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Ontogenetic Characteristics of Field Pea in a Semiarid Environment

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Abstract: Identifying key yield components can help establish better crop management strategies to increase crop yield. The present research was conducted in south-western Saskatchewan in 1999 and 2000 to determine the interrelationships among various yield components and their direct and indirect effects of each component on seed yield of field pea *(Pisum sativum* L.). The semi-leafless cultivar Carrera was planted at the populations of 35, 50, 65 and 80 plants m^{-2} on conventional summerfallow (CS) and no-till wheat stubble (NT). The coefficients (b values) from path analyses revealed that the seed yield of field pea depended primarily upon total number of pods per unit area (b = 1.41 for the pea on CS and 1.39 on NT) and secondarily upon seeds per pod (b = 0.59 for the pea on CS and 0.44 on NT). The association between weight per seed and yield was either weak (b = 0.14 for the pea on CS) or negligible (b = 0.07 for the pea on NT). Among the various yield-related variables, total number of pods per unit area was the greatest yield contributor that largely relied on plants m^{-2} (b = 1.35 for the pea on CS and 0.97 on NT) and on pods $plant^{-1}$ (b = 0.78 for the pea on CS and 0.74 on NT). Plants m^{-2} had a negative, indirect effect through pods $plant^{-1}$, as did pods $plant^{-1}$ through plants m^{-2}, but those indirect effects were counterbalanced by the direct effects of the components on total pod production. Weight per seed was highly and positively related to the length of reproductive growth. Seed yield in a dry environment can be increased by increasing pod production, whereas weight per seed can be improved by prolonging reproductive growth to increase the cotyledon cell size.

Key words: *Pisum sativum* · zero tillage · summerfallow · seed size · plant density

INTRODUCTION

Field pea *(Pisum sativum* L.) is one of the most important grain legumes in the world and the grain is a major source of plant-based dietary protein for animals. This annual legume is a significant contributor to agricultural sustainability through N_2-fixation and as a rotation crop allowing the diversification of agricultural production systems. Inclusion of this nitrogen fixer in cropping systems has shown to improve nutrient and water use efficiency [1], increase the yield and quality of subsequent cereals and oilseeds [2] and improve the economic sustainability of agriculture [3]. In some regions of the world such as the semiarid Northern Great Plains of North America or Australia, field pea is grown on either conventional summerfallow (CS) or no-till (NT) cereal stubble such as wheat (*Triticum aestivum* L) stubble. In drier years, field pea grown on CS performs better in terms of grain yield compared to NT conditions, whereas in wetter years it seems that CS-grown field pea produces similar grain yields as NT-grown field pea.

In commercial production of field pea, the cost of seed is the major input expense, often exceeding US$50 to $90 ha^{-1}, which accounts for approximately ½ of the total cash costs. Use of a low seed rate can potentially reduce the input expenditure, but a thin crop population usually results in severe weed problems and decreases seed yield [4]. In Western Canada, field pea increased the seed yield at a rate of 15 kg ha^{-1} in a wet year and 6 kg ha^{-1} in a dry year for every single plant increase in plant population from 35 to 80 plants m^{-2}. The increase in seed yield is more pronounced for the CS-grown pea compared to the NT-grown pea. However, little is known about the interrelationships between individual yield components and the total seed yield of field pea. It is unknown how pea plants would adjust their

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ontogenetic characteristics to maximize seed yields under CS and NT growing conditions. Information on the relative importance of various yield components to seed yields is useful for producers to manage the crop by focusing on key yield components. This type of information also is useful for breeders to improve selection criteria in genetic manipulation. Selection for high yielding genotypes in annual pulses requires knowledge on the mechanisms of seed formation and the physiological processes of pod forming [5] and seed setting [6].

