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Flower, Berry and True Potato Seed Productions in Potato Mother Plants (*Solanum tuberosum* L.). 1. Effects of Nitrogen and Phosphorus Fertilizers

[1]Tuhin Suvra Roy, [2]Takashi Nishizawa and [1]Mohammed Hazrat Ali
[1]Faculty of Agriculture, Sher-e-Bangla Agricultural University, Sher-e-Bangla Nagar, Dhaka-1207, Bangladesh
[2]Faculty of Agriculture, Yamagata University, Tsuruoka, 997-8555, Japan

Abstract: This study was conducted to examine the effects of combinations of different levels of nitrogen and phosphorus fertilizers on sexual reproductive characters of potato mother plants using a cross of ♀ MF-II and ♂ TPS-67. Sixteen treatment combinations consisting of each of 4 different levels of N (0, 150, 225 and 300 kg ha^{-1}) and P (0, 60, 120 and 180 kg ha^{-1}) were applied to MF-II. Both N and P had significant effects on the production of inflorescence and berries on TPS yield. Combined treatment with N and P also had significant effects on most of the parameters, except for the weight of large berries and number of TPS berry^{-1}. Out of the 16 treatment combinations, 150 kg N and 60 kg P ha^{-1} produced the maximum number of berries plant^{-1} (22.9), whereas 150 kg N and 120 kg P ha^{-1} produced maximum berry yield (199.2 g) and 150 kg N and 180 kg P ha^{-1} produced the highest mean berry weight (9.1 g). The highest 100-TPS weight (84.1 mg) was obtained with 300 kg N and 120 kg P ha^{-1}, while the highest TPS yield (136.1 kg ha^{-1}) was obtained with 225 kg N and 120 kg P ha^{-1}. The results of correlation analysis revealed that the yield of TPS was correlated more strongly with both the size and weight of berries and seeds than the number of berries plant^{-1}.

Key words: Berry, flower, nitrogen, phosphorus, true potato seed, yield

INTRODUCTION

Potato (*Solanum tuberosum* L.) is generally grown by vegetative production (Struik and Wiersema, 1999; Horton and Sawyer, 1985). Although farmers must obtain quality seed tubers for good production of tubers, such seed tubers are often too expensive, especially for marginal farmers in developing countries (Roy *et al*., 2005; Almekinders, 1992; Burton, 1989; Sawyer, 1987). In this respect, True Potato Seed (TPS) has good prospects because it can reduce the cost of production and thus farmers can become independent from conventional seed sources (Roy *et al*., 1999; Renia and Hest, 1998; Malagamba, 1988; Wiersema, 1986). However, the success of potato production using TPS largely depends on the productivity of quality TPS (Upadhya *et al*., 2003). Nutrient conditions in the mother plants directly affect the production of quality TPS through the flowering and subsequent reproductive growth, including the formation of the gametophytes (Pallais *et al*., 1987). Among various fertilizers, application of a higher level of Nitrogen (N) than that required for the production of maximum tuber yield increases shoot biomass and enhances the bloom of potato mother plants (Pallais *et al*., 1984; Krauss, 1978). Application of N also affects TPS weight (Pallais, 1987), which is an important criterion for selecting high-yielding progenies (Dayal *et al*., 1984). In addition, combinations of different levels of N and P also affect flowering, berry setting and TPS production (Upadhya *et al*., 1984). Upadhya *et al*. (1984) showed that application of 240 kg N and 140 kg P ha^{-1} increased TPS yield of Atzimba x TPS-13 over the base rate (150 kg N and 80 kg P ha^{-1}). The combination of 240 kg N and 140 kg P ha^{-1} can also improve the quality of TPS by reducing the competition within and between flowering bunches if the first inflorescence stem^{-1}, with only the first 6 flowers, is retained (Upadhya *et al*., 1984).

However, the nutritional requirements of potato mother plants for the production of quality TPS have not been investigated well, especially under conditions in which the most promising parental lines (♀ MF-II and ♂ TPS-67) in Bangladesh were grown for TPS production. In the present study, therefore, an attempt has been made to determine the optimum combination of N and P fertilizers for the production of TPS.

