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THE EFFECTS OF N, P AND K FERTILIZERS ON THE CONCENTRATIONS OF THESE ELEMENTS IN PETIOLES AND TUBERS OF POTATO[1]

M.R. KHAJEHPOUR, F. REISI AND A. JALALIAN[2]

College of Agriculture, Isfahan University of Technology, Isfahan, Iran
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ABSTRACT

The effects of N, P and K fertilizers on the concentrations of these elements in petioles and tubers of potato (*Solanum tuberosum* L.) were assessed under Isfahan potato production conditions using cv. "Cozima". Nitrogen fertilization significantly increased the petiole NO_3-N concentrations at all samplings. A curvilinear relationship between fresh tuber yield and petiole NO_3-N concentration at the second sampling (45 days after emergence) was obtained. The critical petiole NO_3-N concentration was around 9.8 g kg^{-1} and the highest yield (38.8 Mg ha^{-1}) was obtained with 180-180-100 fertilizer treatment at the petiole NO_3-N concentration around 13.5 g kg^{-1}. Use of N fertilizer beyond the plant need considerably increased protein content of tubers with no excessive NO_3-N accumulation. Fertilization with P and K did not affect NO_3-N concentration of petioles. Fertilization with P significantly increased the petiole PO_4-P content only at

[1]Part of the M.S.thesis of the second author.
[2]Assistant Professor, former Graduate Student and Assistant Professor, respectively.

the first sampling (22 days after emergence). However, a significant negative correlation was obtained between fresh tuber yield and petiole PO_4-P concentration at the second sampling. This was attributed to N increasing tuber yield and haulm dry weight leading to the dilution of PO_4-P in petioles. Potassium fertilization significantly increased K concentration of petioles at the second and third (65 days after emergence) samplings. However, the degree of dependency (r^2 = 0.31) of tuber yield on petiole K content was considered low for appropriate evaluation of petioles. The results indicate that potato is a heavy K user. Potassium fertilization might be recommended for very high potato tuber yields or when a heavy K user crop follows potato in rotation.

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اثرات کودهای ازت، فسفر و پتاسیم بر غلظت این عناصر در دمبرگ و غده‌های سیب زمینی

محمدرضا خواجه‌پور، فرهود رئیسی و احمد جلالیان

به‌ترتیب استادیار زراعت، دانشجوی سابق کارشناسی ارشد باغبانی و استادیار خاکشناسی دانشکده کشاورزی دانشگاه صنعتی اصفهان.

چکیده

اثرات کودهای ازت، فسفر و پتاسیم بر غلظت این عناصر در دمبرگ و غده سیب زمینی (Solanum tuberosum L.) تحت شرایط تولید سیب زمینی در اصفهان و با استفاده از رقم کوزیما مورد ارزیابی قرار گرفت. کاربرد کود ازت موجب افزایش معنی دار در غلظت ازت نیترات دمبرگ در کلیه نمونه برداریها گردید. رابطه ای غیرخطی بین عملکرد غده تر و غلظت ازت نیترات دمبرگ در دومین نمونه برداری (۴۵ روز بعد از سبز شدن) بدست آمد. غلظت بحرانی ازت نیترات حدود ۹/۸ گرم بر کیلوگرم بود و بالاترین عملکرد (۳۸۸۰۰ کیلوگرم در هکتار) با تیمار ۱۰۰–۱۸۰–۱۸۰ و غلظت ازت نیترات دمبرگ حدود ۱۳/۵ گرم بر کیلوگرم تولید شد. کودهای فسفات و پتاسیم تاثیری بر غلظت ازت نیترات دمبرگ نداشتند. کاربرد کود فسفر فقط موجب افزایش معنی دار غلظت فسفر فسفات دمبرگ در اولین نمونه برداری (۲۲ روز بعد از سبز شدن) گردید. اما همبستگی منفی معنی دار بین عملکرد غده تر و غلظت فسفر فسفات در دومین نمونه برداری بدست آمد. تاثیر ازت بر عملکرد غده و وزن خشک قسمت های هوائی و در نتیجه رقیق شدن فسفر فسفات در دمبرگ بعنوان عامل احتمالی وجود این همبستگی شناخته شد. کاربرد کود پتاسیم موجب افزایش غلظت پتاسیم دمبرگ در دومین و سومین (۶۵ روز بعد از سبز شدن) نمونه برداری گردید. با این حال میزان وابستگی عملکرد غده به مقدار پتاسیم دمبرگ برای ارزیابی

