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Path-coefficient Analysis of Correlation Between Honey Bee Activity and Seed Yield in (Allium cepa L.)

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Path-Coefficient Analysis of Correlation Between Honey Bee Activity and Seed Yield in *Allium cepa* L.[1]

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Abstract. A path-coefficient analysis was used to furnish information on the inter-relationships of pollinating insect activity and components of seed yield in inbreds of *Allium cepa* L. The inbreds differed very significantly in their attractiveness to pollinating insects. Only one inbred exhibited a significant correlation (P <0.05 positive) between numbers of honey bees and seed yields. Separating the correlation coefficients into components of direct and indirect effects indicated that pollination attractiveness was not the limiting factor in seed set for inbreds in the experiment. Moreover, most of the variation in seed yield could be attributed to indirect effects on the components of yield, umbels per plant, flowers per umbel, percent per fertilized flower, and seeds per fertilized flower.

Low yields from commercial onion seed fields constitute an increasingly serious economic problem for the seed industry and growers of onion seed (3). Low yields have been related to insufficient pollinator activity during flowering. Nye et al. (11) observed that onion flowers were less attractive to honey bees as a source of pollen than were competing flowers in Idaho. However, Lederhouse et al. (7) reported that high nectar sugar concentration in the onion flower made it competitive with most other flowers in New York. They reported that nectar produced by male-fertile flowers contained about 10% more sugar than male-sterile flowers. Bohart et al. (1) noted that onion nectar sugar concentration was inversely proportional to insect visitation. When insect visitation increased, the amount of sugar in the nectar decreased. At very low insect visitation, seed yield was reduced even at high sugar concentrations because of inadequate pollination. LeFever (8) reported that alfalfa seed yield was positively correlated with the amount of sugar in the nectar.

Bohart et al. (1) observed that though most onion lines demonstrated highly significant positive correlations between numbers of honey bees and seed yields, some lines had negative correlations. They reported that although highest yields were obtained from lightly shaded plots, the pollination index (PI) was lower in shaded than in open plots. They also found that confining honey bees to caged plots resulted in lower seed yields than when the bees were present intermittently. Moreover, pollen collectors confined in cages were more harmful to male-sterile lines than to male-fertile lines. The percentage of blasted flowers increased under caged-bee conditions on male-sterile lines, but not on male-fertile ones. When not confined to cages, honey bees were reported to have no harmful effect.

A knowledge of the inter-relationships among, and the independent contributions of each component of seed yield, such as number of umbels per plant, number of flowers per umbel, fertility, and other related variables, is necessary before onion seed yields can be improved. Moreover, with a cross-pollinated crop, such as onions, the extent of pollinating insect activity as it relates to these other variables is important. The research described here sought to use path coefficients in the analysis of correlation to help define the association of these variables in onion seed production.

Materials and Methods

Six inbreds of *Allium cepa* L. were separated into 3 groups and referred to as populations (P 1 to 3). P-1 contained 2 low-yielding male-sterile inbreds (B5546A and B2264A); P-2 contained 2 male-fertile inbreds (B12115-2C and MSU611C); and P-3 contained 2 high yielding male-sterile inbreds (B2149A and B2267A). The experimental plots were in Millville silt loam at the Greenville Farm, Logan, Utah. Each plot consisted of three 10-ft rows with 20 bulbs per row planted April 4, 1970. The 3 populations were assigned in numerical order to the 3 rows within each plot. This arrangement allowed us to collect separate data and run separate analysis for each of the 3 populations by considering each row in a plot as the plot (4).

Harmful insects were controlled by preplanting application of heptachlor (1/2 lbs. actual/acre) and an application of dimethoate (1/2 lb. actual/acre) 10 days before bloom.

