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The Production and Utilization of Seed Tubers Derived from True Potato Seed

by

Siert G. Wiersema

A thesis submitted for the degree of
Doctor of Philosophy

University of Reading

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U N I V E R S I T Y O F R E A D I N G

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ABSTRACT

Poor seed tuber quality and high costs of healthy seed tubers may hamper potato production in developing countries. Potato production from seed tubers derived from true potato seed (seedling tubers) combines the rapid plant development from seed tubers with the high health standard and low cost of true seed. A study was carried out at CIP, Lima, Peru during 1981-1983 with the objectives of developing methods of production of seedling tubers and evaluating the performance of seedling tubers in comparison with alternative planting material.

To optimize growing conditions seedling tubers were produced in nursery beds containing a suitable medium. Fertilizer use was investigated with particular reference to detrimental effects of high salt concentrations on seedling growth. Direct sowing in beds gave similar tuber yields to transplanted seedlings and reduced the total growing period from sowing. The application of additional medium to direct-sown beds after seedling emergence increased tuber number. The highest yield (12 kg m^{-2} bed) and the highest number (1242 m^{-2} bed) of useable tubers (>1 g) were obtained with 150 plants m^{-2} bed. Application of B nine did not increase tuber weight or number.

The quality of seedling tubers with respect to health and size was evaluated. The total yield from 1-20 g

seedling tubers was more closely related to the seedling-tuber rate than to the number of above-ground stems. The tendency to produce relatively small tubers increased with decreasing seedling tuber size; causes of this tendency and implications are discussed.

The comparison of the performance of seedling tubers with that of seedling transplants and clonal seed tubers was influenced by true -seed line, transplanting method, length of the growing period and rate and size of seedling tubers.

A method for evaluating the potential for adoption of this system of seed-potato production was presented.

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ABBREVIATIONS

APLV	-	Andean potato latent virus
APMV	-	Andean potato mottle virus
B nine	-	N-dimethyl aminosuccinamic acid
C	-	degree celcius
CCC	-	cycocel
CIP	-	International Potato Center
cm	-	centimeter
CPE	-	centrally planned economies
CV	-	coefficient of variation
EC	-	electrical conductivity
ELISA	-	enzyme-linked immuno-sorbent assay
et al.	-	and others
Exp.	-	experiment
Fig.	-	figure
g	-	gram
GA	-	gibberellic acid
ha	-	hectare
K	-	potassium
K_2O	-	potash
kg	-	kilogram
LAI	-	leaf area index
LSD	-	least significant difference
m	-	meter
Max	-	maximum
Min	-	minimum
mm	-	millimeter
mmho	-	millimohs
N	-	nitrogen
No.	-	number
NS	-	not significant
OP	-	open pollinated
P	-	phosphorus
P_2O_5	-	phosphate
PLRV	-	potato leaf roll virus

ppm	-	parts per million
PSTV	-	potato spindle tuber viroid
PVS	-	potato virus S
PVX	-	potato virus X
PVY	-	potato virus Y
SE	-	standard error
t	-	ton(s)
TPS	-	True Potato Seed

Chapter One
INTRODUCTION

1.1 Problems associated with the use of seed tubers

The most important factors influencing the yield of a potato crop are environmental conditions during growth, agronomic practices, genetic yield potential and the physiological status and health of the seed tubers. Several diseases and pests are transmitted by the tuber resulting in degeneration of seed tuber stocks during their multiplication. Organizations of various degrees of complexity have been developed to produce seed tubers of adequate health standard for the production of consumer potatoes. In addition, appropriate storage structures are required to ensure an appropriate physiological condition of the seed tubers at the time of planting. The technical and institutional complexity of the seed potato industry has prohibited the development of such an industry in many developing countries, while importation of healthy seed tubers from the temperate zone is often expensive. This has resulted in the limited availability and high costs of healthy seed tubers in most of the potato growing developing countries. The costs of seed tubers in these countries can account for more than half of the total production costs (International Potato Center, unpublished).

Furthermore, seed tubers are bulky and perishable, creating transport problems to distant or inaccessible production areas. Areas suitable for the production of ware potatoes but not for seed potatoes, often cannot grow the crop for this reason. Also, in areas where potatoes

have been introduced recently, seed tubers are often the source of disease and pest introduction.