MATERIALS AND METHODS

This study was carried out during 2004-2005 at the experimental field of the Tuber Crops Research Center

Corresponding Author: Takashi Nishizawa, Faculty of Agriculture, Yamagata University, Tsuruoka, 997-8555, Japan
Tel: + 81-235-28-2828 Fax: +81-235-28-2812

(TCRC), Bangladesh Agricultural Research Institute, Joydevpur, Bangladesh. The soil of the experimental plots was clay loam in texture, having pH 6.8 (Jackson, 1962) and containing 1.64% organic matter (Pase *et al.*, 1982), 0.09% N (Jones, 1991), 0.0012% available P (Olsen *et al.*, 1984), 0.13 me% exchangeable K (Black, 1965) and 0.00124% available S content (Pase *et al.*, 1982).

The parental lines for the production of hybrid TPS were MF-II (*Solanum tuberosum* L.) and TPS-67 (*Solanum andigena* L.) as female and male parent, respectively (Thakur and Upadhya, 1996), which were promising parental lines for the production of quality TPS in Bangladesh (Moniruzzaman, 2000).

On 28 October 2004, the experimental plots were fertilized at 260-120-12-6 kg of Muriate of potash (50% K)-Gypsum (18% S)-$ZnSO_4$ (36% Zn)-Borax (10.5% B) and 10 t farm yard manure ha^{-1} (1.2% N, 0.5% P and 1.7% K), which are recommended rates of fertilizers for tuber production (Anonymous, 2004).

Sixteen combinations of 4 different levels of N and P, respectively, i.e., 0 (N_0), 150 (N_{150}), 225 (N_{225}) and 300 (N_{300}) kg N ha^{-1} and 0 (P_0), 60 (P_{60}), 120 (P_{120}) and 180 (P_{180}) kg P ha^{-1}, were applied in a split-plot design with 3 replications. Nitrogen was assigned to the main plots and P to sub-plots (Gomez and Gomez, 1984). Urea (45.6% N) and triple super phosphate (20% P) were used as sources of N and P, respectively. The entire quantity of P and one-third of N fertilizers were applied into furrows and incorporated into the soil 3 days before planting of the seed tubers. The remaining quantity of N fertilizer was applied in rows 10 to 15 cm apart from the female plants and at a depth of 4 to 5 cm in 4 installments at 10 day intervals starting from just before blooming (30 days after planting).

On 1 November 2004, seed tubers of the female parent with uniform size (60-70 g) were planted with a spacing of 1.0×0.4 m in unit plots of 3.0×2.8 m. In contrast to standard procedures for growing potatoes, these plants were not ridged. Female plants were thinned soon after the emergence of 2 stems $hill^{-1}$. Male plants were planted in separate plots at least 7 days earlier than female plants to harmonize their flowering with that of the female plants.

For 70 days from 15 November 2004 to 25 January 2005, the photoperiod was maintained at 14 h to induce profuse amounts of flowering and berry sets (Van der Vossen, 1998; Almekinders and Struik, 1996). Additional light was given by sodium-vapor lamps to provide a light intensity of 0.4-0.6 $\mu E\ m^{-2}\ sec^{-1}$ at the plant surface and plants were irradiated from 7 days after emergence (Almekinders and Struik, 1996). Only 2 uniform stems $plant^{-1}$ were allowed to grow and first and second inflorescences $stem^{-1}$ were also allowed to develop for the pollination (6 buds $inflorescence^{-1}$) because the best quality TPS is produced from primary and secondary inflorescences (Almekinders and Wiersema, 1991).

At 35 to 40 DAP, pollen was collected from male plants and female parents were hand pollinated in the morning (9.00-11.00 am). Berries were harvested 5 to 6 weeks after pollination, when they just started to ripen. Berries from 5 plants in the middle row of each plot were collected in net bags and stored for 7 to 10 days at room temperature to induce after-ripening. Berries were then classified into 3 sizes, i.e., large: >10 g, medium: 10-5 g and small: < 5 g. Well ripened soft berries were crushed mechanically, allowed to ferment for 24 h at room temperature, then washed under running tap water through a 0.5 mm mesh strainer. The collected seeds were treated with 10% HCl for 20 min with continuous stirring and then washed well with tap water. The seeds were then treated with 0.5% sodium hypochlorite solution for 10 min and finally washed 3 to 4 times with distilled water. The seeds were dried at room temperature until the moisture content was reduced to about 7% and then stored in a desiccator for 15 days for further reduction of the moisture content to 4-4.5%. Thereafter, the seeds were weighed. The number of TPS $berry^{-1}$ was counted and 100-TPS weight was recorded.