Six colonies of honey bees (8 colonies per acre) were placed at the south end of the plots when the onions were about 25% in bloom. Counts of all species of pollinating insects were made from 10 to 12 a.m. for 5 days and from 2 to 4 p.m. for 10 days during the peak blooming period. A pollination efficiency rating for each pollinator species was assigned by estimating the quantity of loose pollen grains from a representative sample of insects and combining this factor with the size, hairiness, and activity pattern (1). The insect pollinators, with their pollination efficiencies were as follows: nectar-collecting honey bees-2; pollen-collecting honey bees-4, *Andrena prunorum* Cockerell-5, *Halictus farinosus* Smith-5, and *Nomia melanderi* Cockerell-5; all other bees-3.5; wasps-1; large Diptera-4; small Diptera-0.5; and all other insects-1. This type of rating is admittedly subjective, but when it is multiplied by the populations to give a pollination index (PI), it can give a more valid picture than population figures alone (1). The overall ratings for honey bees were based upon the proportion of the 2 activity patterns taking place. Pollination index was computed on a 100-umbel basis.

Data were collected on: 1) number of plants per row that survived and bolted; 2) number of umbels per plant; 3) number of flowers per umbel; 4) percent fertilized flowers; 5) number of seeds per fertilized flower; 6) weight per seed; 7) honey bees (nectar) per 100 umbels; 8) honey bees (pollen) per 100 umbels; 9) PI per 100 umbels; and 10) seed yield.

Correlation coefficients (r_{ij}) and path-coefficients (P_{ij}) were computed separately for each inbred. A path-coefficient is a standardized partial-regression coefficient that measures the direct influence of one variable upon another and permits the

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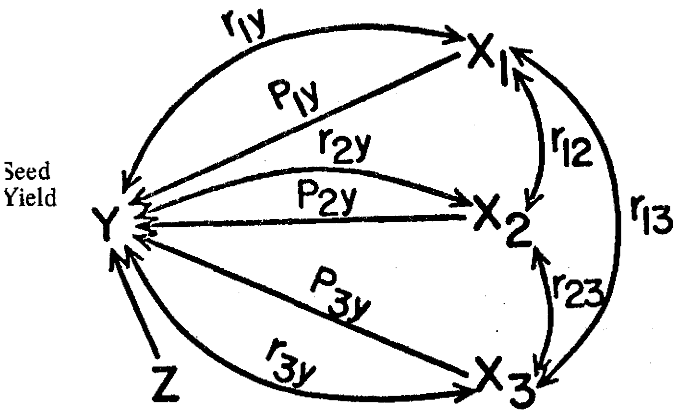
correlation coefficient to be separated into direct and indirect effects (5, 9, 13, 15).

The nature of the causal system is represented in the condensed generalized path analysis diagram.



In the path diagram the double-arrowed lines indicate mutual association as measured by correlation coefficients, r_{ij}, and the single-arrowed lines represent direct influence as measured by path coefficients, P_{ij}. In our studies the path coefficient analysis diagram was expanded to include nine variables. The relationships between the specified correlations and path coefficients in the analysis are expressed by the following set of linear equations:

Honey bees (nectar) vs. seed yield, $r_{7y} = P_{7y} + r_{17}P_{1y} + r_{27}P_{2y} + r_{37}P_{3y} + r_{47}P_{4y} + r_{57}P_{5y} + r_{67}P_{6y} + r_{78}P_{8y} + r_{79}P_{9y}$

Honey bees (pollen) vs. seed yield, $r_{8y} = P_{8y} + r_{18}P_{1y} + r_{28}P_{2y} + r_{38}P_{3y} + r_{48}P_{4y} + r_{58}P_{5y} + r_{68}P_{6y} + r_{78}P_{7y} + r_{89}P_{9y}$

PI vs. seed yield, $r_{9y} = P_{9y} + r_{19}P_{1y} + r_{29}P_{2y} + r_{39}P_{3y} + r_{49}P_{4y} + r_{59}P_{5y} + r_{69}P_{6y} + r_{79}P_{7y} + r_{89}P_{8y}$

where r is the linear correlation coefficient between 2 variables, P is the path coefficient of Wright (15) measuring the direct effect, and $r_{ij}P_{ij}$ is the measure of the indirect effect of one variable upon another.