These problems and the high costs associated with the use of seed tubers may hamper the adoption and expansion of potato production in developing countries. Furthermore, the amount of seed tubers required for planting represents food that cannot be consumed. In developing countries where yields are often low this may represent as much as 18% of the total production (Table 1).

These problems associated with the use of seed tubers have led to the search for alternative planting materials for the production of potatoes.

1.2 Potential role of true seed in potato production

True potato seed (TPS) can potentially overcome some of the problems associated with the use of seed tubers. Disease transmission by TPS is of little importance compared with that by seed tubers. TPS is known to transmit only a limited number of viruses and one viroid (Jones, 1982) while only the viroid, potato spindle tuber viroid, is generally considered to pose a potential problem. Also storage is relatively simple compared with that of seed tubers. TPS can be stored for several years at room temperature with little loss in germination capacity (Wollenweber, 1942; Haig, 1952; Simmonds, 1968). Since storage and also transport of TPS is relatively simple, TPS can be easily distributed to any distant potato growing

Table 1. Proportion of total potato production used as planting material by World Region, 1972-74*

Region	Total domestic availability (%)	Seed tubers (%)
WORLD	100	13.9
Developed Market Economies	100	8.9
North America	100	7.9
Western Europe	100	9.2
Oceania	100	7.6
Other	100	8.3
Developing Market Economies	100	14.5
Africa	100	18.1
Latin America	100	12.9
Near East	100	13.1
Far East	100	16.4
Centrally Planned Economies	100	15.8
Asian CPE	100	8.3
Eastern Europe and USSR	100	17.4

* From International Potato Center (1982 a)

area thus making production of the crop less dependent on infrastructure. These attributes of TPS would make it a potentially low cost planting material.

The use of TPS as planting material also prerents some disadvantages. Crops grown from TPS are less uniform in plant type and maturity, while the tubers produced from them may show more variation in shape, colour and dry matter than tubers produced from a clone or variety. Furthermore, crops from TPS may be more vulnerable to environmental stress while labour requirements tend to be higher (Monares *et al.*, 1983).

It is therefore clear that some problems can be overcome with the use of TPS while others are introduced. A production system whereby the use of TPS and seed tubers are combined may offer a promising alternative (International Potato Center, 1981 a) and could potentially solve some of the present problems with potato planting material in developing countries.

1.3 Research objectives

The research objectives are:

- To develop a system of seed tuber production whereby TPS is used as source of healthy material.
- To study methods of producing seed tubers from TPS ("seedling tubers").
- To evaluate seedling tubers as planting material.
- To compare the performance of seedling tubers with

that of alternative planting material.

1.4 Organization of the thesis

At first a literature review on the application of TPS in potato production is presented. This review revealed that although TPS has been used in the Andean Region for many years, only during the last few years has the attention of research workers been drawn to its wider application in potato production systems. The amount of literature on TPS is therefore limited, especially with regard to regular potato production from TPS.

The organization of experiments to develop a system to produce potatoes from seedling tubers is schematically presented in Fig. 1 and the thesis organization follows a similar pattern. Since the system involves two distinct areas of research, the production of seedling tubers and their use as planting material, both areas are dealt with in different chapters. The research subjects within each chapter are distinct and the sections on experimental procedures are therefore preceded by separate introductions, in which the state of knowledge on each subject is presented as well as the assumptions that influenced the design and execution of the experiments.

In the General Discussion the various components of the seedling tuber system are integrated, which permits an interpretation and evaluation of the system as a whole.

