

**Studies on the production and utilization of
hybrid true potato seed (*Solanum tuberosum* L.)
in Bangladesh**

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Chapter 1

General Introduction

Potato (*Solanum tuberosum* L.) is one of the major food crops of the world and ranks fourth after rice (*Oryza sativa* L.), wheat (*Triticum aestivum* L.), and corn (*Zea mays*) in production (Anonymous, 2007). In Bangladesh, it is mainly used as a vegetable, and alone contributes as much as 71% of the total annual vegetable production (BBS, 2006). It provides not only energy, but also substantial amount of high quality protein and essential vitamins, minerals, and trace elements to the human diet (Horton, 1987).

The national average yield in Bangladesh is 13.8 t ha^{-1} , which is much lower than those of many other potato growing countries like New Zealand (45.1 t ha^{-1}), Netherlands (41.7 t ha^{-1}), USA (43.7 t ha^{-1}), Japan (29.9 t ha^{-1}), and even in India (17.1 t ha^{-1}) (FAOSTAT, 2006). This low yield of potato might be due to lack of quality seeds, high cost of quality seed, unavailability and uneven distribution of certified seeds, and use of indigenous cultivars having low yield potential are noticeable (Accatino and Malagamba, 1983; Wiersema, 1984). Resource poor farmers of Bangladesh can not afford to buy the expensive seed.

The total requirement of seed potatoes in Bangladesh is about 380,000 t considering the seed rate of 1.7 t ha^{-1} . The amount of quality seed potatoes supplied by the public and private sectors is about 4 to 6% of the total requirement (BBS, 2006). The rest 94 to 96% of the required seed is covered by the poor quality farmers' own seed potatoes, the quality of which is not known. Therefore, the high cost and inadequate availability of healthy tuber seed are the major constraints in the production and productivity of potato in the country (Siddique and Rashid, 2000). To overcome this, an alternative technology of true potato seed (TPS) or use of botanical seed for

commercial potato production has shown great promise for producing both disease-free and cheaper seed and thereby, reducing the cost of cultivation and help farmers to be less dependent on conventional seed sources (Umaerus, 1987; Malagamba, 1988; Pallais, 1994). The concept of producing potato crop from TPS is not new. During the 18th, 19th, and 20th centuries, farmers in Europe, Northern America, and Asia also used TPS to replace degenerated material or to produce planting material when tubers were not available (Umaerus, 1987; Malagamba and Monares, 1988; Burton, 1989). Various means of reducing the cost of production of potato and ways of getting quality seed (mostly virus and other diseases-free), the use of TPS has been emerged as a new viable technology for potato production in the developing countries like Egypt, India, Vietnam, Indonesia, the Philippines, Nicaragua, Bangladesh, and Sri Lanka (Accatino and Malagamba, 1983; Song, 1984; Malagamba, 1988; Rashid et al., 1993; Singh, 1999).

Bangladesh imports basic seed tubers mostly from the Netherlands, which is really costly for the small and marginal farmers. The agro-ecological conditions of Bangladesh favor the use of TPS technology as a supplemental to the traditional use of seed tubers in potato production. The use of TPS would be an alternative to capital intensive seed tubers.

1.1 True Potato Seed (TPS)

TPS, which is very small, is obtained from potato berries that look like small green tomato fruits and which grows on the above-portion of the potato plants (*Solanum tuberosum* L.), produced through open or artificial pollination between two known parents (Fig. 1-1H).

Two types of TPS are available: (i) Hybrid seeds and (ii) open pollinated seeds. Hybrid seeds, which result in higher and more uniform plants, are relatively expensive because of hand pollination and more sophisticated breeding techniques are required for seed production (Golmirzaie and Mendoza, 1988; Ortiz and Peloquin, 1990), while open-pollinated seeds, are less expensive to produce but the resulting in lower tuber yields than those of hybrid seeds (Arndt et al., 1990).

1.2 Characteristics of TPS

TPS is the result of sexual reproduction. Each TPS in a family is genetically distinct from another. Individual true seeds measure 1.0 to 1.8 mm and weigh on average 0.5 to 1.0 mg. Size and weight of seed depends on the TPS family and on conditions during seed production. Within a certain true seed lot, the smaller seeds are less vigorous, generally due to a less developed embryo, and are not suitable for sowing. After eliminating the smaller seeds, one gram of good quality TPS contains 1,000 to 1,500 seeds (Struik and Wiersema, 1999).

1.3 Priority areas for TPS dissemination

TPS technology has a wider scope for its adoption in areas where quality seed tuber of a variety can not be produced sufficiently; yields are extremely low due to unavailability of quality seed, seed tuber storage and transportation are expensive, skilled labour is available and consumers do not have any preference for specific tuber characteristics. In Bangladesh perspective, TPS technology is suitable for commercial potato production.

1.4 Potential and advantages of TPS technology

TPS has an edge over tuber seed for various attributes of potato production.

Thus, it can effectively overcome some of the problems associated with seed tubers and can be used easily by the resource poor farmers to produce healthy planting material.

TPS offers many advantages to the farmers to overcome weaknesses of clonally propagated tuber seeds.

- # **Source of healthy planting material:** Except potato virus T (PVT) and potato spindle tuber viroid (PSTVd), no other major pathogen is transmitted through TPS as they are filtered out during pollination and fertilization. (Wiersema, 1985; Rowell et al., 1986; Khurana, 1999; Thakur et al., 2002).
- # **Low cost of cultivation:** Cost of planting material produced through TPS is approximately one-tenth of the cost of quality seed tubers (Thakur et al., 2002).
- # **Low seed rate:** Only 60 to 100 g TPS or 700 to 750 kg seedling tubers (Fig. 1-3F) can be replaced 2.0 to 2.5 t of seed tubers required for planting one-hectare land (Sadik, 1983; Wiersema, 1985; Singh, 1999; Roy et al., 1999).
- # **Easy storage:** TPS with 3 to 4% seed moisture can be stored under ambient conditions in dark with practically no loss in germinability for at least up to 25 years (Howard, 1980).
- # **Environment friendly:** The pathogens unlike in clonally propagated crop are unable to affect the TPS crop due to in-built resistance (multi-line effect) for diseases/pests. Consequently, fewer amounts of pesticides are needed for spraying TPS crop. Thus, TPS is not only cost effective but also environment friendly (Thakur et al., 2002).
- # **Save edible potatoes:** The amount of edible potatoes used for seed could be reduced.

- # **Easy transport:** Transport of TPS from seed production site to the farmer, even in areas of difficult access, is inexpensive and relatively simple.

1.5 Constraints/shortcomings in the adoption of TPS technology

TPS presents following disadvantages, which have been the major bottlenecks in adoption of TPS technology (Rowell et al., 1986).

- # Lack of uniform emergence and low seedling vigor are the major problem, particularly in subtropical environments.
- # TPS produced crop took about 15 to 20 days more for maturity compared to that from seed tubers.
- # TPS crops are labor intensive especially during the initial phases of growth and establishment in transplanted crop.
- # Crop from TPS populations is generally less uniform in plant type/maturity, tuber shape, size, and dry matter.

1.6 Production of hybrid TPS

TPS yields can be expressed as the quantity of seed produced per plant, per stem, or per m². TPS yields are determined by the number of flowers produced, by berry set, number of seeds per berry, and seed weight. Since seed weight (or 100-seed weight) is a significant quality factor, it is also a component of TPS yield. TPS yields vary with genotype (mother parent), environmental conditions, particularly day length and temperature, and nutritional status in the soil (Struik and Weirsema, 1999).

Potato needs cool (15-18.5⁰C) and long day for growth, development, and flowering (Almekinders and Struik, 1996; Struik and Wiersema, 1999). But in Bangladesh, potato is grown in short winter (November - February). The average winter

temperature in Bangladesh ranges from 16.7 to 18.5⁰C (Islam, 1996). Timely planting of tubers is a very important determinant in getting proper growth and flowering of potato plant, which is needed for good quality TPS production.

Song (1984) indicated a photoperiodic effect on the quality of TPS in the People's Republic of China where TPS is used extensively. Besides photoperiod, high temperatures (Haynes et al., 1987) and low relative humidity (Purohit, 1970) have been recognized as having an adverse effect on potato flowering. Spraying of growth regulators (Banik, 2005) to potato plants have been suggested to prevent bud abscission and obtained flowers during unfavorable climatic conditions. But these methods are cost-intensive for the commercial production of hybrid TPS. An economically viable low cost method for inducing flowering in TPS parental lines during short winter days in the Sub-Tropical Indo-Gangetic plains of Bangladesh is to extend the photoperiod for a period of 5 h, by using 400 W sodium vapour lamps per 100 m² of area (Thakur and Upadhy, 1996) (Fig. 1-1A).

Induction of flowering is not the only requirement for successful TPS production. It is also required suitable parental lines and selecting cross combinations with high combining ability. Therefore, parental lines should be selected with high yield potential, resistance to major potato diseases, ability to bloom under short day conditions and set berries containing a higher proportion of large size seed (> 1.18 mm) with attributes for high germination percentage (Thakur and Upadhy, 1996).

At present, most TPS used for potato tuber production is hand pollinated hybrid seed (Almekinders et al., 1996). Hand pollination is the only effective method to produce hybrid seed.

Since hand pollination is labor intensive, it is more effective and economic to use only those flowers that give the best results in terms of number of seeds and seed

quality. Studies have shown that the best production of TPS is obtained from primary and secondary inflorescences since those have the best berry set and produce heavier seed, and consequently produce more and better quality seed per pollination (Almekinders and Wiersema, 1991). The later produced flowers usually have lower berry set, fewer seeds per berry, and lower 100-seed weight (Almekinders and Wiersema, 1991).

The first step in hybrid seed production is harvesting pollen from male plants. In large scale hybrid seed production, pollen may be extracted from pre-dried anthers using a battery operated vibrator and then sieved through nylon netting with 1 mm perforations (Thakur et al., 1994). Pollen may be dried with the help of silica gel and stored under cold (5°C) and dry conditions. Hand pollination is done by opening the flower buds of the female plants and by placing the pollens on the stigmas of the female flowers (Fig. 1-1E). In some cultivars, when self fertilization must be avoided, the anthers of the flowers of the female parent should be removed (emasculation). However, considering the fact that the stigma of flowers of the female parent is receptive before the pollen of the same flower can fertilize the ovules, hand pollination when flowers have just opened may make emasculation unnecessary. In fact, emasculation may also have a negative effect on TPS yield, resulting from damage to the female organs and subsequent fruit abortion.

All other practices and procedures of production, extraction, and drying of TPS are described by Roy et al (2007a). Production costs largely depend on the flowering capacity of the parents and local costs of labor. Production costs of hybrid seed may be as low as 160 to 180 US dollars per kg in countries like India and Bangladesh (Struik and Wiersema, 1999). However, selling prices to farmers are more in the range of 600 to 1000 US dollars per kg (Khatana et al., 1996).

1.7 Utilization of TPS for potato production

TPS can be used in following three ways:

- # TPS is sown directly in the field after which seedling tubers (i.e., tuberlets produced from TPS) are harvested (Fig. 1-2A)(Martin, 1983).
- # TPS seedlings are raised in seed beds and transplanted to the field after which seedling tubers are harvested (Fig. 1-2B)(Wiersema, 1983).
- # Seedling tubers are produced under protected conditions in nursery beds at high plant densities (Fig. 1-2C) (Wiersema, 1986a; Malagamba, 1988).

In the first two methods, the health standard of the seedling tubers will depend on the disease pressure in the area. In area with high degeneration rates the health standard of seedling tubers will be poor due to relatively high risk of virus infection. As a result of the long growing period of seedlings, virus infection in seedlings will be higher than that in crops grown from seed tubers. In the third method, where seedling tubers are produced under protected conditions, the health standard can be high. In a nursery, diseases and disease vectors can be better controlled.

The direct seeding of TPS to grow commercial potato crop in the field has not been practically feasible due to the uneven germination, slow growth of the plants, heavy weed problem etc leading to poor yield (Thakur et al., 2002). However, potato cultivation through transplanting seedlings and by planting first generation seedling tubers has been achieved successfully. Among those, seedling tuber production in nursery beds is probably the most suitable way of using TPS in the developing countries (Almekinders et al., 1996; Roy et al., 1999). The method of producing seedling tubers from TPS is described by Roy et al (1999) (Figs. 1-3A-F). Nursery beds contain a suitable substrate, e.g., 1:1:1(v/v) mixture of soil, sand, and farm yard manure (Roy et al., 1997). Nursery beds provided with intensive water and soil management to ensure

rapid germination and seedling growth. The maximum yields in nursery beds are obtained at plant densities of 100 seedlings per m² (Wiersema, 1984, 1986b; Roy et al., 1999). Yields of seedling tubers (>1 g) reach up to 13 kg, or 700 to 800 seedling tubers per m² in warm short-day conditions (Wiersema, 1984, 1985; El-Bedewy and Crissman, 1991; Benz et al., 1995). The seedling tubers (generation 1) (Fig. 1-3F) derived from TPS in nursery beds are stored in refrigerator for planting the next year as seed tuber for ware or seed potato production. These seed potatoes (generation 2) are also stored in refrigerator and used as planting materials in 3rd year for ware potato production (Fig.1-3H). Only 700 to 750 kg of seedling tubers of an average size of 15 g suffice to plant 1 ha of land against 2 to 2.5 t of seed tubers (Wiersema, 1985). The agronomic management of seedling tubers derived from TPS is similar to that of conventional tubers. Also the yield potential of seedling tubers and later generations of selected TPS progenies competes well with that of clonal cultivars (Wiersema, 1984; CIP, 1987, 1989; Love et al., 1994; Benz et al., 1995). The variation in performance of the tubers derived from selected TPS progenies is not significantly larger than that of tubers from a clonal cultivar (Love et al., 1994).

1.8 Status of the TPS technology in Bangladesh

During early eighties, research on TPS was started in Bangladesh with technical assistance of the International Potato Center (CIP), Peru. Up to early nineties, TPS works were almost research oriented pertaining to standardization of different aspects of TPS production and utilization like agronomic management, selection of parental lines for their performance to produce maximum seeds with bigger embryo size, uniformity in their plant type, tuber shape, size, color etc.

As an alternative to the traditional methods of potato production, TPS technology has been critically verified under different agro-ecological zones of Bangladesh. A large number of hybrid TPS progenies were tested both on-station and on-farm trials. Most of the materials were received from CIP. During early nineties, the promotional activities of TPS technology were started, which involved training of farmers, Non-Governmental Organization (NGO), and Department of Agricultural Extension (DAE) personnel of some selected potato growing areas of the country. TPS was also supplied to the trainees and demonstration trials were set in some potential potato growing areas of the country. The successful technological results of the demonstration trials created much interest to farmers to use TPS for potato production. In the early days of promotion, the non-availability of TPS was the major limitation for the diffusion of the technology. Governmental, NGOs, and private seed companies have realized the potential of this technology and its success, and have been encouraged to take up the commercial production of hybrid seed of TPS progenies which are jointly identified by the Tuber Crops Research Center (TCRC) of Bangladesh and CIP. The TPS production program has been started by TCRC during 1990 indicating its prospect in Bangladesh (Brown, 1987; Rashid, 1987; Upadhya, 1987) During 1996 to 1997, about 25 kg hybrid TPS were produced by TCRC (Roy et al., 1999).

In spite of suggested potential, sustained research, and promotion efforts, TPS has not reached a significant number of farmers in Bangladesh. In other countries (e.g., Tunisia, Pakistan, Philippines, Indonesia, Sri Lanka, Paraguay, Nicaragua) TPS utilization has remained at a low level (Malagamba and Monares, 1988; CIP, 1993, 1994) because the produced TPS is not high-quality enough. Low-quality TPS usually does not germinate uniformly and produces slow-growing seedlings vulnerable to transplanting shock. Thus, plant maturity is extended and production of large tubers is

delayed or small tubers must be harvested due to the usually short growing seasons in sub-tropical areas (Pallais, 1991). High-quality TPS has a high level of germination, and will produce uniform, vigorous fast growing seedlings (Dickson, 1980; Pallais, 1987). Vigorous seedling performance is needed to enhance the attractiveness of TPS technology as it is transferred from research stations to farmers' fields in developing countries. Increased TPS size and weight is associated with high-quality seed (CIP, 1983; Dayal et al., 1984). The production of vigorous seed is generally associated with ideal growing conditions and the availability of fertilizers (George and Varies, 1980; Siddique and Goodwin, 1980; Deloche, 1980; Gray and Thomas, 1982; Gutterman, 1982; Van et al., 1982; Pet and Garretsen, 1983). A number of factors, such as inflorescence position (Almekinders and Wiersema, 1991), stem density (Almekinders, 1991), competition between flower and tuber and nutrient level (Bamberg and Hanneman, 1988; Otazu and Amoros, 1991) also are known to influence production of quality TPS.

Potato production from TPS has emphasized that the success of this technology depends largely on the quality and quantity of TPS produced at relatively low cost. These two factors will ensure that the farmers of the developing countries, who are expected to benefit from this alternative method of potato production, not only get the TPS cheap but also assured high yield potential.

In Bangladesh, TPS technology will not sustain as a successful program unless high quality TPS could be produced locally at a reasonable cost. In the recent years, TCRC of Bangladesh, Bangladesh Agricultural Development Cooperation (BADC), and some private entrepreneurs have started commercial production of hybrid TPS in Bangladesh. (Siddique and Rashid, 2000). The technologies being used is in accordance with the experience of other countries, and has not yet been standardized

considering the agro-ecological conditions of this country. The price of TPS in Bangladesh is still high and not within the reach of majority farmers. The price of TPS can be kept at a reasonable level in two ways: either by increasing the yield of quality TPS per unit area or by applying appropriate crop management practices leading to the reduced cost of production.

1.9 Storage conditions in Bangladesh

In Bangladesh, potatoes are grown in the winter season, from November to February, TPS varieties are evaluated on the basis of set criteria (Anonymous, 2006): storage quality is an important one because farmers need to store their potato tubers from March to September. This is the period in Bangladesh with the highest temperature (32.7°C) and humidity (91.5%) conditions, which are responsible for quick deterioration of potato tubers. Roughly 50% of total potato in Bangladesh preserved in cold storages (Anonymous, 2006). Farmers store the remaining portion of tubers in their homes at ambient storage conditions (Rashid and Hossain, 1985; Hossain et al., 1995). Under such condition, 20 to 80% of the tubers have been damaged (Hasem, 1979).

As the cold storage facility is limited, huge amount of potato are damaged in the farmer's home mainly due to breaking of dormancy and sprout initiation (Anonymous, 2006). TPS cultivars having less evaporation loss and long dormancy are highly desirable for marginal farmers as they store their produce in home. So, the search for TPS cultivars having long dormancy period is prime need.

In view of the above facts, a study has been planned to standardize the fertilizer management practices that would ensure higher yield of quality TPS as well as higher economic return in the commercial production of hybrid TPS in Bangladesh and their utilization in clonal generations.

In order to standardize the technology of hybrid TPS production under Bangladesh conditions, the proposed study has been undertaken with the following objectives:

- i. to find out the optimum combination of N, P, and K fertilizers in order to get high yield of quality hybrid TPS;
- ii. to assess the effect of N and K application to potato mother plants on the quality of harvested TPS;
- iii. to find out the optimum level of supplemental N and stem density on the production of quality TPS, and to evaluate the cost effectiveness of the treatments;
- iv. to assess the field performance under successive clonal generations by using the hybrid TPS;
- v. to study the storage performance of tubers derived from TPS under ambient conditions.