The analyses of variance were carried out using MSTAT-C statistical software (MSTAT-C, 1991). Means were compared using the Least Significant Differences (LSDs) test at the 5% probability level.

RESULTS

Flowering characteristics: The number of inflorescences $plant^{-1}$ (NIPP) and flowers $inflorescence^{-1}$ (NFPI) were positively influenced ($p\leq0.01$) by increasing the rates of N or P (Table 1). Combined application of N and P also had a significant influence ($p\leq0.05$) on these parameters (Table 1).

A trend of gradual increase in NFPI and NIPP with increasing rates of N and P was also observed (Fig. 1A and B). NIPP ranged between 3.6 (under N_0P_0) and 7.2 (under $N_{300}P_{180}$) among the treatment combinations (Fig. 1A). The maximum number of NFPI was found at $N_{300}P_{180}$ (20.5) followed by $N_{225}P_{180}$ (19.8), $N_{300}P_{120}$ (19.6) and $N_{300}P_{60}$ (18.5) (Fig. 1B).

Production of berries: Different levels of N or P significantly ($p\leq0.01$) affected the number of berries $plant^{-1}$ (Table 1), which was inversely related to N or P rates. In other words, increased application of N or P rate decreased this parameter (Table 1). The combined effect of N and P was also significant ($p\leq0.05$) (Table 1). It