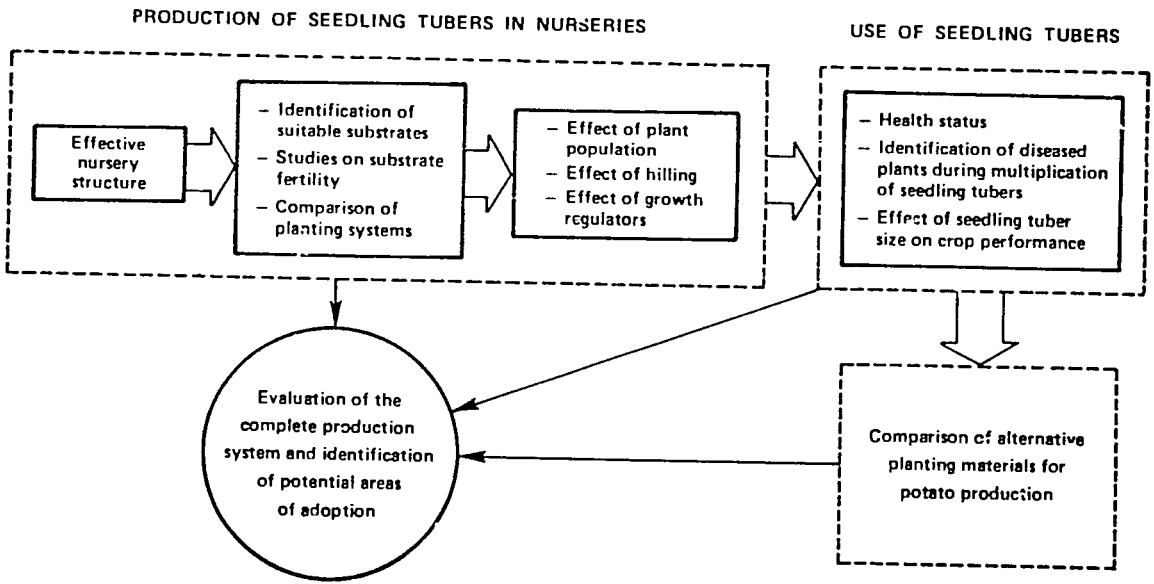

Fig. 1. Organization of experiments to develop a system to produce potatoes from seedling tubers.

Chapter Two
LITERATURE REVIEW

2.1 History of use of true potato seed

In the centre of origin of the potato, South American Indians have used TPS to rejuvenate their potato stocks from time to time (Salaman, 1949). The large number of Andean cultivars, presently being maintained at CIP (International Potato Center, 1981 b, 1982 b), may also have resulted from selection of plants from TPS by ancient farmers. Also the present generations living in the Andean Region of Peru are familiar with TPS as a source of planting material and some farmers reportedly have used TPS in recent years (Monares and Wiersema, unpublished). In Europe, Haan (1953) reported that when the blight epidemics of 1845 wiped out most of the potato crops in the Netherlands, the country imported TPS from abroad. Similarly, potato breeding programmes have used TPS for many years by raising seedlings and subsequent vegetative propagation of selected plants (Poos, 1955; Howard, 1963; Dorst, 1964). In China (Li, 1983), potato production from TPS has been practised since 1967 in many communes and state farms in Inner Mongolia, Ninghsia, Yunnan, Kweichow, Szechuan, Heilungkiang, Honan and Anhwei provinces. In 1979 seed tubers derived from TPS were planted on 21,660 hectares in various provinces (Li and Shen, 1979). In Russia, trials with TPS are reported to have been taking place since 1961 (Kushnareva, 1976), while in India studies with TPS were carried out as early as the late 40's (Upadhya, 1979). More recently researchers

at CIP and other institutions have shown interest in exploring the possibilities of using TPS for potato production (Sawyer, 1979; Accatino *et al.*, 1979; Hermsen, 1980 a; Wiersema, 1981, 1983; Accatino and Malagamba, 1982; Harris, 1983; White and Sadik, 1983 a; Sadik, 1983).

TPS has been used for potato production using three different methods:

- Direct field sowing
- Transplanting seedlings from a nursery to the field
- Planting seedling tubers.

2.2 Direct field sowing

Success with direct field sowing has been variable. Kunkel (1979) failed to obtain emergence in an irrigated field of six hectares after sowing TPS that showed 87% germination in the laboratory. Accatino (1979) observed field emergence, after direct field sowing in the highlands of Peru, in only 11 out of 52 TPS-lines with a maximum germination of 18%. However, in the coastal desert of Peru he obtained 85% field emergence during the cool season. Bedi (1978) obtained in New Zealand only 3-6% field emergence when TPS was sown with a cone seeder at a depth of 5-20 mm. When TPS was surface sown and covered by 5 mm sand he obtained 42-50% emergence, but only 6% of the total number of direct sown seeds survived until mature harvest. He also reported an average emergence of 10 TPS-lines of 22% in the field compared with 88% in the glass

house. The only favourable results seem to have been obtained by Martin (1983) in the USA who reported 50-80% field emergence when TPS was sown with a precision seeder. He obtained the best stand of seedlings on silt loam or sandy loam soils where alfalfa had been ploughed under or manure had been applied, due to less soil crusting and more rapid infiltration of irrigation water.

