights, leaf counts or heights were observed between plants that were sole or intercropped. Thus, it might be that intercropping oats with peas does not positively affect yields when plants are not nutrient limited, and that increased yields obtained when these two species are intercropped results primarily from an increase in planting density.

To validate these observations, I recommend repeating this study with a larger number of replicates and harvesting all treatments at the same stage of maturity.

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INTRODUCTION

Oats (*Avena sativa*) and peas (*Pisum sativum*) are commonly grown in Canada and around the world as nutritious cattle forage (Aasen *et al.,* 2004; Begna *et al.,* 2010). Individually, oats are high yielding but low in protein, whereas peas are high in protein but low yielding (Kocer and Albayrak, 2012). As both crops mature within the same amount of time, farmers often grow oats and peas together (i.e., intercropped) to produce a high-yielding, high protein animal feed (Chapko *et al.,* 1991). Given how important oats and peas are to the cattle industry, understanding how different factors influence forage yields has been the subject of much research. The effects of temperature, planting density, and intercropping have been greatly studied.

Studies have found that oat forage yields are greatest when daytime temperatures are between 13°C and 19°C (Tamm, 2003). When temperatures rise above 20°C, yields begin to decline. This is in part because oat maturity is dependent upon the amount of heat each plant receives (Olesen *et al.,* 2012). Therefore, as daytime temperatures rise, oats mature faster and take less time to grow (Contreras-Govea and Albrecht, 2006; Peltonen-Sainio *et al.,* 2011). As a result, yields decline when temperatures are greater than 20°C (Tamm, 2003; Hellewell *et al.,* 1996).

High daytime temperatures affect peas in a similar way. Pea yields are greatest when daytime temperatures are between 5°C and 18°C (Peltonen-Sainio *et al.,* 2011; Herath *et al.,* 1971). As temperatures rise above 18°C, pea yields begin to decline. Like oats, as temperatures rise, peas take less time to mature and yield less overall (Lambert *et al.,* 1958; Nonnecke *et al.,* 1971).

Planting density (the number of plants growing per area) also affects oat and pea yields. By increasing planting density, an area's total forage yield is increased. When the planting densities of sole-cropped oats or peas are doubled, their forage yields greatly increase (Carr *et al.,* 1996; Hauggaard-Nielsen *et al.,* 2006; Blackshaw *et al.,* 2005).

Many studies have also investigated how intercropping oats and peas affect total forage yields. The general consensus is that intercropping results in higher forage yields compared to sole-cropped oats or peas alone (Begna, 2011; Chapko *et al.,* 1991). In most studies, pea yields per hectare were lower than oats (Mustafa *et al.,* 2004) although that was not always the case (Jaster *et al.*, 1985). As pea plants are capable of nitrogen fixation, it has been suggested that intercropping yield increases are due to oat plants utilizing the nitrogen fixed by the peas (Geijersstam and Martensson, 2006).

While previous studies have investigated the effect of temperature, planting density and intercropping upon oat and pea yields, I have not found any studies that investigated all three factors together. Additionally, no one has investigated the effect of these three factors upon individual oat and pea plants. Therefore, in my study, I examined the effect of temperature, planting density and intercropping upon total dry oat and pea forage yields, as well as the effect of these three factors upon individual oat and pea heights, leaf counts and plant dry weights.

Based on the results of previous studies, I expect overall yields to be greatest when oats and peas are planted together at the greatest density and lowest temperature. Individually, I expect oat and pea plants to be heaviest when grown together at low temperatures and low planting densities.

METHODS

This study was conducted in November and December 2012 at the Thompson Rivers University Research Greenhouse in Kamloops, British Columbia. This greenhouse features four independent pods, each with its own computer-controlled heater, gable vents and 1000 Watt Halide lights. In my experiment, lights in all pods were positioned about 1.5 m above the table upon which my plants were grown. Thus the estimated light intensity at potting mix level was 46,500 lumens/m^2. This value is within the range of that for sunlight reaching the earth's surface, which varies between 10750 and 107500 lumens/m^2 (Clegg and Watkins, 1981). In counter-clockwise order, the pods are referred to as 1 to 4 (Figure 1).

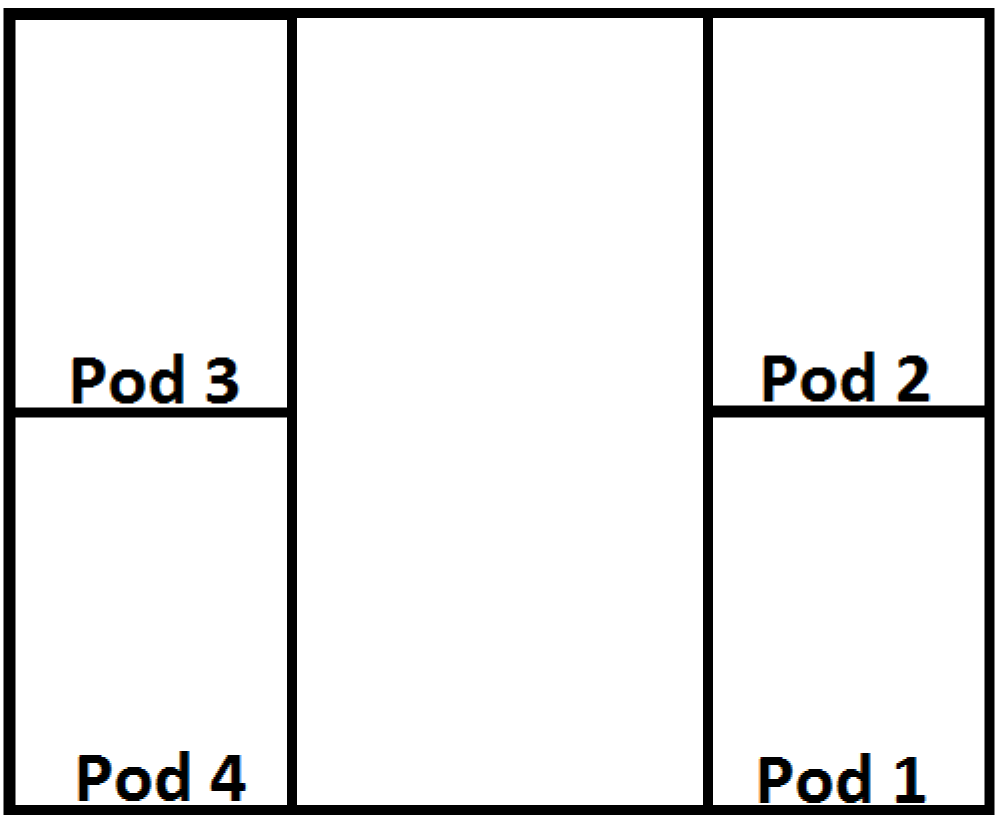

Figure 1. Greenhouse layout and pod designations. Each pod is approximately 7m wide and 3.5m deep, with one central and two side tables.

Greenhouse settings

For all pods, a day-night cycle of 14 hours light and 10 hours dark was simulated, as per Haldimann and Feller (2005). Lights automatically turned on at 5:40 am and turned off at 7:40 pm. Daytime temperatures in Pods 4, 2, and 3 were set to 17°C, 22°C and 27°C respectively. As previous studies have found 20°C to be the upper limit for optimal oat and pea yields (Tamm, 2003; Herath *et al.,* 1971), temperatures were chosen to be just below, just above and well above this limit (17°C, 22°C and 27°C respectively). Initially, night temperatures were set to 17°C in all pods. However on Day 12 (November 20th) this was reduced to 14°C to ensure all pods experienced a distinct day-night temperature difference.

The relative humidity in all pods was initially set to 60% during the day and 80% at night, a compromise between the relative humidity settings used by previous oat and pea greenhouse studies (Hellewell *et al.,* 1996; Lambert and Linck, 1958). After a few days at this setting, extreme condensation was observed in the high temperature pod (Pod 3). Therefore on Day 11 (November 19th), relative humidity set-points for all pods were lowered to 40% during the day and 75% at night in an effort to reduce condensation and prevent plant disease.

Growing methods

All treatments were grown in 26.5 L GrowBags filled with PRO-MIX BX. From Premier Tech Horticulture, PRO-MIX BX is a general-purpose soil-less growing medium in which most plant species do well. It contains Canadian peat moss, perlite, vermiculite, limestone and a wetting agent. It is pH-balanced and has excellent water retention (Premier Tech Horticulture, 2011).

The oat variety “Baler” was grown as it is highly recommended for silage and forage production (Dyck, 2010). The pea variety “Trapper” was chosen because it does well when grown with oats and has been used in previous intercropping studies (Carr *et al.,* 1996; Chapko *et al.,* 1991).

On November 9th 2012 (Day 1), oats and peas were planted in the greenhouse. No rhizobia inoculant was applied. Planting densities were 2, 4 or 6 plants per GrowBag, similar to seeding rates used in previous studies (Kocer and Albayrak, 2012). As the area of each GrowBag was about 0.046 m^2 (0.5 ft^2) this corresponds to approximately 43, 86, or 129 plants/m^2 (4, 8 and 12 plants/ft^2), respectively. For intercropping trials, oats and peas were planted in a 1 to 1 ratio. That is, for intercropping treatments there were 1, 2 or 3 oat plants and 1, 2, or 3 pea plants per GrowBag, respectively. All twenty-seven treatment combinations were replicated six times (Figure 2).

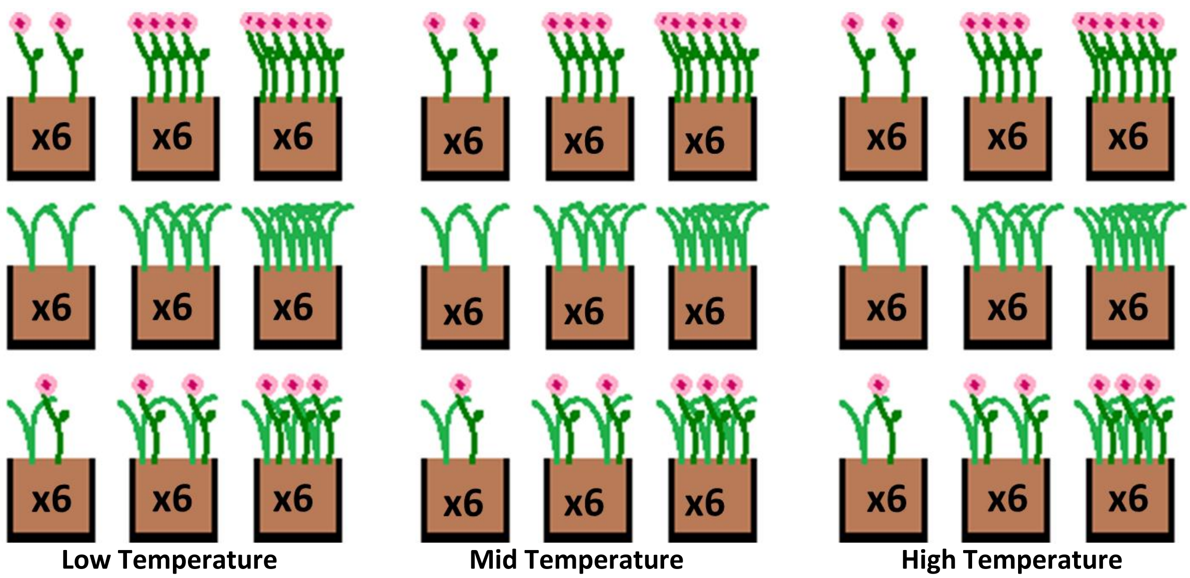

Figure 2. A schematic representation of experimental setup. Oats (middle row) and peas (top row) were sole-cropped and intercropped together in a one-to-one ratio (bottom row) at three different planting densities (2, 4, or 6 plants per GrowBag) and daytime temperatures (17°C, 22°C and 27°C).

Each pod's fifty-six GrowBags were divided into six groups of nine GrowBags each (Figure 3). Each group contained one replicate of each intercropping and density treatment. Within each group, treatment positions were systematically assigned.