صحیح وضعیت پتاسیم در دمبرگ کافی شناخته نشد. کودهای ازت وفسفر موجب
کاهش غلظت پتاسیم در دمبرگ گردید. مصرف کود ازت به میزان بیش از حد مورد
نیاز گیاه موجب افزایش قابل ملاحظه ای در مقدار پروتئین غده شد بدون اینکه
موجب تجمع ازت نیترا ته گردد. مصرف کود پتاسیم برای حصول عملکردهای
بسیار بالائی از سیب زمینی ویا هنگامی که یک محصول پرنیاز برای پتاسیم
پس از سیب زمینی درتناوب قرار می گیرد قابل توصیه است.

INTRODUCTION

Maintaining nutrient concentrations in potato plants above certain limits helps insure high yields. Nutrient content of potato petiole has been shown to be an appropriate indicator of soil nutrient availability and tuber yield potential (11, 12, 13, 14). This relationship might be used to predict the need for or probable yield response to fertilization. In this respect, the timing of sampling is of prime importance (12). Nutrient concentrations usually increase after fertilization, but generally decrease as plants approach maturity (11, 12, 13).

Sufficiency of petiole nutritional status might be identified by either critical nutrient concentration (3) or critical nutrient ranges (12). The former considers concentrations that reduce yield more than 10% of the maximum as deficient and the latter defines deficient, intermediate and sufficient levels of nutrients in petioles. Fertilization should be practiced when the petiole nutrient concentration is at the deficient level. However, soil available nutrients interact through both plant absorption and dilution effects (7).

Nitrogen fertilization beyond an adequate level increases the total N content of tubers. This practice may result in low fertilization efficiency (5) and high NO_3-N content of tubers. However, nutritious value of tubers might be increased due to the added protein content of tubers.

The purpose of this study was to evaluate the effects of N, P and K fertilization on their concentrations in potato petioles and tubers and to investigate the appropriate levels of N, P and K in petioles for high tuber yields under Isfahan potato production conditions.

MATERIALS AND METHODS

"Cozima" potato (*Solanum tuberosum* L.) seed pieces (averaging 53 g) were planted 0.15 m deep at the Agricultural Experiment Station, Isfahan University of Technology (32°, 23′ N and 52°, 22 E) on a Khomeinishahr series clay loam soil (typic Haplargids, Mixed, Thermic) on April 20, 1985. The field was under clover during the previous year and was plowed in fall 1984. The organic carbon, total N, available P and K content of soil were determined by standard procedures commonly used by the Institute of Pedalogy and Soil Fertility (6). These results are presented in Table 1.

Table 1. Soil nutrient content before fertilization.

Soil depth (cm)	Organic carbon (%)	Total N (%)	Available P (mg kg^{-1})	Available K (mg kg^{-1})
0-30	0.48	0.067	16.0	170
30-60	0.29	0.061	4.5	180

A factorial experiment using a randomized complete block design with three replications was employed with four rates of N (0, 90, 180 and 270 kg ha^{-1}) as urea, three rates of P_2O_5 (0, 90 and 180 kg ha^{-1}) as treble superphosphate and three rates of K_2O (0, 100 and 200 kg ha^{-1}) as potassium sulfate. Fifty percent of N of each treatment and all P and K fertilizers were band placed in soil before planting about 0.15 m at each side and 0.06 m below potato seed pieces. The remainder of N fertilizer of each treatment was side placed about a week after tuber initiation (about 50% flowering) by digging narrow furrows on each side of the beds. The furrows were covered with soil after N fertilizer placement. Each experimental plot consisted of four beds, 0.25 m high, 1 m apart and 10 m long.

The experiment was furrow irrigated three times until 50% emergence (30 days after planting) and then was irrigated as the average of three tensiometers (placed 0.30 m deep and between two successive plants on three different spots of the field) indicated a matric potential of -0.5 atmosphere for soil water. Each irrigation brought the soil moisture back to near field capacity to the depth of 0.60 m.

A 0.15% suspension of benomyl (a wettable powder containing 50% methyl-benzimidazole carbamate) was used to disinfect potato seed pieces before planting. Weeds were controlled by a combination of hand weeding and a preemergence application of DCPA (dimethyl-tetrachloroterephthalate) herbicide at 9.0 kg a.i. ha^{-1}.

