YIELD DEVELOPMENT IN POTATOES AS INFLUENCED BY CULTIVAR AND THE TIMING AND LEVEL OF NITROGEN FERTILIZATION

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Abstract

Path-coefficient analysis based on an ontogenetic model was used to study the relationships between tuber yield and yield components as influenced by cultivar and nitrogen fertilization. Four experiments were carried out from 1987 to 1989 in Granada, southern Spain. Two of these experiments used six potato cultivars with a single N rate, while the other two experiments used one cultivar and nine levels of N, split between planting and top-dressing. Variation in tuber yield between cultivars resulted mainly from differences in stem number per m^2 followed by tubers per stem and, to a lesser extent, average tuber weight. In N experiments, however, average tuber weight was the only yield component that showed a significant direct effect on yield, while the number of stems per m^2 and tubers per stem had negligible direct effects. In addition, the ontogenetic model used indicated compensatory mechanisms during the formation of the three yield components in the potato, which resulted stronger in the N experiments.

Compendio

Para estudiar las relaciones entre la producción de tubérculos y los componentes del rendimiento en función de la variedad y fertilización nitrogenada en el cultivo de patata, se ha realizadado un análisis mediante coeficientes de sendero (path-coefficient analysis) basado en un diagrama ontogénico. Se han llevado a cabo para ello cuatro experimentos entre 1987 y 1989 en Granada, Sur de España. Dos de ellos con seis variedades, y otros dos con nueve dosis de N total, repartido entre fondo y cobertera. Las variaciones en la producción de tubérculos debidas a la variedad han dependido principalmente del número de tallos por m^2, del número de tubérculos por tallo y en menor proporción del peso medio de los tubérculos. Sin embargo, en los experimentos de aplicación de N, el peso medio por tubérculo fue el único componente del rendimiento que mostró un

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efecto directo significativo sobre la producción final, mientras que el número de tallos por m² y el número de tubérculos por tallo sólo ejercieron efectos directos insignificantes. El diagrama ontogénico utilizado reveló también la existencia de mecanismos de compensación durante la formación de los tres componentes del rendimiento en la patata, que resultaron más pronunciados en los experimentos de N.

Introduction

Yield in the potato is influenced by cultivar and nitrogen availability. Yield development in potatoes is the result of three physiological processes leading to the formation of yield components. After planting, stems emerge from "eyes" on the seed piece, tubers grow from stolons that develop from the basal buds on the stems, and the tubers then enter a period of growth and weight increase called "bulking". These processes result in three yield components: number of stems per m², number of tubers per stem and average tuber weight.

Of the three yield components, stem number per plant is most affected by cultivars (Susnoschi (14) and Petr *et al.* (12)). Nitrogen stimulates haulm growth and reduces available dry matter for the tubers in the first growth period, but tuber weight is finally favored by the increased size and duration of the haulm (Moorby (11); Beukema and Van der Zaag (3)). Thus, tuber yield responds to nitrogen mainly through tuber weight and, to a lesser extent, to variations in the other two yield components (Petr *et al.* (12); Giardini *et al.* (7)).

The sequential system of yield development of the potato involves interactions among individual yield components, with later-developing components dependent upon earlier-developing ones. Path-coefficient analysis, originally developed by Wright (15), separates the direct effects of each yield component on tuber yield from the indirect effects caused by the mutual relationships among yield components. This analysis has been used successfully to clarify the relationships between yield and its components in many crops, including wheat (Bahtt (2)), barley (García del Moral *et al.* (6)), and field beans (Duarte and Adams (5)). Studying the potato, Lynch and Tai (9) used path-coefficient analysis to determine the differential tolerance of eight cultivars to water stress.

The purpose of this research was to examine the influence of genotype as well as time and rate of N fertilization on yield development, by using path-coefficient analysis.

Material and Methods

Four field experiments at the Agricultural Research and Development Centre in Granada (southern Spain) were conducted on typic xerofluvent

TABLE 1.—*Soils characteristics at the beginning of the four potato experiments.*

Soil Characteristic	1987	1988	1989
Sand (%)	37.20	34.95	38.85
Silt (%)	52.33	52.69	47.73
Clay (%)	10.47	12.36	13.42
pH /H_2O	7.9	7.9	7.9
Total N (%)	0.097	0.120	0.143
Available P (µg g^{-1})	37.0	57.0	47.0
Exchangeable K (µg g^{-1})	95.0	129.0	89.0
O.M. (g Kg^{-1})	16.1	17.6	17.7

soils. Physico-chemical characteristics of the soils are shown in Table 1.