Path coefficient analysis, developed originally by Wright [7] and elaborated by Dewey and Lu [8] and others, has been used to determine the direct and indirect effects of individual yield components on final seed yields in annual pulses such as dry bean (*Phaseolus vulgaris* L.), soybean (*Glycine max* L.) and chickpea (*Cicer arietinum* L.) [6, 9, 10, 11]. Path analysis also has been used to determine the interrelationships between seed yields and morphological characteristics in crops such as crested wheatgrass (*Agropyron desertorum* F.) [8], spring wheat [12] and spring barley (*Hordeum vulgare* L.) [13]. Path coefficient analyses usually partition correlation coefficients into direct and indirect effects of various yield components, based on the assumption of mutual relationships among yield components. Statistically, path coefficient is a standardized partial-regression coefficient, obtained from equations, where the yield-related variables are expressed as deviations from the means in units of standard deviation [14]. In these analyses, seed yield and yield components are regarded as a system of interrelated variables, with yield components considered at the same ontogenetic level.

The objectives of present research were (I) to determine the relative importance of various yield components to final seed yield of field pea grown under conventional summerfallow and no-till wheat stubble in a semiarid environment and (ii) to assess the relationships among seed yield, yield components and the length of vegetative and reproductive growth periods of field pea using path coefficient analysis.

MATERIALS AND METHODS

Field experiments were conducted in 1999 and 2000 at two sites in southwestern Saskatchewan. The first site was on an Orthic Brown Chernozem (Aridic Haploborolls) with loam to silt loam texture and a saturated-paste pH of 6.5 in the 0-15 cm depth [15]. This site was at the Agriculture and Agri-Food Canada Semiarid Prairie Agricultural Research Center near Swift Current (50.2°N, 107.4°W). The second site was on Rego Brown Chernozem (Vertic Cryoborolls) with heavy clay texture and a saturated-paste pH of 6.8 in the 0-15 cm depth [15], on a farmer's field near Stewart Valley (50.6°N, 107.4°W).

Table 1: Seed and seedling emergence of field pea (cv. Carrera) grown at four target plant population densities in southwest Saskatchewan, Canada, 1999-2000

Years	Seed weight (mg seed^{-1})	Pre-seed germination (%)	Target plant population density (plants m^{-2}) 35	50	65	80
			Seedling emergence, %			
1999	230	99.3	92.9	96.0	90.8	93.8
2000	233	98.5	99.5	94.0	95.4	91.3

Experiment design and plot management: A semi-leafless field pea cultivar 'Carriera' with yellow cotyledons was planted at four seeding rates to obtain the target Plant Population Density (PPD) of 35, 50, 65 and 80 plants m^{-2} (Table 1). The amount of seed used for the specific PPD targets was based on seed size, pre-seed germination and an estimated field emergence rate of 75%. The various rates of seeding were accomplished with a 2 m wide hoe press drill equipped with a spinner seed meter. The experiment was arranged in a Randomized Complete Block Design with four replicates. The same set of treatments was layout both on CS and on NT; these two conditions were established side-by-side in the field, for ease of field operations.

The pea was planted at a depth of 50 mm on 7 May 1999 and 2 May 2000 at Swift Current and on 20 May 1999 and 5 May 2000 at Stewart Valley, Saskatchewan, Canada. At planting, the noon soil temperature at a 10 cm depth was between 9 and 13°C. Each plot was 7.5 m long, consisting of 10 rows with 20 cm row spacing. Monoammonium phosphate was applied in the seed rows at a rate of 7.5 kg P ha^{-1}. All plots received an appropriate soil implant *Rhizobium* inoculant applied to the seed rows. Weeds were controlled with appropriately labeled herbicides to minimize the overall weed pressure. All plots were sprayed with chlorothalonil at recommended rates to control foliar fungal diseases.