Figure 3. Researcher on planting day (November 9^{th} 2012), demonstrating the systematic blocked GrowBag layout within the low temperature pod. Photo credit to J. Wigmore.

When oat and pea seeds were planted, all GrowBags were thoroughly soaked with water. In the week prior to seedling emergence, all GrowBags were saturated every two to three days. Afterwards, GrowBags were watered on an as-needed basis. The two higher temperatures pods required watering two to three times a week, while the lower temperature pod needed watering only once a week, if at all.

On Day 15 (November 23^{rd}), approximately 5 mL of “Miracle-Gro Shake ‘n Feed” 10-10-10 (NPK) slow release fertilizer was applied to each GrowBag (Table 1).

Table 1. Nutrient content of “Miracle-Gro Shake ‘n Feed” 10-10-10 (NPK) fertilizer.

Nutrient	**Guaranteed Minimum Analysis**
Nitrogen (N)	10%
Phosphate (P_2O_5)	10%
Potash (K_2O)	10%
Sulphur (S)	20%

On Day 22 (November 30th), plants were fertilized with 20-20-20 (NPK) “Plant-Prod” liquid fertilizer (Table 2). As “Plant-Prod” did not contain any calcium (an important plant nutrient), powdered milk was added to the fertilizer mix. All GrowBags received 1.1 mL of tap water containing 0.0744 g fertilizer and 0.1026 g powdered milk. By accident, the low temperature pod received an additional 0.0742 g fertilizer and 0.1004 g powdered milk.

Table 2. Nutrient content of “Plant-Prod” 20-20-20 (NPK) fertilizer.

Nutrient	**Guaranteed Minimum Analysis**
Nitrogen (N)	20%
Phosphate (P_2O_5)	20%
Potash (K_2O)	20%
Boron (B)	0.02%
Copper (Cu)	0.05%
Iron (Fe)	0.1%
Manganese (Mn)	0.005%
Molybdenum (Mo)	0.0005%
Zinc (Zn)	0.05%
Ethylene diamine tetraacetate (EDTA)	1%

Harvest

All GrowBags were harvested on December 26th 2012, 48 days from planting (Figure 4). Plants were cut ± 0.5cm from soil level, leaves were counted, and plant heights measured. Plants were individually bagged and air-dried for 2 weeks. Then plants were oven-dried at 60°C for 48 hours and individually weighed.


Figure 4. Pod 3 on harvest day (December 26th 2012). Photo credit to J. Wigmore.

Statistical analysis

Due to mice and greenhouse mechanical issues, not all replicates survived to harvest. Only undamaged replicates with 100% germination were analyzed. As a result, the number of surviving replicates was very low (Table 3).

Table 3. Number of surviving replicates for each treatment combination. "D2", "D4", and "D6" indicate planting densities of 2, 4 or 6 plants per GrowBag respectively.

	15°C			20°C			25°C		
	D2	**D4**	**D6**	**D2**	**D4**	**D6**	**D2**	**D4**	**D6**
Oats	6	5	3	4	3	3	4	1	1
Oats + Peas	3	4	3	2	3	1	4	6	4
Peas	5	6	5	5	6	5	6	6	6

For GrowBag total dry yields, replicate numbers were very low, so parametric tests were impossible. While Mann-Whitney U-tests were considered, it was decided that the data were insufficient to support any conclusions drawn.

For analysis of plant heights, leaf counts and individual plant weights, pseudoreplication became an issue. This was because every plant within each GrowBag was analyzed as if it were independent of any other. Thus for all measurements (total dry yields, plant heights, leaves per plant, and individual plant dry weights), line graphs showing the mean values for all treatment combinations were created.

To individually assess the effect of individual factors upon each measurement, data points for every factor were pooled and plotted using Box-and-Whisker graphs. While this method does not allow for any assessment of interactions or for all treatment combinations to be analyzed together, it does provide a rough estimate as to the effect of each factor upon oats and peas. However, these graphs are only valid if interactions between factors did not occur. Given the variability and nonparametric nature of the data, this cannot be ruled out. Thus, boxplots assessing the effect of individual factors upon oats and peas should be viewed only as a general representation of trends observed within the data.

RESULTS

On harvest day (Day 48, December 26th 2012), two pea flowers were observed in the high temperature pod. Of the 162 GrowBags initially planted, about 66% survived to maturity. From these 110 surviving GrowBags, a total of 165 oat plants and 259 pea plants were harvested (Figure 5). Oat plants were 28.4 to 79 cm tall and had 3 to 11 leaves. Pea plants were between 37.4 and 194.0 cm tall and had 7 to 20 leaves. After being oven dried for 48 hours, oat plants weighed between 0.04 and 0.63 g and pea plants weighed between 0.13 and 1.17 g.

Figure 5. Researcher and research assistant with individually bagged oat and pea plants on harvest day (December 26th 2012). Photo credit to J. Wigmore.

Total dry yields

There are several clear trends within the total dry yields of oats and peas (Figure 6). Across all densities and cropping methods, total dry yields increased as daytime temperatures rose. For all temperatures and cropping methods, total dry yields rose as planting density increased. Across all temperatures and planting densities, intercropped oats and peas yielded less than sole-cropped peas but more than sole-cropped oats.

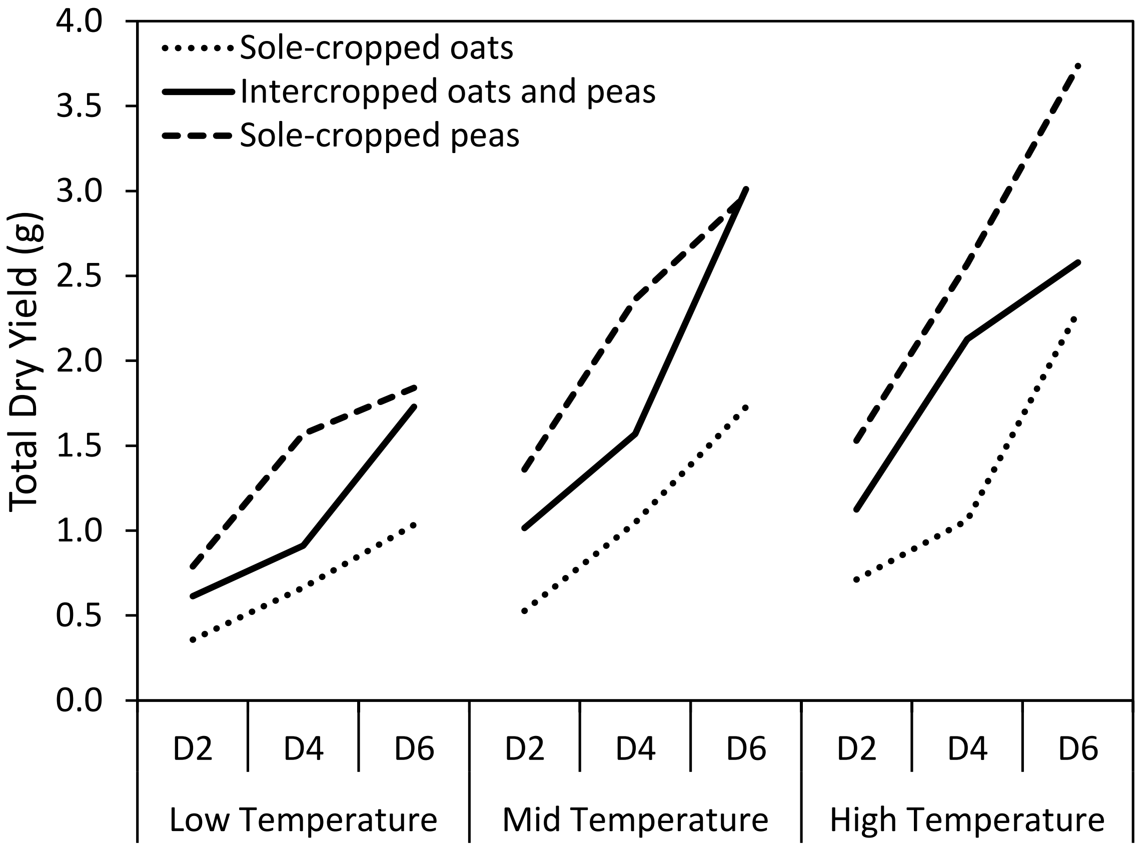

Figure 6. Mean total dry yield per GrowBag for the twenty-seven combinations of daytime temperature, planting density and cropping method. “D2”, “D4”, and “D6” indicate planting densities of 2, 4 or 6 plants per GrowBag, respectively.

When all three factors are analyzed individually (Figure 7), these findings become even more obvious. Figure 7a suggests that total dry yields were lower at the low daytime temperature and higher at both the mid and high temperature. As planting density increased, yields increased as well (Figure 7b). Finally, Figure 7c clearly shows that oat yields were lowest and pea yields greatest, while intercropping oats and peas together resulted in intermediate yields.

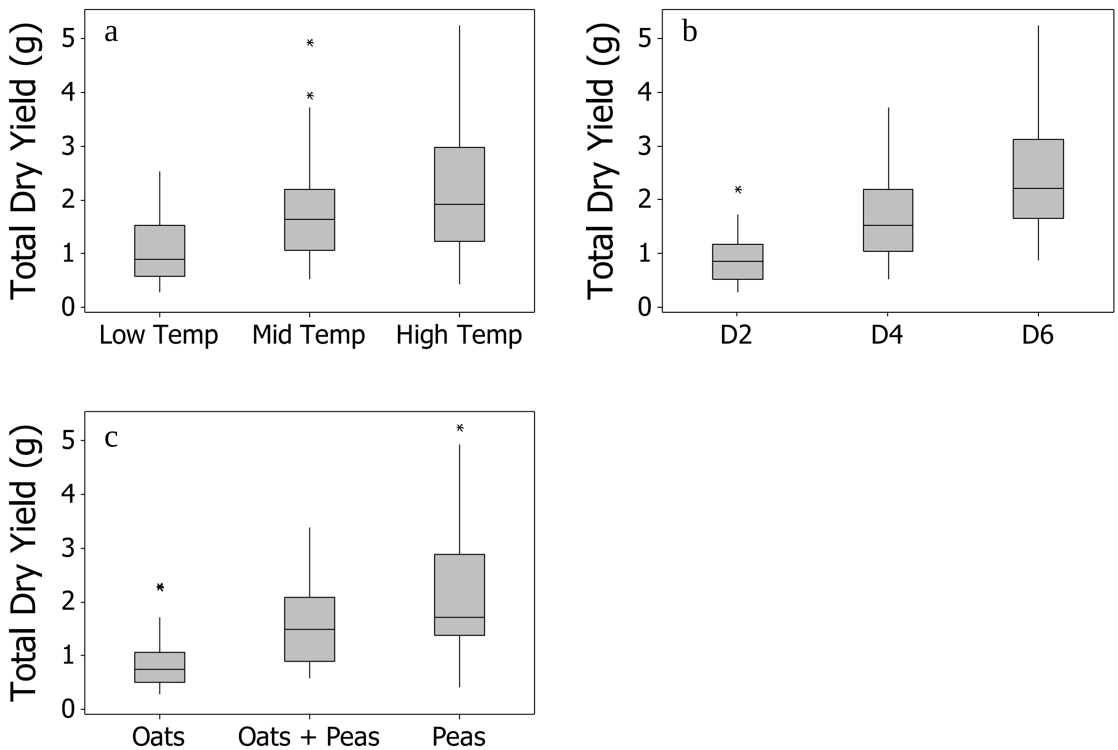

Figure 7. Pooled total yields per GrowBag for daytime temperatures (a), planting densities (b) and cropping types (c). Asterisks indicate outlying data points.

Oat plant heights

When average oat plant heights are examined across all eighteen daytime temperatures, planting density and cropping combinations (Figure 8), one clear trend emerges: regardless of planting density or cropping type, as temperatures rose, plant heights increased as well. Plant heights were very variable across all three densities at each temperature and cropping type. There does not appear to be any clear pattern regarding how cropping type affected plant heights.