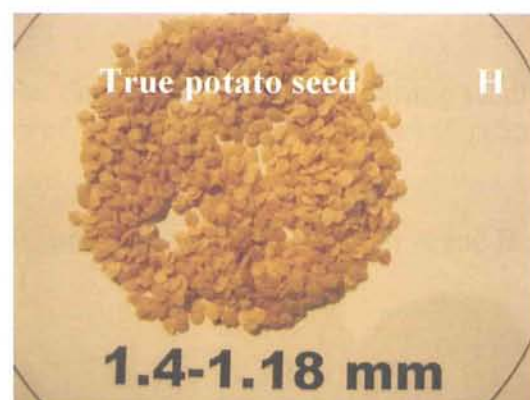
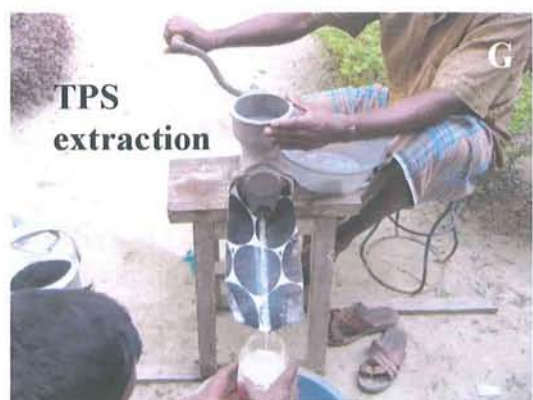
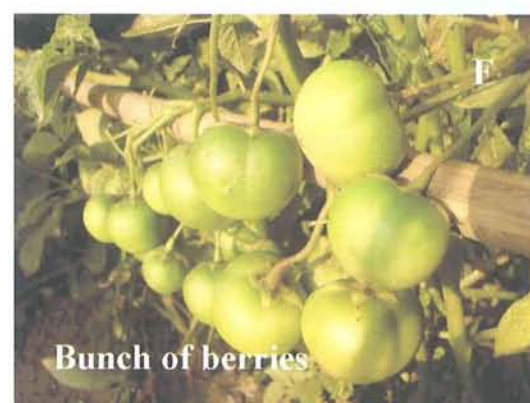
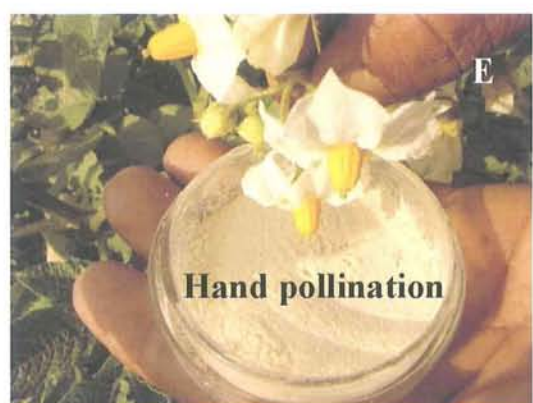
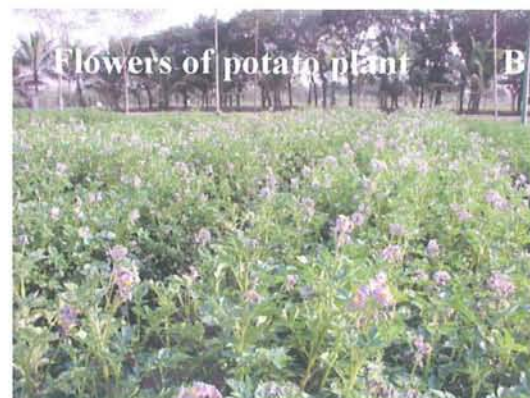
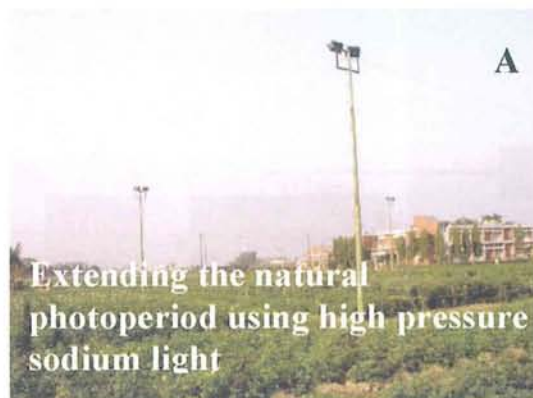


Figure 1-1 A-H. Chain of figures representing production of TPS

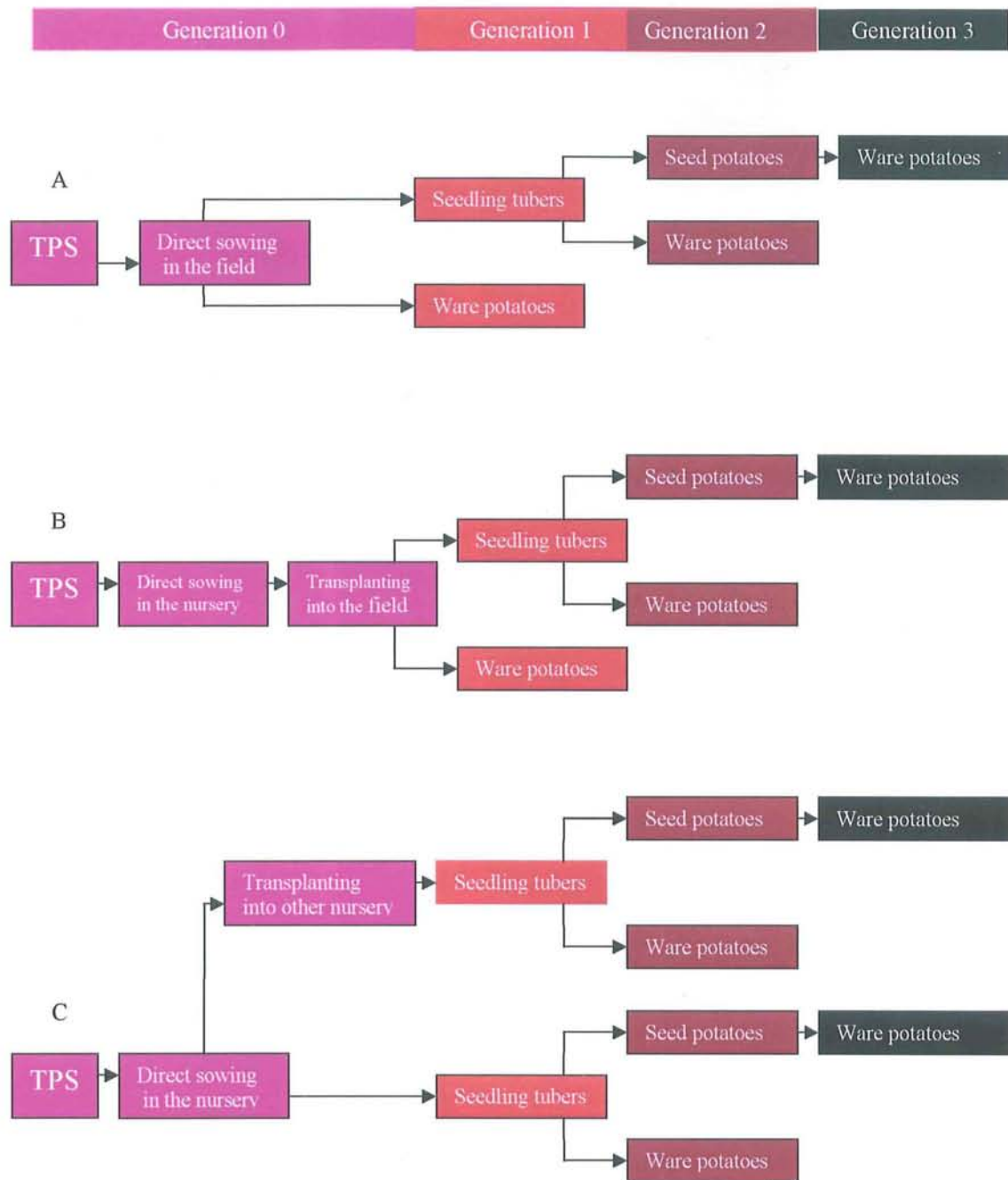


Figure 1-2. Alternative methods of TPS use: direct field sowing (A), raising seedling transplants (B), and production of seedling tubers in nurseries (C) (Sturik and Wiersema, 1999)

(Method C generation 1 is produced in the nursery, whereas in Methods A and B generation 1 is produced in the open field)

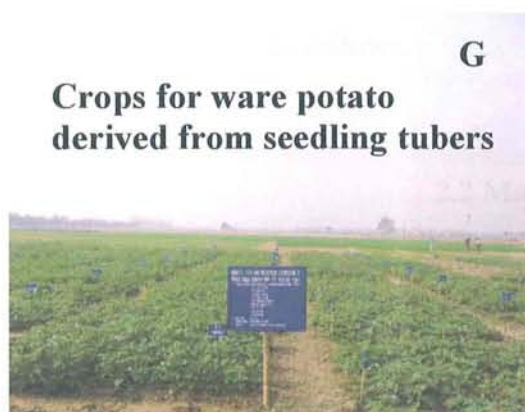
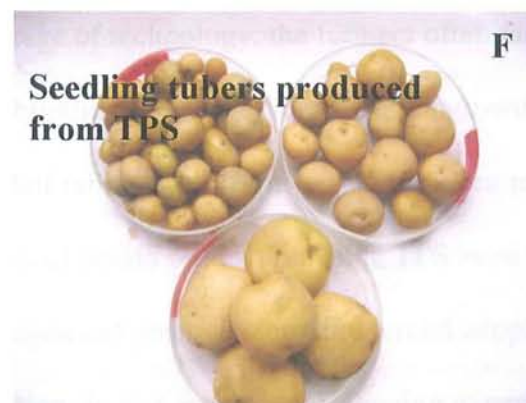
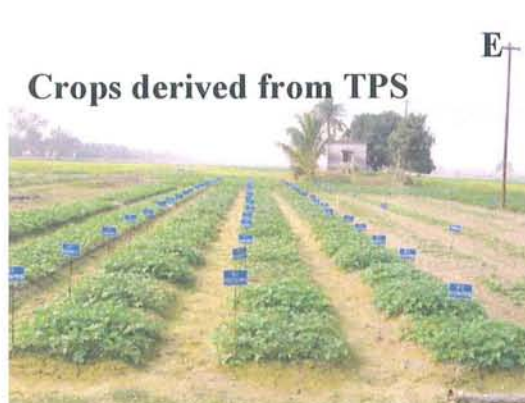
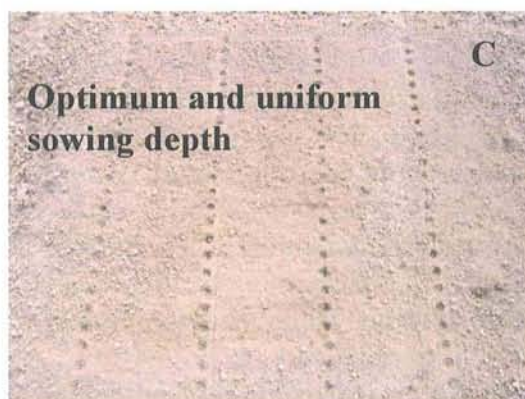
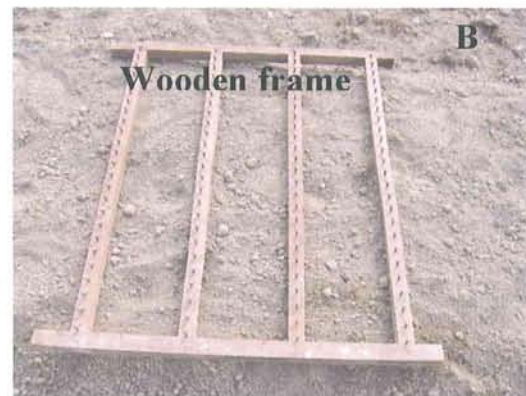


Figure 1-3 A-H. Chain of figures representing utilization of TPS

Chapter 2

Agronomic management and promotional activities of TPS technology during 1993 to 1997

2.1 Introduction

The production of seedling tubers derived from TPS is greatly influenced by several factors, such as emergence uniformity, establishment of seedlings, plant population, earthing-up, fertilizer management, and other crop production practices. Potato production from seedling tuber is also influenced by crop management practices. To make TPS more attractive to the farmers and consumers, it is essential to increase the yield and reduce the production cost along with promotional activities of TPS technology. Seedling tubers are normally produced in raised nursery beds under high planting density, and a considerable success has been achieved in research stations under the agro-ecological conditions of Bangladesh (Sikka, 1987). But due to lack of a recommended suitable and standard package of technology, the farmers often face problems like, inadequate emergence, suboptimal or excessive vegetative growth of plants, and low yield of tubers. The yield of tubers in the farmers field is often much lower than expectation. So, the techniques of potato production using TPS need to be improved in the areas of agronomic management practices for commercial adoption of TPS technology under Bangladesh condition. In this aspect, the following experiments were undertaken as follows.

2.2 Materials and Methods

Experiment 2.2.1 A comparative study of 31 hybrid true potato seed progenies

The experiment was carried out during 1994 to 1995 and 1995 to 1996 at the TCRC, Bangladesh Agricultural Research Institute (BARI), Gazipur. Thirty one hybrid

TPS progenies (shown in Table 2.2.1-1) were evaluated for their performance in seedling tuber and second generation, respectively. Raised nursery beds (20 cm high from the land level) of 1 m² size were prepared with the help of spade. Soils of the nursery beds were specially prepared by mixing soil, sand, and well decomposed sun dried cowdung in the ratio of 1 : 1 : 1 (v/v). The cowdung was hammered to powder and then sieved through a 20 mm diameter strainer. The soil was also prepared very nicely so that no clods remained. These nursery bed substrates were spread very nicely making a fine nursery bed (Fig. 1-3A). The nursery beds were fertilized at the rate of 325-220-280-120-14-6 kg ha⁻¹ of urea, triple super phosphate (TSP), muriate of potash (MP), gypsum, zinc sulphate, borax (Anonymous, 1993). During final preparation of beds 50% urea, 50% MP, and full dosage of other fertilizers were mixed very well with the beds soils. The experiment was laid out in a randomized complete block (RCB) design with 3 replications. The unit plot size was 1 x 1 m. Before sowing TPS, a 1 m² wooden frame with 1 cm nails fitted at 25 cm row space and 4 cm between nails in row (Fig. 1-3B) was used to make 100 holes with optimum sowing depth in 1 m² beds. Three seeds were sown in each hole on 20 November 1994. After emergence, the seedlings were thinned out to 1 seedling per hole. As such, 100 seedlings were accommodated in each 1 m² nursery bed. The nursery beds were watered as and when necessary. With the development of plants, the nursery beds kept weed less by hand pulling very carefully. Earthing-up of the crops was done at 25, 35, and 45 days after sowing (DAS) of TPS with extra amended nursery bed soil substrates. The rest amount of urea and MP were applied to crops in 3 installments after 30, 40, and 55 DAS. The crops were raised following the methods described by Elias et al (1992a). Statistical analysis of recorded data was carried out by MSTAT 5 (Arbin Instruments, TX, USA)

computer package. Means were compared using the least significant differences (LSDs) test at a 5% probability level.

Experiment 2.2.2 Influence of plant spacing on seedling tuber production from true potato seed and its economic return

The experiment was conducted at the TCRC, BARI, Gazipur in 2 consecutive seasons of 1994 to 1995 and 1995 to 1996. TPS of 4 promising hybrid TPS progenies, TS-7 X TPS-67, MF-II X TPS-67, MF-II X TPS-13, and P-364 X TPS-67 were sown at 4 different spacings, such as 10 x 10, 14 x 7, 20 x 5, and 25 x 4 cm. Two-factor (progeny x spacing) RCB design with 3 replications was followed. Raised nursery beds of 20 cm height from land level were prepared following the method described in experiment 2.2.1. Three seeds were sown at the above mentioned spacings. After sowing the seeds, care for the beds for raising seedlings and all other practices for the production of seedling tubers were similar to those described by Elias et al (1992a). The crops were harvested at 100 DAS. From nursery bed preparation to seedling tuber harvesting, labor cost was calculated. Data on different growths and yield contributing characters were recorded and analyzed by MSTAT 5 computer package. Means were compared using the LSD test at a 5% probability level.

Experiment 2.2.3 Performance of ten promising true potato seed progenies over generations

The ten TPS progenies included in this study were MF-II X TPS-67, TS-7 X TPS-67, MF-II X TPS-13, MF-1 X TPS-67, MF-I X TPS-13, P-364 X TPS-67, P-364 X TS-9, TS-7 X TPS-13, TS-9 X TPS-67, and TS-6 X TS-9 were evaluated at the TCRC, BARI, Gazipur, Bangladesh during 1994 to 1995, 1995 to 1996, and 1996 to 1997. True seeds of these progenies were used to produce seedling tubers in nursery

beds following the procedure described in experiment 2.2.1. The seeds were sown on 7 November 1994. The seedling tubers produced from TPS in beds are termed as first generation seeds. For the second and third generations, the seedling tubers and seed tubers were planted at 60 x 25 cm spacing on 14 November 1995 and 12 November 1996, respectively. The experiments were conducted in a RCB design with 4 replicates. All practices and procedures of production of potato were similar to those described by Elias et al (1992a). The seedling tubers were harvested at 106 DAS, while the second and third generation crops were harvested at 94 to 96 DAS. Data on different growth parameters, disease incidence, and yield attributes were analyzed statistically using MSTAT-C software and means were compared using the LSD test at a 5% probability level.

Experiment 2.2.4 Performance of two promising hybrid TPS progenies in the farmer's field trials

Two promising hybrid TPS progenies, MF-II X TPS-67 and TS-7 X TPS-67, were evaluated at farmer's field of some potential potato growing areas of Bangladesh during 1993 to 1997. Performance of these progenies was evaluated in 2 ways. In the first year, the TPS were sown in 1 x 5 m raised nursery beds for seedling tubers production. In the following year, the seedling tubers were planted in the field for tuber production. In each year, innovative farmers were selected by the Department of Agricultural Extension (DAE) and one-day training on potato production with TPS was conducted in each location. Each participant was supplied with a handout (production technology of potato using TPS) and 5 g TPS of each of MF-II X TPS-67 and TS-7 X TPS-67 for sowing an area of 40 m². Farmers were provided with a data recording sheet. The data were compiled and analyzed following a MSTAT 5 program.

2.3 Results and Discussion

2.3.1 Experiment 2.2.1: The growth parameters of the TPS progenies in nursery beds are presented in Table 2.2.1-1. Sixty percent seed emergence occurred significantly earlier (10 days) in 6 progenies like MF-II X TPS-67, MF-II X TPS-13, MF-II X TS-19, TS-7 X TS-III, P-364 X TS-III, and TS-5 X TS-9, while TS-14 X TS-9 was found to be late (19 days) (Table 2.2.1-1). Though the dormancy of TPS was released before sowing, this variation might be due to a number of reasons, such as soil moisture, soil temperature, genetic constitution etc which was reported by Thakur and Upadhyya (1995). All progenies had more than 80% final emergence except P-364 X TPS-13, TS-6 X TS-9, P-501 X TS-9, P-501 X 'Lalmadda', and 'Lalmadda' X P-501. Only 5 progenies, such as MF-II X TPS-67, MF-II X TPS-13, P-364 X TS-9, TS-9 X TPS-67, and TS-9 X P-364 had more than 95% emergence (Table 2.2.1-1). The percentage of foliage coverage (FC%) at 50 DAS was significantly higher for MF-I X TS 13 (84%) which was similar to 8 progenies MF-II X TPS-13, P-364 X TPS-67, P-364 X TS-9, MF-II X TS-19, P-364 X TS-III, TS-9 X TPS-67, TS-12 X TS-9, and TS-9 X TS-8. Foliage coverage, which was estimated by visual observation, mainly depends on the number of leaves plant⁻¹ and leaf size. As the hybrid materials were highly heterozygous, they showed wide variation in some parameters. However, 80% FC at 50 DAS was really a very good score likely due to closer spacing. The reported results are in agreement with the results described earlier (Sarker and Kabir, 1989; Elias et al., 1992a).

Close planting caused mutual shading of plants which resulted in taller plants. Only 3 progenies, such as MF-II X TPS-67, P-364 X TS-9, and P-364 X P-457 attained a height of more than 100 cm and they were statistically identical (Table 2.2.1-1). Most

of the progenies ranged between 80 and 90 cm, although a few were below 80 cm. The variation of plant height may be due to the length of internodes.

The progenies showed wide variations in the yield attributes. The progeny P-364 X TPS-67 produced significantly higher number of seedling tubers m^{-2} which was similar to MF-II X TPS-67 (1050 and 1042, respectively), while 12 progenies produced 800 to 1000 and only MF-II X P-348 produced less than 500 seedling tubers m^{-2} (Table 2.2.1-1). Elias et al (1992a) reported almost similar results. The progenies, which produced the highest number of seedling tubers plant^{-1} also had the maximum seedling tubers weight m^{-2} (data not shown). In nursery beds, the yield of seedling tubers was usually high, due to close spacing. However, among the TPS progenies, the yield of seedling tubers was exceptionally high in P-364 X TPS-67 (73.4 t ha^{-1}), which was similar to those produced with TS-7 X TPS-67, MF-II X TPS-67, and P-364 X TS-9 (68.6 , 69.3 , and 68.8 t ha^{-1} , respectively). The lowest yield was 33.1 t ha^{-1} for the progeny 'Lalmadda' X P-301 (Table 2.2.1-1). Chaudhury and Rasul (1995) evaluated 6 promising hybrid TPS progenies and obtained 60 to 70 t ha^{-1} seedling tubers.