Data collection: After seedling emergence was complete (≈ 2 wk after initial emergence), plants were counted from two 0.5 m^2 quadrants per plot, one in the front of the plot and the other in the back of the plot. Phonologic stages of the crop were recorded based on the Universal Growth Staging Scales [16]. Calendar dates were recorded for seedling emergence (when 50% of the seedlings had

Table 2: Pearson correlation coefficients for seed yield and yield-related variables of field pea (cv. Carrera) grown on conventional summerfallow (below diagonal) and on no-till wheat stubble (above diagonal) in southwest Saskatchewan, Canada, 1999-2000

		No-till wheat stubble						
Variables	Plants m^{-2}	Vegetative period	Pods $plant^{-1}$	Reproductive period	Pods m^{-2}	Seeds pod^{-1}	Seed weight (mg $seed^{-1}$)	Seed yield (kg ha^{-1})
Plants m^{-2}	-	0.06	-0.41	-0.14	0.66**	-0.63**	-0.24	0.58**
Vegetative period	0.07	-	0.54*	-0.18	0.46*	-0.42*	0.03	0.50**
Pods $plant^{-1}$	-0.72**	0.19	-	0.26	0.34	-0.24	0.02	0.43*
Reproductive period	-0.17	-0.28*	0.09	-	-0.58**	0.42**	0.81**	-0.20
Pods m^{-2}	0.78**	0.18	-0.19	-0.35	-	-0.88**	-0.54*	0.97**
Seeds pod^{-1}	-0.49*	-0.14	-0.03	0.18	-0.73**	-	0.34	-0.76**
Seed weight (mg $seed^{-1}$)	-0.09	0.18	0.40	0.58**	-0.35	0.04	-	-0.10
Seed yield (kg ha^{-1})	0.47**	0.27	-0.22	0.08	0.92**	-0.42*	0.55**	-
	Conventional summerfallow							

Table 3: Path coefficients for the seed yield (kg ha^{-1}) of field pea (cv. Carrera) grown on conventional summerfallow and no-till wheat stubble in southwest Saskatchewan, Canada, 1999-2000

Pathway[a]	Conventional summerfallow	No-till wheat stubble
Multiple r	0.995	0.986
Pods m^{-2} vs seed yield		
Correlation (r_{58})[b]	0.920**	0.970**
Direct effect (P_{58})[b]	1.410**	1.390**
Indirect effect via		
seeds pod^{-1} ($r_{56}P_{68}$)	-0.435	-0.384
seed weight ($r_{57}P_{78}$)	-0.048	-0.038
Seeds pod^{-1} vs seed yield		
Correlation (r_{68})	-0.420*	-0.760**
Direct effect (P_{68})	0.590**	0.440**
Indirect effect via		
pods m^{-2} ($r_{56}P_{58}$)	-1.033	-1.222
seed weight ($r_{67}P_{78}$)	0.005	0.024
Seed weight vs seed yield		
Correlation (r_{78})	0.550**	-0.104
Direct effect (P_{78})	0.140*	0.070
Indirect effect via		
pods m^{-2} ($r_{57}P_{58}$)	-0.487	-0.756
seeds pod ($r_{67}P_{68}$)	0.023	0.150

[a]The r and P refer to path coefficient analysis of direct and indirect effects among yield components or variables indicated by subscripts: 1 = plants m^{-2}, 2 = vegetative period, 3 = pods $plant^{-1}$, 4 = reproductive period, 5 = pods m^{-2}, 6 = seeds pod^{-1}, 7 = seed weight (g $seed^{-1}$) and 8 = seed yield (kg ha^{-1}),

[b] r_{15} and P_{15} refer to correlation coefficient and path coefficient between variable 1 and 5, respectively. The same definitions apply to the other coefficients,

*, ** significant at $p \leq 0.05$ and 0.01, respectively

emerged in a plot), anthesis (when 50% of the plants in a plot were blooming) and maturity (when seed moisture approaching 300 to 350 g kg^{-1}). At plant maturity, we determined the average number of seeds per pod by randomly sampling two, 50 pods from each plot, with ≈1/3 of the pods taken from the bottom of the crop canopy, 1/3 the middle and 1/3 the top of the canopy. The center eight rows of each plot (9.7 m^2) were combined with a plot combine when the crop had dried sufficiently for satisfactory threshing. The seed samples were air-dried, cleaned and weighed. Seed yield per unit area was presented on a dry weight basis. From the dried seed sample, we took subsamples and determined weight per seed based on two, 500 individual seed samples. The number of pods per plant was calculated using the plant counts, seed weight and seeds pod^{-1}.