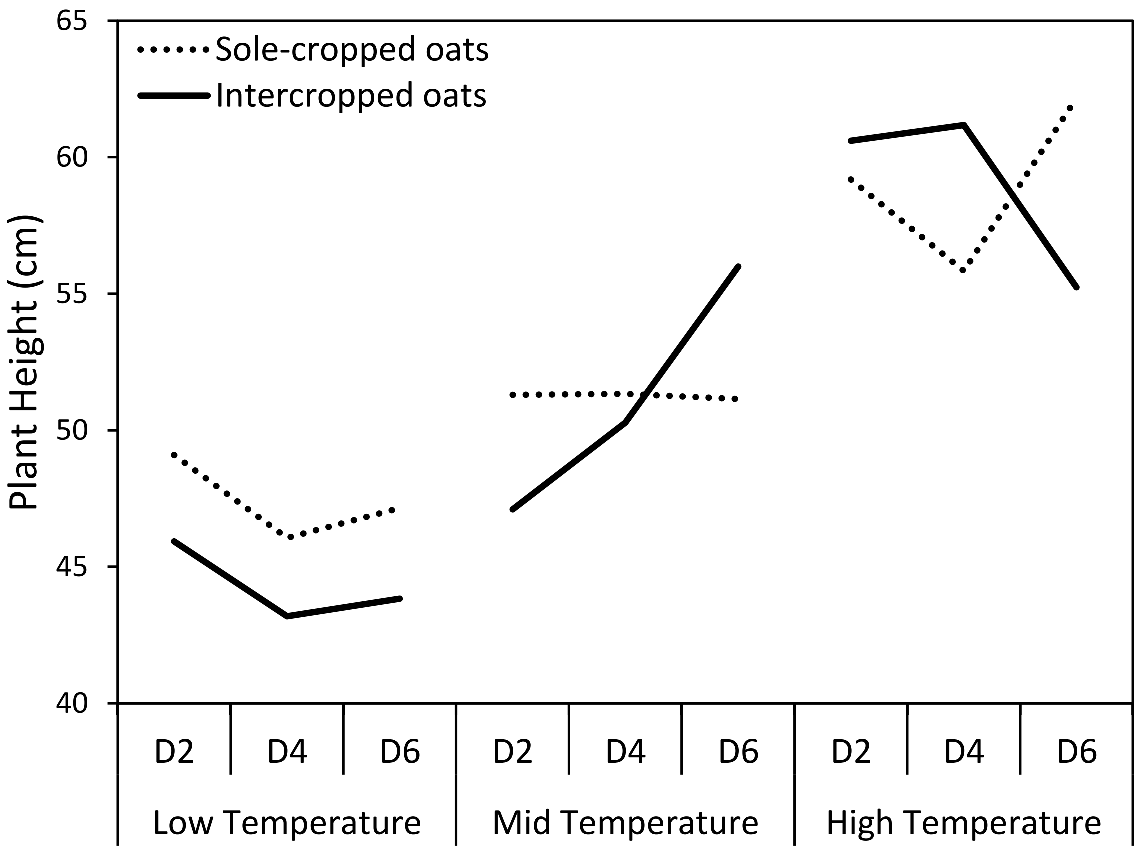

Figure 8. Mean oat plant heights for the eighteen combinations of daytime temperature, planting density and cropping method. D2, D4, D6 = densities of 2, 4, or 6 plants, respectively.

By examining each factor individually (Figure 9), plant height data becomes less variable. Figure 9a shows that as temperatures increased, plant heights increased as well. Across all densities, median plant heights were very similar (Figure 9b). Finally, the heights of sole-cropped plants do not appear to differ from the height of oat plants that were intercropped with peas (Figure 9c).

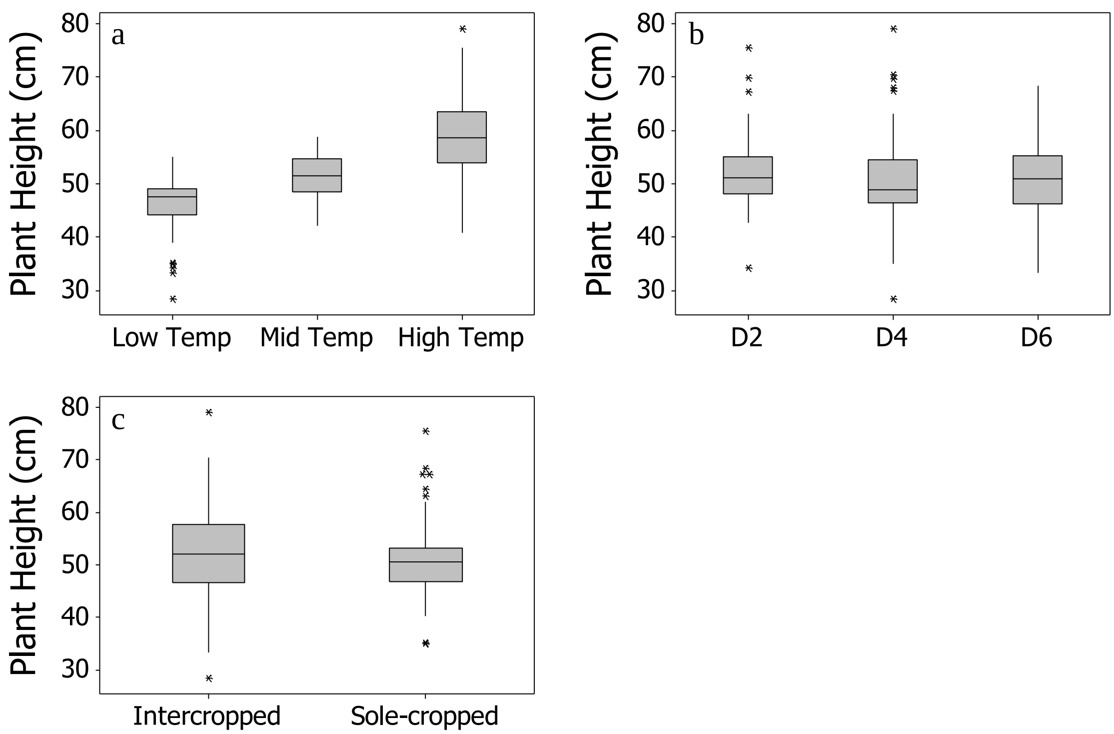

Figure 9. Pooled oat plant heights for daytime temperatures (a), planting densities (b) and cropping types (c). Asterisks indicate outlying data points.

Pea plant heights

Figure 10 clearly shows how pea plant heights are affected by temperature: as daytime temperatures rose, pea plant heights increased. Between the low and high temperature treatments, plant heights almost doubled. Neither planting density nor intercropping appears to have a clear effect upon pea plant heights.

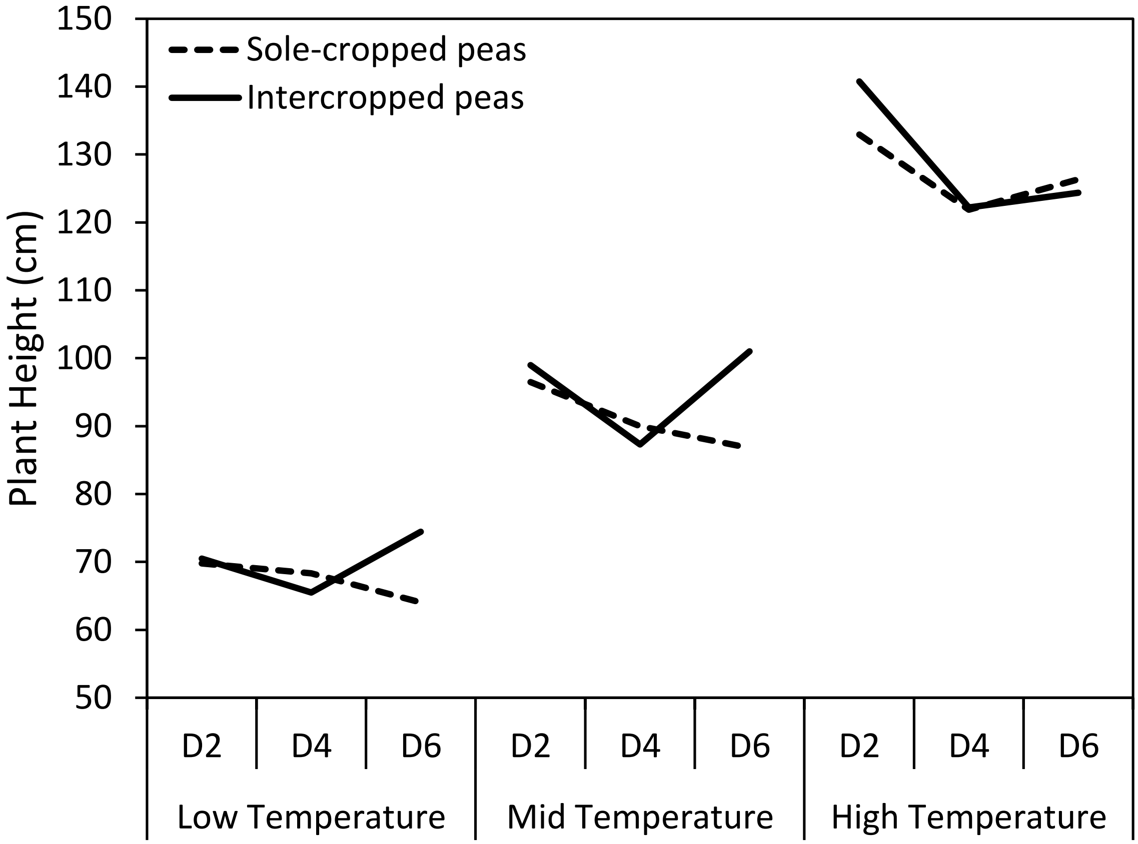

Figure 10. Mean pea plant heights for the eighteen combinations of daytime temperature, planting density and cropping method. D2, D4, D6 = densities of 2, 4, or 6 plants, respectively.

By analyzing the effect of temperature, planting density and cropping type individually upon pea plant heights, similar findings appear. Figure 11a provides further support to the suggestion in Figure 10 that plant heights increased with temperature. Figure 11b show that the range over which plant heights varied did not differ across planting density. Finally, Figure 11c indicates that intercropping had no overall effect upon pea plant heights.

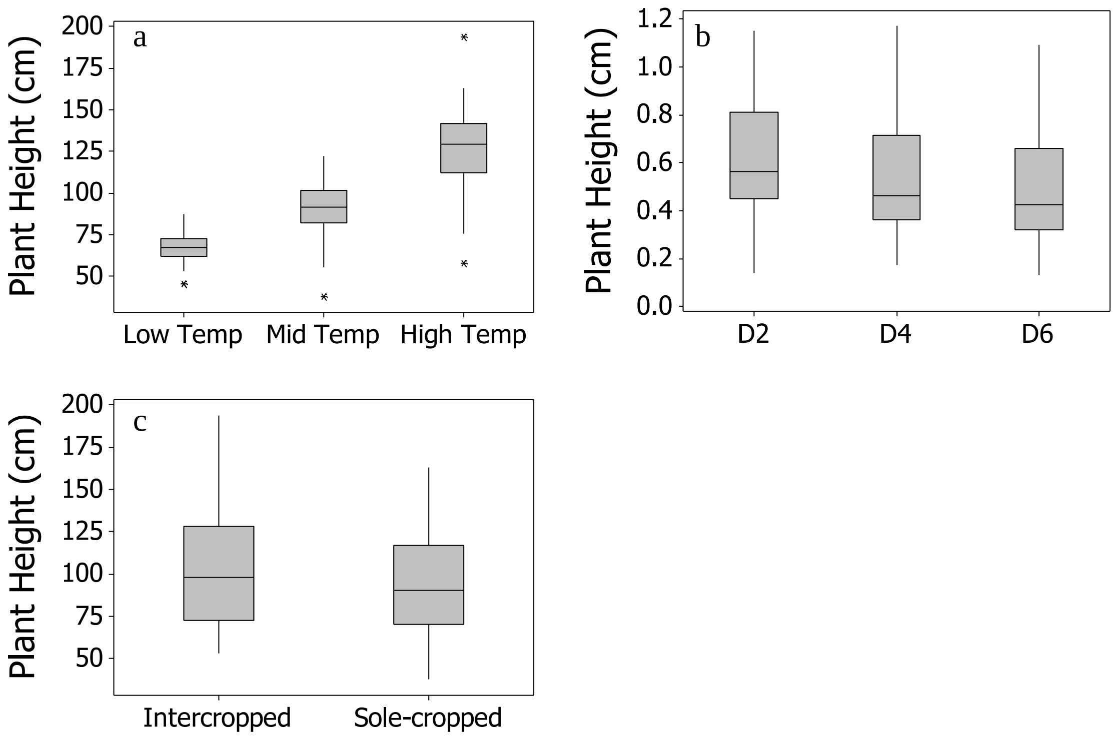

Figure 11. Pooled pea plant heights for daytime temperatures (a), planting densities (b) and cropping types (c). Asterisks indicate outlying data points.