Results

Influence of honey bee nectar collectors. The correlation between honey bees (nectar) and seed yield in B5546A was insignificant ($r = 0.2018$) (Table 1). The direct influence on seed yield, $P_{7y} = 0.0842$ was small, which suggests that increasing the number of nectar collectors would probably not increase yield when onions are grown under the environmental stresses of this study. This may mean that adequate pollination was achieved on this line at the level of 4.41 honey bees (nectar) per 100 umbels (Table 2). Most of the influence of nectar collectors on yield was indirect, largely through percent fertilized flowers, $r_{47}P_{4y} = 0.1478$ (Table 1). The negative influence through seeds per fertilized flower, although small, suggests that the

Table 1. Path-coefficient analysis of correlations between insect pollinators and seed yield in line B5546A (n = 32).

Association and designation of effect	Cor. coef. r_{ij}	Path coef. P_{ij}		Influence $r_{ij}-P_{ij}$
Honey bee (nectar, X_7 vs. seed yield, $r_{7y} = .201$				
Direct effect on seed yield, P_{7y}		.0842	=	.0842
Indirect, via plants/row, $r_{17}P_{1y}$	(−.2089	(.0956)	=	−.0199
Indirect, via umbels/plant, $r_{27}P_{2y}$	(.3729)	(.2466)	=	.0920
Indirect, via flowers/umbel, $r_{37}P_{3y}$	(.1307)	(.0430)	=	.0056
Indirect, via % fert. flowers, $r_{47}P_{4y}$	(.1919)	(.7704)	=	.1478
Indirect, via seeds/fert. flowers, $r_{57}P_{5y}$	(−.0045)	(.2071)	=	−.0009
Indirect, via seed weight, $r_{87}P_{6y}$	(.1075)	(−.0271)	=	−.0029
Indirect, via honeybee (pollen), $r_{78}P_{8y}$	(.2507)	(−.1755)	=	−.0440
Indirect, via PI, $r_{79}P_{9y}$	(.6969)	(−.0862)	=	−.0601
Total Correlation; r_{7y}				.2018
Honey bee (pollen), X_8 vs. seed yield, $r_{8y} = .233$				
Direct effect on seed yield, P_{8y}		−.1755	=	−.1755
Indirect, via plants/row, $r_{18}P_{1y}$	(.1613)	(.0956)	=	.0154
Indirect, via umbels/plant, $r_{28}P_{2y}$	(.6972)	(.2466)	=	.1719
Indirect, via flowers/umbel, $r_{38}P_{3y}$	(.1496)	(.0430)	=	.0064
Indirect, via % fert. flowers, $r_{48}P_{4y}$	(.2366)	(.7704)	=	.1823
Indirect, via seeds/fert. flower, $r_{58}P_{5y}$	(.1634)	(.2071)	=	.0338
Indirect, via seed weight, $r_{68}P_{6y}$	(.1906)	(−.0271)	=	−.0051
Indirect, via honeybee (nectar), $r_{78}P_{7y}$	(.2507)	(.0842)	=	.0211
Indirect, via PI, $r_{89}P_{9y}$	(.2006)	(−.0862)	=	−.0173
Total correltaion; r_{8y}				.2330
PI, X_9 vs. seed yield, $r_{9y} = .327$				
Direct effect on seed yield, P_{9y}		−.0862	=	−.0862
Indirect, via plants/row, $r_{19}P_{1y}$	(−.4062)	(.0956)	=	−.0389
Indirect, via umbels/plant, $r_{29}P_{2y}$	(.3339)	(.2466)	=	.0823
Indirect, via flowers/umbel, $r_{39}P_{3y}$	(.0939)	(.0430)	=	.0040
Indirect, via % fert. flowers, $r_{49}P_{4y}$	(.4192)	(.7704)	=	.3230
Indirect, via seeds/fert. flower, $r_{59}P_{5y}$	(.0911)	(.2071)	=	.0189
Indirect, via seed weight, $r_{69}P_{6y}$	(−.0364)	(−.0271)	=	.0010
Indirect, via honeybee (nectar), $r_{79}P_{6y}$	(.6968)	(.0842)	=	.0587
Indirect, via honeybee (pollen), $r_{89}P_{8y}$	(.2006)	(.1755)	=	.0352
Total correlation, r_{9y}				.3276