Statistical analysis: Data were analyzed using the PROC GLM and PROC MIXED procedure of SAS [17], with block and site-yr as random effects and PPD as fixed effect. A separate analysis was performed for the two field conditions (CS and NT). The PROC MIXED procedure tests the hypothesis concerning the fixed effects with correct error terms, but it does not return significant levels for random effects. The PROC GLM statistics revealed no significant site-yr by treatment interactions for most of the variables measured in the research. Therefore, the four site-yr data were combined in the statistical analysis.

We first determined correlation coefficients among yield components (Table 2) and then we partitioned the correlation coefficients into direct and indirect effects using path coefficient analyses (Tables 3-5). The variables used in these analyses were (1) PPD, (2) the length of vegetative growth period (from seedling emergence to anthesis), (3) number of pods per plant, (4) the length of reproductive period (from anthesis to maturity), (5) number of pods per unit area, (6) number of seeds per pod, (7) weight per seed and (8) seed yield per unit area. The cause-effect systems used in the path analyses were based on the ontogeny of field pea plants (Fig. 1). In this logistics, the number of pods $plant^{-1}$ and the length of vegetative growth have a mutual relationship, as both characteristics may exercise a reciprocal influence during the early growth stages under normal conditions. The two growth periods (vegetative and reproductive growth) were included in the logistics,

Table 4: Path coefficients for pod production of field pea (cv. Carrera) grown on conventional summerfallow and on no-till wheat stubble in southwest Saskatchewan, Canada, 1999-2000

Pathway[a]	Conventional summerfallow	No-till wheat stubble
Multiple r	0.948	0.944
Plants m^{-2} vs pods m^{-2}		
Correlation (r_{15}) [b]	0.780**	0.660**
Direct effect (P_{15}) [b]	1.350**	0.970**
Indirect effect via		
pods $plant^{-1}$ ($r_{13}P_{35}$)	-0.565	-0.303
Pods $plant^{-1}$ vs pods m^{-2}		
Correlation (r_{35})	-0.193	0.339
Direct effect (P_{35})	0.780**	0.740**
Indirect effect via		
plants m^{-2} ($r_{13}P_{15}$)	-0.970	-0.397

Table 5: Path coefficients for weight per seed (mg $seed^{-1}$) of field pea grown on conventional summerfallow and on no-till wheat stubble in southwest Saskatchewan, Canada, 1999-2000

Pathway[a]	Conventional summerfallow	No-till wheat stubble
Multiple r	0.444	0.750
Pods $plant^{-1}$ vs seed weight		
Correlation (r_{37}) [b]	0.398	0.022
Direct effect (P_{37}) [b]	0.379	-0.195
Indirect effect via		
reproductive period ($r_{34}P_{47}$)	0.018	0.208
seed pod-1 ($r_{36}P_{67}$)	0.001	0.009
Reproductive period vs seed weight		
Correlation (r_{47})	0.580**	0.810**
Direct effect (P_{47})	0.490*	0.80**
Indirect effect via		
pods $plant^{-1}$ ($r_{34}P_{37}$)	0.033	-0.051
seeds pod^{-1} ($r_{46}P_{67}$)	-0.006	-0.016
Seeds pod^{-1} vs seed weight		
Correlation (r_{67})	0.039	0.343
Direct effect (P_{67})	-0.035	-0.039
Indirect effect via		
pods $plant^{-1}$ ($r_{36}P_{37}$)	-0.013	0.047
reproductive period ($r_{46}P_{47}$)	0.036	0.334