Oat leaf counts

As shown by Figure 12 below, the number of leaves per oat plant increased with temperature. Across all densities and cropping types, it appears that leaf numbers increased slightly between the low and mid temperature and increased greatly between the mid and high temperatures. The effect of planting density and intercropping upon oat leaf counts were variable across all treatments.

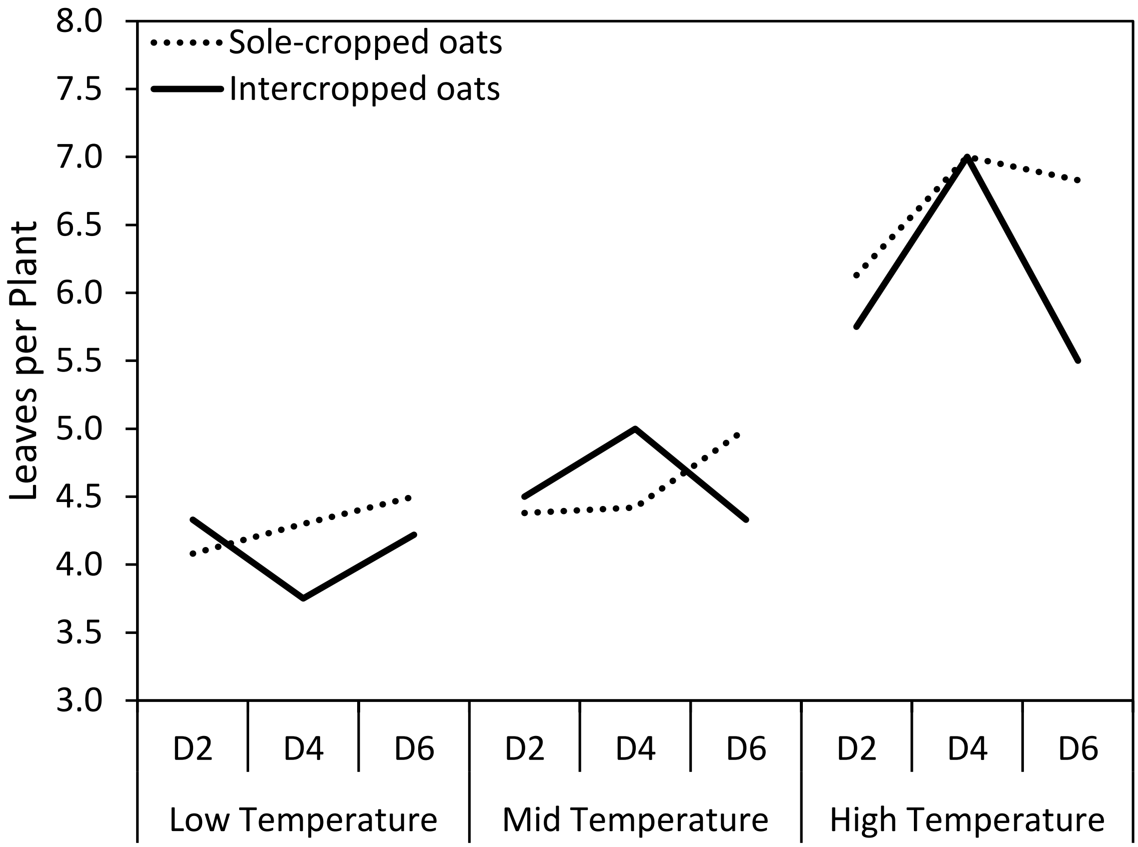

Figure 12. Mean oat plant leaf counts for the eighteen combinations of daytime temperature, planting density and cropping method. D2, D4, D6 = densities of 2, 4, or 6 plants, respectively.

By analyzing oat leaf counts by temperature, planting density and cropping type separately, clearer trends emerge (Figure 13). Leaf counts are lowest at the low and mid temperatures and greatest at the high temperature (Figure 13a). The number of leaves per oat plant does not appear to be affected by either density (Figure 13b) or intercropping (Figure 13c).

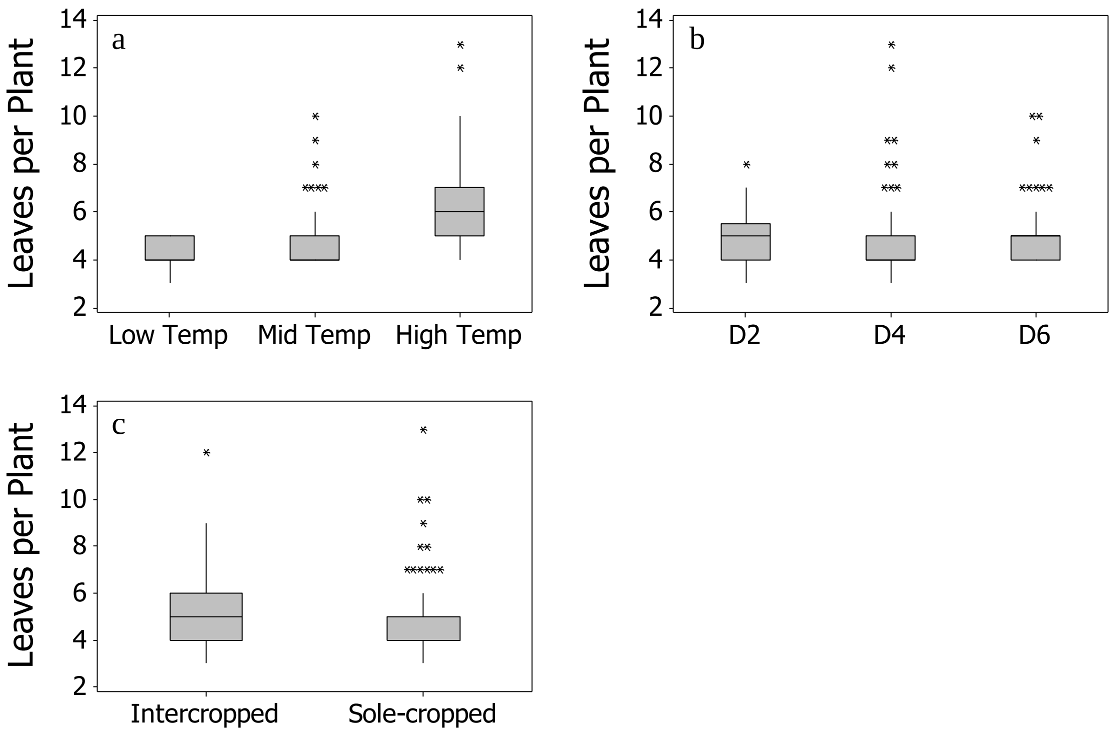

Figure 13. Pooled oat plant leaf counts for daytime temperatures (a), planting densities (b) and cropping types (c). Asterisks indicate outlying data points.

Pea leaf counts

As is clear in Figure 14 below, the number of leaves per pea plant increased greatly with increasing daytime temperatures. Density appears to have no obvious effect upon leaf numbers across all temperatures and cropping types. For the low and mid temperatures, intercropping peas with oats does not appear to affect leaf counts. At the high temperature, it appears that intercropping peas with oats increased leaf numbers. However, due to low replicate numbers and pseudoreplication, the statistical accuracy of this observation cannot be substantiated.

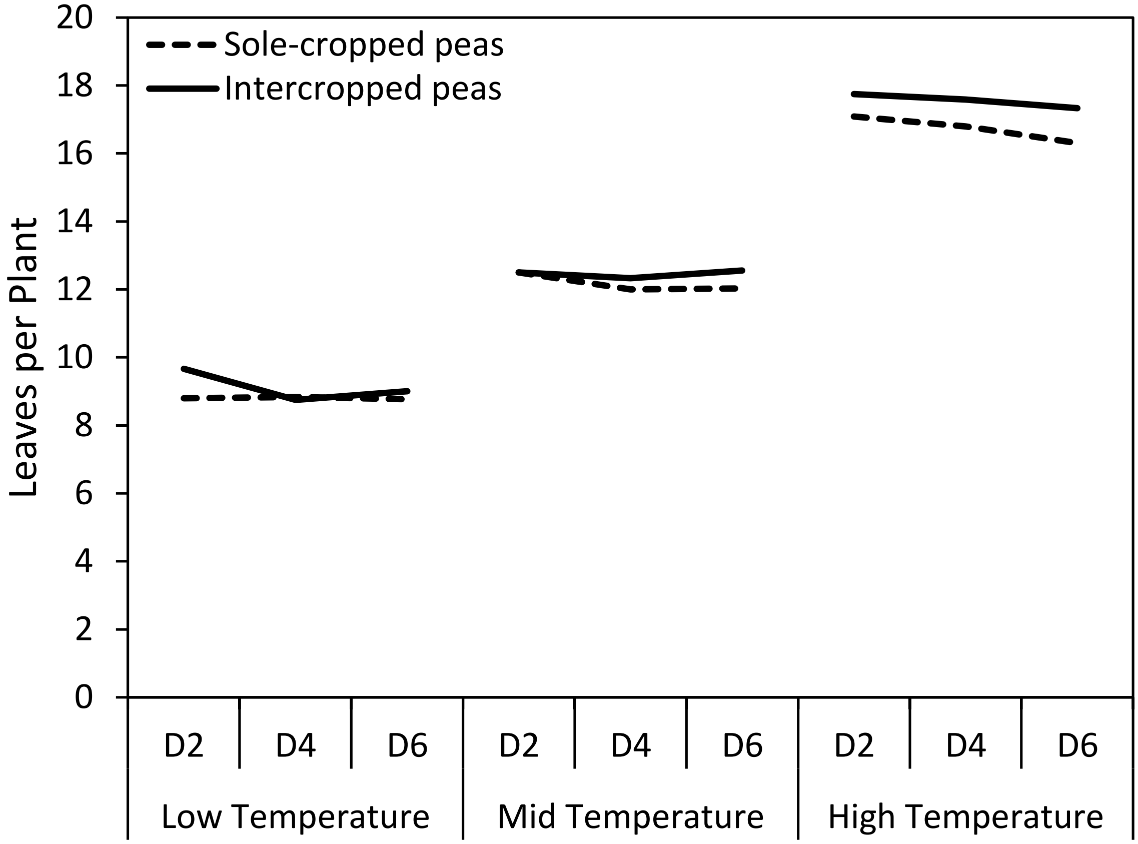

Figure 14. Mean pea plant leaf counts for the eighteen combinations of daytime temperature, planting density and cropping method. D2, D4, D6 = densities of 2, 4, or 6 plants, respectively.

When the number of leaves per pea plant was analyzed according to daytime temperature, planting density and cropping type, the aforementioned trends remain. Figure 15a clearly shows that as temperatures increased, the number of leaves per pea plant greatly increased. Across all densities and cropping types, leaf counts did not vary (Figures 15b and c).