Fifty petiole samples per plot were taken from the fourth fully expanded leaves (3) at 22, 45 and 65 days after emergence. Petioles were oven-dried at 65°C for 48 hr, milled to pass 1 mm screen and then analyzed for NO_3-N and PO_4-P by spectrophotometry (4) and for total K by flame photometry (2).

Experimental plots (the middle two rows, 10 m long) were hand harvested for tuber yield determination when about 90% of leaves turned yellow (0 and 90 kg ha^{-1} N fertilizer levels) or when secondary growth was noticed on tubers (180 and 270 kg ha^{-1} N fertilizer levels). A random sample (around 1 kg) was taken from harvested tubers of each plot, washed to remove soil and towel dried. Tubers were then sliced, oven-dried at 65°C for 48 hr and milled to pass 1 mm sieve. Samples taken from each treatment over replications were thoroughly mixed to provide a composite sample for chemical analysis. Total N was determined by wet ash digestion and micro-Kjeldahl method (8). The NO_3-N concentration was determined by spectrophotometry (4). Tuber protein content was estimated by organic N times 6.25. Potassium and P contents were determined using spectrophotometry and flame photometry procedures, respectively (2).

Data were subjected to analysis of variance and means were compared using Duncan s multiple range test. The relationships between fresh tuber yield and petiole nutrient content were determined using correlation and regression procedures (10).

RESULTS AND DISCUSSION

Petioles NO_3-N

Nitrate-N content of petioles was significantly ($P<0.01$) affected by N fertilization at all sampling dates (Table 2). The petiole NO_3-N concentration increased as higher rates of N fertilizer were applied (Table 3). Similar results are reported by Timm *et al.* (11) and Westermann and Kleinkopf (14). The highest petiole NO_3-N concentrations were obtained at the second sampling, which was 10 days after side placing N fertilizer and about two weeks after tuber initiation. Petiole NO_3-N concentrations (g kg^{-1}) ranged between 2.6 - 14.5 at the first sampling, 1.1 - 16.5 at the second sampling and 0.3 - 11.2 at the third sampling.

Fresh tuber yield showed highly significant ($P<0.01$) linear correlations with the petiole NO_3-N concentration at all samplings (0.61, 0.87 and 0.62 at 22, 45 and 65 days after emergence, respectively). Curvilinear regression of the fresh tuber yield on the petiole NO_3-N concentration at 45 days after emergence was significant ($P<0.01$) over linear regression. This curvilinear relationship is shown in Fig. 1. According to this regression analysis, the maximum yield (about 31.8 Mg ha^{-1}) may be obtained with 16.6 g kg^{-1} petiole NO_3-N concentration. However, a much higher yield was obtained with a lower petiole NO_3-N concentration (as will

Table 2. Analysis of variance for petiole nutrient concentration at 22, 45 and 65 days after emergence.

Source of Variation	Petiole NO_3-N			Petiole PO_4-P			Petiole K		
	22	45	65	22	45	65	22	45	65
N	**	**	**	-	**	-	**	**	**
P	-	-	-	**	-	-	**	*	-
K	-	-	-	-	-	-	-	**	**
NxP	-	-	-	-	-	*	-	-	-
NxK	-	-	-	*	-	-	-	-	-
PxK	-	-	-	-	-	-	-	-	-
NxPxK	-	-	-	-	-	-	-	-	-

* and ** indicate significance at 5% and 1% probability level, respectively.

Table 3. Effects of N fertilizer (kg ha^{-1}) on NO_3-N, PO_4-P and K contents of petioles at 22†, 45 and 65 days after emergence.

Fertilizer	NO_3-N (g kg^{-1})			PO_4-P (g kg^{-1})			K (% of dry weight)		
rate	22	45	65	22	45	65	22	45	65
0	4.0c	2.1d	1.2d	3.4a	2.5a	1.2a	10.6a	9.9a	9.0a
90	8.5b	7.7c	2.4c	3.3a	2.1b	1.2a	10.3b	9.3b	8.7b
180	7.3b	12.5b	4.5b	3.5a	1.9b	1.3a	10.1b	9.0c	8.6b
270	11.5a	14.9a	8.3a	3.5a	2.0b	1.3a	10.2b	8.9c	8.6b

†Only 50% of N was applied at this sampling.

‡Treatment means (averages over all rates of applied P_2O_5 and K_2O) within a category and column followed by the same letter are not significantly different at the 5% probability level according to the Duncan's multiple range test.