[a]The r and P refer to path coefficient analysis of direct and indirect effects among yield components or variables indicated by subscripts: 1 = plants m^{-2}, 2 = vegetative period, 3 = pods $plant^{-1}$, 4 = reproductive period, 5 = pods m^{-2}, 6 = seeds pod^{-1}, 7 = seed weight (g $seed^{-1}$) and 8 = seed yield (kg ha^{-1}),

[b] r_{37} and P_{37} refer to correlation coefficient and path coefficient between variable 3 and 7, respectively. The same definitions apply to the other coefficients,

*, ** significant at $p \leq 0.05$ and 0.01, respectively

based on previous findings [18] that a prolonged period of reproductive growth allowed annual pulses to accumulate more heat units that benefit pod setting and seed formation. In the present research, the period from seedling emergence to anthesis averaged 42d and from anthesis to maturity 32d for field pea. During the reproductive growth period, new pods were continuously formed, while the pods formed at the early-podding stage were in seed-filling process. Therefore, the length of reproductive period may have modified pods $plant^{-1}$ and seeds pod^{-1}. The number of pods per unit area may directly influence yield components that were formed in the later part of the development stages. Finally, seed weight depended on the duration of the reproductive period, pods $plant^{-1}$ and seeds pod^{-1}.

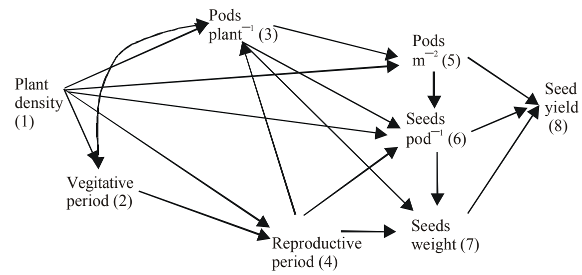

Fig. 1: Pathways showing the cause-effect relationships among yield components and their effects on seed yield of field pea grown in the semiarid environment of southwestern Saskatchewan, Canada, 1999-2000

The path coefficient analysis, similar to those used by other researchers [6, 13], was used to partition the correlation coefficients among yield-related variables into direct and indirect effects by solving the following sets of equations simultaneously:

$$r_{58} = P_{58} + r_{56}P_{68} + r_{57}P_{78}$$
$$r_{68} = r_{56}P_{58} + P_{68} + r_{67}P_{78}$$
$$r_{78} = r_{57}P_{58} + r_{67}P_{68} + P_{78}$$

$$r_{37} = r_{43}P_{47} + P_{37} + r_{36}P_{67}$$
$$r_{47} = P_{47} + r_{43}P_{37} + r_{46}P_{67}$$
$$r_{67} = r_{46}P_{47} + r_{36}P_{37} + P_{67}$$

$$r_{15} = P_{15} + r_{13}P_{35}$$
$$r_{35} = r_{13}P_{15} + P_{35}$$

$$r_{16} = P_{16} + r_{14}P_{46} + r_{13}P_{36} + r_{15}P_{56}$$
$$r_{36} = r_{13}P_{16} + P_{36} + r_{34}P_{46} + r_{35}P_{56}$$
$$r_{46} = r_{14}P_{16} + r_{34}P_{36} + P_{46}$$
$$r_{56} = r_{15}P_{16} + r_{35}P_{36} + P_{56}$$

$$r_{14} = P_{14} + r_{12}P_{24}$$
$$r_{24} = r_{12}P_{14} + P_{24}$$

$$r_{34} = r_{14}P_{13} + P_{34}$$
$$r_{13} = P_{13} + r_{14}P_{34}$$

In the equation of $r_{15} = P_{15} + r_{13}P_{35}$, r_{15} is the correlation coefficient between variable 1 (plant density in Fig. 1) and variable 5 (pods m^{-2} in Fig. 1), the P_{15} is the path coefficient for the direct effect of variable 1 on variable 5 and $r_{13}P_{35}$ is the indirect effect of variable 1 on variable 5 via variable 3 (pods plant^{-1} in Fig. 1). Similar definitions apply to the rest of the equations. Test for significance of path coefficients was achieved by testing for partial regression coefficient.