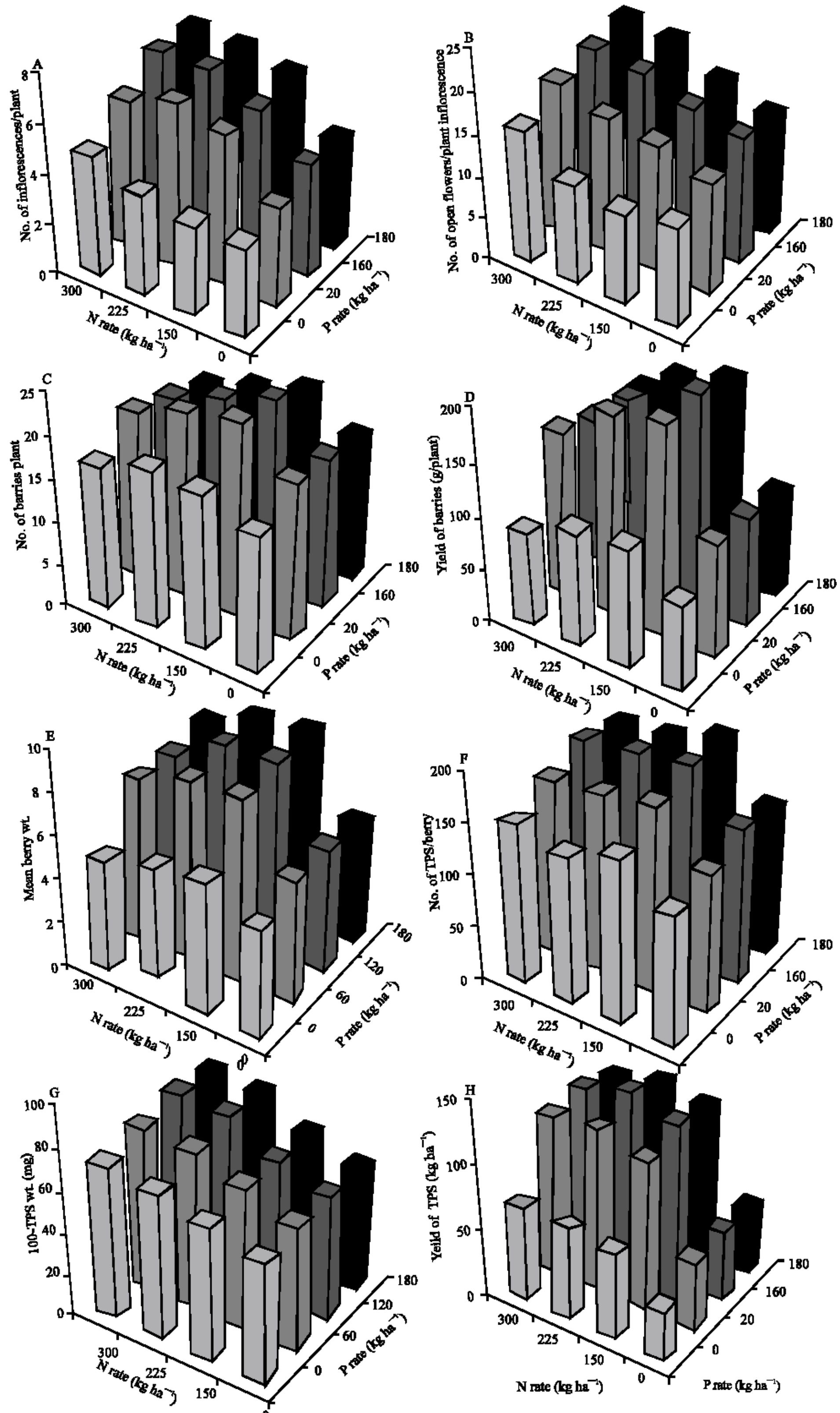

Fig. 1: Combined effects of different rates of N and P fertilizers on NIPP (A), NFPI (B), number of berries plant^{-1} (C), yield berries plant^{-1} (D), mean berry weight (E), number of TPS berry^{-1} (F), 100-TPS weight (G) and yield of TPS (H)

ranged between 15.9 and 22.9 across the treatment combinations (Fig. 1C).

Nitrogen and P affected the berry size (Table 2). The number of medium-sized berries plant^{-1} was always higher than that of small and large ones irrespective of the treatment combination (Table 2).

Different levels of N or P significantly ($p \leq 0.01$) affected the yield of berries plant^{-1} (Table 1). The variation in the yield of berries plant^{-1} among the treatment combinations of N and P was also significant ($p \leq 0.01$) (Table 1). The yield of berries plant^{-1} ranged from 80.0 to 199.2 g (Fig. 1D). The combination of N_{150} P_{120} resulted in the highest yield (199.2 g plant^{-1}), which was also similar to that obtained with N_{150} P_{60}, N_{150} P_{180} and N_{225} P_{120} (194.9, 189.5 and 187.5 g plant^{-1}, respectively) (Fig. 1D).

Mean berry weight also showed significant variation among the treatment combinations of N and P for small- and medium-size berries but not for large one (Table 2). The mean weight of small-, medium-and large-size berries ranged from 3.3 to 4.9, 5.5 to 9.4 and 10.9 to 14.3 g, respectively, among the treatment combinations (Table 2). The highest mean berry weight (9.1 g) was obtained with the combination of N_{150} P_{180}, whereas the lowest (5.0 g) was obtained with N_0 P_0 (Fig. 1E).

Production of TPS: Nitrogen or P application had a significant effect ($p \leq 0.01$) on the number of TPS berry^{-1}, but their interaction was non-significant (Table 1). There was a wide variation in the number of TPS berry^{-1} among different berry sizes (Table 2). The medium-and large-size berries had remarkably higher numbers of TPS berry^{-1} but their interaction was non-significant (Table 1). There was a wide variation in the number of TPS berry-1 among different berry sizes (Table 2). The medium- and large- size berries had remarkably higher numbers of TPS berry-1 than those of small ones. The number of TPS in small-, medium- and large-size berries ranged from 40 to 76, 134 to

Table 1: Effect of nitrogen, phosphorus and nitrogen x phosphorus on sexual and reproductive characters of MF-II x TPS-67

Application (kg ha^{-1})	NIPP	NFPI^x	No. of berries plant^{-1}	Yield of berries (g plant^{-1})	No. of TPS berry^{-1}	Weight of 100-TPS (mg)	Yield of TPS (kg ha^{-1})
N_0	4.2c	13.8b	17.3d	97.6c	73b	59.6d	49.1c
N_{150}	5.6b	14.9b	21.3a	173.7a	175a	67.2c	103.1b
N_{225}	6.2a	16.7a	20.2b	164.8a	176a	77.1b	113.9a
N_{300}	6.3a	17.2a	18.4c	134.3b	176a	81.9a	110.5ab
P_0	4.1c	11.2c	17.5d	97.1c	98c	66.1c	60.1c
P_{60}	5.7b	16.0b	20.8a	161.6a	158b	71.6b	103.2b
P_{120}	6.2a	17.5a	20.0b	159.3a	170a	74.3a	110.2a
P_{180}	6.3a	18.0a	19.0c	152.5b	174a	73.8a	104.4ab
Significance							
N	**	**	**	**	**	**	**
P	**	**	**	**	**	**	**
N x P	*	*	*	**	ns^y	**	**