During 1995 to 1996, the seedling tubers were planted in the field to observe their performance at the second generation. Most of the progenies attained height of 60 to 70 cm although a few were below this range (Table 2.2.1-2). The progenies TS-7 X TPS-67, MF-II X TPS-67, P-364 X TPS-67, and P-364 X TS-9 had above 5 stems hill^{-1} , while the other progenies had 3 to 4 stems hill^{-1} (data not shown). All progenies, except P-501 X TS-9, P-501 X 'Lalmadda' and 'Lalmadda' X P-501 showed a tuber uniformity of 6, which indicates that tuber uniformity was satisfactory for the progenies. In the open field, the potato plants were exposed to natural virus infection, which ranged from 0 to 13.8%. All progenies, except P-364 X TS-9 and P-364 X TS-III were infected by viruses. The infection may be of primary and secondary but there is

indication of some degree of resistant of the progenies against virus diseases. The progenies had a yield range of 14.1 to 34.6 t ha⁻¹ though most of them had more than 20 t ha⁻¹. Four progenies, TS-7 X TPS-67, MF-II X TPS-67, P-364 X TPS-67, and TS-9 X TPS-67 had tuber yield of more than 30 t ha⁻¹, which were statistically similar (Table 2.2.1-2). Almost similar yield was obtained by Chaudhury and Rasul (1995). The tubers were graded in 3 sizes. On the average, about 12.14, 66.54, and 21.32% tubers were of < 28, 28-45, and > 45 mm sizes, respectively. All progenies produced 7.7 to 17.3% tubers of < 28 mm, 61.6 to 69.0% of 28-45 mm, and 15.7 to 24.3% of > 45 mm sizes, respectively (Table 2.2.1-2). A similar trend of tuber grades for TPS progenies were reported by Sarker et al (1987); Kadian et al (1992); Batra et al (1992).

From the results presented above, it appears that among the 31 progenies, the performance of 3, namely TS-7 X TPS-67, MF-II X TPS-67, and P-364 X TPS-67 were satisfactory.

2.3.2 Experiment 2.2.2: As the results of the 2 years did not vary significantly, the average values are presented in Tables (2.2.2-1, 2.2.2-2, and 2.2.2-3). All the 4 progenies differed significantly ($p=0.05$) from all parameters but not on grade of seedling tubers (Table 2.2.2-1). The plant height was as high as 98.3 cm and produced the maximum number of seedling tubers m⁻² by P-364 X TPS-67 while minimum by MF-II X TPS-13 (1114 and 940, respectively) (Table 2.2.2-1). The maximum yield was also recorded in P-364 X TPS-67, whereas the minimum was in MF-II X TPS-13 (73.8 and 62.2 t ha⁻¹, respectively). On the average, the percentage of seedling tubers in number in different grades showed that TPS progenies produced more than 50% seedling tubers below 10 mm grade and only 1 to 2% above 35 mm (Table 2.2.2-1).

In all the 4 different spacings, about 100 plants were accommodated in 1 m² area. The plant height was significantly the highest (102 cm) for the widest row spacing (25 x 4 cm) while decreased with decreasing row spacing (Table 2.2.2-2). The widest row spacing produced the maximum number of seedling tubers m⁻² (1150), which decreased with decreasing row spacing. The maximum seedling tubers yield was 71.9 t ha⁻¹ for 25 x 4 cm spacing and the minimum was 63.5 t for 10 x 10 cm spacing (Table 2.2.2-2). The grades of seedling tubers in percentage by number were found to be more than 50% in < 10 mm size which decreased onward (Table 2.2.2-2).

Economic study showed that the labor cost for seedling tuber production at different spacings was varied (Table 2.2.2-3). It appeared that labor cost reduced with increasing row spacing. The 25 x 4 cm spacing incurred minimum labor cost (US \$ 3167.3 ha⁻¹) as compared to the other spacings. Keeping 25 x 4 cm spacing as standard, 10 x 10, 14 x 7, and 20 x 5 cm had 13.3, 10.3, and 3.6% higher cost, respectively (Table 2.2.2-3).

All the 4 progenies in this study are known to be promising as reported earlier (Chaudhury and Rasul, 1995). They performed almost equally for most of the parameters. In terms of yield contributing characters, P-364 X TPS-67 gave significantly the highest tuber yield. In general, the TPS is sown in beds in close spacing for seedling tubers production and thus most of the TPS progenies produced about 50% seedling tubers in < 10 mm sizes (Sarker and Kabir, 1989), which are in agreement with the findings of the present investigation. TPS progenies produced negligible amount of seedling tubers in > 35 mm grade.

One hundred plants were accommodated in 1 m² bed. The spacing 25 x 4 cm had the tallest plant probably closer plant to plant distance caused early shading which resulted in increasing tallness and lanky, and vice-versa for wider distance. Closer row

spacing produced minimum number of seedling tubers m^{-2} , which increased with increasing spacing. Sarker and Kabir (1989) and Chaudhury and Rasul (1995) reported similar results. Among the 4 different spacings, 25 x 4 cm gave maximum seedling tubers yield in terms of number and weight per hectare. Wider row spacing enhanced plant growth with more photosynthetic areas than closer spacing resulted in increasing the yield contributing characters.

It was observed that closer row spacing required more labor hours for all crop production operations. Labor input among the different spacings varied significantly. Higher the row spacing, lower the labor cost involved for seedling tubers production in beds. Wider row spacing facilitated intercultural operations. The closer row spacing make intercultural operations cumbersome, which was ultimately reflected economics of production.

In view of above discussion, it is appeared that a plant spacing of 25 x 4 cm was found to be most economic for the production of seedling tubers in beds with TPS.

2.3.3 Experiment 2.2.3: Plant height differed significantly among the progenies. The first generation (F_1C_0) crops were raised in nursery beds, the true seeds were sown at 25 x 4 cm spacing, which seemed to encourage elongation of the stems. In the beds, the plant attained an average height of 96.7 cm as compared to 67.9 cm in the second generation (F_1C_1) and 61.6 cm in the third generation (F_1C_2) (Table 2.2.3-1). The F_1C_1 and F_1C_2 crops were grown with normal tubers and they were statistically identical in respect of plant height. Hossain et al (1992) found that closer spacing made the plants lanky and taller than those grown with wider spacings. The progenies attained the normal height of 66.3 to 69.5 cm in the F_1C_1 and F_1C_2 as reported earlier (Anonymous, 1992), but the height decreased slightly from the F_1C_1 to F_1C_2 . Hossain et al (1992)

reported a similar trend of height reduction with other TPS progenies. Most of the progenies in the F_1C_1 and F_1C_2 matured within 94 to 98 days after planting, while the first generation crop in beds required 10 to 11 more days to mature. The longer life cycle of the F_1C_0 crop raised in nursery beds is probably due to higher dosage of N and better care that encouraged the plants to continue vegetative growth for a longer period. In the nursery beds, plants were grown from true seeds which are supposed to be free from the major virus diseases (Chaudhury and Rasul, 1995), but some latent viruses may be there (Acatino and Malagamba, 1982). Though the latent viruses are transmitted through the true seeds, they seldom show symptoms in the growing crops. In the F_1C_0 crops, virus symptoms were not observed, but in the F_1C_1 and F_1C_2 , 2.2 and 10.0% of the plants were found to be virus infected, respectively (Table 2.2.3-1). The virus infection was found to increase rapidly with advancing generation, as was also found earlier (Hossain et al., 1992). The reaction of the progenies to the virus diseases varied significantly with a mean value of 4.1% infection. Most of the progenies had a mean infection of 4% except P-364 X TS-9 and TS-9 X TPS-67 (2.4 and 3.2%, respectively) (Table 2.2.3-1). Leaf spot complex caused by fungi, reduced the yield of potato. These diseases are not always transmitted through the seed tubers or the TPS. Their incidence depends on the prevalence of the organisms in the environment, but was found to increase over generations, although these disease incidences do not seem to have any correlation with generation. Most of the progeny, except P-364 X TS-9 in the F_1C_0 were infected by the leaf spot complex organisms (average 1.1%) and it increased to 2.2% in the F_1C_1 and 9.6% in the F_1C_2 (Table 2.2.3-1). The reaction of the progenies to the leaf spot complex was also significant. The highest mean infection was in TS-6 X TS-9 while the lowest in P-364 X TS-9 (5.8 and 3.4%, respectively) (Table 2.2.3-1).

The number of tubers m^{-2} was higher in the F_1C_0 due to close planting at the spacing of 25 x 4 cm accommodating 100 plants m^{-2} . There were significant differences among the progenies in this parameter. The F_1C_1 and F_1C_2 that were raised from tuber seeds represent the usual potato crops. In both these generations, significant difference were observed among the progenies in respect of number of tubers m^{-2} , but within each progeny, there was no difference between the 2 generations (Table 2.2.3-2). The F_1C_0 is not comparable to the other generations due to the difference in the method of production.

The number of tubers plant^{-1} was more or less the same for the 3 generations, although there were significant differences among the progenies in each generation. It may be noted that in the F_1C_0 , where the crop was raised from TPS, the plants produced the same number of tubers as those raised from seed tubers in the subsequent generations. The average number of tubers plant^{-1} in the F_1C_1 and F_1C_2 was identical (Table 2.2.3-2). As expected, the highest average yield of tubers (65.9 t ha^{-1}) was obtained from the F_1C_0 . The yield of the progenies ranged from 70.4 to 61.6 t ha^{-1} and there were significant differences among the progenies (Table 2.2.3-2). The average yield came down to 29.5 t ha^{-1} in the F_1C_1 . Here again, there were significant differences among the progenies in respect of yield. The mean yield reduction from the F_1C_0 to F_1C_1 was 36.4 t ha^{-1} . In the F_1C_2 , the yields ranged from 29.8 to 21.8 t ha^{-1} and the average was 26.4 t ha^{-1} . The mean yield reduction from the F_1C_1 to F_1C_2 was 3.1 t ha^{-1} . The highest yield of 29.8 t ha^{-1} in the F_1C_2 was obtained from TS-7 X TPS-67 which was similar to MF-II X TPS-67, P-364 X TPS-67, and TS-9 X TPS-67 (29.4, 29.3, and 29.3 t ha^{-1} , respectively) (Table 2.2.3-2). The other progenies gave significantly lower yields.

Progenies included in this study exhibited variations in yield reduction. While yield reduction is basically the results of degeneration, part of it may be due to differences in the environmental and crop management conditions which vary from year to year. However, the rate of reduction is an important criterion of selecting TPS progenies for commercial cultivation. The results of this study are thus useful in the development of the TPS technology for Bangladesh.

2.3.4 Experiment 2.2.4: During 1993 to 1994, TPS of MF-II X TPS-67 and TS-7 X TPS-67 were supplied to 281 farmers of 3 locations (shown in Table 2.2.4-1). The 2 hybrid TPS progenies, MF-II X TPS-67 and TS-7 X TPS-67 did not differ in their seedling tubers yield (Table 2.2.4-1). Mean yield ranged from 3.8 to 6.6 kg m⁻² which was equivalent to 41 t ha⁻¹ (Table 2.2.4-1). However, performance of the progenies in respect of seedling tuber production was significantly different at different locations. Performance at Comilla was the best closely followed by that of Munshiganj and Narayanganj. Both the progenies produced the highest yield at Comilla (42 and 43 t ha⁻¹ for MF-II X TPS-67 and TS-7 X TPS 67, respectively) (Table 2.2.4-1). In the following year (1994-1995), the seedling tubers were planted in the field at wide spacing (60 x 25 cm), for potato production. The progenies did not differ in their tuber yield which ranged from 27 to 31 t ha⁻¹. However, yield of tubers of the 2 progenies differed significantly at different locations (Table 2.2.4-1). Munshiganj had the highest yield (31 t ha⁻¹) closely followed by Comilla and Narayanganj. The progeny TS-7 X TPS-67 at Munshiganj gave the highest yield (31 t ha⁻¹) while MF-II X TPS-67 at Munshiganj and TS-7 X TPS-67 at Comilla performed equally well. Chaudhury and Rasul (1995) obtained 60.1 and 59.7 t ha⁻¹ seedling tubers for MF-II X TPS-67 and TS-7 X TPS-67, respectively and the subsequent planting of these seedling tubers in the

following year gave 29.6 and 29.8 t ha⁻¹, respectively in farmers field trials in 4 different locations. Siddique (1995) using MF-II X TPS-67 in farmer's field trials conducted through different NGOs and private seed companies and obtained the highest 61.0 t ha⁻¹ seedling tubers.

During 1994 to 1995, true seeds of MF-II X TPS-67 and TS-7 X TPS-67 were supplied to 189 farmers of 4 locations (shown in Table 2.2.4-2). On an average, TS-7 X TPS-67 gave significantly higher yield than MF-II X TPS-67 (46 and 43 t ha⁻¹, respectively). Performance of the progenies in 4 locations varied significantly. The highest yield was obtained in Debiganj and the lowest in Bogra (57 and 32 t ha⁻¹, respectively). Low seedling tubers yield in some locations was caused due to rain, immediately after sowing of TPS. The seeds were virtually washed out. Both progenies gave the highest yield of 46 and 59 t ha⁻¹, respectively, at Debiganj. But these performed poorly at Bogra, producing only 32 and 34 t ha⁻¹, respectively (Table 2.2.4-2).

Seedling tubers produced during 1994 to 1995 were planted at 60 x 25 cm spacing in the field, for tuber production during 1995 to 1996. The progeny MF-II X TPS-67 gave higher mean tuber yield than TS-7 X TPS-67 (30.5 and 29.5 t ha⁻¹, respectively) (Table 2.2.4-2). The yield at Munshiganj was the highest while Debiganj had the lowest yield (32 and 27 t ha⁻¹, respectively). It may be mentioned that performance of the progenies at Debiganj was the best for seedling tuber production. It might be due to difference in soil nutrient status and temperature.

During 1995 to 1996, TPS of MF-II X TPS-67 and TS-7 X TPS-67 were supplied to the 281 farmers of Munshiganj, Jessore, and Bogra, respectively. The yield of Munshiganj was the highest and that of Jessore was the lowest (43 and 33 t ha⁻¹, respectively) (Table 2.2.4-3). Both MF-II X TPS-67 and TS-7 X TPS-67 gave

maximum seedling tuber yield at Munshiganj (43 and 42 t ha⁻¹, respectively) while both progenies had poor performance at Jessore (33 and 35 t ha⁻¹, respectively). The seedling tubers produced during 1995 to 1996 were planted at 60 x 25 cm for tuber production during 1996 to 1997. The progenies MF-II X TPS-67 and TS-7 X TPS-67 had similar yield while their yield differed insignificant in different locations. The progenies MF-II X TPS-67 and TS-7 X TPS-67 gave maximum tuber yield in Munshiganj (34 and 35 t ha⁻¹, respectively) and their performance at Jessore were poor (29 and 30 t ha⁻¹, respectively) (Table 2.2.4-3). Siddique (1995) conducted farmers field trials with MF-II X TPS-67 and TS-7 X TPS-67 in 5 locations and obtained the highest 76 t ha⁻¹ seedling tuber for MF-II X TPS-67 at Munshiganj and 30 t ha⁻¹ tuber for MF-II X TPS-67 at Rangpur. Elias et al (1992a) studied seedling tuber production potential of 14 TPS progenies and obtained the maximum 51.1 t ha⁻¹. Elias et al (1992b) studied the yield potential of seedling tuber of 8 TPS progenies and obtained a yield range of 15.2 to 26.2 t ha⁻¹.

Since 1993 to 1996, 2589 farmer's field trials were conducted and farmers obtained very high seedling tuber yield and satisfactory tuber yield. So, farmers are very much interested in this TPS technology.

Table 2.2.1-1. Growth parameters and yield attributes of different TPS progenies in their seedling tuber generation

Progeny	Days to 60% seed emergence	Total emergence (%)	Foliage coverage at 50 DAS	Plant height (cm)	No. of seedling tubers m ⁻²	Yield of seedling tubers (t ha ⁻¹)
TS-7 X TPS-67	12	94	78	96	994	68.6
MF-II X TPS-67	10	96	78	101	1042	69.3
MF-II X TPS-13	10	97	79	93	895	63.1
MF-I X TPS-67	13	88	78	92	884	62.6
MF-I X TPS-13	13	84	84	90	863	61.1
P-364 X TPS-67	13	94	81	96	1050	73.4
P-364 X TS-9	12	97	83	101	899	68.8
TS-7 X TPS-13	16	86	76	85	824	60.4
MF-II X TS-5	13	87	72	81	819	61.8
MF-II X TS-III	15	89	77	90	663	52.1
MF-II X P-457	14	87	72	65	678	52.1
MF-II X P-221	11	85	75	82	623	47.8
MF-II X P-501	15	88	64	81	831	61.1
MF-II X P-348	12	91	66	88	451	34.8
MF-II X TS-19	10	97	79	78	538	51.4
TS-7 X TS-III	10	86	67	81	634	51.4
P-364 X TS-III	10	86	80	85	668	45.8
P-457 X TS-5	13	84	72	98	678	44.8
P-364 X TPS-13	11	78	75	75	507	36.1
P-364 X P-457	13	82	71	102	647	51.1
TS-9 X TPS-67	13	96	83	95	845	66.7
TS-5 X TS-9	10	82	76	95	703	53.1
TS-12 X TS-9	11	87	80	94	723	54.1
TS-6 X TS-9	13	61	79	90	844	63.1
TS-14 X TS-9	19	91	66	83	527	35.8
TS-9 X P-364	12	96	70	93	591	43.1
TS-9 X TS-8	13	87	81	93	654	50.4
TS-8 X TS-9	13	85	78	89	738	53.8
P-501 X TS-9	15	78	65	70	863	60.9
P-501 X Lalmadda	15	79	63	68	965	53.4
Lalmadda X P-501	14	75	50	67	462	33.1
LSD (0.05) ^z	1.38	4.63	5.42	2.06	7.41	3.55

^z LSD (p=0.05) for comparing means in columns

Table 2.2.1-2. Performance of different TPS progenies in their first ware potato production generation

Progeny	Plant height (cm)	Tuber uniformity (1-10 scale)	Virus infection (%)	Tuber yield (t ha ⁻¹)	Tuber grades (% by weight)		
					< 28 mm	28-45 mm	> 45 mm
TS-6 X TPS-67	68.0	6.8	2.4	33.5	7.7	68.0	24.3
MF-II X TPS-67	68.0	6.8	2.4	34.6	7.7	68.3	23.6
MF-II X TPS-13	68.3	6.6	2.9	29.3	9.6	68.3	22.0
MF-I X TPS-67	67.2	6.3	2.7	28.1	10.3	67.7	22.0
MF-I X TPS-13	66.3	6.5	2.4	26.5	8.7	68.7	22.7
P-364 X TPS-67	68.0	6.8	2.5	33.5	9.7	68.3	22.0
P-364 X TS-9	69.0	6.9	0	28.4	14.3	64.6	21.0
TS-7 X TPS-13	65.3	6.1	2.7	26.2	13.6	61.6	24.0
M F-II X TS-5	65.2	6.3	2.3	24.4	10.3	69.7	20.0
MF-II X TS-III	63.3	6.4	1.9	23.4	11.3	64.3	23.7
MF-II X P-457	63.0	6.4	11.7	23.4	11.7	64.3	24.0
MF-II X P-221	60.0	6.6	0.6	25.4	12.0	66.0	22.0
MF-II X P-501	61.7	6.4	11.4	23.4	11.3	66.7	22.0
MF-II X P-348	59.6	6.1	1.1	24.7	12.7	64.7	22.7
MF-II X TS-19	64.7	6.3	0.5	24.8	12.7	64.3	23.0
TS-7 X TS-III	62.6	6.2	1.8	19.2	15.6	65.3	19.3
P-364 X TS-III	64.7	6.3	0	23.5	10.5	67.0	21.3
P-457 X TS-5	63.0	6.0	2.0	20.8	13.7	67.6	19.6
P-364 X TPS-13	65.5	6.1	5.5	14.1	15.6	64.6	19.6
P-364 X P-457	68.3	6.0	5.9	16.9	14.6	64.6	20.7
TS-9 X TPS-67	60.0	6.9	1.5	32.7	8.3	67.6	24.3
TS-5 X TS-9	59.3	6.3	3.7	20.5	13.3	69.0	20.3
TS-12 X TS-9	61.0	6.1	3.5	17.7	15.3	66.7	18.1
TS-6 X TS-9	58.7	6.7	1.6	28.3	9.3	68.3	22.3
TS-14 X TS-9	64.7	6.0	3.3	15.4	17.3	67.0	15.7
TS-9 X P-364	62.6	6.1	4.9	21.3	13.2	66.8	20.0
TS-9 X TS-8	60.6	6.0	5.8	21.6	13.7	67.3	19.0
TS-8 X TS-9	61.7	6.2	5.7	24.4	12.3	68.6	20.3
P-501 X TS-9	62.6	5.6	13.0	27.9	9.0	65.7	22.3
P-501 X Lalmadda	62.0	5.9	11.5	20.4	13.0	65.6	19.3
Lalmadda X P-501	61.8	5.8	13.8	15.6	16.3	66.3	18.0
LSD (0.05) ^z	1.52	0.18	0.62	0.82	1.00	0.23	1.97

^z LSD (p=0.05) for comparing means in columns

Table 2.2.2-1. Plant growth and yield attributes of 4 promising TPS progenies as influenced by progeny

Progeny	Plant height (cm)	No. of seedling tubers m ⁻²	Yield (t ha ⁻¹)	Grade of seedling tubers (% by number)				
				< 10 mm	10-20 mm	20-28 mm	28-35 mm	> 35 mm
TS-7 X TPS-67	95.5	1012	67.0	55.7	20.5	13.9	7.9	2.0
MF-II X TPS-67	95.8	1040	69.3	55.8	20.4	13.8	8.1	1.9
MF-II X TPS-13	93.8	940	62.2	55.9	20.7	13.9	7.9	1.6
P-364 X TPS-67	98.3	1114	73.8	55.7	20.4	14.1	7.8	2.0
LSD (0.05) ^z	2.50	35.11	2.55	NS ^y	NS	NS	NS	NS

^z LSD (p=0.05) for comparing means in columns.