RESULTS AND DISCUSSION

Growing season (May through August) precipitation was 250 mm in both study-years, 15% greater than the 40 yr (1961-2000) averages, whereas the mean air temperatures (15.2°C) were close to the long-term averages. The favorable moisture conditions in the early spring allowed a good seedling establishment, with the average seedling emergence >91% in both years (Table 1). The actual plant density was close to the targets at all levels (i.e., from 35 to 80 plants m^{-2}) designed in the experiment. The wide range of PPD provided an excellent opportunity to examine the interrelationship among yield components of field pea grown under both CS and NT conditions.

Seed yield: Results of the effects of PPD on seed yields have been reported elsewhere [18]. In brief, seed yields increased with increasing PPD from 35 to 80 plants m^{-2} regardless of growing conditions. Yield increases with increasing PPD were more pronounced for the pea grown on CS compared to when grown on NT. Greater soil moisture in the CS field promoted more fertile pod production under the semiarid conditions. Pearson correlation analyses revealed that the seed yield of field pea highly and positively depended on pods m^{-2} and plants m^{-2} and was negatively correlated with seeds pod^{-1} (Table 2). Similar types of correlation existed for the pea grown on CS (coefficients below diagonal) as those grown on NT (coefficients above diagonal). The only difference was that the seed yield was positively affected by weight per seed when the pea was grown on CS, while it was positively affected by the period of vegetative growth when the crop was grown on NT.

Path coefficient analyses provided more insights on the interrelationship among yield components and their effects on seed yields, because path coefficients partitioned correlation coefficients into direct and indirect effects. The direct effects of path coefficients (Table 3) revealed that the seed yield of field pea depended primarily upon pods m^{-2} and secondarily upon seeds pod^{-1}, with the direct effect of weight per seed on seed yield being either slight ($b = 0.14$, $p < 0.05$, for the pea grown on CS) or negligible ($b = 0.07$, $p = 0.23$, for the pea grown on NT). Path coefficients showed that seeds pod^{-1} positively affected seed yield in both growing environments, while this effect was not shown in the correlation analyses, where such an effect was probably overshadowed by indirect effect of pods m^{-2} ($r_{56}P_{58}$ = -1.03 to -1.22 in Table 3). Conversely, the correlation analysis revealed a strong association between weight per seed and seed yield for the pea grown on CS, but this effect was counterbalanced by the negative effect of weight per seed on seed yield through pods m^{-2}. As a result, there was only a slight direct effect of weigh per seed on seed yields (path coefficient $b = 0.14$) only when the crop was grown on CS. Most of the indirect effects of yield components on seed yield were weak (Table 3), except the indirect effect of seeds pod^{-1} on seed yield via pods m^{-2} was high, which was probably due to great direct effect of pods m^{-2} on seed yield. Previous studies found no direct effect of weight per seed on seed yield in chickpea [11], though those two traits were highly correlated in a correlation analysis. In soybean, weight per seed had no phenotypic effect on seed yield [6, 10]. However, weight per seed expressed genetic correlation with seed yields when different genotypes were compared in tests.