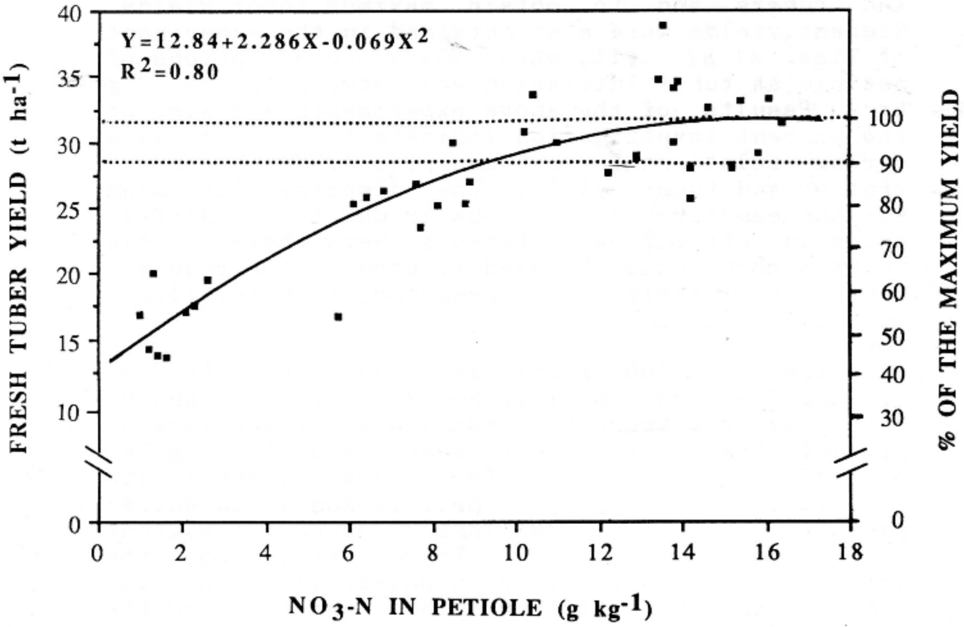

Fig. 1. The relationship between final tuber yield and NO_3-N in petioles at 45 days after emergence.

be discussed later) indicating the importance of sufficiency and interaction with other nutrients. Nevertheless, the petiole NO_3-N concentration at 90% of the maximum yield was considered as the critical N concentration level (3) which was 9.8 g kg^{-1}. Tyler *et al.* (12) have considered petiole NO_3-N concentrations at mid-season sampling (from early tuber set until tubers are half grown) greater than 9.0 g kg^{-1} as sufficient and 6.0 to 9.0 g kg^{-1} as intermediate level for California potato production conditions. Westermann and Kleinkopf (14) found that petiole NO_3-N concentrations about 15 g kg^{-1} during linear tuber growth was sufficient to maintain N and dry matter balance between tops and tubers and to obtain maximum tuber yields. Highest yields were also obtained in the experiment of Timm *et al.* (11) when NO_3-N concentrations of petiole at tuber initiation was between 12 and 18 g kg^{-1}. Results of the above experiments and also of the present investigation indicate that there is a strong relationship between petiole NO_3-N concentration and tuber yield. The discrepancies among various experiments are probably due to the differences in other growth factors. Nevertheless, this relationship could be used to predict the requirement or the likely yield response to N fertilization (12).

The 0-90-100 fertilizer treatment with 2.6, 1.6 and 0.6 g kg^{-1} petiole NO_3-N at 22, 45 and 65 days after emergence samplings, respectively, produced the minimum fresh tuber yield (13.7 Mg ha^{-1}) and the 180-180-100 fertilizer treatment with 8.7, 13.5 and 2.6 g kg^{-1} petiole NO_3-N concentrations at successive samplings produced the highest tuber yield (38.8 Mg ha^{-1}). These results show the importance of N fertilizer on potato yield and also indicate that N fertilizer levels that bring up the petiole NO_3-N concentrations to about 13.5 g kg^{-1} at around two weeks after tuber initiation may produce high yields, provided that P and K are not deficient. In addition, the results obtained with the 180-180-100 treatment and the data presented in Table 3, suggest that the petiole NO_3-N concentrations may drop from a range of 12.5 to 13.5 g kg^{-1} at about two weeks after tuber initiation to as low as 4.5 to 2.6 g kg^{-1} at around five weeks after tuber initiation with no significant effect on yield under the conditions similar to the present experiment.