Six different potato cultivars were used, four of these in 1987 (Claustar, Red Pontiac, Spunta and Turia), and five in 1988 (Draga, Jaerla, Red Pontiac, Spunta and Turia). The experimental design was a randomized complete block with four replicates. Plots were fertilized uniformly with 56 kg N/ha, 112 kg P_2O_5/ha and 168 kg K_2O/ha prior to planting, and top-dressed before tuber initiation with 78 kg N/ha.

Two other experiments on the same farm in 1987 and 1989 using the cultivar Jaerla. Prior to planting each year, three nitrogen treatments (0, 56 and 112 kg N/ha) were followed by three top-dress N treatments before tuber initiation (0, 78 and 156 kg N/ha), in a 2 x 3 factorial design with three replicates in 1987 and four in 1989. These plots also received 112 kg P_2O_5 kg/ha and 168 kg K_2O/ha before planting.

The four experiments were sown in the first two weeks of March each year in rows 10m long with 75 cm between rows and 30 cm between plants. Plots were furrow irrigated to field capacity as required, according to conventional practices. Dates of planting, N top-dressing, crop watering and harvest each year are shown in Table 2.

For measuring yield components, stems were counted from two rows 5m long in the middle of each plot at harvest, and tuber number and weight were obtained after harvesting these rows by hand. The tuber number per stem was then calculated dividing the number of tubers by the number of stems.

Variance techniques were used to analyze the data, and differences between means were compared by using the Least Significance Difference test (Steel and Torrie (13)).

Direct effects between yield components in the ontogenetic diagram were obtained by using the method described by Dofing and Knight (4). Path coefficients were calculated by sequentially solving three linear models in which tuber yield, tuber weight, and tuber per stem were each in turn considered dependent variables.

TABLE 2.—*Dates of planting, top-dressing, harvest, watering and amount of rainfall (mm/month) for the four potato experiments.*

	March	April	May	June	July
1987					
Planting	9				
Top-dressing		21			
Watering		15,23	8,15,29	4,10,19	
Harvest					1
Rainfall	5	14	0	2	
1988					
Planting	8				
Top-dressing			5		
Watering	24	18,22	3,20	3,17	
Harvest					13
Rainfall	16	57	39	10	
1989					
Planting	1				
Top-dressing		21			
Watering			5,26	9	
Harvest				27	
Rainfall	35	38	32	26	

TABLE 3.—*Mean square values of yield characteristics of potato crops grown in Granada (Spain) from 1987 to 1989.*

Year	Source	df	Yield (kg/100 m^2) x 10^3 §	Stems per m^2	Tubers per stem	Tuber weight (g)
1987	Cultivar	3	11.9 *	42.5 *	2.74 **	435.8
	Error	9	2.9	10.6	0.44	273.8
1988	Cultivar	4	14.7 *	15.3 **	0.19	395.8
	Error	12	4.1	1.4	0.14	135.9
1987	N.at planting (P)	2	22.3 **	2.1	0.02	1724.1 *
	N.at top-dressing (D)	2	16.5 **	0.8	1.27	1213.5 *
	P x D	4	7.2	0.4	3.33 **	727.6
	Error	18	2.4	2.4	0.76	285.1
1989	N.at planting (P)	2	2.3 *	1.0	0.33	399.7 *
	N.at top-dressing (D)	2	1.1	3.2	0.78	35.4
	P x D	4	1.0	2.8	0.36	284.7
	Error	27	0.6	2.1	0.27	109.9

*,** : significant at 0.05 and 0.01 probability levels, respectively.
§ Multiply reported value by 10^3 to get the actual value.

TABLE 4.—*Mean values of yield characteristics of potato crop grown in Granada (Spain) from 1987 to 1989.*

Year	Experiment	Source	Tuber yield (Kg/100 m^2)	Stems per m^2	Tubers per stem	Tuber weight (g)
1987	Cultivar	Claustar	418.95	8.72	4.25	113.71
		Red Pontiac	433.87	14.46	2.88	90.59
		Spunta	488.27	15.93	2.64	111.31
		Turia	355.38	11.08	2.39	107.38
		LSD (0.05)	87.59	5.22	1.07	ns
1988	Cultivar	Draga	514.00	13.17	3.92	100.51
		Jaerla	539.50	12.85	3.90	107.77
		Red Pontiac	585.47	16.31	3.76	97.14
		Spunta	596.47	14.49	3.38	122.91
		Turia	445.58	11.06	3.84	105.25
		LSD (0.05)	98.42	1.85	ns	ns
1987	Nitrogen	P_0	314.09	7.67	4.30	93.23
		P_1	402.97	7.54	4.38	104.38
		P_2	397.30	6.76	4.39	120.75
		D_0	326.51	7.56	4.79	94.91
		D_1	376.00	6.99	4.15	105.36
		D_2	411.84	7.43	4.13	118.10
		LSD (0.05)	48.09	ns	ns	16.73
1989	Nitrogen	P_0	445.27	8.46	3.28	159.92
		P_1	456.77	8.11	3.58	169.23
		P_2	472.73	8.69	3.30	170.49
		D_0	447.68	9.02	3.09	165.94
		D_1	461.12	8.11	3.56	168.48
		D_2	465.97	8.13	3.50	165.21
		LSD (0.05)	20.81	ns	ns	8.78