Pod production: Total number of pods per unit area functioned as a major contributor to seed yields of field pea under both CS and NT conditions (Table 2 and 3). This variable was a product of plants m^{-2} and pods plant^{-1}, thus it is worthwhile to examine the relative magnitude of these two components. Path coefficients revealed that total pods mainly depended on plants m^{-2} and secondly on pods plant^{-1} (Table 4). The growing environment did not alter these associations, although field pea grown on CS had stronger relationship (path coefficient $b = 1.35$) between plants m^{-2} and total pods compared to when the crop was grown on NT (path coefficient $b = 0.97$). Linear regressions strongly supported these observations (Fig. 2a) where the total number of pods increased significantly as PPD increased. The slope of the linear regression was greater for the pea grown on CS compared to NT. There was a negative indirect effect of plants m^{-2} on total pod production through pods plant^{-1} ($r_{13}P_{35}$ = -0.31 to -0.57) (Table 4). This negative relationship was due to the fact that increasing PPD significantly reduced number of pods per plant (Fig. 2b). However, such a negative effect of pods plant^{-1} on total pod production was counterbalanced by the strong, direct effect of plants m^{-2} (Table 4). In addition, path coefficient revealed a negative, indirect effect of pods plant^{-1} on total pod production through plants m^{-2} ($r_{13}P_{15}$ = -0.40 to -0.97 in Table 4). Again, the

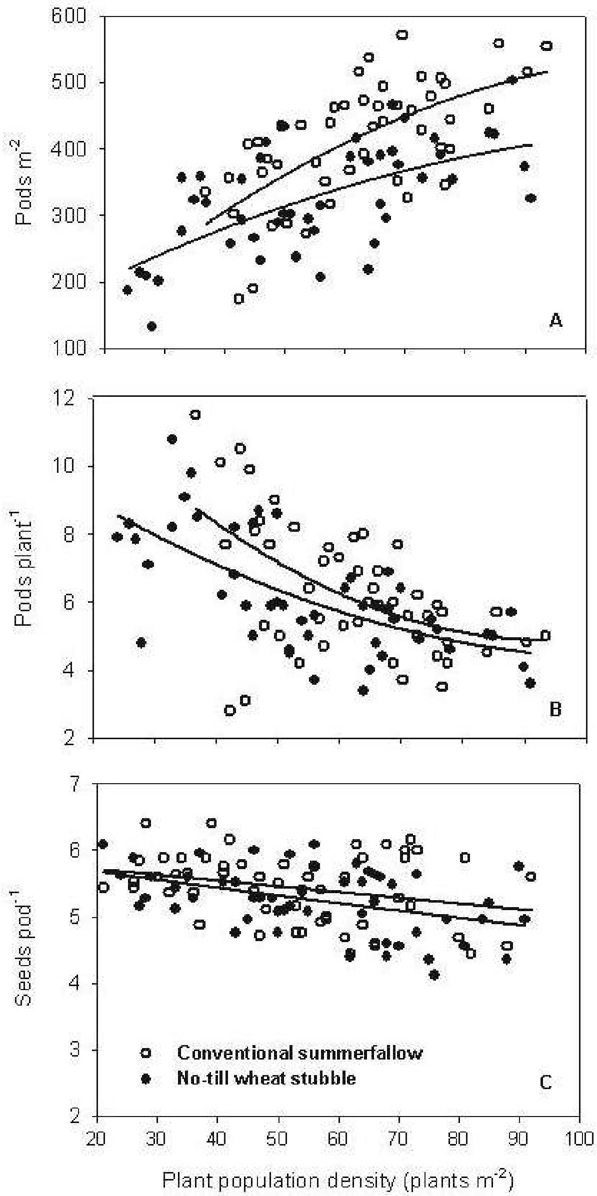

Fig. 2: The effects of plant population density on pod production and seeds per pod for field pea (cv. Carrera) grown at southwestern Saskatchewan, Canada, 1999-2000

strong, direct effect of pods plant^{-1} overshadowed the negative and indirect effect. Correlation between pods plant^{-1} and total pod production was not significant, but path coefficient showed a highly significant direct effect. It was possible that the negative, indirect effect of pods plant^{-1} on total pod production through plants m^{-2} may have masked the positive, direct effect of pods plant^{-1} on total pod production in the correlation analyses. In the present research, the number of pods produced on each plant decreased from 10 to 4 as PPD increased from 35 to 80 plants m^{-2} under both CS and NT conditions (Fig. 2b). Nevertheless, the pods plant^{-1} acted as a factor, second to plants m^{-2}, significantly influencing total pod production in field pea. These results indicate that increasing plant population density is the key to produce sufficient number of pods for maximizing seed yield of field pea in the semiarid environment.