^y Non-significance

Table 2.2.2-2. Plant growth and yield attributes of 4 promising TPS progenies as influenced by plant spacing

Spacing (cm)	Plant height (cm)	No. of seedling tubers m ⁻²	Yield (t ha ⁻¹)	Grade of seedling tubers (% by number)				
				< 10 mm	10-20 mm	20-28 mm	28-35 mm	> 35 mm
10 x 10	90.3	888	63.5	54.7	20.8	14.8	8.2	1.6
14 x 7	94.0	984	66.6	55.2	21.2	13.9	8.1	1.5
20 x 5	97.0	1090	70.4	56.1	20.9	13.1	8.5	1.4
25 x 4	102.0	1150	71.9	57.1	19.2	13.9	8.0	1.8
LSD (0.05) ^z	5.18	28.6	2.18	NS ^y	NS	NS	NS	NS

^z LSD (p=0.05) for comparing means in columns.

^y Non-significance

Table 2.2.2-3. Labor input as affected by different spacing for seedling tuber production in nursery beds by TPS

Spacing (cm)	Labor hours of different operations for seedling tuber production in one hectare land								Working- day ^z	Labor cost (US \$ ha ⁻¹ @ 1.2 US \$)	% Excess cost over 25 x 4 cm
	Bed making	TPS sowing	Irrigation	Weeding and thinning	Earthing up	Haulm pulling	Harvesting	Total hours			
10 x 10	4452.0	2035.2	5755.8	4579.2	4483.8	445.2	2162.4	23913.6	2989.2	3587.1	13.3
14 x 7	4388.4	2003.4	5660.4	4515.6	4324.8	445.2	2130.6	23468.4	2925.6	3510.7	10.3
20 x 5	4324.8	1908.0	5342.4	4452.0	3943.2	318.0	1749.0	22005.6	2734.8	3281.8	3.6
25 x 4	4293.0	1844.4	5151.6	4229.4	3816.0	254.4	1653.6	21242.0	2639.4	3167.3	100.0

^z 1 Working-day = 8 hours

Table 2.2.3-1. Field performance of ten promising TPS progenies over three subsequent generations

Progeny	Plant height (cm)			Crop duration (days)			Virus infection (%)			Leaf spot complex (%)		
	F ₁ C ₀	F ₁ C ₁	F ₁ C ₂	F ₁ C ₀	F ₁ C ₁	F ₁ C ₂	F ₁ C ₀	F ₁ C ₁	F ₁ C ₂	F ₁ C ₀	F ₁ C ₁	F ₁ C ₂
MF-II X TPS-67	99.3	69.5	62.0	107	97	95	0	2.2	10.4 (4.2) ^z	0.3	2.3	6.0 (3.5) ^y
TS-7 X TPS-67	100.7	68.8	63.0	108	98	94	0	2.4	9.6 (4.0)	0.6	2.3	7.7 (3.5)
MF-II X TPS-13	96.3	68.3	60.3	105	95	94	0	2.6	9.7 (4.1)	1.2	3.3	10.7 (5.1)
MF-I X TPS-67	93.9	66.3	62.0	106	96	94	0	3.5	10.1 (4.2)	0.8	2.6	10.3 (4.6)
MF-I X TPS-13	92.7	66.8	60.3	104	97	94	0	2.4	10.1 (4.2)	1.5	2.3	10.3 (4.7)
P-364 X TPS-67	95.7	66.6	60.3	107	95	93	0	2.5	10.6 (4.4)	0.8	2.7	11.0 (3.8)
P-364 X TS-9	100.3	69.5	61.7	104	97	95	0	1.1	6.2 (2.4)	0	2.0	8.3 (3.4)
TS-7 X TPS-13	89.0	65.8	60.2	104	96	95	0	2.7	10.5 (4.4)	2.4	3.7	11.0 (5.7)
TS-9 X TPS-67	102.0	68.8	62.7	109	97	94	0	1.5	8.2 (3.2)	1.4	2.3	9.7 (4.5)
TS-6 X TS-9	97.3	68.1	63.0	107	96	95	0	2.2	10.4 (4.2)	2.0	3.1	12.0 (5.8)
Mean	96.7	67.9	61.6	106	96	94	0	2.2	10.0 (4.1)	1.1	2.7	9.6 (4.7)
LSD (0.05) ^x for progeny	5.45	NS ^w	2.41	1.30	1.07	1.13	-	0.21	1.58 (1.31)	1.43	0.46	1.78 (1.06)
LSD (0.05) for generation		9.09			5.39		-	0.20			2.09	

^{z, y} Values in parenthesis are mean virus infection and leaf spot complex, respectively.

^x LSD(p=0.05) for comparing means in columns.

^w Non-significance

Table 2.2.3-2. Yield attributes of ten promising TPS progenies over three subsequent generations

Progeny	No. of tubers m ⁻²			No. of tubers plant ⁻¹			Yield (t ha ⁻¹)		
	F ₁ C ₀	F ₁ C ₁	F ₁ C ₂	F ₁ C ₀	F ₁ C ₁	F ₁ C ₂	F ₁ C ₀	F ₁ C ₁	F ₁ C ₂
MF-II X TPS-67	1253	78	75	13	12	11	69.1	33.5 (35.6) ^z	29.4 (4.1) ^y
TS-7 X TPS-67	1202	75	75	12	11	11	69.6	34.4 (35.2)	29.8 (4.6)
MF-II X TPS-13	1045	71	73	10	11	11	64.0	30.0 (33.7)	27.8 (2.5)
MF-I X TPS-67	1030	65	67	10	10	10	61.6	26.4 (35.2)	22.0 (4.4)
MF-I X TPS-13	995	57	53	10	9	8	62.4	24.7 (37.7)	21.8 (2.9)
P-364 X TPS-67	1239	74	70	12	11	11	69.6	32.6 (37.0)	29.3 (3.3)
P-364 X TS-9	1218	67	67	12	10	10	69.2	29.2 (40.0)	26.2 (3.0)
TS-7 X TPS-13	1002	63	61	12	10	9	61.8	27.4 (34.4)	25.6 (1.8)
TS-9 X TPS-67	1213	72	79	12	11	12	70.4	31.4 (39.0)	29.3 (2.1)
TS-6 X TS-9	1039	54	55	10	8	9	61.8	25.4 (36.4)	23.2 (2.2)
Mean	1123	68	68	11	10	10	65.9	29.5 (36.4)	26.4 (3.1)
LSD (0.05) ^x for progeny	53.08	6.32	9.80	0.99	0.99	1.02	3.05	1.54	1.84
LSD (0.05) for generation		75.32			0.63			9.11	

^{z,y} Values in parenthesis are yield reduction from F₁C₀ and F₁C₁, respectively.

^x LSD(p=0.05) for comparing means in columns

Table 2.2.4-1. Results of on-farm trials of TPS for seedling tuber production in 1993 to 1994 and tuber production in 1994 to 1995

Progeny	Location	No. of demonstrations	Yield range (kg m ⁻²)	Yield of seedling tubers (t ha ⁻¹)	No. of demonstrations	Yield range (kg m ⁻²)	Yield of tubers (t ha ⁻¹)
		1993-1994			1994-1995		
MF-II X TPS-67	Munshiganj	100	3.6-6.0	41	116	2.9-3.1	30
	Narayanganj	49	3.4-6.1	40	42	2.5-2.9	27
	Comilla	132	4.5-7.5	42	136	2.7-3.1	29
Mean			3.8-6.5	41		2.7-3.0	28.6
TS-7 X TPS-67	Munshiganj	100	3.8-6.3	42	116	2.8-3.4	31
	Narayanganj	49	3.5-6.0	39	42	2.7-2.9	28
	Comilla	132	4.1-7.6	43	136	2.9-3.4	30
Mean			3.8-6.6	41		2.8-3.2	29.6
LSD (0.05) for mean yield of progeny is NS ^z					LSD (0.05) for mean yield of progeny is NS		
LSD (0.05) the yield of progenies at different locations is 0.060					LSD (0.05) the yield of progenies at different locations is 0.156		
LSD (0.05)for progeny x location is 0.063					LSD (0.05) for progeny x location is 0.063		

^z Non-significant

Table 2.2.4-2. Results of on-farm trials of TPS for seedling tuber production in 1994 to 1995 and tuber production in 1995 to 1996

Progeny	Location	No. of demonstrations	Yield range (kg m ⁻²)	Yield of seedling tubers (t ha ⁻¹)	No. of demonstrations	Yield range (kg m ⁻²)	Yield of tubers (t ha ⁻¹)
		1994-1995			1995-1996		
MF-II X TPS-67	Munshiganj	54	2.5-7.9	46	50	3.1-3.4	32
	Bogra	60	0.4-5.5	32	61	2.8-3.2	29
	Comilla	60	1.8-7.0	36	67	3.0-3.4	31
	Debiganj	15	4.5-7.0	36	19	2.5-2.9	27
Mean			2.3-7.0	43		2.9-3.2	30.5
TS-7 X TPS-67	Munshiganj	54	2.7-7.5	47	50	3.0-3.3	31
	Bogra	60	0.4-5.5	34	61	2.7-3.1	28
	Comilla	60	1.7-8.0	37	67	3.0-3.3	31
	Debiganj	15	4.9-7.3	59	19	2.6-2.9	28
Mean			2.4-7.3	46		2.6-3.2	29.5
LSD (0.05) for mean yield of progeny is 0.153					LSD (0.05) for mean yield of progeny is NS		
LSD (0.05) the yield of progenies at different locations is NS ^z					LSD (0.05) the yield of progenies at different locations is 0.161		
LSD (0.05) for progeny x location is NS					LSD (0.05) for progeny x location is 0.068		

^z Non-significant

Table 2.2.4-3. Results of on-farm trials of TPS for seedling tuber production in 1995 to 1996 and tuber production in 1996 to 1997

Progeny	Location	No. of demonstrations	Yield range (kg m ⁻²)	Yield of seedling tubers (t ha ⁻¹)	No. of demonstrations	Yield range (kg m ⁻²)	Yield of tubers (t ha ⁻¹)
		1995-1996			1996-1997		
MF-II X TPS-67	Munshiganj	100	2.3-7.6	43	70	3.0-3.7	34
	Jessore	49	2.1-5.2	33	75	2.7-3.1	29
	Bogra	132	21.-5.8	42	65	2.8-3.3	31
	Mean		2.2-6.2	39		2.8-3.4	31
TS-7 X TPS-67	Munshiganj	48	2.0-7.4	42	70	3.2-3.8	35
	Jessore	48	2.2-5.5	35	75	2.8-3.2	30
	Bogra	48	2.1-5.9	41	65	3.0-3.2	32
	Mean		2.1-6.3	39		3.0-3.5	33
LSD (0.05) for mean yield of progeny is NS ^z					LSD (0.05) for mean yield of progeny is NS		
LSD (0.05) the yield of progenies at different locations is 0.282					LSD (0.05) the yield of progenies at different locations is 0.565		
LSD (0.05)for progeny x location is 0.316					LSD (0.05)for progeny x location is 0.724		

^z Non-significant

A series of experiments and thousands of demonstration trials of TPS have generated great enthusiasm among the potato farmers as well as consumers of Bangladesh. This, however, does not mean that potato production from TPS is an easy technique. There are major problems associated with the use of this technique such as poor germination percentage, lack of uniform germination, poor survival rate of seedlings, lack of uniformity of tubers in terms of shape, size, and color. In order to exploit the merits of TPS a number of experiments have been undertaken as follows.

Chapter 3

Flower, berry, and true potato seed production in potato mother plants (*Solanum tuberosum* L.). 1. Effects of nitrogen and phosphorus fertilizers

3.1 Introduction

Potato (*Solanum tuberosum* L.) is generally grown by vegetative production (Horton and Sawyer, 1985; Struik and Wiersema, 1999). 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 (Sawyer, 1987; Burton, 1989; Almekinders, 1992; Roy et al., 2005). In this respect, TPS has good prospects because it can reduce the cost of production and thus farmers can become independent from conventional seed sources (Wiersema, 1986a; Malagamba, 1988; Renia and Hest, 1998; Roy et al., 1999). However, the success of potato production using TPS largely depends on the productivity of quality TPS (Upadhyia 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 (Krauss, 1978; Pallais et al., 1984). 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 (Upadhyia et al., 1984). Upadhyia 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 (Upadhyaya 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.

3.2 Materials and Methods

This study was carried out during 2004 to 2005 at the experimental field of the Tuber Crops Research Center (TCRC), Bangladesh Agricultural Research Institute (BARI), 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 (Page 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 (Page 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 Upadhyaya, 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)-ZnSO₄ (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 (N₀), 150 (N₁₅₀), 225 (N₂₂₅), and 300 (N₃₀₀) kg N ha⁻¹ and 0 (P₀), 60 (P₆₀), 120 (P₁₂₀), 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 x 0.4 m in unit plots of 2.0 x 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 (Almekinders and Struik, 1996; Van der Vossen, 1998). Additional light was given by sodium-vapor lamps to provide a light intensity of 0.4-0.6 $\mu\text{E m}^{-2} \text{sec}^{-1}$ 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 a.m.). Berries were harvested 5 to 6

weeks after pollination, when they just started to ripen. Berries from 5 plants 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 to 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.

3.3 Results

3.3.1 Flowering characteristics

The number of inflorescences plant⁻¹ (NIPP) and flowers inflorescence⁻¹ (NFPI) were positively influenced ($p=0.01$) by increasing the rates of N or P (Table 3-1). Combined application of N and P also had a significant influence ($p=0.05$) on these parameters (Table 3-1).

A trend of gradual increase in NIPP and NFPI with increasing rates of N and P was also observed (Figs. 3-1A and 3-1B). NIPP ranged between 3.6 (under $N_0 P_0$) and

7.2 (under $N_{300} P_{180}$) among the treatment combinations (Fig. 3-1A). 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. 3-1B).

3.3.2 Berry characteristics

Different levels of N or P significantly ($p=0.01$) affected the number of berries plant⁻¹ (Table 3-1), which was inversely related to N or P rates. In other words, increased application of N or P rate decreased this parameter (Table 3-1). The combined effect of N and P was also significant ($p=0.05$) (Table 3-1). It ranged between 15.9 and 22.9 across the treatment combinations (Fig. 3-1C).

Nitrogen and P affected the berry size (Table 3-2). The number of medium-sized berries plant⁻¹ was always higher than that of small and large ones irrespective of the treatment combination (Table 3-2).

Different levels of N or P significantly ($P=0.01$) affected the yield of berries plant⁻¹ (Table 3-1). The variation in the yield of berries plant⁻¹ among the treatment combinations of N and P was also significant ($p=0.01$) (Table 3-1). The yield of berries plant⁻¹ ranged from 80.0 to 199.2 g (Fig. 3-1D). 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. 3-1D).

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 3-2). The mean weight of small-, medium-, and large-size berries ranged from 3.3 to 5.0, 5.5 to 9.4, and 10.9 to 14.3 g, respectively, among the treatment combinations (Table 3-2). 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. 3-1E).

3.3.3 TPS characteristics

Nitrogen or P application had a significant effect ($p=0.01$) on the number of TPS berry⁻¹, but their interaction was non-significant (Table 3-1). There was a wide variation in the number of TPS berry⁻¹ among different berry sizes (Table 3-2). The medium- and large- size berries had remarkably higher numbers of TPS berry⁻¹ but their interaction was non-significant (Table 3-1). There was a wide variation in the number of TPS berry⁻¹ among different berry sizes (Table 3-2). 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 234, and 201 to 297, respectively (Table 3-2). The highest average number of TPS berry⁻¹ (195) was produced by the application of N₁₅₀ P₁₈₀ combination (Fig. 3-1F).

Nitrogen or P showed a significant effect ($p=0.01$) on 100-TPS weight (Table 3-1). 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 3-1). The interaction between N and P was also significant ($p=0.01$) in the case of this parameter (Table 3-1). The highest 100-TPS weight was produced by the combination of N₃₀₀ P₁₂₀ (84.1 mg), and was similar to that produced with N₃₀₀ P₁₈₀ (83.6 mg) (Fig. 3-1G).

The weight of 100-TPS also showed significant variation among the treatment combinations of N and P, irrespective of berry size (Table 3-2). 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 3-2).

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 3-1). In addition, combined application of N and P was also significant ($p=0.01$) with respect to this parameter (Table 3-1). The highest

total yield of TPS ha^{-1} was obtained with the application of $\text{N}_{225} \text{P}_{120}$, followed by $\text{N}_{300} \text{P}_{120}$ and $\text{N}_{225} \text{P}_{180}$ (136.1, 126.7, and 126.4 kg, respectively) (Fig. 3-1H). Treatment with a combination of $\text{N}_{225} \text{P}_{120}$ was found to be optimal for promoting TPS production.

3.3.4 Analysis of correlation coefficients

The correlation coefficient among yield components and yield of TPS with $\text{N} \times \text{P}$ were analyzed. All components showed significantly positive correlation with the yield of TPS (Table 3-3). 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.

3.4 Discussion

Although all the parameters showed a significant single effect of P or N, the highest values of the parameters were obtained at 225 to 300 kg N and/or 120 to 180 kg P ha^{-1} , except for the number of berries plant^{-1} (Table 3-1). Moreover, the highest combination effect was also obtained at 225 to 300 kg N and 120 to 180 kg P ha^{-1} , except for the number of berries plant^{-1} , yield of berries plant^{-1} , and number of TPS berry $^{-1}$ (Figs. 3-1A-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 Upadhyaya et al (1984), i.e., the combination of 240 kg N and 140 kg P ha^{-1} resulted in a good TPS production in 'Atzimba' X 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 3-2). 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 seedling 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 3-1 and Fig. 3-1G) 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 3-2).

All the parameters which were measured in our experiments also showed a significant single effect of P at the 1% level (Table 3-1) 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 N₃₀₀ P₁₂₀ (Fig. 3-1G), while the highest TPS yield ha⁻¹ was obtained with N₂₂₅ P₁₂₀ (Fig. 3-1H).

The number of berries plant⁻¹ is also regarded as an important parameter for obtaining the highest yield of TPS (Upadhyaya 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 3-3). 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.

Table 3-1. Effect of nitrogen, phosphorus, and nitrogen x phosphorus on sexual reproductive characters of MF-II X TPS-67

Application (kg ha ⁻¹)	NIPP	NFPI ^z	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	4.2 c	13.8 b	17.3 d	97.6 c	73 b	59.6 d	49.1 c
N ₁₅₀	5.6 b	14.9 b	21.3 a	173.7 a	175 a	67.2 c	103.1 b
N ₂₂₅	6.2 a	16.7 a	20.2 b	164.8 a	176 a	77.1 b	113.9 a
N ₃₀₀	6.3 a	17.2 a	18.4 c	134.3 b	176 a	81.9 a	110.5 ab
P ₀	4.1 c	11.2 c	17.5 d	97.1 c	98 c	66.1 c	60.1 c
P ₆₀	5.7 b	16.0 b	20.8 a	161.6 a	158 b	71.6 b	103.2 b
P ₁₂₀	6.2 a	17.5 a	20.0 b	159.3 a	170 a	74.3 a	110.2 a
P ₁₈₀	6.3 a	18.0 a	19.0 c	152.5 b	174 a	73.8 a	104.4 ab
Significance							
N	**	**	**	**	**	**	**
P	**	**	**	**	**	**	**
N x P	*	*	*	**	NS ^y	**	**

NIPP = Number of inflorescences plant⁻¹. NFPI = Number of open flowers inflorescence⁻¹. ^z values are the mean of the 1st and 2nd inflorescences.