Table 2. Means and main effect of inbred differences on various characters and average number honeybees (nectar) and honeybees (pollen) studies in populations 1 to 3.

	P-1			P-2			P-3		
Variables	B5546A	B2264A	Eff. of B2264A on B5546A	MSU611C	B12115-2C	Eff. of B12115-2C on MSU611C	B2149A	B2267A	Eff. of B2267A on B2149A
Plants/row	14.72	18.00	3.28***	17.78	18.63	0.85**	17.72	19.78	2.06***
Umbels/plant	1.86	3.35	1.49***	1.88	2.39	0.51***	2.09	3.73	1.64***
Flowers/umbel	325	281	−44***	365	445	80***	424	399	−25*
% fertilized flowers	18.83	24.41	5.58	45.30	28.32	−16.98***	21.97	33.59	11.62***
Seeds/fert. flowers	1.45	1.99	0.54*	3.10	2.38	−0.72**	2.05	1.58	−0.47**
Weight/seed mg.	3.82	3.41	−0.41***	3.27	3.34	0.07	4.13	4.15	0.02
PI/100 umbels	16.35	11.71	−4.64***	49.47	36.18	−13.29***	13.47	35.01	21.54***
Seed yield/row	11.60	30.35	18.75***	57.12	45.67	−11.45*	32.88	64.41	31.53***
Honeybee (nectar)[z]	4.41	3.26	–	8.10	5.34	–	3.23	7.71	–
Honeybees (pollen)	0.295	0.13	–	4.14	3.01	–	0.28	0.49	–

[z]Bees/100 umbels.
*Significant at 5% level;
**significant at 1% level;
***significant at 0.1% level.

number of nectar collectors we recorded may represent a close-to-maximum level for line B5546A under conditions of this study.

In B2264A, the correlation between honey bees (nectar) and seed yield, r = 0.3662, was significant and positive (P<0.05) (Table 3). An examination of the components of this correlation reveals that the direct influence of nectar collectors, P_{7y} = -0.0129, was small and negative. It is noteworthy that this line had the least number of flowers among the lines tested with only 281 flowers per umbel (Table 2). Consequently, 3.26 nectar collectors per 100 umbels may have been more than adequate for the number of flowers involved. Furthermore, the number of flowers per umbel had a negative direct influence on seed yield in this line, P_{3y} = -0.0492. This suggests that an

Table 3. Path-coefficient analysis of correlations between insect pollinators and seed yield in line B2264A (n = 32).