Three total dosages of nitrogen applied prior to planting (P_0=0, P_1=56 and P_2=112 Kg/Ha) or at top-dressing (D_0=0, D_1=78 and D_2=156 Kg/Ha)

These equations are:

$$Y = P_{14}X_1 + P_{24}X_2 + P_{34}X_3$$

$$X_3 = P_{13}X_1 + P_{23}X_2$$

$$X_2 = P_{12}X_1$$

where X_1 = stem per m^2
X_2 = tuber per stem
X_3 = average tuber weight

Data were log-transformed and then standardized prior to analysis. Log-transformation was performed to obtain linear relationships between tuber yield and yield components, and standardization was necessary to calculate path coefficients.

Results

The analysis of variance (Table 3) revealed that genotype affected the tuber yield and stem number per m^2 in both years, and the number of tubers per stem in 1987. The effect on average tuber weight was not significant in any experiment. Spunta and Red Pontiac cultivars (Table 4) had the highest yield in both years, due mainly to a greater number of stems per m^2.

Nitrogen treatments at planting (Table 3) affected tuber yield and average tuber weight in both years. Nitrogen applied at top-dressing significantly modified tuber yield and tuber weight in 1987 but not in 1989. The N fertilization at planting (Table 4) increased tuber yield and tuber weight in both years, but no statistical differences were found between the levels tested, P_1 (56 kg/ha) and P_2 (112 kg/ha). The top-dressing N treatments increased yield and tuber weight in 1987, but not in 1989 (Table 4). The two top-dressed N applications, D_1 (78 kg/ha) and D_2 (156 kg/ha) produced no significant differences in yield or tuber weight in 1987 (Table 4).

To investigate the compensatory mechanisms related to yield development, as well as the direct effects between yield components, an ontogenetic diagram was used (Figs. 1 and 2). For the six cultivars, the direct effects obtained (Fig. 1) indicated that tuber yield depended mainly upon the number of stems per m^2, followed by the tuber number per stem and, to a lesser extent, tuber weight. The path coefficients obtained between the three yield components (Fig. 1) showed a negative relationship between the stem number per m^2 and the other two yield components, probably caused by competition during plant development. These negative direct effects, however, were not significant for cultivars.

The path-coefficient analysis for N-treatment experiments (Fig. 2) revealed that the tuber production depended mainly on tuber weight, with no significant direct effect from the other two yield components. The analysis also showed strongly significant compensatory mechanisms between the stems per m^2 and tuber per stem, and between tuber per stem and tuber weight. These compensatory phenomena between components affected by nitrogen were stronger than those for cultivar experiments.

Discussion

In this study, variation in the tuber yield among cultivars was associated with the density of stems per unit area. Allen and Scott (1) indicated the importance of rapid development of a high leaf area index by increasing the number of stems per unit area to improve assimilation processes during early growth. The Mediterranean growing season is approximately 16 weeks,

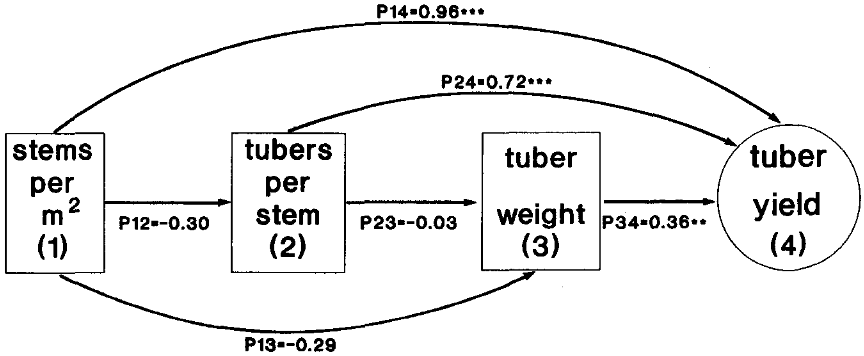

FIG. 1. Path-coefficient diagram showing the interrelationships of four yield characteristics of six potato cultivars grown during 1987 and 1988 in Granada (Spain). Arrows indicate path coefficients. *, **, ***, significant at 0.05, 0.01 and 0.001 probability levels, respectively.