*, ** Significant at p= 0.05 and 0.01, respectively. Different letter (s) within columns indicates a significant difference by LSD test at p=0.05.

^y Non-significance

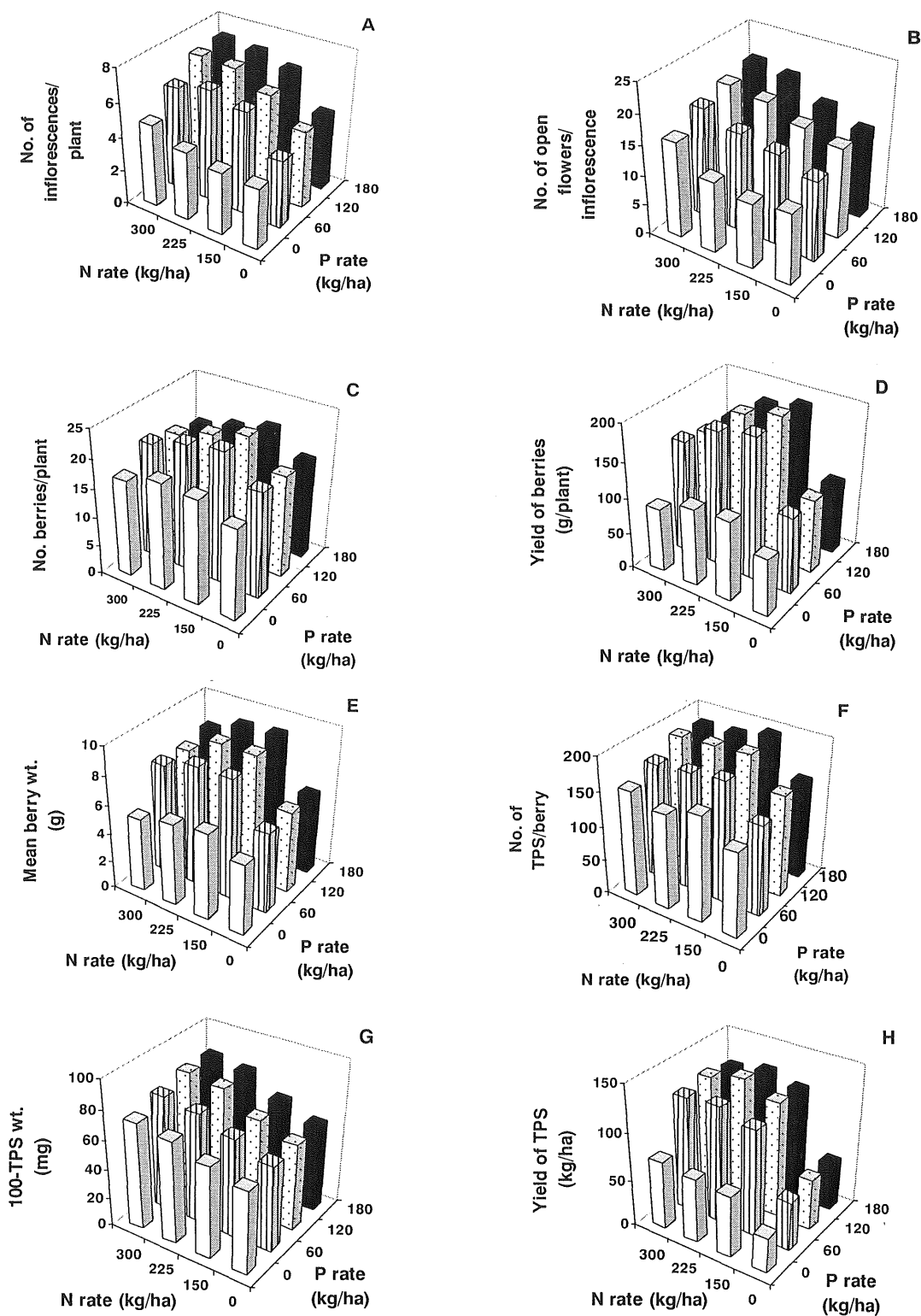


Figure 3-1. Combined effects of different rates of N and P fertilizers on NIPP (A), NFPI (B), number of berries plant⁻¹(C), yield of berries plant⁻¹(D), mean berry weight (E), number of TPS berry⁻¹ (F), 100-TPS weight (G), and yield of TPS (H)

Table 3-2. 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 berry	Medium berry	Large berry	Small berry	Medium berry	Large berry	Small berry	Medium berry	Large berry	Small berry	Medium berry	Large berry
N ₀ P ₀	6.2	8.6	1.1	3.3	5.5	10.9	40	134	201	56.1	57.4	58.5
N ₀ P ₆₀	6.1	9.9	2.3	3.7	5.8	11.3	45	141	211	58.0	59.3	60.5
N ₀ P ₁₂₀	6.4	9.3	2.1	3.8	5.9	11.4	51	151	247	59.8	61.1	62.0
N ₀ P 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) ^z	1.12	1.67	0.60	0.40	0.66	NS ^y	NS	NS	NS	2.04	2.54	2.59

^z LSD (p=0.05) for comparing means in columns.^y Non-significance

Table 3-3. Correlation coefficients of different yield components and yield of TPS
with combination of N x P

Yield components	Correlation coefficient
Number 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



Figure 3-2. Field of experiment 3



Figure 3-3. Inflorescence after pollination

Chapter 4

Flower, berry, and true potato seed production in potato mother plants (*Solanum tuberosum* L.). 2. Effects of nitrogen and potassium fertilizers

4.1 Introduction

Although potato production using TPS is becoming popular in many areas of the world, especially in developing countries, how to obtain quality seeds from female potato plants has remained a problem which urgently needs to be solved (Pallais, 1987, 1991; Islam et al., 2000; Upadhyaya et al., 2003). The production of quality seed is strongly influenced by fertilizers. Among them, N, P, K, and their combinations are the most important for improving not only the quality but also the yield of TPS (Upadhyaya et al., 1984; Kanzikwera et al., 2000).

Nitrogen applications higher than 225 kg ha⁻¹ have been reported to increase flower production, pollen germination, berry setting, and 100-TPS weight (Pallais et al., 1984, 1987; Roy et al., 2007a). An increase in N supply enhances the export of cytokinins from the roots to the shoots, resulting in delayed senescence of the plants. Thus, berries have a longer period to mature on the mother plants and a better chance for high quality seed production (Van et al., 1982; Pallais, 1987).

Application of P up to a certain amount also positively correlates with flowering, berry setting, seed weight, and TPS production (Upadhyaya et al., 1984). In a previous study (Roy et al., 2007a), we showed that the application of 120 to 180 kg P ha⁻¹ produced the highest 100-TPS weight and TPS yield.

The effects of K, however, are different from those of N and P. With a high rate (>132.8 kg ha⁻¹) of K application, the TPS mother plant shows a negative response of 100-TPS weight and poor response of TPS production (Kanzikwera et al., 2000).

The effects of combinations of N, P and/or K are more complicated and have been less studied comparing with the effects of the single applications. In a previous study (Roy et al., 2007a), we demonstrated that the optimum dosages of N and P combinations to obtain the highest 100-TPS weight and TPS yield were different, i.e., the combination of 300 kg N and 120 kg P ha⁻¹ and 225 kg N and 120 kg P ha⁻¹ produced the highest 100-TPS weight and TPS yield, respectively, of MF-II, which was the most promising female parent in Bangladesh (Moniruzzaman, 2000; Roy et al., 2005). Upadhyaya et al (1984) showed that application of 240 kg N and 140 kg P ha⁻¹ produced the highest TPS yield. The combinations of 240 kg N and 132.8 to 265.6 kg K ha⁻¹ depressed 100-TPS weight, indicating a negative interaction between the two nutrients (Kanzikwera et al., 2000).

In this study, therefore, we examined the effects of combinations of N and K at the optimum dosage for P application (120 kg ha⁻¹) (Roy et al., 2007a) and tried to find the best combinations of N, P, and K application for the production of hybrid TPS from MF-II x TPS-67.

4.2 Materials and Methods

The experiment was conducted at the experimental field of the TCRC, BARI, Joydevpur, Bangladesh, during 2005 to 2006. The soil had a pH of 6.82 (Jackson, 1962) and contained 1.63% organic matter (Page et al., 1982), 0.095% N (Jones, 1991), 0.0011% available P (Olsen et al., 1984), 0.133 me% exchangeable K (Black, 1965), and 0.00126% available S content (Page et al., 1982).

Considering the findings of our previous study, 2 levels of N (225 and 300 kg ha⁻¹) and a fixed value of P (120 kg ha⁻¹) were selected for testing as promising for TPS production. In this experiment, therefore, factor 1 comprising 3 levels of N: 0, 225, and 300 kg ha⁻¹ (N₀, N₂₂₅, and N₃₀₀ kg ha⁻¹, respectively) and factor 2 comprising 4 levels of K: 0, 125, 175, and

225 kg ha⁻¹ (K₀, K₁₂₅, K₁₇₅, and K₂₂₅ kg ha⁻¹, respectively) were applied in a split-plot design with 3 replications. Nitrogen was assigned to main-plots and K to sub-plots. Urea, muriate of potash, and triple super phosphate were the N, K, and P sources. The mother plants were planted on 21 October 2005, and received the recommended rates of fertilizers for tuber production of 120-12-6 kg ha⁻¹ Gypsum-ZnSO₄-Borax and 10 t ha⁻¹ farmyard manure, at 3 days before planting (Anonymous, 2004). Based on our previous findings, 120 kg P ha⁻¹ was applied in all treatments (Roy et al., 2007a). Male plants (TPS-67) were planted in separate plots on 14 October 2005 to harmonize their flowering with that of the female plants. All other practices and procedures of production, extraction, and drying of TPS were similar to those described in our previous report (Roy et al., 2007a).

After proper drying, TPS were separated into fractions of large-(> 1.4 mm), medium-(1.4-1.18 mm), and small-(1.18-1.00 mm) sized seed, using testing sieves (Tokyo Screen, Japan).

The analysis of variance was carried out using MSTAT-C statistical software (MSTAT-C, 1991). Means were compared using the LSD test at a 5% probability level.

4.3 Results

4.3.1 Effects of N and/or K on flowering

Nitrogen showed significant effects ($p=0.01$) on the number of inflorescences plant⁻¹ (NIPP) and number of flowers inflorescence⁻¹ (NFPI), both of which increased with increasing N rates (Table 4-1). Although K also showed significant effects ($p=0.01$) on these parameters, K₁₇₅₋₂₂₅ showed similar effects. The combined effect of N and K on NIPP was also significant ($p=0.05$), but that on NFPI was not significant.

A tendency of gradual increases in NIPP and NFPI with increasing rates of N and K was also observed (Figs. 4-1A and 4-1B). Application of N₃₀₀K₂₂₅ produced the maximum

NIPP (9.7), and N₃₀₀K₁₇₅ and N₃₀₀K₁₂₅ had similar effects (9.2 and 8.4, respectively) (Fig. 4-1A). The maximum NFPI was found at N₃₀₀K₂₂₅ (22.1) (Fig. 4-1B).

4.3.2 Effect of N and/or K on the number of berries plant⁻¹, mean berry weight, and yield of berries

Different levels of N or K significantly ($p=0.01$) affected the number of berries plant⁻¹, but the effect of their combination was not significant, except for large size berries (Tables 4-1 and 2). Mother plants supplied with N₂₂₅K₂₂₅ (22.8) produced 52% more berries plant⁻¹ than those supplied with N₀K₀ (14.9) (Fig. 4-1C). The number of medium-size berries was always higher than that of large and small ones, irrespective of the treatment combination (Table 4-2).

Different levels of N, K, or their combination significantly ($p=0.01$) affected the mean berry weight (Table 4-1). The highest mean berry weight (9.1 g) was obtained with the combination of N₂₂₅K₂₂₅, whereas the lowest (5.1 g) was obtained with N₀K₀ (Fig. 4-1D).

Different levels of N, K, or their combination significantly ($p=0.01$) affected the yield of berries plant⁻¹ (Table 4-1). The yield of berries plant⁻¹ decreased with increasing N rates, but increased with increasing K rates. The combination of N₂₂₅K₂₂₅ resulted in the highest yield, followed by N₂₂₅K₁₇₅ and N₃₀₀K₂₂₅ (207.2, 193.7, and 189.1 g plant⁻¹, respectively) (Fig. 4-1E).

4.3.3 Effect of N and/or K on the number of TPS berry⁻¹

Different levels of N or K significantly ($p=0.01$) affected the number of TPS berry⁻¹, and their combination also had a significant effect ($p=0.05$) but not on small- and medium-size berries (Tables 4-1 and 2). There was a wide variation in the number of TPS berry⁻¹ among small-, medium-, and large-size berries (60, 184, and 252 TPS berry⁻¹, respectively) (Table 4-2). The combination of N₂₂₅K₁₂₅ resulted in the maximum number of TPS berry⁻¹

which was similar to that obtained with N₃₀₀K₁₂₅ and N₂₂₅K₁₇₅ (196, 189, and 184, respectively) (Fig. 4-1F).

4.3.4 Effect of N and/or K on 100-TPS weight

Different levels of N or K significantly ($p=0.01$) affected 100-TPS weight (Table 4-1). The weight of TPS increased with increasing N rates, but decreased with increasing K rates (Table 4-1). The N and K rates had opposite relationships with this parameter. Their interaction was also significant ($p=0.05$) (Tables 4-1 and 4-2). The weight of 100-TPS in small-, medium-, and large-size berries ranged from 56.6 to 81.3 mg, 57.9 to 84.3 mg, and 59.3 to 85.8 mg, respectively, among the treatment combinations (Table 4-2). The highest 100-TPS weight was produced by the combination of N₃₀₀K₁₂₅, closely followed by N₂₂₅K₁₂₅ and N₃₀₀K₁₇₅ (83.8, 81.5, and 80.7 mg, respectively) (Fig. 4-1G).

4.3.5 Effect of N and/or K on yield of TPS

Different levels of N or K significantly affected ($p=0.01$) the yield of TPS (Table 4-1). The value increased up to 225 kg N ha⁻¹, while K₁₂₅₋₂₂₅ produced similar yields (Table 4-1). The combination effect on total TPS yield was also significant ($p=0.01$) (Table 4-1). The highest value was obtained with the combination of N₂₂₅K₁₂₅, followed by N₃₀₀K₁₂₅ (145.3 and 137.2 kg, respectively) (Fig. 4-1H).

4.3.6 Combined effects of different levels of N and K on TPS size distribution

Out of 12 treatment combinations, the highest yield of large-, medium- and small-sized TPS was obtained from N₃₀₀K₁₂₅ (59.3 kg ha⁻¹), N₂₂₅K₁₂₅ (55.6 kg ha⁻¹), and N₂₂₅K₂₂₅ (44.6 kg ha⁻¹), respectively (Fig. 4-2). Although total TPS yield was the highest with N₂₂₅K₁₂₅, followed by N₃₀₀K₁₂₅ (145.3 and 137.4 kg ha⁻¹, respectively), the distribution of large- and

medium-sized TPS with the latter was higher than that with the former (35 and 38% vs. 43 and 39%, respectively) (data not shown).

4.4 Discussion

In the present study, all characters showed a significant single effect of N rate (Table 4-1). The highest values of number of berries plant⁻¹, mean berry weight, yield of berries plant⁻¹, number of TPS berry⁻¹, and yield of TPS were found at 225 kg N ha⁻¹, which is similar to the findings of Upadhyaya et al (1984), who made similar findings at 240 kg N ha⁻¹. All other reproductive characters, however, showed the highest values at 300 kg N ha⁻¹. The development of potato tubers strongly affects the reproductive growth because of competition between shoots and tubers (Dwelle, 1985; Veerman, 1998). Rapid tuberization, however, is prevented when N is applied interspatially because of successive growth of both shoots and roots (Krauss, 1978). In the present experiments, N was applied in 4 installments (at 10-day intervals starting 30 days after sowing) suggesting that tuberization should have been well prevented. Therefore, the effects of different N levels on the reproductive characters would not have been due to differences of tuber development. In our experiments, 100-TPS weight increased with increasing N rate (Table 4-1). This was probably due to the fact that delayed senescence caused by N application allowed berries enough time to receive assimilates until a late stage of development. Some other researchers observed a similar relationship between N rate and 100-TPS weight (Delouche, 1980; Pallais et al., 1987; Marschner, 1995).

Although K also affected reproductive characters of the potato mother plant, the effects were different from those of N (Table 4-1) and P (Roy et al., 2007a); i.e., flowering, berry setting and berry yield showed a positive response to K, while there was either a negative or poor response of the number of TPS berry⁻¹, 100-TPS weight, and yield of TPS (Table 4-1). Moreover, the number of TPS berry⁻¹ and 100-TPS weight decreased with increasing K rate

(> 125 kg ha⁻¹), while K₁₂₅₋₂₂₅ produced similar TPS yields (Table 4-1). This was probably due to competition between tubers and aerial plant parts, because K which is absorbed from the soil is predominantly incorporated into tubers rather than shoots (Dubetz and Bole, 1975; Kanzikwera et al., 2001). In our experiments, tubers were not pruned in order to avoid mechanical damage of the roots, and this might have contributed to the poor response of mother plants to K application. Kanzikwera et al (2000) also found a similar relationship between K rate and TPS weight in 'Kisoro' x 'Rutuku' crosses.

Seed weight has been proposed as a character for selecting high-yielding TPS progenies (Dayal et al., 1984). In our experiments, however, N and K applications showed an opposite relationship with 100-TPS weight (Table 4-1), as reported by Karien et al (1987) and Kanzikwera et al (2000) found for maize and potato, respectively.

The highest 100-TPS weight and yield were found with the combination of N₃₀₀K₁₂₅ and N₂₂₅K₁₂₅, respectively (Figs 4-1G and 4-1H). Moreover, these combinations produced the highest yield of large-size TPS (Fig. 4-2). Seed size and 100-TPS weight larger than 1.18 mm and 75 mg, respectively, are regarded as indicating high quality seed (CIP, 1983; Dayal et al., 1984; Singh et al., 1990; Upadhyya et al., 2003). Application of N at 215 kg ha⁻¹ increases seed size, and larger seeds show faster germination and better seedling growth (Almekinders and Wiersema, 1991). Although N₂₂₅K₁₂₅ produced the highest TPS yield in our experiments, N₃₀₀K₁₂₅ would be better because the distribution of the seeds larger than 1.18 mm was the highest with this combination (Fig. 4-2).

Considering the present results together with those of our previous study (Roy et al., 2007a), we conclude that the combination of 300 kg N, 120 kg P, and 125 kg K ha⁻¹ was the most suitable for the commercial production of hybrid TPS from ♀MF-II X ♂TPS-67.

Table 4-1. Effect of nitrogen, potassium, and nitrogen x potassium on sexual reproductive characters in MF-II X TPS-67

Application (kg ha ⁻¹)	NIPP	NFPI ^z	No. of berries plant ⁻¹	Mean berry wt. (g)	Yield of berry (g plant ⁻¹)	No. of TPS berry ⁻¹	Wt. of 100-TPS (mg)	Yield of TPS (kg ha ⁻¹)
N ₀	5.1 c	14.5 c	16.8 c	5.6 c	94.1 c	146 b	60.3 c	49.5 c
N ₂₂₅	6.5 b	16.8 b	21.3 a	8.2 a	175.7 a	178 a	77.2 b	123.6 a
N ₃₀₀	8.1 a	18.7 a	20.1 b	7.6 b	156.5 b	172 a	79.4 a	114.2 b
K ₀	4.6 c	12.8 c	16.9 c	5.6 c	94.6 d	143 d	68.1 d	61.9 b
K ₁₂₅	6.7 b	16.5 b	19.2 b	7.5 b	148.0 c	180 a	75.6 a	108.4 a
K ₁₇₅	7.3 a	18.1 a	20.2 ab	7.6 ab	157.1 b	171 b	73.7 b	107.5 a
K ₂₂₅	7.7 a	19.3 a	21.2 a	7.8 a	168.7 a	167 c	72.1 c	105.4 a
Significance								
N	**	**	**	**	**	**	**	**
K	**	**	**	**	**	**	**	**
N x K	*	NS ^y	NS	**	*	*	*	**

NIPP = Number of inflorescences plant⁻¹.