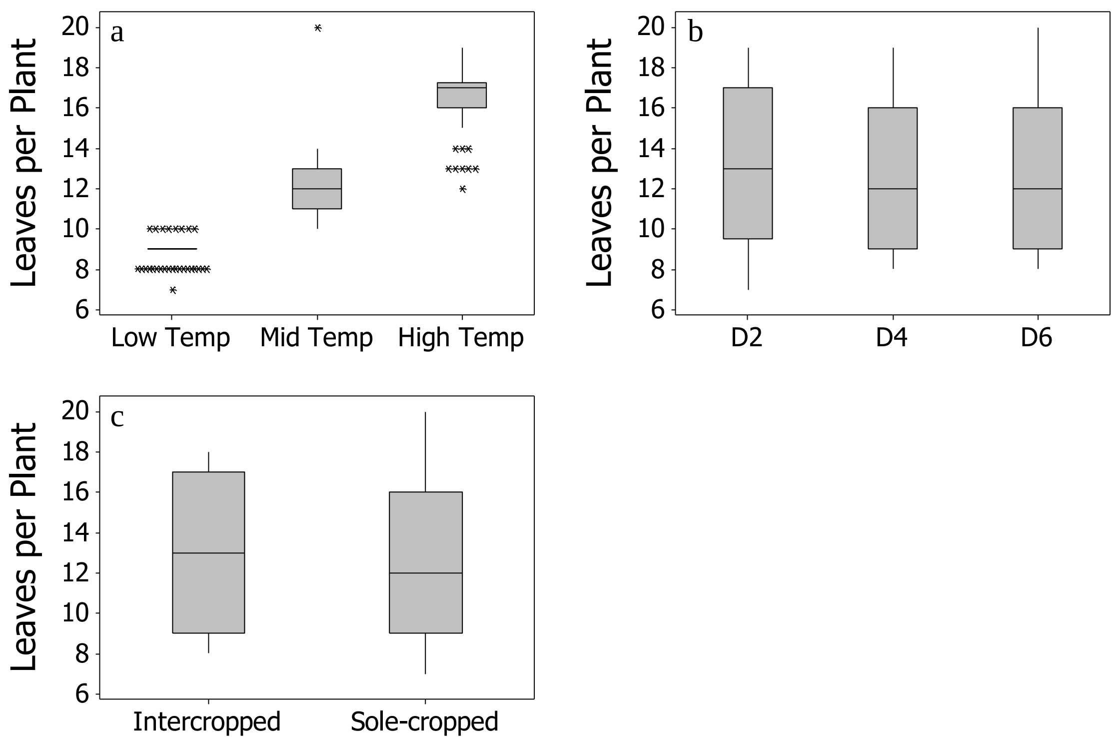

Figure 15. Pooled pea plant leaf counts for daytime temperatures (a), planting densities (b) and cropping types (c). Asterisks indicate outlying data points.

Oat plant dry weights

As shown by Figure 16, as temperatures increased, the weight of individual oat plants increased as well. Individual yields varied with planting density and cropping type, but in no predictable order.

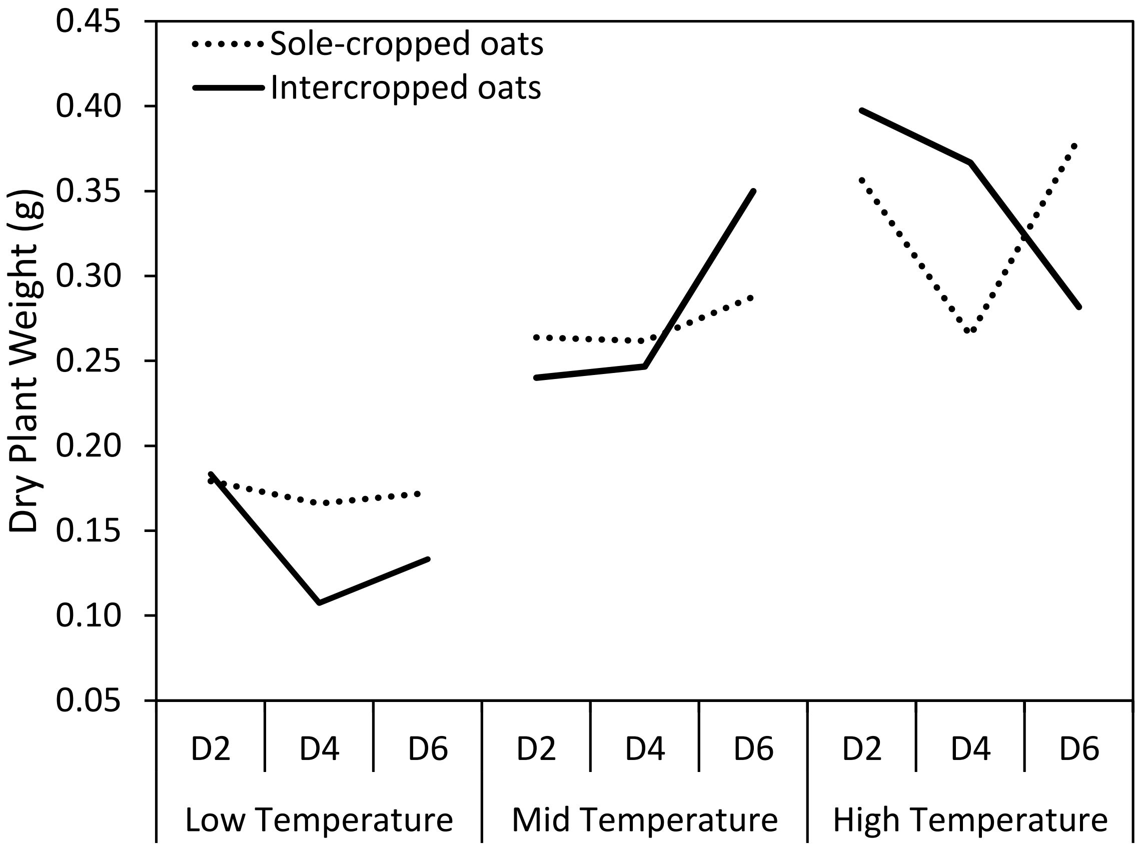

Figure 16. Mean oat plant dry weights for the eighteen combinations of daytime temperature, planting density and cropping method. D2, D4, D6 = densities of 2, 4, or 6 plants, respectively.

When each factor is analyzed individually, a simplified picture emerges (Figure 17). Figure 17a shows that while individual plant weights increased as temperatures increased, plant weights at the mid and high temperatures do not appear to differ much. Figures 17b and 17c reveal that overall, individual plant weights did not vary with planting density or cropping type.

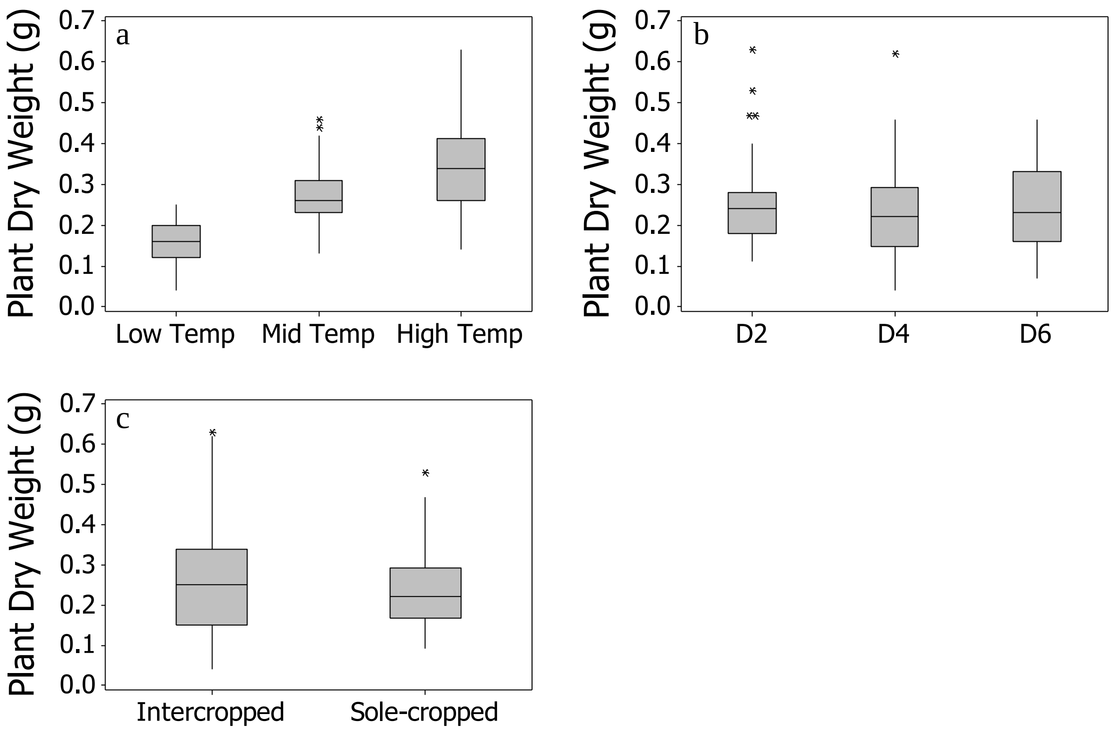

Figure 17. Pooled oat plant dry weights for daytime temperatures (a), planting densities (b) and cropping types (c). Asterisks indicate outlying data points.

Pea plant dry weights

Figure 18 below shows the effect of daytime temperature, planting density and cropping type upon individual pea yields. Overall, it appears that individual plant yields at the low temperature were lower than yields at the two upper temperatures. With regard to density, Figure 18 suggests that peas intercropped with oats may have been affected differently than peas that were sole-cropped. Across all three temperatures it appears that as density increased, yields of sole-cropped peas declined. Comparatively, intercropped pea yields varied as planting density increased.

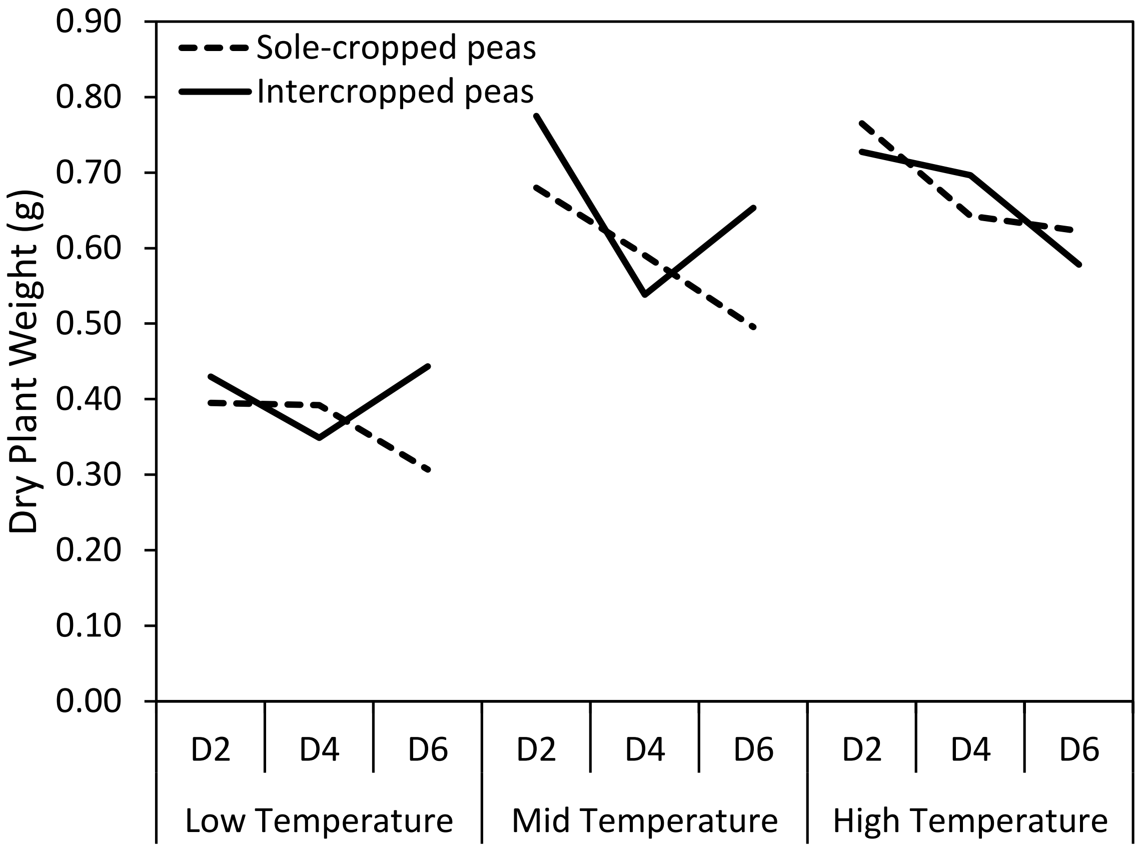

Figure 18. Mean pea plant dry weights for the eighteen combinations of daytime temperature, planting density and cropping method. D2, D4, D6 = densities of 2, 4, or 6 plants, respectively.