Association and designation of effect	Cor. coef. r_{ij}	Path coef. P_{ij}		Influence $r_{ij} \cdot P_{ij}$
Honeybee (nectar), X_7 vs. seed yield, r_{7y} = .366*				
Direct effect on seed yield, P_{7y}		−.0129	=	−.0129
Indirect, via plants/row, $r_{17}P_{1y}$	(−.1396)	(.1309)	=	−.0182
Indirect, via umbels/plant, $r_{27}P_{2y}$	(.0025)	(.2848)	=	.0007
Indirect, via flowers/umbel, $r_{37}P_{3y}$	(.3206)	(−.0492)	=	−.0157
Indirect, via % fert. flowers, $r_{47}P_{4y}$	(.4102)	(.4836)	=	.1984
Indirect, via seeds/fert. flower, $r_{57}P_{5y}$	(.3478)	(.3249)	=	.1130
Indirect, via seed weight, $r_{67}P_{6y}$	(.0893)	(.2550)	=	.0228
Indirect, via honeybee (pollen), $r_{78}P_{8y}$	(.2378)	(.1482)	=	.0352
Indirect, via PI, $r_{79}P_{9y}$	(.7502)	(.0573)	=	.0429
Total correlation; r_{7y}				.3662
Honeybee (pollen), X_8 vs. seed yield, r_{8y} = .348*				
Direct effect on seed yield, P_{8y}		.1482	=	.1482
Indirect, via plants/row, $r_{18}P_{1y}$	(−.1239)	(.1309)	=	−.0162
Indirect, via umbels/plant, $r_{28}P_{2y}$	(.0644)	(.2848)	=	.0183
Indirect, via flowers/umbel, $r_{38}P_{3y}$	(.2682)	(−.0492)	=	−.0131
Indirect, via % fert. flowers, $r_{48}P_{4y}$	(.2961)	(.4836)	=	.1432
Indirect, via seeds/fert. flower, $r_{58}P_{5y}$	(.2035)	(.3249)	=	.0661
Indirect, via seed weight, $r_{68}P_{6y}$	(−.0980)	(.2550)	=	−.0249
Indirect, via honeybee (nectar), $r_{78}P_{7y}$	(.2378)	(−.0129)	=	−.0031
Indirect, via PI, $r_{89}P_{9y}$	(.5312)	(.0573)	=	.0304
Total correlation; r_{8y}				.3489
PI, X_9 vs. seed yield, r_{9y} = .684**				
Direct effect on seed yield, P_{9y}		.0573	=	.0573
Indirect, via plants/row, $r_{19}P_{1y}$	(−.2206)	(.1309)	=	−.0289
Indirect, via umbels/plant, $r_{29}P_{2y}$	(.1819)	(.2848)	=	.0518
Indirect, via flowers/umbel, $r_{39}P_{3y}$	(.2497)	(−.0492)	=	−.0123
Indirect, via % fert. flowers, $r_{49}P_{4y}$	(.6790)	(.4836)	=	.3284
Indirect, via seeds/fert. flower, $r_{59}P_{5y}$	(.5293)	(.3249)	=	.1720
Indirect, via seed weight, $r_{69}P_{6y}$	(.1860)	(.2550)	=	.0474
Indirect, via honeybee (nectar), $r_{79}P_{7y}$	(.7502)	(−.0129)	=	−.0096
Indirect, via honeybee (pollen), $r_{89}P_{8y}$	(.5312)	(.1482)	=	.0787
Total correlation; r_{9y}				.6848

*Significant at 5% level.
**Significant at 1% level.

Table 4. Path-coefficient analysis of correlations between insect pollinators and seed yield in line B2149A (n = 32).