NIPP = Number of inflorescences plant^{-1}, NFPI = Number of open flowers inflorescence^{-1}, ^{x} values are the mean of the 1st and 2nd inflorescences *,** Significant at $p \leq 0.05$ and 0.01, respectively. Different letter(s) within columns indicate a significant difference by LSD test at $p \leq 0.05$ ^{y} ns: Non-significant

Table 2: Combined effects of different levels of N and P fertilizers on berry and TPS characteristics in MF-II x TPS-67

Treatment combinations	No. of berries plant^{-1}			Mean berry weight (g)			No. of TPS berry^{-1}			Wt. of 100-TPS		
	Small	Medium	Large	Small	Medium	Large	Small	Medium	Large	Small	Medium	Large
N_0P_0	6.2	8.6	1.1	3.3	5.5	10.9	40	134	201	56.1	57.4	58.5
N_0P_{60}	6.1	9.9	2.3	3.7	5.8	11.3	45	141	211	58.0	59.3	60.5
N_0P_{120}	6.4	9.3	2.1	3.8	5.9	11.4	51	151	247	59.8	61.1	62.0
N_0P_{180}	6.9	9.1	1.3	3.8	6.5	11.1	49	173	214	59.4	60.3	61.2
$N_{150}P_0$	7.8	8.5	2.0	3.6	6.9	12.3	47	215	206	61.3	63.6	64.3
$N_{150}P_{60}$	6.2	13.4	3.4	4.0	9.1	14.2	71	218	248	66.3	68.3	69.1
$N_{150}P_{120}$	5.1	13.8	3.5	4.1	9.3	14.3	75	232	269	66.1	68.8	68.9
$N_{150}P_{180}$	4.3	14.9	2.3	4.2	9.4	14.3	76	234	276	66.9	68.8	69.3
$N_{225}P_0$	6.8	8.5	3.3	3.3	5.7	11.2	45	165	209	69.1	70.8	71.5
$N_{225}P_{60}$	3.8	13.6	4.4	4.8	8.3	12.7	52	198	270	73.5	76.2	77.3
$N_{225}P_{120}$	4.3	11.8	4.7	5.0	8.7	13.8	55	214	297	76.2	83.3	83.7
$N_{225}P_{180}$	3.0	11.0	5.5	5.0	8.2	13.0	58	210	284	76.1	83.3	83.4
$N_{300}P_0$	6.4	8.9	1.6	3.8	5.5	10.0	42	210	213	72.4	73.6	73.8
$N_{300}P_{60}$	4.3	11.3	4.4	4.3	7.5	12.3	59	207	235	78.2	78.9	80.2
$N_{300}P_{120}$	4.2	11.9	2.9	4.5	7.6	12.8	70	225	266	83.1	84.0	85.3
$N_{300}P_{180}$	2.9	12.1	2.7	4.6	7.9	13.3	71	222	253	82.8	83.4	84.6
Mean	5.3	11.1	2.9	4.1	7.4	12.4	57	197	244	69.1	71.4	72.1
LSD (0.05)^x	1.12	1.67	0.60	0.40	0.66	ns^y	ns	ns	ns	2.04	2.54	2.59

^{x} LSD ($p \leq 0.05$) for comparing means in columns, ^{y} ns: Non-significant

Table 3: Correlation coefficients of different yield components and yield of TPS with combination of NxP

Yield components	Correlation coefficient
No. of berries plant^{-1}	0.70*
Yield of berry (g plant^{-1})	0.81**
Average berry weight (g)	0.94**
No. of TPS berry^{-1}	0.94**
Weight of 100-TPS (mg)	0.91**

*, **Significant at p≤0.05 and 0.01, respectively

234 and 201 to 297, respectively (Table 2). The highest average number of TPS berry-1 (195) was produced by the application of N150P180 combination (Fig. 1F).

Nitrogen or P showed a significant effect (p≤0.01) on 100-TPS weight (Table 1). The weight progressively increased with an increase in the rate of N, whereas P increased 100-TPS weight up to 120 kg ha^{-1} and caused a similar value thereafter (Table 1). The interaction between N and P was also significant (p≤0.01) in the case of this parameter (Table 1). The highest 100-TPS weight was produced by the combination of N_{300} P_{120} (84.1 mg) and was similar to that produced with N_{300} P_{180} (83.6 mg) (Fig. 1G).