Figure 19 assesses the impact of each factor upon pea dry weights individually. Figure 19a shows that individual yields at the two upper temperatures were very similar, while at the lower temperature, yields were reduced. Figure 19b suggests that as densities increased, yields were very similar overall. However median values did decrease slightly. Finally, Figure 19c suggests that intercropping peas with oats did not affect individual yields, as yields for both sole-cropped and intercropped peas were very similar.

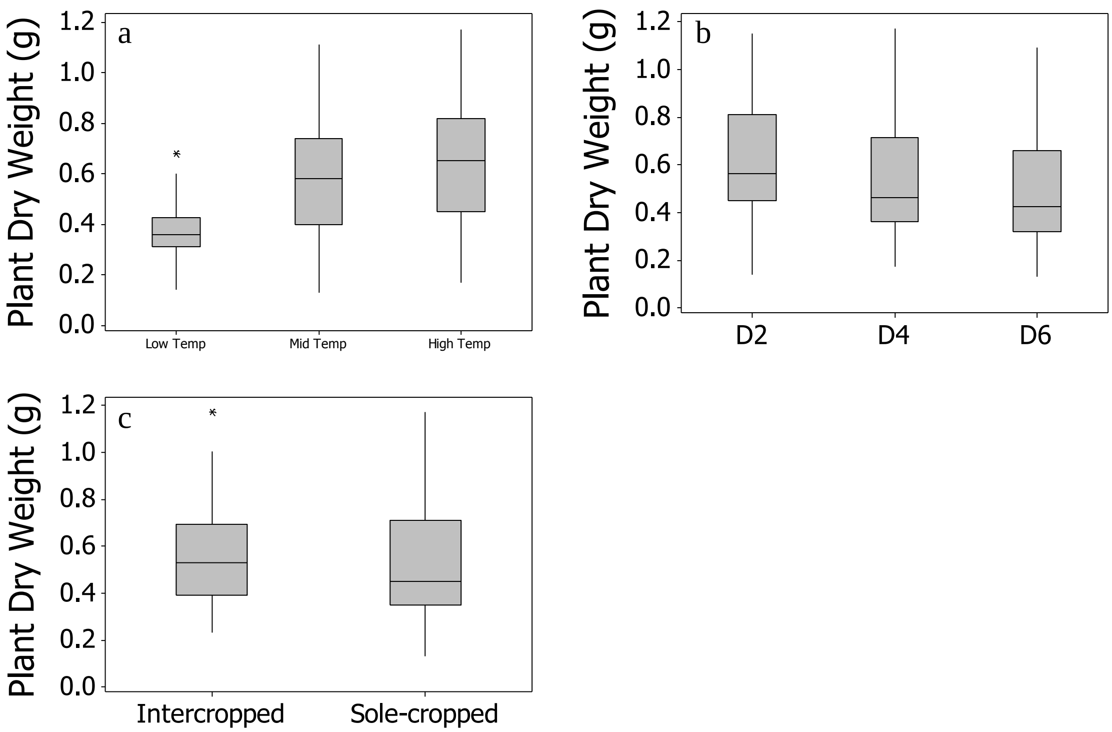

Figure 19. Pooled pea plant dry weights for daytime temperatures (a), planting densities (b) and cropping types (c). Asterisks indicate outlying data points.

DISCUSSION

Previous studies suggest that oats and pea forage yields are highest when plants are harvested at the anthesis stage and early flowering stage, respectively (Kaiser *et al.,* 2007). Initially, the plan for this study was to harvest all treatments as these development stages were reached (Table 4). However when the nighttime temperatures within two pods plummeted to near 0°C on Day 46 (Appendix A), all plants were harvested on Day 48 regardless of plant height or maturity.

Table 4. The correlation between growing time and oat and pea maturity, leaf numbers and plant heights[1,2].

Appx. days from planting	Oats Development Stage	Oats Height (cm)	Peas Development Stage	Peas Height (cm)
36	6 leaves	30	8-10 leaves	28
44	Pre-boot	46	10-12 leaves	48
55	Boot	74	Early bloom	94
63	Early anthesis	91	0-4 flowers/plant	119
70	**Late anthesis**	**107**	**Flowering, 0-2 pods/plant,**	**140**
78	Early milk	119	Flowering, 3-4 pods/plant,	157
87	Late milk	122	Flowering. Lower pods with small peas.	178
97	Soft dough	122	Flowering. Middle pods with small peas; lower pods filled and green.	198
115	Hard dough	122	Flowering. 6-12 pods per plant. Middle pods filled, lower pods turning yellow.	240

[1]The initial planned harvest stage of my experiment is denoted by bolded text.
[2]As this table has been adapted from Klebesadel (1969), it should be noted that all values stated within are specific to that experiment.

Mechanical issues

Throughout the duration of this study, there were many mechanical issues with temperature and relative humidity control in the low and mid temperature pods. As a result, described set-points were not always reached. See Appendix A for more details.

Biological issues

Another problem faced in this study was that across all temperature, density and intercropping treatments, the number of surviving replicates was very low (Table 3). Indeed, of the 162 GrowBags planted on Day 1, about two-thirds (110 GrowBags) survived to harvest. This was because mice ate many of the oat seeds and seedlings.

Watering

Previous studies have found that increased irrigation and precipitation positively affects oat and pea growth (Gantner *et al.*, 2008; Peltonen-Sainio *et al.*, 2011). In my study, the two higher temperature pods required more frequent watering than the low temperature pod. However as the growing medium was kept moist (but not saturated) in all GrowBags, water was not limited. Thus it is unlikely that watering directly affected the growth of oats and peas. Rather, if water had been limited, the growth of plants at the higher temperature would have likely been stunted.

Temperature

Figures 6, 7 and 16-19 show that oat and pea dry yields (both in total and individually) were observably greatest when plants were grown at high daytime temperatures. This result is quite unexpected, as previous studies concluded that oat and pea yields decline as temperatures rise (Tamm, 2003; Herath *et al.*, 1971).

However the contrary results found by my study are likely a result of differing methodology. Previous studies investigating the effect of daytime temperature upon forage yields harvested oat and pea treatments when they reached maturity, not all at the same time (Kaiser *et al.*, 2007; Klebesadel, 1969). As I harvested all treatments on Day 48 regardless of maturity stage, my finding that yields were higher at higher temperatures is likely due to temperature-related maturity differences.

Previous studies have found that maturity time in oats and peas is correlated with the amount of heat plants receive (Olesen *et al.*, 2012; Lambert *et al.*, 1958). At high temperatures, heat units accumulate faster and as a result, plants grow faster and mature earlier (Contreras-Govea and Albrecht, 2006; Nonnecke *et al.*, 1971).

As leaf numbers and plant heights are highly correlated with maturity in oats and peas (Klebesadel, 1969), observations made on harvest day support this explanation. Oats and peas grown at the low temperature treatment had an average of 4.2 and 9.0 leaves and were 45.9 and 68.8 cm tall, respectively (Figures 8 to 15). Comparatively, at the high temperature treatment, oat and pea leaf counts and plant heights were almost doubled, to 6.4 and 16.9 leaves and 59.0 and 128.1 cm tall, respectively (Figures 8 to 15). Thus treatments grown at mid and high temperatures were higher yielding than those grown at the low temperature simply because they were more mature (Table 4).

Planting density

Total yields for all cropping types and all daytime temperatures were greatest at the maximum planting density (Figures 6 and 7). Plant heights, leaf counts and individual plant weights did not differ observably with density (Figures 8 to 19). This observation suggests that as planting density increased, plants did not become nutrient limited. That is, plants growing at higher densities were no more limited than those growing at low densities. This suggests that across all planting densities, oats and peas did not grow differently. Thus, total dry yields were greatest at the highest planting density most likely because there were simply more plants growing per area. Numerous other studies involving both oats and peas have consistently observed that as planting densities increase, total forage yields increase as well (Carr *et al.*, 1996; Hauggaard-Nielsen *et al.*, 2006).

Intercropping and individual plants

Previous studies have suggested a synergistic effect occurs when oats and peas are intercropped. Because peas are indirectly capable of nitrogen fixation, it has been proposed that growing these two crops together allows for higher individual plant yields due to increased nitrogen availability and differential nutrient usage (Jaster *et al.,* 1985; Dordas *et al.,* 2012; Geijersstam and Martensson, 2006).

However, as no differences in plant height, leaf count or individual weight were observed when oats and peas were intercropped (Figures 8 to 19), it is unlikely that a synergistic effect occurred. This suggests that, in my study at least, when oats and peas were grown together, they did not affect each other's individual yields.

Intercropping and overall yields

Previous studies have found that sole-cropped peas yield less than sole-cropped oats (Mustafa *et al.,* 2004), and that intercropping oats and peas results in higher yields than sole-cropping either oats or peas (Begna, 2011; Chapko *et al.,* 1991). In this study, the exact opposite was observed. As can be seen in Figures 6 and 7 above, across all temperatures and planting densities, sole-cropped oats yielded the least while sole-cropped peas yielded the most. Intercropping oats and peas resulted in yields intermediate to both sole-cropped oats and peas.

In this study's intercropped treatments, oats and peas were grown together in a fifty-fifty non-additive ratio (for every oat seed, one pea seed was planted). Similarly, sole-cropped oat or pea treatments at the same planting density contained equal numbers of oat or pea seeds respectively. Thus GrowBags containing sole-cropped and intercropped treatments at the same planting density all contained the same number of plants.

Comparatively, most previous studies that found intercropping oats and peas to result in yields higher than sole-cropped oats or peas were additive in their seeding rates (Begna, 2011; Chapko *et al.,* 1991; Mustafa *et al.,* 2004). That is to say, if sole-cropped oats and peas were planted separately at 107.5 and 215 plants/m^2 (20 and 10 plants/ft^2) respectively, then the intercropping treatment contained a total of 322.5 plants/m^2 (30 plants/ft^2) (Chapko *et al.*, 1991). As increasing planting density increases overall yields in both oats and peas (Carr *et al.*, 1996), it is clear why these studies found intercropped oats and peas to yield more than sole-cropped oats or peas alone.

This issue of unequal seeding rates also helps explain why in my study, sole-cropped peas were higher yielding than sole-cropped oats. Previous studies stating that oats out-yield peas planted oats at a greater density than their comparison pea crop (Carr *et al.*, 1996; Mustafa *et al.*, 2004). Thus in these studies as the seeding rate for oats exceeded that of peas, the total biomass yield of oats was far greater than the total biomass yield of peas.

However, in one study, sole-cropped oat and pea yields were almost identical (Jaster *et al.*, 1985). Their seeding rates were 22 kg/ha for oats and 17 kg/ha for peas, which is approximately 75 and 32 plants/m^2 (7 oat and 3 pea plants/ft^2) respectively (Dordas *et al.*, 2012; Jaster *et al.*, 1985). As oat and pea yields were equal but twice as many oat plants were grown, this suggests that a single mature pea plant weighs twice as much as one mature oat plant (Jaster *et al.*, 1985).