Petiole NO_3-N concentration was not significantly affected by P or K fertilizers (Table 2). However, petiole NO_3-N concentration decreased slightly as higher rates of P fertilizer were used (Table 4), but no specific trend could be distinguished for K fertilizer effect (Table 5). In the experiment of Murarka *et al.* (7) on a Deschutes sandy loam soil with 152 mg kg^{-1} K content, fertilizing with 200 mg kg^{-1} K as KCl resulted in a

Table 4. Effects of P_2O_5 fertilizer (kg ha^{-1}) on NO_3-N, PO_4-P and K contents of petioles at 22†, 45 and 65 days after emergence.‡

Fertilizer	NO_3-N (g kg^{-1})			PO_4-P (g kg^{-1})			K (% of dry weight)		
rate	22	45	65	22	45	65	22	45	65
0	8.5a	9.9a	4.3a	2.8c	2.1a	1.2a	10.5a	9.4a	8.8a
90	7.5a	9.1a	4.2a	3.5b	2.1a	1.2a	10.3a	9.3a	8.6a
180	7.5a	9.0a	3.7a	3.9a	2.2a	1.3a	10.0b	9.1b	8.8a

†Only 50% of N was applied at this sampling.
‡Treatment means (averages over all rates of applied N and K_2O) within a category and column followed by the same letter are not significantly different at the 5% probability level according to the Duncan s multiple range test.

Table 5. Effects of K_2O fertilizer (kg ha^{-1}) on NO_3-N, PO_4-P and K contents of petioles at 22†, 45 and 65 days after emergence.‡

Fertilizer	NO_3-N (g kg^{-1})			PO_4-P (g kg^{-1})			K (% of dry weight)		
rate	22	45	65	22	45	65	22	45	65
0	8.0a	8.8a	3.9a	3.5a	2.1a	1.2a	10.1a	9.0b	8.5b
100	7.8a	9.5a	4.6a	3.4a	2.2a	1.3a	10.3a	9.3a	8.8a
200	7.7a	9.7a	3.7a	3.3a	2.1a	1.3a	10.4a	9.4a	8.8a

†Only 50% of N was applied at this sampling.
‡Treatment means (averages over all rates of applied N and P_2O_5) within a category and column followed by the same letter are not significantly different at the 5% probability level according to the Duncan's multiple range test.

higher N uptake but lower NO_3-N concentration in potato plant tops. The soil available K in the present study was estimated to be 175 mg kg^{-1} down to 0.6 m soil depth (Table 1). Lack of effect of K fertilizer on NO_3-N concentration in our experiment conducted on a clay loam soil indicates that various soils may behave differently with respect to K release and availability during the growing season.

Petiole PO_4-P

Fertilization with P significantly ($P<0.01$) affected petiole soluble PO_4-P concentration only at the first sampling (Table 2). Petiole PO_4-P concentration increased as higher P fertilizer rates were applied, but the concentrations decreased to about the same levels with all rates of P fertilizer as time passed (Table 4). A similar response was shown by Tyler *et al.* (12) and might also be concluded from the data presented by Roberts and Dow (9) and Timm *et al.* (11). This trend may emphasize the necessity of early sampling for PO_4-P determination (12). According to the above investigations and also our results, the peak in petiole PO_4-P concentration generally occurs from three weeks after emergence till early tuberization depending on the experimental conditions. The overall reduction in petiole PO_4-P concentration as plants matured was reported by Westermann and Kleinkopf (13) to follow a semi-logarithmic relation. In their experiments, the total P absorption was sufficient for haulm and tuber growth when the petiole soluble PO_4-P was greater than 1.0 g kg^{-1} and dry matter was not lost from the tops to tubers until the petiole soluble PO_4-P was less than 0.7 g kg^{-1}. The soluble PO_4-P concentration of petioles (g kg^{-1}) in the present experiment ranged between 2.2 to 4.6 at the first sampling, 1.4 to 2.9 at the second sampling and 0.8 to 2.2 at the third sampling.

Linear correlation coefficients between fresh tuber yield and petiole PO_4-P concentrations at the successive samplings were 0.21 (n.s.), -0.48 ($P<0.01$) and 0.16 (n.s.), respectively. The significant negative correlation between yield and PO_4P concentration at the second samplings might be attributed to the N fertilizer effect. The N fertilizer significantly increased both tuber yield and haulm dry weight (data not shown here) resulting in the dilution of PO_4-P concentration in petioles and consequently negative relationship between petiole soluble PO_4-P and yield at the second sampling. This is also evident from significant negative correlation ($r = -0.39$ $P<0.05$) between NO_3-N and PO_4-P concentrations of petioles and from the highly significant effect of petiole NO_3-N concentration on yield at the second sampling (Fig. 1).