The weight of 100-TPS also showed significant variation among the treatment combinations of N and P, irrespective of berry size (Table 2). The mean weight of small-, medium-and large-size berries ranged from 56.1 to 83.2 mg, 57.4 to 84.0 mg and 58.5 to 85.3 mg, respectively among the treatment combinations (Table 2).

The yield of TPS increased significantly with increasing rates of N or P up to 225 kg N or 120 kg P ha^{-1} (Table 1). In addition, combined application of N and P was also significant (p≤0.01) with respect to this parameter (Table 1). The highest total yield of TPS ha^{-1} was obtained with the application of $N_{225}P_{120}$, followed by N_{300} P_{120} and N_{225} P_{180} (136.1, 126.7 and 126.4 kg, respectively) (Fig. 1H). Treatment with a combination of N_{225} P_{120} was found to be optimal for promoting TPS production.

Analysis of correlation coefficients: The correlation coefficient among yield components and yield of TPS with NxP were analyzed. All components showed significantly positive correlation with the yield of TPS (Table 3). Among these relationships, the correlation for number of berries plant^{-1} was significant at the 5% level, while those for all other factors were significant at the 1% level.

DISCUSSION

Although all the parameters showed a significant single effect of P or N, the highest values of the parameters were obtained at 225-300 kg N and/or 120-180 kg P ha^{-1}, except for the number of berries plant^{-1} (Table 1). Moreover, the highest combination effect was also obtained at 225-300 kg N and 120-180 kg P ha^{-1}, except for the number of berries plant^{-1}, yield of berries plant^{-1} and number of TPS berry^{-1} (Fig. 1A-H). The range of N and/or P for obtaining the highest values which were obtained in our experiments was similar to that reported by Upadhya *et al.* (1984), i.e., the combination of 240 kg N and 140 kg P ha^{-1} resulted in a good TPS production in Atzimbax TPS-13. However, the optimal range which was found in our experiments was higher than that of the recommended amount of fertilizers for vegetative potato production, i.e., the combination of 150 kg N and 50 kg P ha^{-1} is recommended for Diamant, a popular potato variety for vegetative production in Bangladesh (Anonymous, 2004). For commercial TPS production, therefore, how to save fertilizer should be planned well in advance.

Dayal *et al.* (1984) pointed out that 100-TPS weight should be used as a parameter for the selection of high-yielding progenies. Although smaller berries produced fewer TPS in our experiments as Pallais *et al.* (1986) showed previously, the 100-TPS weight was similar among three berry sizes (Table 2). This result indicates that the seed weight is not affected by berry size but by fertilization. Singh *et al.* (1990) indicated that seeds bigger than 75 mg 100-TPS^{-1} showed good quality for raising tuber production from TPS. Thus, more than 225 kg N ha^{-1} should be applied, as shown by the single and/or combination effects of N (Table 1 and Fig. 1G) because the seeds bigger than 75 mg 100-TPS^{-1} were obtained only when more than 225 kg N ha^{-1} was applied, irrespective of berry size (Table 2).

All the parameters which were measured in our experiments also showed a significant single effect of P at the 1% level (Table 1) indicating that P also played an important role in producing TPS (Guerra and Tremols, 1985). However, the quality and quantity of TPS might be affected more directly by N rather than P if a certain amount of P is mixed with N, because the highest 100-TPS weight was found with the combination of N_{300} P_{120} (Fig. 1G), while the highest TPS yield ha^{-1} was obtained with N_{225} P_{120} (Fig. 1H).

The number of berries plant^{-1} is also regarded as an important parameter for obtaining the highest yield of TPS (Upadhya *et al.*, 1984). Although the yield of TPS was significantly correlated with the number of berries plant^{-1} at the 5% level in our study, the yield of berries plant^{-1}, average berry weight, number of TPS berry^{-1} and 100-TPS weight were correlated with the yield at the 1% level (Table 3). This result indicates that the yield of TPS is strongly controlled by factors other than the number of berries plant^{-1}. In commercial TPS production by using MF-II, therefore, attention should be paid to the size and weight of berries and seeds rather than the number of berries plant^{-1}.

In conclusion, the combination of 300 kg N and 120 kg P ha^{-1} should be used to obtain the highest 100-TPS weight, while 225 kg N and 120 kg P ha^{-1} should be used to obtain the highest TPS yield.

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