Analysis of individual oat and pea plant weights in my study reveals that on average, individual pea plants weighed more than twice as much as individual oat plants (Figures 16 to 19). At the low temperature, the average oat plant weight was 0.157 g while pea plants weighed 0.386 g. At the high temperature, oats weighed an average of 0.341 g each while peas weighed 0.672 g each. Therefore, in my study as oats and peas were grown at equal planting densities, peas were higher yielding than oats simply because pea plants were about twice as heavy as their comparative oat plants.

General conclusions

My study suggests that oat and pea yields are positively affected by daytime temperatures. However, leaf count and plant height data indicate that plants grown at higher temperatures were simply maturing earlier than plants grown at low temperatures.

Planting density was found to increase total dry yields in both species. Individual yield data shows that per-plant yields did not vary with density. This indicates that (1) plants were not nutrient limited; and, (2) the increase in yield is almost wholly attributable to the increased number of plants per area.

Finally, I found that intercropping oats and peas together resulted in yields intermediate to sole-cropped oats and peas. This is primarily because individual pea plants weigh about twice as much as individual oat plants (Figures 16 to 19).

Furthermore no difference in individual plant weights, leaf counts or plant heights was observed between plants that were sole or intercropped. Thus, it might be that intercropping oats with peas does not positively affect yields when plants are not nutrient limited, or that increased yields obtained when these two species are intercropped results primarily from an increase in planting density.

Suggestions for future work

To validate these observations, I recommend repeating this study with a larger number of replicates, ample mouse-traps and a fully functioning greenhouse. This would allow a three-way ANOVA to be performed and thereby elucidate the presence of any interactions between all three factors investigated in this study.

I also suggest extending the study duration to ensure that all treatments reach the same stage of maturity before harvest time. By doing so, this study’s results would be comparable to previous studies and be similar to conditions actually experienced by farmers in the field.

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APPENDIX A – TEMPERATURE AND RELATIVE HUMIDITY ISSUES

Low temperature issues

Initially, Pod 4 housed the "low temperature" treatment (Figure 20). Unlike the other greenhouse pods, this one featured an air conditioner in its external wall. This device was poorly installed, allowing air flow between the warm pod and the cold outside. Additionally, the side gable vent was damaged and did not close fully. Both roof vents were also warped and stuck in an open position. As a result, much heat was lost.

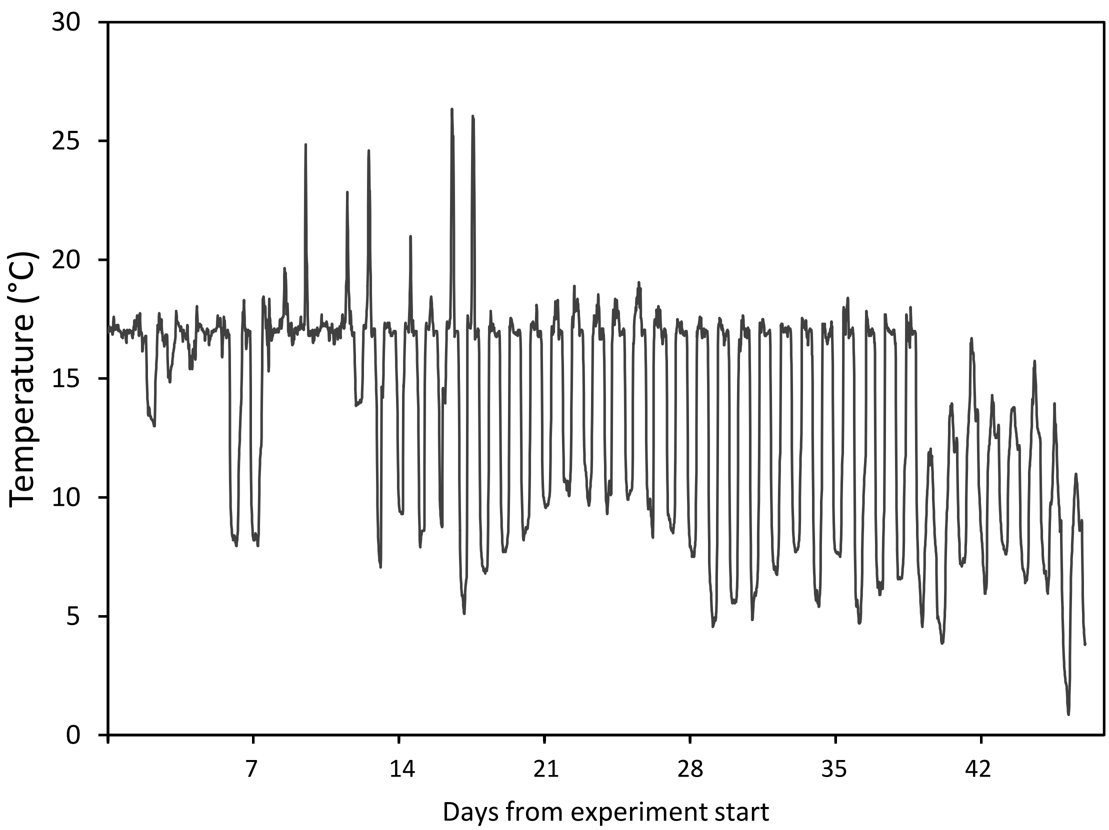

Figure 20. Temperature readings in the low temperature pod, from Day 1 to Day 48.

Initially temperature set-points were maintained, but on the nights of November 14th and 15th (Days 6 and 7), temperatures in Pod 4 fell to below 8°C. Thus on November 16th (Day 8), the 56 GrowBags of Pod 4 were moved to Pod 1. Temperature control remained stable in Pod 1 until Day 13, when that pod's gable vent got stuck in an "open" position. That night, Pod 1's temperature dropped to 8°C. The nighttime temperature continued to drop to about 10°C, until the night of Day 16 when nighttime temperatures plunged to 5°C. As a result, on Day 18 the GrowBags in Pod 1 were moved back into Pod 4.

The hole in the wall of Pod 4 was enclosed and covered with plastic, but the roof vents remained open until mid-December. During most days, the set-point of 17°C was reached, but at night severe temperature drops continued.

On Day 39, the heater in Pod 4 stopped working and remained broken for the remainder of this experiment. Temperatures fluctuated erratically, ranging from 5°C at night to 12°C to 15°C during the day. On Day 46 (Christmas Eve), the temperature in Pod 4 dropped to below 2°C. Because of this, on Day 48 all GrowBags in all pods were harvested, regardless of growth or maturity stage.

Middle temperature issues

Pod 2 housed the middle temperature experiment (Figure 21). Before and after temperature set-points were changed on Day 12, day and nighttime set-points were maintained +/- 0.5C. Unfortunately on November 30th (Day 22), the heater broke. It was fixed on Day 35 (December 13th) but on Day 40 (December 18th), the heater broke again and remained unfixed for the rest of the experiment. On Day 46 (Christmas Eve), the temperature in Pod 2 dropped to 0°C. Because of this, on Day 48 all GrowBags in all pods were harvested, regardless of growth or maturity stage.

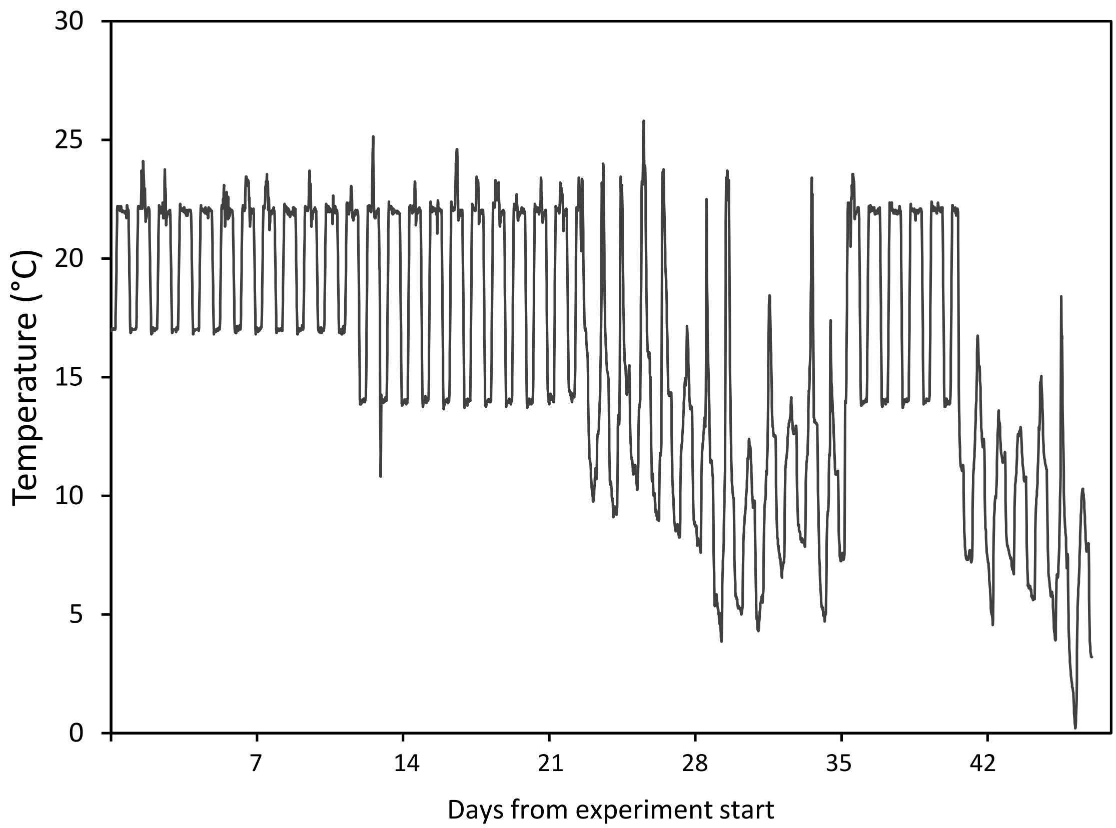

Figure 21. Temperature readings in Pod 2, from Day 1 to Day 48.

High temperature issues

No issues were observed with Pod 3 aside from minor day-time temperature spikes that were swiftly compensated for by the greenhouse's automatic mechanisms (Figure 22).

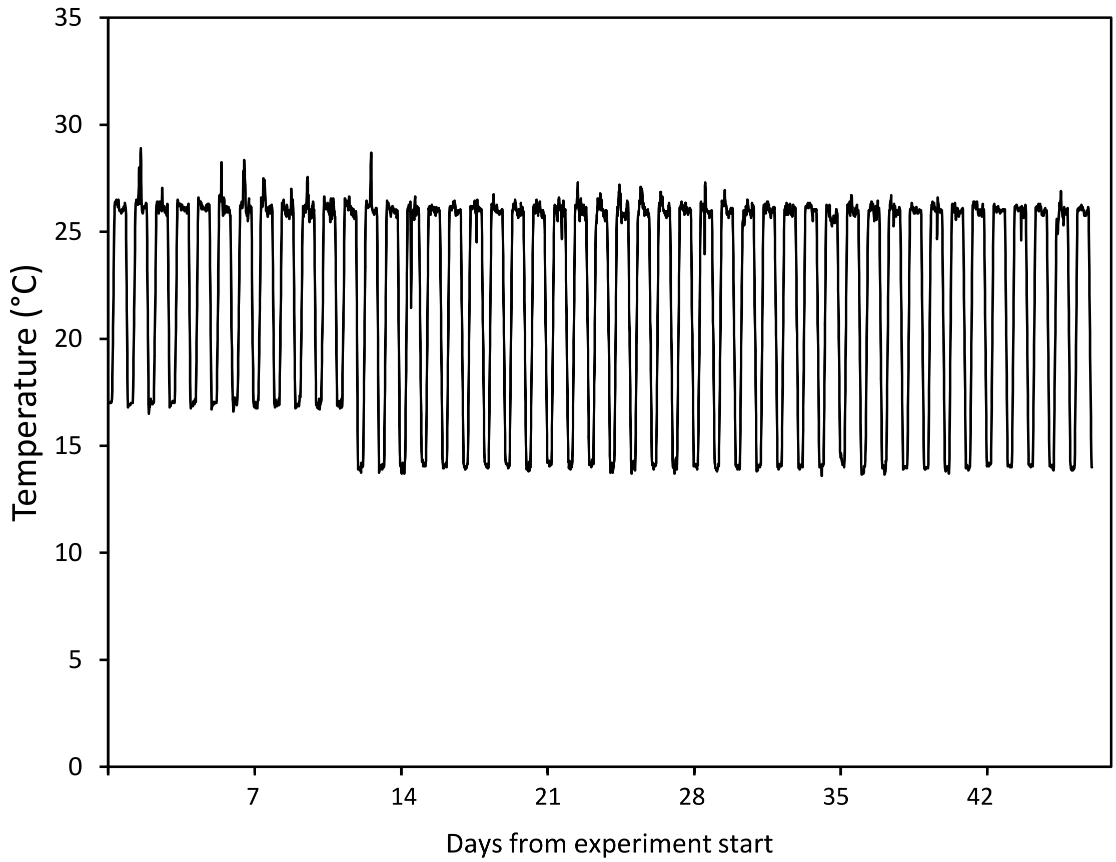

Figure 22. Temperature readings in Pod 3, from Day 1 to Day 48.