Association and designation of effect	Cor. coef. r_{ij}	Path coef. P_{ij}		Influence $r_{ij} \cdot P_{ij}$
Honeybee (nectar), X_7 vs. seed yield, $r_{7y} = -.058$				
Direct effect on seed yield, P_{7y}		−.2751	=	−.2751
Indirect, via plants/row, $r_{17}P_{1y}$	(−.1091)	(.0565)	=	−.0062
Indirect, via umbels/plant, $r_{27}P_{2y}$	(−.2107)	(.2483)	=	−.0523
Indirect, via flowers/umbel, $r_{37}P_{3y}$	(.0727)	(.3113)	=	.0226
Indirect, via % fert. flowers, $r_{47}P_{4y}$	(−.0430)	(.4451)	=	−.0191
Indirect, via seeds/fert. flower, $r_{57}P_{5y}$	(.1285)	(.1868)	=	.0240
Indirect, via seed weight, $r_{67}P_{6y}$	(.0438)	(.1046)	=	.0046
Indirect, via honeybee (pollen), $r_{78}P_{8y}$	(.2383)	(.0876)	=	.0209
Indirect, via PI, $r_{79}P_{9y}$	(.9320)	(.2388)	=	.2226
Total correlation; r_{7y}				−.0580
Honeybee (pollen), X_8 vs. seed yield, $r_{8y} = .113$				
Direct effect on seed yield, P_{8y}		.0876	=	.0876
Indirect, via plants/row, $r_{18}P_{1y}$	(−.0023)	(.0565)	=	−.0001
Indirect, via umbels/plant, $r_{28}P_{2y}$	(−.1858)	(.2483)	=	−.0461
Indirect, via flowers/umbel, $r_{38}P_{3y}$	(−.1158)	(.3113)	=	−.0360
Indirect, via % fert. flowers, $r_{48}P_{4y}$	(.1056)	(.4451)	=	.0470
Indirect, via seeds/fert. flower, $r_{58}P_{5y}$	(.1169)	(.1869)	=	.0218
Indirect, via seed weight, $r_{68}P_{6y}$	(−.0136)	(.1046)	=	−.0014
Indirect, via honeybee (nectar), $r_{78}P_{7y}$	(.2383)	(−.2751)	=	−.0656
Indirect, via PI, $r_{89}P_{9y}$	(.4455)	(.2388)	=	.1064
Total correlation; r_{8y}				.1136
PI, X_9 vs. seed yield, $r_{9y} = .138$				
Direct effect on seed yield, P_{9y}		.2388	=	.2388
Indirect, via plants/row, $r_{19}P_{1y}$	(.0090)	(.0565)	=	.0005
Indirect, via umbels/plant, $r_{29}P_{2y}$	(−.1499)	(.2483)	=	−.0372
Indirect, via flowers/umbel, $r_{39}P_{3y}$	(.1315)	(.3113)	=	.0421
Indirect, via % fert. flowers, $r_{49}P_{4y}$	(.1357)	(.4451)	=	.0604
Indirect, via seeds/fert. flowers, $r_{59}P_{5y}$	(.2353)	(.1868)	=	.0440
Indirect, via seed weight, $r_{69}P_{6y}$	(.0740)	(.1046)	=	.0077
Indirect, via honeybee (nectar), $r_{79}P_{7y}$	(.9320)	(−.2751)	=	−.2564
Indirect, via honeybee (pollen), $r_{89}P_{8y}$	(.4455)	(.0876)	=	.0390
Total correlation; r_{9y}				.1389

increase in the number of flowers per umbel would probably not be adequately supported, even though such an increase would attract more bees. The indirect effects on seed yield through both percent fertilized flowers, $r_{47}P_{4y} = 0.1984$, and seeds per fertilized flowers, $r_{57}P_{5y} = 0.1130$, were positive.

In B2149A, the correlation between honey bees (nectar) and seed yield, $r = -0.0580$, was insignificant (Table 4). A rather large, direct negative influence ($P_{7y} = -0.2751$) suggests that adverse environmental stresses on the flowers may have affected seed yield. The observed average of 3.23 nectar collectors per 100 umbels may therefore have been more than adequate for the line under existing conditions (Table 2). The negative influence on seed yield through percent fertilized flowers, $r_{47}P_{4y} = -0.0191$, because nectar collectors were negatively correlated with percent fertilized flowers, $r_{47} = -0.0430$, further substantiates this view.

In lines B2267A, B12115-2C, and MSU611C, the negative correlations between nector collectors and seed yield, and the negative indirect influences of nectar collectors on seed yield through percent fertilized flowers and seeds per fertilized flowers suggest that the levels of visitations were more than adequate for all of these inbreds (Tables 5-7). In line B12115-2C, however, the direct influence of nectar collectors was positive, $P_{7y} = 0.1494$. This may indicate that, with other variables held constant, an increase in nectar collectors would increase yield. Nevertheless, the negative indirect influences through percent fertilized flowers, $r_{47}P_{4y} = -0.2167$, and seeds per fertilized flowers, $r_{57}P_{5y} = -0.1431$, suggest that, in this inbred, losses caused by environmental stresses more than counterbalance anything gained through more insect visitation.