NFPI = Number of open flowers inflorescence⁻¹.

^z Values are the mean of the 1st and 2nd inflorescences.

*, ** Significant at p= 0.05 and 0.01, respectively. Different letter(s) within columns indicate a significant difference by LSD test at p=0.05.

^y Non-significance

Table 4-2. Combined effects of different rates of N and K fertilizers on berry and TPS characteristics in MF-II X TPS-67

Treatment combination	No. of berries plant ⁻¹			No. of TPS berry ⁻¹			Wt. of 100-TPS (mg)		
	Small berry	Medium berry	Large berry	Small berry	Medium berry	Large berry	Small berry	Medium berry	Large berry
N ₀ K ₀	6.6	7.3	1.0	46	140	207	56.6	57.9	59.3
N ₀ K ₁₂₅	6.4	8.6	1.4	57	157	249	60.4	61.6	62.5
N ₀ K ₁₇₅	6.2	9.3	1.3	54	152	242	59.3	60.8	64.5
N ₀ K ₂₂₅	6.4	11.0	2.2	55	149	243	59.2	60.7	61.8
N ₂₂₅ K ₀	6.2	11.2	1.6	59	185	214	70.2	72.5	73.5
N ₂₂₅ K ₁₂₅	5.3	13.6	3.6	69	223	296	78.8	82.1	83.7
N ₂₂₅ K ₁₇₅	4.0	14.4	3.7	66	209	277	76.7	79.5	80.2
N ₂₂₅ K ₂₂₅	3.9	15.0	3.9	64	205	266	74.9	76.6	78.1
N ₃₀₀ K ₀	4.2	9.9	1.8	54	177	205	72.4	74.3	75.8
N ₃₀₀ K ₁₂₅	4.0	12.0	3.0	67	212	288	81.3	84.3	85.8
N ₃₀₀ K ₁₇₅	4.0	14.1	3.2	64	205	271	78.2	81.6	82.3
N ₃₀₀ K ₂₂₅	4.5	14.4	3.5	59	198	267	76.5	79.3	81.4
Mean	5.2	11.8	2.5	60	184	252	70.4	72.6	74.1
LSD (0.05) ^z	NS ^y	NS	0.55	NS	NS	16.16	1.64	1.71	2.02

^z LSD(p=0.05) for comparing means in columns.

^y Non-significance

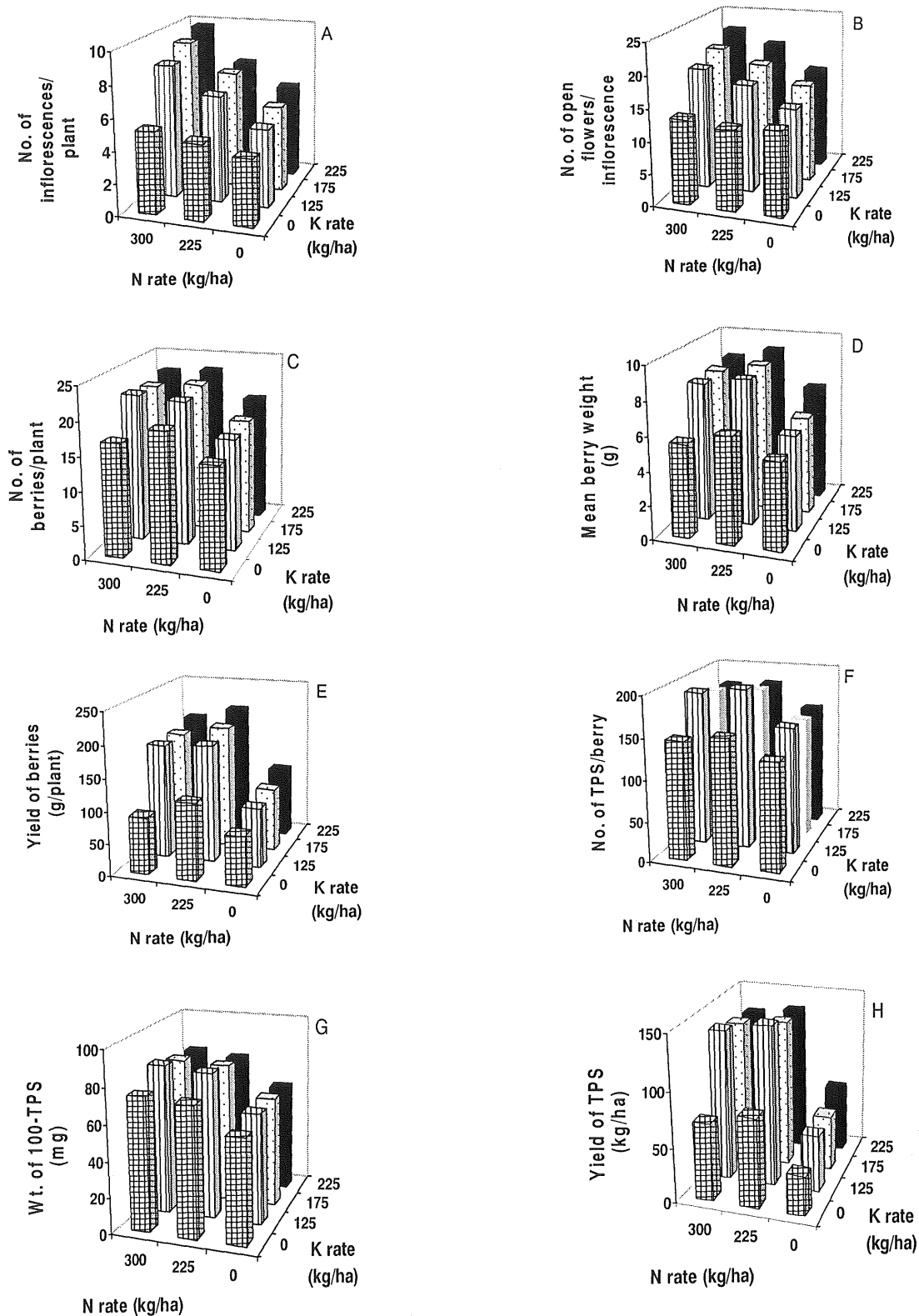


Figure 4-1. Combined effects of different rates of N and K fertilizers on NIPP (A), NFPI (B), number of berries plant⁻¹(C), mean berry weight (D), yield of berries plant⁻¹ (E), number of TPS berry⁻¹ (F), weight of 100-TPS (G), and yield of TPS (H)

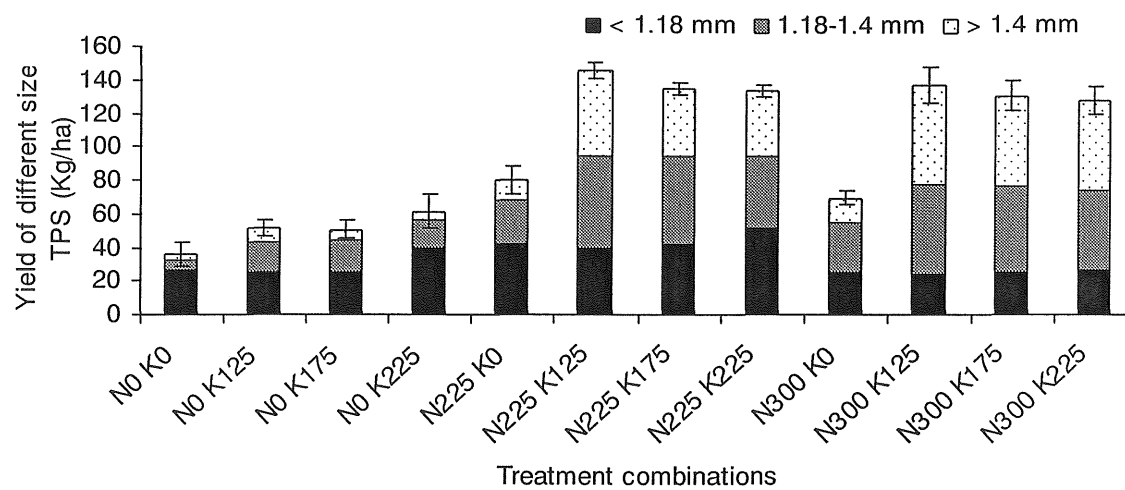


Figure 4-2. Combined effects of different levels of N and K on size distribution of TPS yield. Vertical bars indicate S.E. (n=3)



Figure 4-3. Field of experiment 4



Figure 4-4. Berries harvested from experiment 4

Chapter 5

Seed quality as affected by nitrogen and potassium during true potato seed production

5.1 Introduction

In a previous report (Roy et al., 2007b), we grew potato mother plants (MF-II) with different levels of nitrogen (N) and potassium (K) fertilizers (twelve combinations in total) to obtain hybridized TPS with TPS-67 (♂), and investigated the flowering habits of the mother plants and yield components of harvested TPS. The results clearly showed that the combination of 225 kg N and 225 kg K ha⁻¹ (hereafter described as N₂₂₅ K₂₂₅), N₃₀₀ K₁₂₅, and N₂₂₅ K₁₂₅ resulted in the highest yield of berries plant⁻¹ (207.2 g plant⁻¹), highest 100-TPS weight (83.8 mg), and highest TPS yield (145.3 kg ha⁻¹), respectively. By considering all the above described results together, we concluded that N₃₀₀ K₁₂₅ was the best combination for the commercial production of TPS that were obtained from the hybrid of MF-II X TPS-67 when the production was focused on the yield and size of TPS.

However, for the production of TPS, seed quality, which is commonly evaluated as high germination rate, uniform germination property, and vigorous seedling growth after germination, is also a crucial element (McDonald, 1980; Dickson, 1980; Pallais, 1987; Islam et al., 2000; Upadhy et al., 2003).

Kanzikwera et al (2000) demonstrated that the combination of N₂₄₀ K_{265.6} resulted in low germination rate and less seedling vigor compared with N₂₄₀ K_{132.8}. Thus, the quality of TPS also varies significantly according to the different combinations of N and K fertilizers applied to the mother plants (Pallais et al., 1984; Roy et al., 2007b), mainly due to the different nutrient levels that are contained in the harvested TPS.

Wheat seeds containing high N germinate faster and develop into larger seedlings than those containing normal N (Lopez and Grabe, 1973). In lettuce, a linear relationship was found between N concentration in the seed and seedling vigor after germination (Soffer and

Smith, 1974). On the other hand, a negative correlation was found between K concentration and germination rate in primrose (*Primula vulgaris* H.) seed (Zerche, 2005).

In addition to the importance of nutrient levels in TPS, the size of TPS also affects germination and subsequent seedling growth. Almekinders and Wiersema (1991) found that large TPS showed better germination and earlier emergence than small TPS. When small TPS take a long time to emerge after sowing, subsequent crop production will be greatly diminished by soil related problems such as fast-growing weeds and pathogens.

The objective of this study was to assess the effect of N and K application to potato mother plants (MF-II) on the growth performance of harvested TPS.

5.2 Materials and Methods

5.2.1 Planting materials and cultivation method

Seed tubers of 2 desired parental lines (MF-II and TPS-67 as female and male lines, respectively) were grown during 2005 to 2006 in the field of the Tuber Crops Research Center, Bangladesh to make hybridized TPS. Farm yard manure which contains approximately 1.0 to 1.2% N was applied (10 t ha^{-1}) in the experimental plots one week before (14 October 2005) the planting of the seed tubers. On 18 October, chemical fertilizers which contain P-Gypsum-Zinc sulphate- Borax at $120\text{-}120\text{-}12\text{-}6 \text{ kg ha}^{-1}$ were applied in the experimental plots. Effect of N x K fertilizers on the quality of TPS was investigated by applying 12 different N x K combinations of 3 levels of nitrogen (N_0 , N_{225} , and $N_{300} \text{ kg ha}^{-1}$ as total amount of application) and 4 levels of potassium (K_0 , K_{125} , K_{175} , and $K_{225} \text{ kg ha}^{-1}$ as total amount of application) for the production of the female plants. The entire quantity of K ($K_{0\text{-}225}$) was applied 3 days before planting of the seed tubers (18 October) because it is slowly absorbed into the plants, while only one-third of entire quantity of N (0 , 75 , and 100 kg ha^{-1} for N_0 , N_{225} , and N_{300}) was applied on 18 October as a basal dressing, irrespective of

total amount of N x K application. On 21 October 2005, seed tubers were planted in a split-plot design with 3 replicates. The rest amount of N fertilizer was equally applied in 4 installments (0, 37.5, and 50 kg ha⁻¹ for N₀, N₂₂₅, and N₃₀₀) at 10 day intervals starting from 30 days after planting (DAP) (21 November, 1, 11, and 21 December). Splitting of N application in 4 equal amounts helped in reducing the loss of excessive N fertilizer applied at planting, and better utilization of the fertilizer particularly during rapid growth of plants, flowering, berry setting, and development of seeds (Pallais et al., 1987; Phillips et al., 2004). The procedure of fertilizer's application was the same as described in our previous reports (Roy et al., 2007a, b). For the production of male plants, seed tubers were planted in separate plots on 14 November. A standard commercial amount of N x K combination (N₁₅₀ K₁₂₅) was applied as basal dressing (Roy et al., 2005). On 30 November (39 DAP), flowering of the female plants was started and they were hand pollinated with the previously collected pollen grains of the male plants. The crossing between the two parental lines and the subsequent production of TPS were the same as described previously (Roy et al., 2007a). Berries were harvested during 12 to 17 January 2006 (42-47 days after pollination). TPS that were produced from the 12 different fertilizer combinations were stored in a desiccator for approximately 5 months at room temperature.

5.2.2 Determination of N level in TPS

Dried TPS samples were homogenized in a mortar and approximately 0.5 g powder was transferred to a 100 ml flask. Approximately 1.1 g digestion mixture (1.0 g Na₂SO₄ + 100 mg mercuric oxide) and 5 ml concentrated H₂SO₄ were added to the sample, and then heated to 160°C for 3 to 4 h in a digestion chamber until the sample was digested completely. The flask was then cooled in tap water and brought up to 100 ml with distilled water. A 10 ml sample of the solution was put into a Micro-Kjeldahl distillation tube with 5 ml 50% NaOH

and 2.5 ml 15% $\text{Na}_2\text{S}_2\text{O}_3$, and the solution was distilled with steam for 10 min. A 15 ml sample of the distillate was decanted into a test tube with 25 ml of 2% boric acid solution, 4 to 6 drops of 0.2% methyl red, and methylene blue as an indicator. The solution was then titrated against 0.02% N HCl. In each analysis, water was also digested and distilled as a blank. The concentration of N in TPS was determined by the method of Ma and Zuazaga (1942).

5.2.3 Determination of P, K, Ca, Mg, and Na in TPS

TPS samples (approximately 50 mg) from each treatment were digested with 2 ml 16 N HNO_3 overnight at room temperature. Two milliliters of 60% HClO_4 was added and then the solution was successively heated to 80°C for 30 min, 120°C for 30 min, and 160°C for 90 min. The digested solutions were then cooled to room temperature, filtered through a glass fiber filter (25 μm in diameter), and brought up to 25 ml with distilled water. Phosphorus, K, Ca, Mg, and Na concentrations in each sample were determined using an Inductively Coupled Plasma (ICP) spectrophotometer (model Liberty 220, Varian, Victoria, Australia).

5.2.4 Seed quality tests *in vitro*

TPS that were produced from each combination of N x K were classified into large-(>1.18 mm) or small-(1.00 -1.18 mm) seed. TPS were then soaked in 0.15% gibberellic acid (GA_3) solution at room temperature for 24 h, one hundred seeds per each size class were sown in Petri dishes (15 cm diameter) equipped with wet filter paper (Whatman No. 1, Middlesex, UK), and then incubated at 20°C for 12 days. The seeds were watered as necessary. The germination rate of TPS was recorded at 6, 9, and 12 days after sowing (DAS). Coefficient of velocity (CoV) of germination was also calculated as follows (Scott and Williams, 1984):

$$\text{CoV} = 100[\sum N_i / \sum N_i T_i]$$

where N= No. of seeds germinated on day i, and T= No. of days after sowing.

The experiment was conducted in a completely randomized design with 3 replicates.

5.2.5 Seed quality tests *in vivo*

Seed quality *in vivo* was determined according to the growth performance of the seedling. The experiment was conducted following a split-plot design with 3 replicates in a nursery bed of Sher-e-Bangla Agricultural University, Bangladesh during 2006 to 2007. Soil substrates of the nursery bed were soil, sand, and farmyard manure (1:1:1 v/v) (Roy et al., 1997). The unit plot size was 1 m². TPS that were harvested under different N x K combinations were sown and grown as described previously (Roy et al., 2005), and the percentage of emerged shoots at 10, 15, and 20 DAS and CoV were recorded.

Seedling vigor was visually evaluated at 21 DAS using 5 staged scales, i.e., 1 = small seedlings with stunted growth, 2 = moderate growth but visually stunted, 3 = good growth, 4 = vigorous, tall plants with green foliage, and 5 = transplantable seedling with vigorous, green, strong stem. At 30 DAS, the seedlings were cut at the soil surface, weighed, oven-dried at 70°C for 72 h, and re-weighed.

5.2.6 Statistical analysis

Analysis of variance was performed according to MSTAT-C statistical software (MSTAT-C, 1991). Means were compared using the LSD test at a 5% probability level.

5.3 Results

5.3.1 Nutrient concentration in TPS as affected by different combination of N and K fertilizers

Nitrogen, P, K, Ca, Mg, and Na concentrations were significantly ($p=0.01$) influenced by different levels of N application. All ions except K showed the highest level when N_{300} was applied (Table 5-1). On the other hand, N, P, and Mg concentrations decreased with increasing K application.

The combined effect of N x K on the nutrient concentration was also significant, except for Ca and Mg (Table 5-1). The highest values of N, P, K, and Na concentrations were obtained when $N_{300} K_{125}$, $N_{225} K_{125}$, $N_{225} K_{175}$, and $N_{225} K_0$ (45.4, 11.4, 8.0, and 2.1 mg g⁻¹ dry weight) were applied, respectively (Table 5-2).

5.3.2 Effect of N x K and TPS size on germination rate and CoV of germination

When N was not applied (N_0), germination of both large and small TPS was strongly inhibited, irrespective of K application level throughout the experimental period (Table 5-3). However, germination rate of TPS changed largely by different K applications even if N was applied together with K; i.e., large TPS showed the highest germination rate (43.0-45.3%) at 6 DAS when $N_{225-300} K_{125}$ was applied, but were largely inhibited (8.6-9.0%) when K_{225} was applied (Table 5-3). Among the small TPS samples the highest germination rate (23.7-18.3%) at 6 DAS was exhibited when $N_{225-300} K_{125}$ was applied, but the rate was less than half of the rate of large TPS, and this lower germination rate of small TPS did not recover even at 12 DAS (Table 5-3).

The combination of $N_{225-300} K_{125}$ also resulted in the highest CoV of germination (10.3-10.4), irrespective of TPS size (Table 5-3).

5.3.3 Performance of TPS in nursery beds

5.3.3.1 Percentage of emerged seedlings

The percentage of emerged seedlings in the nursery beds was significantly influenced by the N x K combination and TPS size (Table 5-4). The rate decreased with increasing K application levels, irrespective of N level or TPS size. Large TPS emerged at rates higher than 90% when N₂₂₅ K₁₂₅ or N₃₀₀ K₁₂₅ was applied (Table 5- 4).

5.3.3.2 CoV of emergence

Coefficient of velocity of emergence was significantly influenced by the N x K combination and TPS size. High CoV of emergence was found in large TPS when N₃₀₀ K₁₂₅, N₃₀₀ K₁₇₅, or N₂₂₅ K₁₂₅ was applied (6.73, 6.65, and 6.64, respectively) (Table 5-4).

5.3.3.3 Seedling vigor

Seedling vigor was also significantly influenced by the N x K combination and TPS size. Among the 12 treatment combinations, large seeds showed the best performance (4.8) compared with all other treatments (less than 4.3) when N₃₀₀ K₁₂₅ was applied (Table 5-4).

5.3.3.4 Seedling weight

Fresh and dry weight of the seedlings was also significantly influenced by the N x K combination and TPS size. Large seeds resulted in the maximum fresh and dry seedling weight when N₃₀₀ K₁₂₅, N₃₀₀ K₁₇₅, or N₂₂₅ K₁₂₅ were applied (6.4 and 0.68 g, 6.23 and 0.64 g, and 6.13 and 0.63 g, respectively) (Table 5-4).