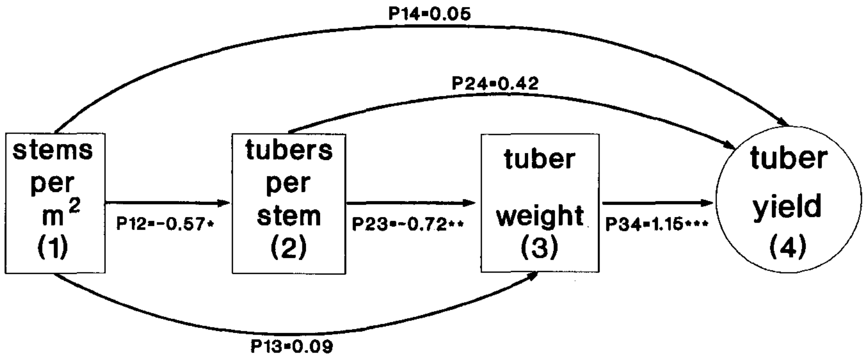

FIG. 2. Path-coefficient diagram showing the interrelationships of four yield characteristics of nine nitrogen doses for six potato cultivars grown during 1987 and 1989 in Granada (Spain). Arrows indicate path coefficients. *, **, ***, significant at 0.05, 0.01 and 0.001 probability levels, respectively.

with the last month characterized by high temperatures, which reduce dry matter gain for the tubers. Thus, a complete leaf cover early in the season when the assimilation processes are favored by weather, could be particularly helpful. In fact, in the studies of Petr *et al.* (12), weight per tuber is closely associated with integral leaf surface and thus influenced by stand density. These conclusions agree with those of Susnoschi (14), who found that high-yielding varieties in Israel were associated with high stem density.

For the cultivar experiments, path analysis (Fig.1) showed that the number of tubers per stem and tuber weight had less influence on yield than did the number of stems. However, the two components were significant and positive, in agreement with Petr *et al.* (12), who reported positive influences of all three yield components on total production in several genotypes of potato.

Variation in tuber yield according to N treatments were related to the tuber weight, while the number of stems and number of tubers per stem were not significantly influenced by N. These results agree with other studies on potatoes, indicating that the potato yield component most affected by N is the mean weight of the tubers (Harris (8); Petr *et al.* (12); Millar and MacKerron (10); Giardini *et al.* (7)). The N application at planting increased tuber yield in both years, whereas N at top-dressing had this effect only in 1987 (Table 4). It is generally accepted that increases in yield due to N applied at top-dressing are associated with conditions which enhanced mineral leaching (e.g. light soils and heavy watering) (Beukema and Van der Zaag (3)). As 1987 was a very dry year (only 5 mm rain in March, Table 2), the crop was watered just a month after planting. This could have leached part of the N applied at planting, thereby causing the N top-dressing treatment to have a significant effect on tuber production. As 1989 was a wetter year (35 mm rain in March, Table 2), the first watering was not necessary until April 21. The late watering, together with the higher N availability in the soil this year (Table 1), might account for the poor response to N top-dressing.

There were no significant differences in yield between the two N rates applied at planting or at top-dressing (Table 4). It is generally accepted that high rates of N stimulate leaf rather than tuber growth. Allen and Scott (1) pointed out that any improvement in light interception achieved by increasing N is likely to be counterbalanced by unfavorable alteration in the partitioning of assimilates. Supporting this, our study showed that doubling the amount of N did not increase tuber yield.

The ontogenetic diagram showed compensatory mechanisms between the three yield components, as reported by several authors for potatoes (Allen and Scott (1); Petr *et al.* (12)), with variation of later-developing yield components being controled by previous ones in the developmental sequence. The standardization of data before analysis allows path-coefficients to be compared to each other in the ontogenetic diagram, for a better understanding of component compensation. For example, in cultivar experiments (Fig. 1), compensation between stems per m^2 and tuber weight (-0.29) represented 81% of the direct effect of this latter yield component on tuber yield (0.36). Meanwhile, in nitrogen experiments (Fig. 2) this compensation effect was negligible. Therefore this ontogenetic approach seems to be of great interest to explain better how competition between organs affect yield formation in potatoes, a matter not yet fully understood, as implied by Petr *et al.* (12).

Conclusions

The results of this research indicate that variation in potato yield as affected by genotype were dependent mainly on stem density, followed by number of tubers per stem and average tuber weight. On the other hand, mean tuber weight was the only yield component having a significant direct effect on tuber yield as affected by N fertilization. Direct effects between yield components, using an ontogenetic diagram, show the existence of compensatory phenomena, which were stronger for N experiments than for cultivar ones.

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