Influence of honey bee pollen collectors. The average number of honey bee pollen collectors on the male-sterile lines ranged from 0.13 to 0.49 per 100 umbels. The range on the male-fertile lines was from 3.01 to 4.14 (Table 2).

A positive insignificant correlation was observed between pollen collectors and seed yield in B5546A, $r = 0.2330$ (Table 1). The relatively large direct negative influence on seed yield, $P_{8y} = -0.1755$, suggests that increasing the numbers of pollen collectors may not increase the yield. It also showed that, even at low visitation levels, pollen collectors may have harmful effects on the male-sterile lines.

Among the male-sterile inbreds, a positive significant correlation ($P < 0.05$) was observed between pollen collectors and seed yield in line B2264A (Table 3), which was least visited by pollen collectors (Table 2). In this line, the direct influence of pollen collectors on seed yield was positive, $P_{8y} = 0.1482$.

In B2149A, which was the second least visited by pollen collectors (Table 2), a positive correlation ($r = 0.113$) between pollen collectors and seed yield was insignificant (Table 4).

Line B2267A had the highest visitation by pollen collectors among the male-sterile inbreds (Table 2). Its correlation between pollen collectors and seed yield was insignificant and positive, r = 0.0986 (Table 5). Both the direct influence on seed yield, $P_{8y} = -0.0613$, and the influence through seeds per fertilized flowers, $r_{58}P_{5y} = 0.0144$, were negative.

In the male-fertile line, B12115-2C, which had an average of 3.01 pollen collectors per 100 umbels (Table 2), the correlation between pollen collectors and seed yield was highly significant

Table 5. Path-coefficient analysis of correlations between insect pollinators and seed yield in line B2267A (n = 32).

Association and designation of effect	Cor. coef. r_{ij}	Path coef. P_{ij}		Influence $r_{ij} \cdot P_{ij}$
Honeybee (nectar), X_7 vs. seed yield, $r_{7y} = -.059$				
Direct effect on seed yield, P_{7y}		.1283	=	.1283
Indirect, via plants/row, $r_{17}P_{1y}$	(.2800)	(.0543)	=	.0152
Indirect, via umbels/plant, $r_{27}P_{2y}$	(−.1385)	(.1121)	=	−.0155
Indirect, via flowers/umbel, $r_{37}P_{3y}$	(.5676)	(.3824)	=	.2171
Indirect, via % fert. flowers, $r_{47}P_{4y}$	(−.1986)	(.5843)	=	−.1160
Indirect, via seeds/fert. flower, $r_{57}P_{5y}$	(−.3700)	(.6136)	=	−.2270
Indirect, via seed weight, $r_{67}P_{6y}$	(−.1057)	(.3634)	=	−.0384
Indirect, via honeybee (pollen), $r_{78}P_{8y}$	(.1693)	(−.0613)	=	−.0103
Indirect, via PI, $r_{79}P_{9y}$	(.5488)	(−.0236)	=	−.0129
Total correlation; r_{7y}				−.0595
Honeybee (pollen), X_8 vs. seed yield, $r_{8y} = .098$				
Direct effect on seed yield, P_{8y}		−.0613	=	−.0613
Indirect, via plants/row, $r_{18}P_{1y}$	(.2377)	(.0543)	=	.0129
Indirect, via umbels/plant, $r_{28}P_{2y}$	(.1815)	(.1121)	=	.0203
Indirect, via flowers/umbel, $r_{38}P_{3y}$	(.0393)	(.3824)	=	.0150
Indirect, via % fert. flowers, $r_{48}P_{4y}$	(.1742)	(.5843)	=	.1018
Indirect, via seeds/fert. flower, $r_{58}P_{5y}$	(−.0236)	(.6136)	=	−.0144
Indirect, via seed weight, $r_{68}P_{6y}$	(.0238)	(.3634)	=	.0086
Indirect, via honeybee (nectar), $r_{78}P_{7y}$	(.1693)	(.1283)	=	.0217
Indirect, via PI, $r_{89}P_{9y}$	(.2549)	(−.0236)	=	−.0060
Total correlation; r_{8y}				.0986
PI, X_9 vs. seed yield, $r_{9y} = .440$*				
Direct effect on seed yield, P_{9y}		−.0236	=	−.0236
Indirect, via plants/row, $r_{19}P_{1y}$	(.1448)	(.0543)	=	.0079
Indirect, via umbels/plant, $r_{29}P_{2y}$	(.0486)	(.1121)	=	.0054
Indirect, via flowers/umbel, $r_{39}P_{3y}$	(.3403)	(.3824)	=	.1301
Indirect, via % fert. flowers, $r_{49}P_{4y}$	(.2497)	(.5843)	=	.1459
Indirect, via seeds/fert. flower, $r_{59}P_{5y}$	(.2162)	(.6136)	=	.1327
Indirect, via seed weight, $r_{69}P_{6y}$	(−.0355)	(.3634)	=	−.0129
Indirect, via honeybee (nectar), $r_{79}P_{7y}$	(.5488)	(.1283)	=	.0704
Indirect, via honeybee (pollen), $r_{89}P_{8y}$	(.2549)	(−.0613)	=	−.0156
Total correlation; r_{9y}				.4403