Relative humidity issues in the low temperature pod

Throughout the duration of this experiment, the minimum and maximum relative humidity values in the low temperature pod was very erratic (Figure 23). When the heater failed, the daytime relative humidity target (40%) was often not met.

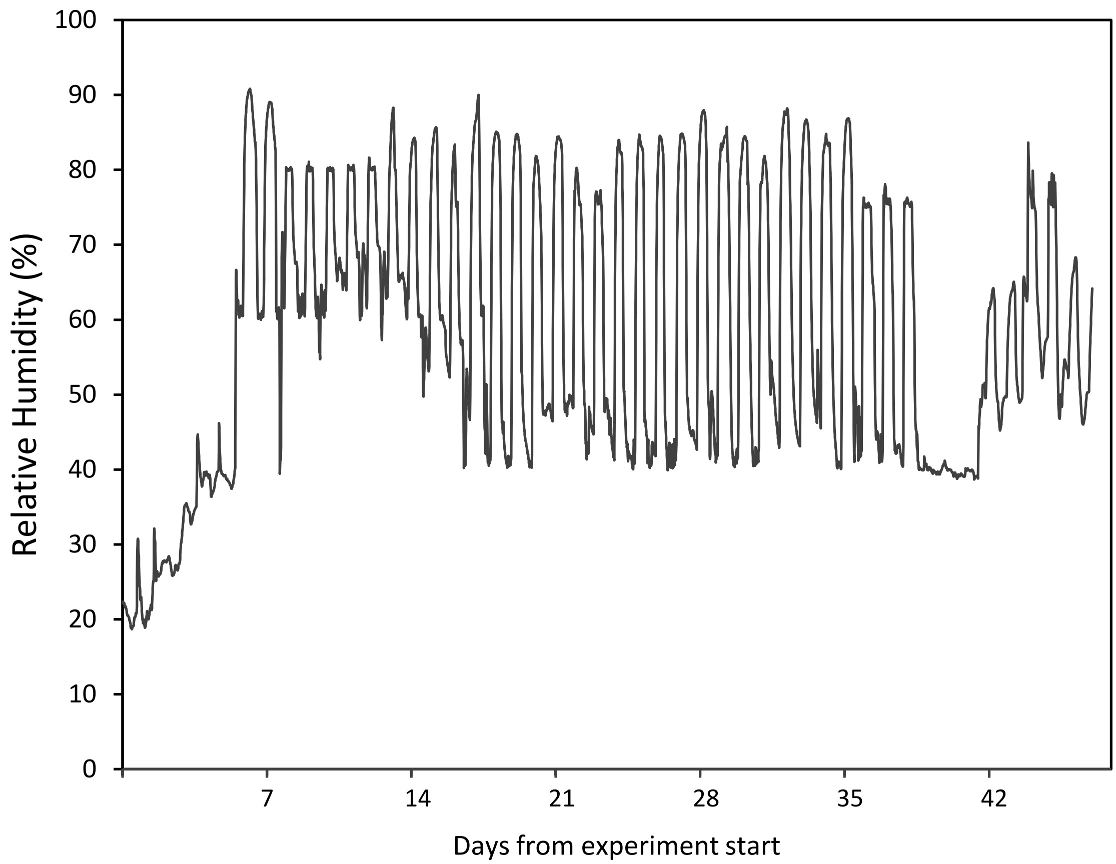

Figure 23. Relative humidity readings in the low temperature pod, from Day 1 to Day 48.

Relative humidity issues in the middle temperature pod

In Pod 2, relative humidity highs and lows were fairly constant throughout most of the experiment (Figure 24). However, both times when the heater failed, the daytime relative humidity was often higher than the daytime set-point (40%).

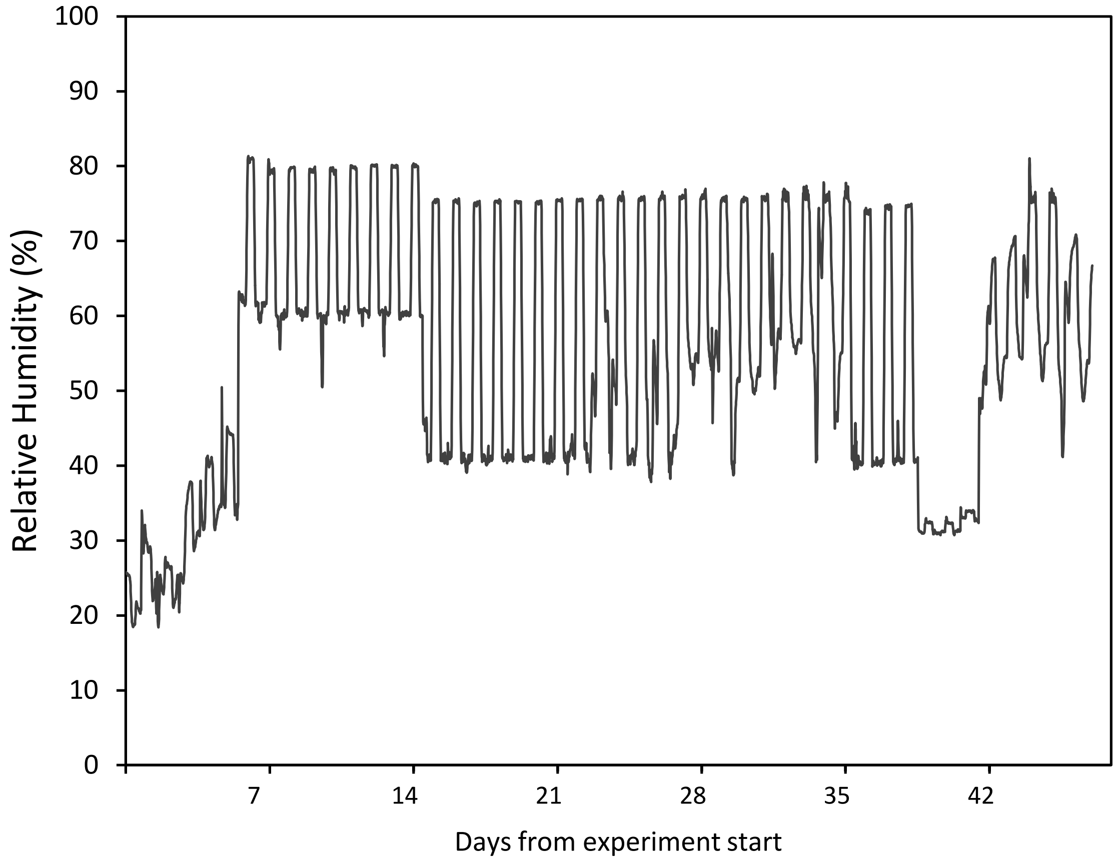

Figure 24. Relative humidity readings in Pod 2, from Day 1 to Day 48.

Relative humidity issues in the high temperature pod

As shown in Figure 25 below, the relative humidity in Pod 3 was well controlled. Humidity was very high until November 23rd (Day 15) when mister nozzles were cleaned and replaced.

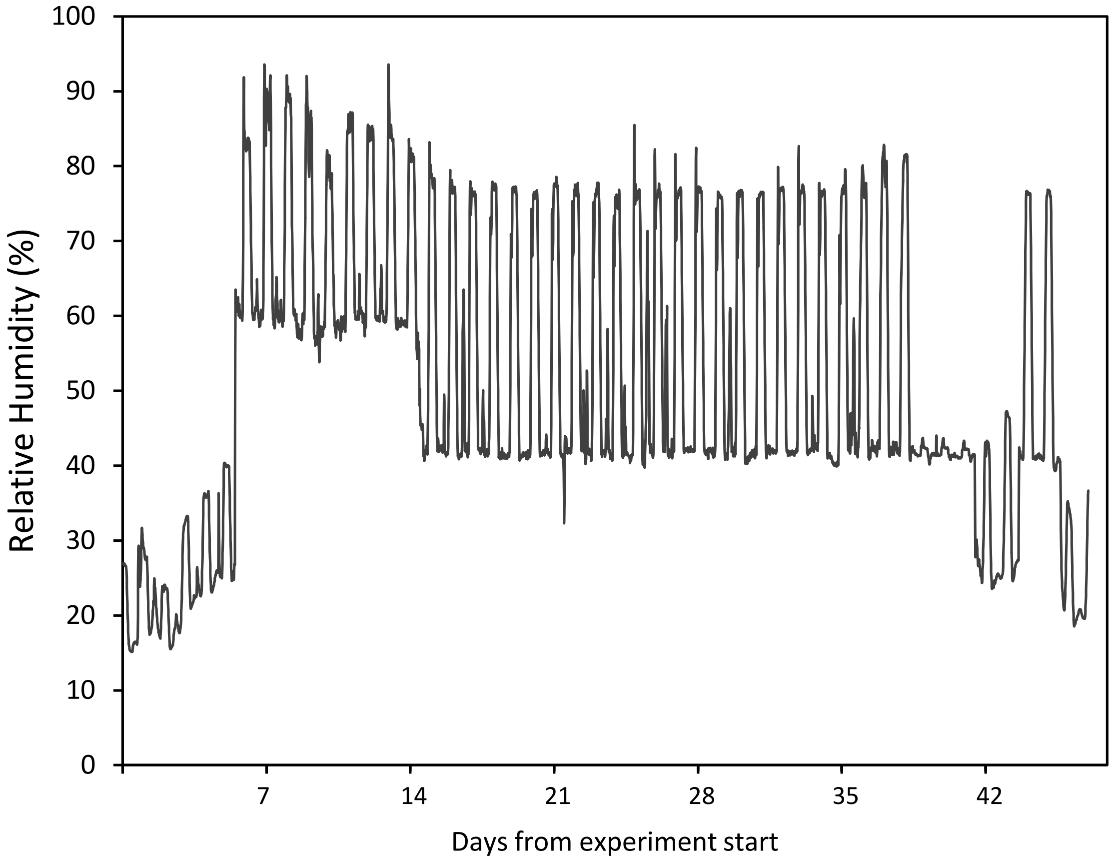

Figure 25. Relative humidity readings in Pod 3, from Day 1 to Day 48.

Overall relative humidity issues

In all pods, misters were not turned on until Day 6 (Figures 23 to 25). On Day 15, relative humidity set-points were lowered to prevent excessive condensation and plant disease. On Day 39, the relative humidity sensors ceased working and a flat-line relative humidity reading was obtained (Figures 23 to 25). Because the sensors did not detect a change in relative humidity, the misters began to spray constantly. On Day 41 when this issue was detected, the misters were manually turned off. Sensors were re-connected on Day 42. Misters were turned on again on Day 44 but were turned off on Day 46. This allowed all plants to dry off for two days before they were harvested on Day 48.