Tyler *et al.* (12) considered petiole PO_4-P concentrations higher than 2.0, 1.6 and 1.0 g kg^{-1} at early, mid- and late season, respectively, as sufficient and 1.2 to 2.0, 0.8 to 1.6 and 0.5 to 1.0 g kg^{-1} at early, mid- and late season, respectively, as intermediate for maximum tuber yields. The petiole PO_4-P concentrations obtained with the highest yielding fertilizer treatment (180-180-100) were 4.5, 2.2 and 2.2 g kg^{-1} at successive samplings, which are much higher than the standards set by Tyler *et al.*(12) or Westermann and Kleinkopf (13). However, critical evaluation of our data (not shown here) suggests that potato tuber yield may not be a linear function of petiole PO_4-P concentration under conditions similar to the present experiment when by Tyler *et al.* (12) standards, the petiole PO_4-P level is close to or higher than the intermediate concentrations.

Petiole PO_4-P concentration was significantly ($P<0.01$) affected by N fertilization at the second sampling (Table 2). This might be attributed to the inability of plants to assimilate the absorbed P due to a low N status in plant tissues (Table 3). The significant effects of N x P at the third sampling and N x K at the first sampling on the petiole PO_4-P concentration were confounded and no explanation could be suggested (data not shown here).

Petiole K Concentration

The concentration of petiole K was significantly ($P<0.01$) affected by K fertilization at the second and third samplings (Table 2). There were no differences between 100 and 200 kg K_2O ha^{-1} at either the second or the third samplings (Table 5). The lack of effect of K fertilization on petiole K content at the samplings before tuber initiation was also reported by Tyler *et al.* (12). However, the highest K concentrations were obtained at the first sampling (Table 5) and decreased as time passed (11, 12). Petiole K content (dry weight %) ranged from 9.6 to 11.0 at the first sampling, 8.2 to 10.2 at the second sampling and 8.1 to 9.4 at the third sampling.

Linear correlation coefficients between fresh tuber yield and petiole K content were around 0.56 ($P<0.01$) at all sampling dates. This level of dependency ($r^2 = 0.31$) of yield on petiole K content may not be large enough for practical purposes. Fong and Ulrich (3) showed that the highest early (32 days) potato plant growth might be obtained when petioles contain above 3.5% K by dry weight. Tyler *et al.* (12) considered 11%, 9%, and 6% or higher K in petiole dry weight as sufficient and 9% to 11%, 7% to 9% and 4% to 6% K as intermediate at early, mid- and late season, respectively. In our experiment, petiole K concentration at zero level of K fertilization was above 9.6% at the first sampling and remained above 8.1% up to the third sampling. In addition, the highest yield (38.8 Mg ha^{-1}) was obtained with 10.0%, 9.2% and 8.7% K in petiole dry weight at the first, second and third samplings, respectively, with 180-180-100 fertilizer treatment. These results indicate that soil had provided an extremely large proportion of the plant need for K and the absorption has continued through out the experiment. However, it appears that soil may not supply enough K at late season under conditions similar to our experiment for very high yields and K fertilization should be practiced.

Petiole K concentration was significantly ($P<0.01$) affected by N fertilizer at all samplings and by P fertilizer at first ($P<0.01$) and second ($P<0.05$) samplings (Table 2). Petioles K concentrations decreased as higher N fertilizer rates were used (Table 3). Apparently, N fertilizer increased haulm growth (data not shown here) resulting in dilution of K content of petioles. Conversely, the dilution effect of K on N content of potato plant top is shown by Murarka *et al.* (7). No explanation could be found for the reduction in petiole K content due to 180 kg P_2O_5 ha^{-1} application (Table 4).