*Significant at 5% level.

and positive, r = 0.5193.

Line MSU611C had the highest number of pollen collectors, an average of 4.14 per 100 umbels (Table 2). Both the correlation between pollen collectors and seed yield, r = -0.1968, and the direct influence on seed yield, P_{8y} = -0.0254 were negative (Table 7). This suggests that under the conditions of this study male-fertile lines may also be harmed by pollen collectors when the visitation level is very high. The rather large negative influence through percent fertilized flowers, $r_{48}P_{4y}$ = -0.2908, provides further evidence that the pollinating insect population was adequate for this study. The effect here obviously was not in terms of shortage of nectar or pollen, but more likely in terms of a water deficit or some other environmental stress (6, 10, 12, 14).

Influence of pollination index. Path-coefficient analysis of correlations between PI and seed yield for the various inbreds indicated no harmful effects of total insect activity (including honey bee nectar - or pollen-collectors) on seed yield (Tables 2-7). This may have been because PI represents all insects available for pollination and not honey bees alone.

Onion inbreds B2149A, B5546A, and MSU611C had been alleged by the seed industry to have low attraction for pollinators, while B2264A, B2267A, and B12115-2C were rated high. Our PI data (Table 2) supported these assumptions for the B2149A (low) and B2267A (high) inbreds in P-3. Further, if we looked only at P-2 and P-3 we might assume that seed yields were directly related to the PI. In the male-steriles of P-1, however, the PI does not follow this pattern especially since B2264A (low) had a 2.5-fold higher seed yield than B5546A (high). Under our experimental conditions the male-fertile, MSU611C (low) inbred was as attractive to the pollinating insects as the B12115-2C (high) line.

When each inbred was considered separately, the correlation between PI and seed yield was significant ($P < 0.01$) and positive in 3 lines (B2264A, B2267A, and B12115-2C). Since the PI represents all insects available for pollination, a correlation between PI and seed yield does not correctly represent the correlation between seed yield and honey bees alone, whether nectar- or pollen-collectors. The correlation between nectar-collecting honey bees and seed yield was significant (positive) only in B2264A, which had the lowest PI (Table 2). Pollen-collecting honey bees were significantly correlated (positive) with seed yield only in B2264A and B12115-2C.

Discussion

Admittedly many of the correlations in this study were low. However, a low correlation does not always mean a lack of relation. By using path-coefficient analysis to partition the correlation coefficients into their direct and indirect components, a critical examination can be made of the specific factors acting to produce a given correlation. Some degree of measure of the relative importance of each causal factor can then be made. Moreover, while the direct effect indicates the obvious fact that, with all other variables held constant, increasing the components of yield will increase seed yield, the indirect effects may mask these direct effects. In this study