The highest percentage of dry matter was found in seedlings grown from large seeds when N₃₀₀ K₁₂₅ was applied; whereas, the lowest was found in seedlings grown from small seeds when N₀ K₂₂₅ was applied (10.5% and 7.8%, respectively) (Table 5-4).

5.4 Discussion

The concentration of nutrients in TPS was influenced by different levels of N and K fertilizers supplied to the mother plants. Nitrogen level in TPS increased as the N fertilizer level increased and just reverse when K fertilizer level increased. Such a negative interaction between N and K application has also been reported in other seed potato plants (Bester and Maree, 1990).

Different levels of N and K fertilizers supplied to the mother plants also affected the accumulation of other cations in TPS. Potassium application at a high (225 kg ha^{-1}) level resulted in decreases in P, Mg, and Na concentrations in TPS, while N application resulted in increases the same (Table 5-1). Similar negative interactions between N and K fertilizers on cation concentrations in the harvested seeds were also reported in wheat (Karien and Whitney, 1980) and corn (Karien et al., 1987). The negative influence of K application on the accumulation of other cations such as Mg and Na (Table 5-1) also suggests K-Mg and K-Na antagonism as reported by Marschner (1990).

A positive correlation between N application and P and Ca concentrations in TPS was found (Table 5-1) as reported by Karien and Whitney (1980) in wheat. In our experiment, TPS with high N, P, and Ca concentrations also showed the highest emergence rate and seedling vigor (Table 5-4) as reported in tobacco (Thomas and Raper, 1979).

Seed quality, which is shown as high germination rate and high seedling vigor, often correlates with the protein concentration in the seeds (Bhatt et al., 1989). The author further observed that the TPS with high protein concentration germinated faster and developed into larger seedlings. Although the protein concentration in TPS was not measured in our experiment, the protein concentration in seeds correlates well with nitrogen concentration, and it can be roughly calculated by multiplying the percentage of N by 6.25 (Ma and Zuazaga, 1942). In this aspect, TPS with a high N concentration in our experiment also contained high

amounts of protein and showed better seedling performance (Table 5-4). On the contrary, high rates of K application reduced N concentration in TPS (Table 5-1) suggesting that excess K application may inhibit protein synthesis in TPS through interference with N uptake, and reduced the growth performance after germination as Karien et al (1987) reported in corn.

Although the germination rate of TPS *in vitro* was always higher than the emergence rate of the seedling *in vivo* as Gallagher and Nabi (1984) reported previously in TPS, the combination effect of N x K on the germination and emergence rates and their CoV were apparent both *in vitro* and *in vivo*. The highest emergence rate of TPS was always obtained when N₃₀₀ K₁₂₅ or N₂₂₅ K₁₂₅ were applied (data not presented), while the rate became lower as K application increased. Kanzikwera et al (2000, 2001) also found a similar effect of N and K combination on the emergence rate of TPS.

A high CoV indicates that more seeds germinated or more seedlings emerged over a shorter time (Scott and Williams, 1984). In our experiment, both CoV of germination and emergence were always higher as N application increased, while they became lower as K application increased, indicating that N is a key factor for obtaining high CoV. In brinjal and soybean seeds, nitrogen application higher than those required levels for optimal crop production has been recognized to improve the seedling vigor (Delouche, 1980; Van et al., 1982; Gray and Thomas, 1982; Naik et al., 1996). In tomato and tobacco, increased N application to the mother plants increased the seed germination rate and enhanced germination uniformity (Thomas and Raper, 1979; Seno et al., 1987).

In our study, large TPS always performed better in all aspects than small TPS (Tables 5-3 and 5-4). Bhatt et al (1989) reported that TPS size was associated with the quality because large seeds contained higher level of protein than small ones and they germinated faster and had the highest percentage of germination. In our experiment, large TPS that were produced under N₃₀₀ K₁₂₅ showed faster emergence and better seedling growth (Table 5-4).

Lopez and Grabe (1973) also reported that the application of high N to wheat plants increased N concentration in the seeds. In addition, seeds with high N concentration germinated faster and developed into larger seedlings with higher dry matter content.

Although the percentage of emergence of TPS at 20 DAS differed little in both large and small TPS especially when $N_{225} K_{125}$, $N_{225} K_{175}$ or $N_{300} K_{125}$ were applied, plant size at 30 DAS was significantly greater in large TPS than in small TPS (Table 5-4), because small TPS with low N concentration emerged slower and also performed less well in terms of seedling vigor than large TPS as reported by Malagamba (1988) in TPS. Baki (1980) also showed that N in soybean seed was important during seedling growth.

As a conclusion, my results show that application of $N_{225-300} K_{125-175}$ to potato mother plants could improve TPS harvest quality when the quality was evaluated as growth performance both *in vitro* and *in vivo*. The range of this N x K combination was within the range of the best combination ($N_{225} K_{125}$) for obtaining the highest TPS yield from the crossing of MF-II and TPS-67 (Roy et al., 2007b). However, less seedling vigor under $N_{225} K_{125}$ as compared with $N_{300} K_{125}$ (Table 5-4) suggests that the application of N at 225 kg ha^{-1} will be too low for obtaining high quality TPS. This is also confirmed from the view point of harvesting large TPS, where the application of N at 300 kg ha^{-1} was required (Roy et al., 2007b). Therefore, we conclude that 300 kg N and 125 kg K ha^{-1} is the best combination for obtaining not only large TPS (Roy et al., 2007b), but also preferable growth performance of the seedlings.

Table 5-1. Single effect of different levels of nitrogen (N) or potassium (K) fertilizers supplied to the potato mother plant on nutrient concentrations in the harvested TPS

Application (kg ha ⁻¹)	Nutrient concentration in TPS (mg g ⁻¹ dry weight)					
	N	P	K	Ca	Mg	Na
N ₀	37.1 c	8.2 b	5.9 b	2.6 c	3.9 c	1.6 b
N ₂₂₅	42.4 b	10.2 a	7.2 a	3.7 b	4.4 b	1.7 a
N ₃₀₀	43.4 a	10.0 a	6.0 b	3.8 a	4.5 a	1.7 a
K ₀	41.1 b	9.5 b	5.8 b	3.5	4.6 a	1.8 a
K ₁₂₅	43.1 a	10.2 a	6.5 a	3.4	4.4 b	1.6 b
K ₁₇₅	40.8 b	9.5 b	6.7 a	3.3	4.1 b	1.6 b
K ₂₂₅	38.9 c	8.8 c	6.5 a	3.3	4.0 c	1.6 b
Significance						
N	**	**	*	**	**	**
K	**	**	**	NS ^z	**	**
N x K	*	**	**	NS	NS	*

N₀ to N₃₀₀ and K₀ to K₂₂₅ indicate that nitrogen and potassium were applied at 0 to 300 kg ha⁻¹ and 0 to 225 kg ha⁻¹, respectively.

*, ** Significant at p= 0.05 and 0.01, respectively.

Different letters within each column indicate significant differences by LSD test at p=0.05.

^z Non-significance

Table 5-2. Combined effect of different levels of N x K fertilizer supplied to the potato mother plants on N, P, K, Ca, Mg, and Na concentrations in the harvested TPS

Fertilizer (N x K)	Nutrient concentration in TPS (mg g ⁻¹ dry weight)					
	N	P	K	Ca	Mg	Na
N ₀ K ₀	37.8	8.4	5.6	2.6	4.4	1.5
N ₀ K ₁₂₅	39.5	8.4	5.8	2.5	3.9	1.5
N ₀ K ₁₇₅	37.8	8.1	6.1	2.5	3.6	1.6
N ₀ K ₂₂₅	33.3	8.0	6.2	2.8	3.7	1.7
N ₂₂₅ K ₀	42.4	9.1	5.7	3.8	4.7	2.1
N ₂₂₅ K ₁₂₅	44.0	11.4	6.9	3.7	4.5	1.8
N ₂₂₅ K ₁₇₅	41.8	10.6	8.0	3.6	4.2	1.6
N ₂₂₅ K ₂₂₅	41.3	9.6	7.2	3.6	4.1	1.7
N ₃₀₀ K ₀	43.0	11.0	6.1	4.0	4.8	1.6
N ₃₀₀ K ₁₂₅	45.4	10.7	5.8	3.9	4.7	1.7
N ₃₀₀ K ₁₇₅	42.4	9.4	6.1	3.7	4.4	1.3
N ₃₀₀ K ₂₂₅	41.9	8.9	6.1	3.6	4.2	1.4
Mean	41.0	9.5	6.4	3.4	4.3	1.6
LSD (0.05) ^z	3.14	0.46	0.52	NS ^y	NS	0.26

^z LSD(p=0.05) for comparing means in column.

^y Non-significance

Table 5-3. Combined effect of different levels of N x K fertilizer supplied to the potato mother plants on the percentage of germination at 6, 9, and 12 DAS and CoV of germination of harvested TPS sown in Petri dishes

Fertilizer Combination x seed size ^z	Germination (%)			CoV of germination
	6 DAS	9 DAS	12 DAS	
N ₀ K ₀ x Large	2.7	16.1	44.0	9.1
N ₀ K ₀ x Small	0.0	9.3	37.6	8.8
N ₀ K ₁₂₅ x Large	7.0	34.6	72.0	9.3
N ₀ K ₁₂₅ x Small	1.3	14.0	59.3	8.8
N ₀ K ₁₇₅ x Large	4.3	27.3	67.0	9.2
N ₀ K ₁₇₅ x Small	1.0	12.0	49.7	8.8
N ₀ K ₂₂₅ x Large	3.0	20.0	62.7	9.0
N ₀ K ₂₂₅ x Small	0.3	13.7	49.3	8.8
N ₂₂₅ K ₀ x Large	18.7	58.0	72.3	9.9
N ₂₂₅ K ₀ x Small	11.3	42.3	60.0	9.7
N ₂₂₅ K ₁₂₅ x Large	43.0	89.6	95.7	10.3
N ₂₂₅ K ₁₂₅ x Small	23.7	70.7	81.0	10.0
N ₂₂₅ K ₁₇₅ x Large	37.0	87.0	90.7	10.2
N ₂₂₅ K ₁₇₅ x Small	16.0	62.3	77.3	9.8
N ₂₂₅ K ₂₂₅ x Large	8.6	40.3	72.3	9.5
N ₂₂₅ K ₂₂₅ x Small	8.0	23.7	55.3	9.4
N ₃₀₀ K ₀ x Large	21.0	57.0	75.7	9.9
N ₃₀₀ K ₀ x Small	12.0	40.0	61.3	9.7
N ₃₀₀ K ₁₂₅ x Large	45.3	94.7	97.7	10.4
N ₃₀₀ K ₁₂₅ x Small	18.3	68.3	80.3	9.9
N ₃₀₀ K ₁₇₅ x Large	36.0	86.0	89.7	10.2
N ₃₀₀ K ₁₇₅ x Small	15.3	60.6	80.0	9.8
N ₃₀₀ K ₂₂₅ x Large	9.0	20.0	55.7	9.4
N ₃₀₀ K ₂₂₅ x Small	7.0	13.0	38.7	9.4
CV (%)	12.41	6.34	3.93	0.85
LSD (0.05) ^y	2.97	4.58	4.37	0.14

^z TPS were classified into large and small sizes (>1.18 mm and 1.00-1.18 mm, respectively).

^y LSD(p=0.05) for comparing means in columns

Table 5-4. Combined effect of different levels of N x K fertilizer supplied to the potato mother plants on the percentage of emerged seedlings at 10, 15, and 20 DAS, CoV of emergence, seedling vigor, seedling fresh weight, seedling dry weight, and percentage of dry matter of harvested TPS grown in nursery beds

Fertilizer combination x seed size ^z	Emergence (%)			CoV of emergence	Seedling Vigor	Seedling wt. (g)		% Dry matter
	10 DAS	15 DAS	20 DAS			Fresh	Dry	
N ₀ K ₀ x Large	70.0	74.3	79.3	6.58	2.7	4.70	0.45	9.5
N ₀ K ₀ x Small	30.0	39.7	50.0	6.32	2.1	3.10	0.29	9.2
N ₀ K ₁₂₅ x Large	76.3	81.0	84.0	6.60	2.9	5.10	0.47	9.2
N ₀ K ₁₂₅ x Small	47.0	61.0	67.7	6.42	2.5	3.30	0.30	9.0
N ₀ K ₁₇₅ x Large	68.0	72.0	78.0	6.57	2.6	4.63	0.42	9.0
N ₀ K ₁₇₅ x Small	16.3	30.0	59.3	5.87	1.9	3.20	0.28	8.7
N ₀ K ₂₂₅ x Large	62.0	67.3	66.7	6.62	2.2	4.01	0.38	8.7
N ₀ K ₂₂₅ x Small	12.0	37.0	57.3	5.80	1.7	3.23	0.27	7.8
N ₂₂₅ K ₀ x Large	77.3	83.3	86.0	6.60	3.7	5.67	0.56	10.0
N ₂₂₅ K ₀ x Small	50.3	60.3	68.7	6.45	3.3	4.10	0.37	9.4
N ₂₂₅ K ₁₂₅ x Large	90.7	92.3	94.3	6.64	4.1	6.13	0.63	10.3
N ₂₂₅ K ₁₂₅ x Small	53.3	78.7	88.3	6.33	3.5	4.83	0.48	9.9
N ₂₂₅ K ₁₇₅ x Large	73.0	78.0	82.0	6.58	3.3	5.83	0.60	10.2
N ₂₂₅ K ₁₇₅ x Small	50.0	71.7	81.3	6.34	2.5	4.87	0.47	9.6
N ₂₂₅ K ₂₂₅ x Large	68.0	73.0	75.3	6.60	3.0	5.87	0.58	9.8
N ₂₂₅ K ₂₂₅ x Small	30.3	45.0	58.0	6.24	2.0	4.43	0.42	9.5
N ₃₀₀ K ₀ x Large	83.0	88.7	89.3	6.71	4.3	4.93	0.51	10.3
N ₃₀₀ K ₀ x Small	47.3	57.0	66.7	6.42	3.5	4.01	0.41	10.1
N ₃₀₀ K ₁₂₅ x Large	90.3	92.3	94.0	6.73	4.8	6.40	0.68	10.5
N ₃₀₀ K ₁₂₅ x Small	52.0	80.0	87.0	6.33	3.6	4.39	0.44	9.9
N ₃₀₀ K ₁₇₅ x Large	79.7	81.0	83.0	6.65	3.6	6.23	0.64	10.2
N ₃₀₀ K ₁₇₅ x Small	44.7	61.7	62.0	6.45	2.7	4.09	0.39	9.4
N ₃₀₀ K ₂₂₅ x Large	65.0	73.3	75.0	6.57	2.6	5.97	0.60	10.0
N ₃₀₀ K ₂₂₅ x Small	25.0	47.0	53.0	6.20	1.7	4.03	0.35	8.7
CV (%)	5.23	11.39	4.58	0.97	5.79	4.58	3.52	2.77
LSD (0.05) ^y	5.0	13.01	5.69	0.10	0.29	0.36	0.05	0.45

^z TPS were classified into large and small sizes (>1.18 mm and 1.00- 1.18 mm, respectively).

^y LSD(p=0.05) for comparing means in columns

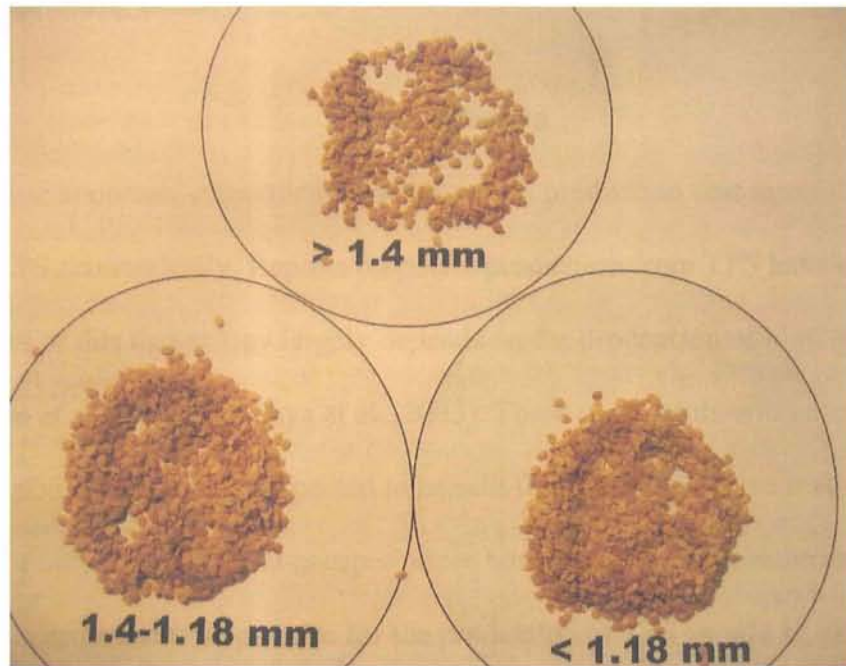


Figure 5-1. Different size TPS

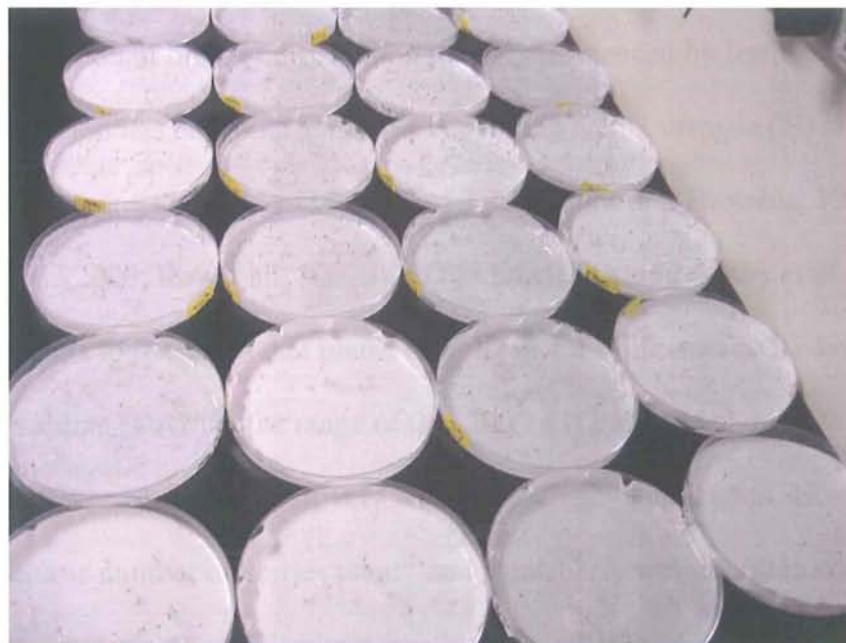


Figure 5-2. Seed quality tests *in vitro* of experiment 5

Chapter 6

True potato seed production and its economic analysis as influenced by supplemental nitrogen and planting density

6.1 Introduction

The most important component to achieve TPS production commercially is to produce high quality TPS economically. Reports on potato production from TPS have emphasized that the success of this technology largely depends on the production of high quality TPS at low cost (Islam et al., 2000; Upadhyaya et al., 2003). These two factors will ensure that farmers in developing countries, who are expected to benefit from this alternative method of potato production, not only get the TPS at cheaper prices but also assure maximum production. Therefore, an appropriate field practice for the production of TPS should be established following the introduction of advanced technologies for potato production from TPS (Simmonds, 1997; Golmirzaie and Ortiz, 2004).

The production of high quality seed is strongly influenced by fertilizers (George and Varis, 1980; Almekinders and Wiersema, 1991). Among them, nitrogen (N) is the most important for improving the yield and quality of TPS (Pallais and Espinola, 1992; Kanzikwera et al., 2000; Roy et al., 2007b). In our previous studies (Roy et al., 2007a,b), we applied N fertilizers to potato mother plants (MF-II) in 4 installments at 10 day intervals from 30 days after planting (DAP) at the range of 0 to 200 kg N ha⁻¹, and showed that the quality of harvested TPS was correlated positively with increasing N application. However, yield components such as number of berries plant⁻¹ and mean berry weight, often correlated negatively with increasing N application when N was applied as 4 separate applications during flowering through to seed developmental stages. This was probably mainly due to a competition for N absorption between tubers and inflorescences (Kinet et al., 1985), because 8.3 to 9.6 t ha⁻¹ of tubers was also produced in our previous studies (data not shown). A similar trend of TPS and tuber production has also been reported by Dayal et al (1984) and

Pallais et al (1987). Thus, 4 separate applications of N at 10 day intervals from 30 DAP is not optimal for the production of high quality TPS. On the other hand, tuberization was inhibited without preventing the steady growth of shoots and roots when N was applied to potato plants at 7 day intervals (Maingi et al., 1994; Banik, 2005), suggesting that competition for N uptake between tubers and inflorescences could be avoided by more frequent N applications.