<u>Nutrient Content of Tubers</u>

Use of N fertilizer caused a slight increase in percent of total N of tubers at harvest (Table 6). This is consistent with the results of Carter and Bosma (1) and Lauer (5) where total N in the potato tubers was directly proportional to the rate of N fertilizer application. The total amounts of N removed by tubers at 0. 90, 180 and 270 kg N ha^{-1} were 44.7, 77.1 92.6 and 111.2 kg ha^{-1}, respectively. The extra amount of N (18.6 kg ha^{-1}) removed by tubers as the result of increasing the N fertilizer level from 180 to 270 kg ha^{-1} might be considered as lost (5), because it did not increase yield but lowered the efficiency of N fertilizer in the present experiment. However, about 99% of this N was converted to organic N. The calculated protein contents of tubers were 7.5%, 8.4%, 8.4% and 10.2% of dry weight at 0, 90, 180 and 270 kg N ha^{-1} fertilizer levels, respectively. Thus the nutritious value of tubers may be increased if N fertilizer rates above sufficient levels are used under conditions similar to this experiment. The effects of P and K fertilizers on total N content of tubers were small and non-conclusive (Table 6). Similar results are reported for P effect by Carter and Bosma (1).

The amount of NO_3-N in tubers was slightly affected by N fertilizer rates (Table 6). The average NO_3-N contents of fresh tubers were 44, 37, 43 and 47 mg kg^{-1} at 0, 90, 180 and 270 kg N ha^{-1}, respectively. Although the tolerance level of NO_3-N in potato tubers depends on the amount and method of tuber consumption, Carter and Bosma (1) after evaluating the available data suggested that NO_3-N contents lower than 67 mg kg^{-1} may be considered safe for human health. The results of the present experiment may suggest that N fertilizer levels sufficient for maximum yields may not lead to excess NO_3-N accumulation in potato tubers under conditions similar to the present investigation. Phosphate fertilizer showed no effect and K fertilization caused only slight increase in NO_3-N level of tubers (Table 6).

The effects of N, P and K fertilizers on P content of tubers were small and no specific trend was noticeable (Table 6). The effect of N fertilizer on K content of tubers was negligible but K content slightly decreased as higher rates of P fertilizer were applied and increased as higher rates of K fertilizer were used, especially at 200 kg K_2O ha^{-1} (Table 6).

The amount of N, P and K removed by the tubers with the maximum yielding fertilizer treatment (180-180-100) were 106.6, 26.2 and 217.5 kg ha^{-1}, respectively. Use of K fertilizers is not common in Isfahan Province and also in most other potato producing areas of Iran. The above results indicate that potato is a heavy K user. Potassium fertilization should be practiced when a very high potato yield is expected or replenishment of the soil might be necessary when a high yielding potato crop is followed by a crop with a high K requirement.

CONCLUSIONS

Nitrogen was the most important determinant of potato tuber yield in this experiment, because the plant need is high and soil may not provide it in sufficient amount for high yields. Addition of a large amount of N fertilizer, in excess of the sufficient level, may result in low nitrogen efficiency, but may increase the nutritious value of tubers without a significant increase in their NO_3-N content.

Nutrient levels in soil affect petiole concentrations of these elements and there is a significant relationship between nutrient concentrations in petiole and tuber yield of potato. This relationship might be used to determine the sufficiency

Table 6. Effects of N, P_2O_5 and K_2O fertilizers (kg ha^{-1}) on nutrient content of potato tubers (% of dry weight).†

Nutrient	N				P_2O_5			K_2O			Means	S.D.
	0	90	180	270	0	90	180	0	100	200		
Total N	1.220	1.370	1.370	1.650	1.400	1.420	1.380	1.390	1.340	1.480	1.400	0.230
NO_3-N	0.020	0.017	0.020	0.022	0.020	0.020	0.020	0.019	0.020	0.021	0.020	0.005
P	0.335	0.327	0.314	0.330	0.323	0.338	0.333	0.336	0.327	0.332	0.331	0.022
K	2.770	2.660	2.560	2.590	2.700	2.610	2.460	2.630	2.660	3.660	2.650	0.160

†Each mean is an average over the respective levels of the two other nutrients with samples from replications mixed to provide a composite sample.

of nutrient levels in plants for high yields. However, petiole nutrient concentrations and the accuracy of the estimates are strongly dependent on the status of other nutrients in soil and plant, because significant interactions often exist. The amount of existing vegetative growth at the time of sampling is one manifest of these interactions.

The timing of sampling is also important not only for accurate estimation of nutrient sufficiency, but also to correct the deficiency. Tuber initiation seemed an appropriate time to sample petioles for N status determination. But, very early sampling should be practiced in the case of phosphorus. At any rates, field fertilization should consider soil nutrient availability, release and balance to obtain a high yield and maintain soil fertility.

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