In addition, the number of pods increased significantly with prolonging vegetative growth, when the pea was grown on NT (Table 2). However, the increase of pod production caused a reduction in the number of seeds per pod. In comparison, when the pea was grown on summer fallow, total pod production was independent of the length of vegetative growth period or the number of seed per pod. We did not determine these relationships with path coefficient analyses because we believe that total pod production is a function of the combination between plants m^{-2} and pods plant^{-1}. The influence of the vegetative growth period on pod production is reflected directly through pods plant^{-1} with the causal-effect relationship taken into consideration. These results indicate that total pod production was the greatest factor contributing the final seed yield in field pea. Pod production potential can be increased through adjusting seeding rates for a higher target plant population and by promoting more pods on a per plant base. Increasing plant population density reduced the number of seed per pod (Fig. 2c), but this reduction could be partly counterbalanced by increased total number of pods per unit area (Fig. 2a). Our findings on the effect of pod production on seed yield agree with those found in other annual pulse crops, including kabuli chickpea [11, 19], desi chickpea [20], faba bean [21], soybean [6] and lentil (*Lens culinaris* Medik.) [22].

Weight per seed: Weight per seed was largely dependent on the length of reproductive period and was unrelated to factors such as pods plant^{-1} or seeds pod^{-1} (Table 5). Similar responses of weight per seed to reproductive growth were observed for the field pea grown on CS and NT, although the response was greater for the NT-grown field pea compared to CS. Reason for the different responses on CS versus NT field pea is unknown, but we speculate that the reproductive growth may influence the mitotic rate during the cell division phase to achieve differences in cell number found in the cotyledons. The endoreduplication level in maturing cotyledons might be closely related to the volume of cotyledon cells. An increased number of endoreduplicating cycles in the cotyledons with prolonging reproductive growth period might hypothetically increase the cotyledon cell size. In a previous research, Gan *et al*. [18] found that field pea planted at an early date accumulated more heat units during the reproductive period and produced higher seed yields with a greater weight per seed than the pea planted at a later planting date. Pea seed weight was closely related to the reproductive nodes on the main stem and branches under the dry conditions of Australia [23]. The cultivars that flower at an earlier date produce more reproductive nodes than did the later flowering cultivars. Individual seed mass of pea largely depends on the sequential processes of reproductive development [24]. Time intervals between the initiation of flowering and physiological maturity varies widely with growing conditions. Field pea plants grown at high plant densities are normally under conditions of higher plant-to-plant competition and have a lower rate of progression in flowering and seed filling than plants grown under lower competition conditions.

CONCLUSIONS

Present research determined the interrelationships among seed yield and yield components of field pea using path coefficient analyses. The results indicate that the some of the yield components were interrelated in a different manner in path analysis than those shown in correlation analysis. Correlation analysis identifies mutual associations among the variables of interest, whereas path coefficient analysis determines the relative magnitude of the effect for each variable. Path coefficient analyses serve as a more useful tool than simple correlation analyses when the aim is to identify the direct and indirect effects of various components that have cause-effect relationships. Present research shows that the number of pods per unit area is the foremost important yield contributor in field pea and that targeting a higher plant population density to increase pod production is the key to increase seed yield of field pea in dry environments. Prolonging the period of reproductive growth increases weight per seed and seed yield significantly. Promotion of earlier flowering can be used as a strategy to increase the number of seeds per pod and to enhance weight per seed for field pea in dry environments. Pea plants favor cool conditions during the early growth stages. In the northern Hemisphere, the field pea could be seeded as the first crop in spring once the seedbed moisture is permitted. Early seeding allows pea plants to take advantage of residual soil water for rapid canopy development, early flowering and lengthen the period of reproductive growth for maximum seed setting.

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