Planting density (PD) also affects the production of TPS. Almekinders (1991) showed that higher stem density increased the number of berries plant⁻¹ and TPS yield but decreased 100-TPS weight. Therefore, the best combination of supplemental N and PD for TPS production should be clarified.

However, such an optimal combination that is obtained by studies of different combinations of supplemental N and PD on the yield and quality of TPS will not be accepted commercially if the combination ignores its economical benefit. Therefore, economic return must be considered as well as clarifying the effect of the combination.

Therefore, the objective of the present study was to evaluate how supplemental N fertilizer and PD affect the yield and quality of TPS. The results were also evaluated for the economic aspects.

6.2 Materials and Methods

The experiment was conducted at the experimental field of the TCRC, BARI, Gazipur, Bangladesh, during 2006 to 2007. The soil characteristics were pH 6.8 (Jackson, 1962) with 1.65% organic matter, 0.096% N, 0.001% available P, 0.131 me% exchangeable K, and 0.00123% available S.

On 19 October 2006, sprouted tubers (50-60 g) of the female parent (MF-II) were planted in the experimental plots of TCRC at a depth of 5 cm. In contrast to the standard procedures for growing potato mother plants (Roy et al., 2007a), the experimental plots were

not hilled to prevent tuberization. The above ground stolons were pruned soon after emergence for better growth of the main shoots. Two to four haulms per tuber were allowed to grow to obtain small, medium, and high PD (8, 12, and 16 potato haulms m⁻², respectively, and hereafter described as PD₈, PD₁₂, and PD₁₆, respectively). Each haulm was supported on trellises. Considering the findings of our previous studies (Roy et al., 2007a, b), N:P:K:Gypsum:ZnSO₄:Borax (150:120:125:120:12:6 kg ha⁻¹) and farm yard manure (10 t ha⁻¹) were applied 3 days before planting as a basal fertilizer.

Four different levels of N (0, 21.4, 28.6, and 35.7 kg ha⁻¹, respectively) were applied supplementary at a depth of 3 to 5 cm and 10 to 15 cm apart from the mother plants, when the first flower bud commenced (27 DAP). This supplemental N application was conducted 7 times at 7 day intervals as described above. Therefore, the total amount of supplemental N application was 0, 150, 200, and 250 kg N ha⁻¹ for each treatment (hereafter described as N₀, N₁₅₀, N₂₀₀, and N₂₅₀ kg N ha⁻¹, respectively).

The experiment was conducted in a split-plot design with 3 replications. Supplemental N was assigned to main-plots and PD to sub-plots. The distance between two rows was 1 m and each seed potato was planted at a distance of 0.25 m apart in a row. The sub-plot was a single row 3 m long and each consisted of 12 plants.

On 12 October 2006, the male parent (TPS-67) was planted in separate plots to harmonize their flowering with the female parent. Only the first and second inflorescence on a stem was allowed to develop for pollination (Almekinders and Wiersema, 1991), and each inflorescence was pruned to 6 flower buds of similar maturity to equalize the date of anthesis. Berries were harvested when they became soft (approximately 6-7 weeks after pollination) and classified into large- (> 10 g) and small-(<10 g) berries. Ten berries from each weight class were selected per replication. All other practices and procedures of production, extraction, and drying of TPS were same as those described in the previous report (Roy et al.,

2007a). After proper drying, TPS were separated into three sizes of small-(1.00-1.18 mm), medium-(1.18-1.4 mm), and large-(>1.4 mm) seeds using testing sieves (Tokyo Screen, Japan).

The benefit cost ratio (BCR) of TPS production under different combinations of supplemental N and PD was estimated from the cost of production, gross return, and net return according to standard labor/material costs of Bangladesh (BADC, 2006).

The analysis of variance was carried out using MSTAT-C statistical software (MSTAT-C, 1991). Means were compared using the LSD test at a 5% probability level.

6.3 Results

6.3.1 Single effect of supplemental N and planting density on plant growth and TPS production

Plant height increased significantly ($p=0.01$) with increasing supplemental application of N fertilizer (Table 6-1). The highest plant height (117.9 cm) was obtained at N_{250} . Supplemental N application significantly ($p=0.01$) affected all characteristics of berry and TPS (Table 6-1). Among them, number of berries plant⁻¹ (28.4 and 14.1 for small and large berries, respectively), mean berry weight (10.9 g), number of seeds berry⁻¹ (175 and 267 for small and large berries, respectively), and yield of TPS (148.0 kg ha⁻¹) showed maximum values at N_{0-150} , but the values decreased thereafter as N application increased, irrespective of berry size. Only mean weight of 100-TPS showed a maximum value at N_{250} , irrespective of berry size (84.4 and 85.1 mg for small and large berries, respectively), but the value did not change significantly between N_{200} and N_{250} .

PD also significantly ($p=0.01$) affected the plant height and all berry and TPS characteristics (Table 6-1). Plant height at 70 DAP was the highest (115.7 cm) at PD_8 , but it decreased thereafter as PD increased. Among the characteristics of berries and TPS, mean

berry weight (10.9 g), number of seeds berry⁻¹ (187 and 265 for small and large berries, respectively), weight of 100-TPS (81.4 and 82.1 mg for small and large berry, respectively), and mean weight of 100-TPS (81.7 mg) showed the maximum values at PD₈, but these values decreased thereafter as PD increased. Only the number of large berries plant⁻¹ (36.6) and yield of TPS (137.6 kg ha⁻¹) showed maximum values at PD₁₆, and the values tended to decrease as PD decreased.

Although the weight of 100-TPS changed significantly as supplemental N application or PD changed, irrespective of berry size, the values did not differ apparently between small and large berries.

6.3.2 Combined effect of supplemental N and planting density on plant growth and TPS production

The combination of different levels of supplemental N and PD significantly ($p=0.01$) affected plant height (Table 6-2). The highest plant height (125.7 cm) was recorded at N₂₅₀ PD₈. The maximum values of the number of berries plant⁻¹ (39.0 and 18.7 for small and large berries, respectively), mean berry weight (11.7 g), number of TPS berry⁻¹ (205 and 294 for small and large berries, respectively), and mean number of TPS berry⁻¹ (249) were obtained with the combinations of N₀₋₁₅₀ PD₈₋₁₆, irrespective of berry size (Table 6-2). On the other hand, the maximum values of the weight of 100-TPS were obtained with the combination of N₂₅₀ PD₈ (86.0, 86.4, and 86.2 mg for small, large berries, and mean weight of 100-TPS, respectively).

6.3.3 Combined effect of supplemental N and planting density on the yield of TPS

Total yield of TPS higher than 150 kg ha⁻¹ was obtained with the combination of N₁₅₀₋₂₀₀ PD₁₂₋₁₆ (Table 6-2). However, among different TPS sizes, the maximum yield was

obtained with the combination of N_{200} PD₁₂ for large TPS, N_{150} PD₁₆ for medium TPS, and N_0 PD₁₆ for small TPS (56.5, 70.7, and 77.2 kg ha⁻¹, respectively) (Table 6-3).

6.3.4 Economic analysis

The cost and return analysis made under different treatment combinations demonstrated that the total cost of production was the most expensive in N_{200} PD₁₂ (US\$ 15,052.0 ha⁻¹), whereas the cheapest was at N_0 PD₈ (US\$ 14,037.8 ha⁻¹) (Table 6-4). The highest gross return, net return, and benefit cost ratio (BCR) (US\$ 28,552.1 ha⁻¹, US\$ 13,500.1 ha⁻¹, and 1.90, respectively) were also obtained with the combination of N_{200} PD₁₂ and this combination was found to be more profitable than the other treatment combinations (Table 6-4). The calculations based on the present information showed that under Bangladesh conditions of land and labor, the cost of production of one kg of hybrid TPS would be US\$ 120.5 (Table 6-4).

6.4 Discussion

The number of large berries plant⁻¹, mean berry weight, number of TPS berry⁻¹, and yield of TPS showed maximum values when lower than N_{200} was applied as supplemental dressing, irrespective of berry size (Table 6-1). Although only plant height and mean weight of 100-TPS increased with increasing supplemental N, the weight of 100-TPS was similar between N_{200} and N_{250} (Table 6-1). Application of N also accelerates the tuberization in potato plants when it is discontinued (Krauss, 1978), and the growth of aerial parts including shoots and fruits is often prevented by the rapid tuberization because of the competition for N uptake (Pallais, 1987; Zrust, 1992). On the other hand, rapid tuberization can be prevented when N is applied inter-spatially, because of successive growth of above-ground parts (Krauss, 1978; Maingi, et al., 1994). In our experiment, N was applied in 7 installments at 7

day intervals from 27 DAP to prevent high competition between above-ground parts and tubers for N uptake, but the role of supplemental N application was maximal at N₂₀₀ or lower (Table 6-1). These results suggest that the decrease in reproductive growth at N₂₅₀ might be due to a competition for N uptake among aerial parts such as shoots and fruits (Kanzikwera et al., 2001). Thus, N₂₅₀ can be concluded as supra-optimal to obtain maximum reproductive growth.

Although high PD (>12 m⁻²) resulted in the maximum number of berries plant⁻¹ and TPS yield, all other harvesting factors were better at the lowest PD (8 m⁻²), irrespective of berry size (Table 6-1). Almekinders (1991) also showed a similar relationship between berry/seed size and PD. Effects of PD are generally attributed to the competition for light, water, and nutrients. In our experiment, nitrogen supply and soil moisture were adjusted, but still a competition for light between stems would occur because stem internodes became longer as PD increased (data not shown).

Although 100-TPS weight increased with increasing supplemental N, irrespective of berry size, the values were similar between large and small TPS (Table 6-1). This result indicates that small berries contain fewer but heavier TPS than large berries, irrespective of PD and supplemental N level. Thus, the assumption that smaller berries must possess lighter TPS is not supported.

The combination effect of supplemental N application and PD showed that the maximum yield of TPS was obtained with the combination N₁₅₀ PD₁₆ (Table 6-2). However, in the previous report (Roy et al., 2007c) we showed that the yield of large TPS was crucial for obtaining seedlings with excellent growing performance after germination. In this aspect, the combination of N₁₅₀₋₂₀₀ PD₁₂ will be better, because the maximum yield of large TPS was obtained with these combinations (Table 6-3).

The result of combination effect of supplemental N application and PD (Table 6-2) revealed that N₀₋₁₅₀ PD₈₋₁₆ and N₂₅₀ PD₈ were the best combinations when the objective of TPS production was focused on number of berries plant⁻¹ or number of TPS berry⁻¹ and weight of 100-TPS, respectively, irrespective of the size of harvested TPS. However, from the economic point of view, the combination of N₂₀₀ PD₁₂ was found to be most profitable compared to other treatment combinations in respect of gross returns, net returns, and BCR values (Table 6-4). This combination was also produced the maximum yield of marketable TPS (> 1.18 mm size). The price of hybrid TPS is still high (US \$ 228.6 kg⁻¹), and not within the reach of majority farmers. It would be reduced either by increasing the yield of quality TPS or by applying appropriate crop management practices.

Therefore, in the commercial aspect 200 kg N ha⁻¹ of supplemental N application in 7 separate installments at 7 day intervals starting from 27 DAP and 3 stems tuber⁻¹ (12 stems m⁻²) is the most suitable combination to produce high quality TPS from ♀MF-II X ♂TPS-67.

Table 6-1. Single effect of supplemental N application or planting density on plant height and berry and TPS characteristics in MF-II X TPS-67

Treatment	Plant height at 70 DAP	NBPP ^z		Mean berry wt. (g)	NSPB ^y		Wt. of 100-TPS (mg)		Mean wt. of 100-TPS (mg)	Yield of TPS (kg ha ⁻¹)
		Small Berry	Large berry		Small berry	Large berry	Small berry	Large berry		
Supplemental N application (kg ha ⁻¹)										
0	92.2 d	28.4 a	6.0 c	9.4 c	145 c	240 b	67.9 c	68.2 c	68.1 c	93.3 c
150	108.8 c	20.0 c	14.1 a	10.9 a	175 a	267 a	83.4 b	84.0 b	83.7 b	148.0 a
200	114.1 b	21.0 bc	13.4 ab	10.3 b	172 a	247 b	84.2 a	84.8 a	84.5 a	141.6 a
250	117.9 a	22.3 b	12.1 b	9.1 c	152 b	214 c	84.4 a	85.1 a	84.8 a	122.1 b
Planting density (number of potato haulms m ⁻²)										
PD ₈ (2) ^x	115.7 a	12.7 c	10.9 b	10.9 a	187 a	265 a	81.4 a	82.1 a	81.7 a	93.3 c
PD ₁₂ (3)	108.4 b	20.6 b	14.3 a	10.1 b	155 b	251 b	80.1 b	80.8 b	80.6 b	133.2 b
PD ₁₆ (4)	100.7 c	36.6 a	9.0 c	8.8 c	140 c	238 c	78.4 c	78.8 c	78.7 c	137.6 a
Significance										
N	**	**	**	**	**	**	**	**	**	**
PD	**	**	**	**	**	**	**	**	**	**
N x PD	*	*	NS ^w	*	*	*	*	*	*	**

^zNo. of berries plant⁻¹, ^yNo. of seeds berry⁻¹.

^xNo. in parenthesis indicates the number of potato haulms tuber⁻¹.

*, ** Significant at p= 0.05 and 0.01, respectively.

Different letter(s) within columns indicate a significant difference by LSD test at p=0.05.

^w Non-significance

Table 6-2. Combined effect of supplemental N application and planting density on plant height and berry and TPS characteristics in MF-II X TPS-67

Treatment Combination	Plant height at 70 DAP (cm)	No. of berries plant ⁻¹		Mean berry wt. (g)	No. of TPS berry ⁻¹		Mean no. of TPS berry ⁻¹	Wt. of 100-TPS (mg)		Mean 100-TPS wt. (mg)	Yield of TPS (kg ha ⁻¹)
		Small berry	Large berry		Small berry	Large berry		Small berry	Large berry		
N ₀ PD ₈	101.0	17.7	6.0	10.4	156	251	203	69.6	70.2	69.9	74.6
N ₀ PD ₁₂	95.3	28.7	6.3	9.6	143	238	191	67.5	68.1	68.4	95.2
N ₀ PD ₁₆	80.3	39.0	5.7	8.0	136	232	184	66.5	66.4	66.7	110.3
N ₁₅₀ PD ₈	115.3	11.0	13.0	11.7	205	294	249	84.3	85.2	84.6	138.8
N ₁₅₀ PD ₁₂	109.0	16.3	18.7	10.8	167	259	233	83.9	84.6	84.3	155.3
N ₁₅₀ PD ₁₆	102.0	32.7	10.7	10.3	151	248	219	81.7	82.0	81.9	160.1
N ₂₀₀ PD ₈	120.7	10.3	13.0	11.3	202	270	236	85.5	86.1	85.8	120.1
N ₂₀₀ PD ₁₂	113.3	18.0	17.3	10.5	165	240	223	84.2	85.0	84.9	151.3
N ₂₀₀ PD ₁₆	108.3	34.7	10.0	9.0	147	229	208	82.9	83.2	83.1	153.3
N ₂₅₀ PD ₈	125.7	11.7	11.7	10.1	186	243	214	86.0	86.4	86.2	108.3
N ₂₅₀ PD ₁₂	116.6	19.3	15.0	9.4	145	208	193	84.6	85.5	85.1	126.3
N ₂₅₀ PD ₁₆	112.0	36.0	9.7	7.9	126	190	173	82.6	83.4	82.9	131.7
LSD (0.05) ^x	4.83	2.2	2.6	0.66	15.8	13.0	11.3	0.6	0.7	0.7	8.3

N₀ to N₂₅₀ and PD₈ to PD₁₆ indicate that supplementary nitrogen was applied at the rate of 0 to 250 kg ha⁻¹ and potato haulms were allowed to grow 8 to 16 m⁻², respectively. See Table 6-1 for details.

^x LSD (p=0.05) for comparing means in columns

Table 6-3. Combined effect of supplemental N application and planting density on the yield of TPS of different sizes

Treatment Combination	Yield of different size TPS ^z (kg ha ⁻¹)		
	1.00-1.18 mm	1.18-1.4 mm	> 1.4 mm
N ₀ PD ₈	48.7	17.7	8.2
N ₀ PD ₁₂	63.8	21.9	9.5
N ₀ PD ₁₆	77.2	23.7	9.4
N ₁₅₀ PD ₈	37.3	53.9	47.8
N ₁₅₀ PD ₁₂	37.4	67.3	50.6
N ₁₅₀ PD ₁₆	49.4	70.7	40.0
N ₂₀₀ PD ₈	15.9	55.6	48.6
N ₂₀₀ PD ₁₂	26.4	68.4	56.5
N ₂₀₀ PD ₁₆	36.5	67.4	49.4
N ₂₅₀ PD ₈	11.8	49.1	47.4
N ₂₅₀ PD ₁₂	17.5	60.1	49.1
N ₂₅₀ PD ₁₆	25.9	60.2	45.6
LSD (0.05) ^y	5.74	3.35	3.66

^z Seed size 1.00-1.18 mm, 1.18-1.4 mm, and > 1.4 mm were counted as small, medium, and large size TPS, respectively. N₀ to N₂₅₀ and PD₈ to PD₁₆ indicate that supplementary nitrogen was applied at the rate of 0 to 250 kg ha⁻¹ and potato haulms were allowed to grow 8 to 16 m⁻², respectively. See Table 6-1 for details.

^y LSD (p=0.05) for comparing means in columns

Table 6-4. Estimation of cost and return in hybrid TPS production in Bangladesh as influenced by different levels of supplemental N and planting density

Treatment combination	Cost of N fertilizer and seed treating chemicals used for the treatments (US \$ ha ⁻¹) ^z	Total cost of production (US \$ ha ⁻¹) ^y	Yield of marketable TPS (kg ha ⁻¹) ^x	Gross return ^w (US \$ ha ⁻¹)	Net return ^v (US \$ ha ⁻¹)	Benefit cost ratio ^u (BCR)
N ₀ PD ₈	170.0	14037.8	25.9	5920.0	- 8117.8	-0.42
N ₀ PD ₁₂	201.1	14079.8	31.4	7178.0	- 6901.8	-0.51
N ₀ PD ₁₆	210.7	14092.7	33.1	7566.7	- 6526.0	-0.54
N ₁₅₀ PD ₈	631.4	14862.5	101.7	23248.6	8386.1	1.56
N ₁₅₀ PD ₁₂	723.3	14986.0	117.9	26951.9	11965.9	1.79
N ₁₅₀ PD ₁₆	682.6	14931.1	110.7	25306.0	10374.9	1.69
N ₂₀₀ PD ₈	655.1	14894.1	104.2	23820.1	8926.0	1.60
N ₂₀₀ PD ₁₂	772.2	15052.0	124.9	28552.1	13500.1	1.90
N ₂₀₀ PD ₁₆	726.4	14990.2	116.8	26700.5	11710.3	1.78
N ₂₅₀ PD ₈	621.0	14848.1	96.5	22059.9	7211.8	1.49
N ₂₅₀ PD ₁₂	692.3	14944.2	109.1	24940.3	9996.1	1.67
N ₂₅₀ PD ₁₆	673.6	14919.0	105.8	24185.9	9266.9	1.62

N₀ to N₂₅₀ and PD₈ to PD₁₆ indicate that supplementary nitrogen was applied at the rate of 0 to 250 kg ha⁻¹ and potato haulms were allowed to grow 8 to 16 m⁻², respectively. See Table 6-1 for details.

^z Price of N fertilizer (Urea) and seed treating chemicals (GA₃, HCl, KOH, and Clorox).

^y Total cost of production = Total input cost + Miscellaneous cost (5% of the total non-material and material cost) + Over head cost (interest on running capital, depending on the amount input cost @ 14% per year for 6 months) + Total cost of production of 0.02 ha of Male parent.

^x Marketable TPS yield means > 1.18 mm size TPS.

^w Gross return = Yield of marketable TPS x price of TPS (sale rate fixed by BADC US \$ 228.6 kg⁻¹).

^v Net return = Gross return – total cost of production.

^u BCR = Gross return (US \$ ha⁻¹) / Total cost of production (US \$ ha⁻¹)



Figure 6-1. Field of experiment 6



Figure 6-2. Berries of experiment 6