Although most authors did not report about soil temperatures in their field experiments, the generally poor emergence after direct field sowing is likely to result largely from unfavourable temperatures. Optimum temperatures for germination are between 15 and 20°C, while above 25°C or below 10°C germination is inhibited (Stier and Cordner, 1937; Steinbauer, 1957; Sadik, 1979; White and Sadik, 1983 b). While at optimum temperatures germination can take place in 4 to 7 days (Sadik, 1979), at sub-optimum temperatures TPS germinates over a period of several weeks. Bedi and Smale (1978), Bedi *et al.* (1979) and Martin (1983) reported that field emergence could take as long as 3-6 weeks from sowing. Besides high soil temperatures, soil conditions resulting in crusting are reported to affect the success of direct field sowing (Accatino, 1979; Martin, 1983).

As a consequence of poor field emergence few authors have given information on yields. Bedi and Smale (1978) obtained 0.52 to 1.86 kg per surviving plant, while Bedi *et al.* (1979) reported that total yields from a range of TPS-lines varied from 20.2-47.2 tons per ha. Following sowing

at a seed rate of 1.5 kg per ha in irrigated fields in the Ukraine, yields of 8.03 tons per ha were obtained of which 7.66 tons were seed size tubers (Luk'yanenko and Khiznyak, 1975). In Kazakhstan yields of 50-180 g per plant have been reported (Anonymous, 1976), while Martin (1983) reported that in the Columbia Basin area of eastern Washington yields from direct sown potato crops were usually less than 60% of those from crops derived from tubers.

The poor results reported from direct field sowing would seem to be largely associated with the required optimal conditions of soil structure, moisture, temperature and absence of weeds. In addition, most TPS-lines were not selected for seed- and seedling vigour, in contrast to many vegetable crops that are propagated by seed where such traits are important breeding objectives. The breeding of special lines for the production of potatoes from true seed may well improve results with direct field sowing. Gray (1979) and Sadik (1983) postulated that the difficulties of establishing a potato crop by direct sowing is unlikely to be any greater than those experienced by vegetable growers when establishing crops directly from seeds. Several techniques are available for the direct field sowing of small-seeded crops. Seed pelleting facilitates seed handling and allows the incorporation of desirable additives such as fungicides and systematic insecticides. Fluid drilling or sowing allows seeds to be sown that have germinated to the point of radical emergence

(Currah *et al.*, 1974). It may reduce the effects of environmental and seed bed conditions on emergence, as was shown by Bussell and Gray (1976) with tomatoes. This method does not exclude the mechanization of sowing (Lickorish and Darby, 1976; Bryan *et al.*, 1978 b; Currah *et al.*, 1974). Another method of sowing pregerminated seed is the plug-mix method (Bryan *et al.*, 1973), which has also been used in combination with fluid drilling using inexpensive equipment (Shaw *et al.*, 1980). Such techniques, with appropriate modifications, may prove to be useful for field sowing of TPS in the future.

2.3 Transplanting seedlings

This system avoids some of the problems associated with direct field sowing since seedlings are raised in a small protected area where environmental conditions can be more easily controlled. Suitable substrates to grow seedlings are a mix of 50% sand and 50% shredded peatmoss, by volume, a mix of 75% peatmoss and 25% sand, and mixtures of well decomposed compost made of bean residues, manure and leaf litter (Malagamba, 1983 a). He showed that phosphorus (P) was by far the most important nutrient for promoting vigorous seedling growth. Accatino and Malagamba (1982) recommended 10-30-10 g NPK per 100 kg of a 1:1 mix of peatmoss and sand. They obtained good germination and seedling growth in hot climates when shading was applied to lower the soil temperature. The optimum stage for trans-

planting seems to be the 4-5 leaf stage, which can be reached under suitable conditions within 4-5 weeks after sowing (Accatino and Malagamba, 1982).

One problem associated with this method is that seedlings are sensitive to transplanting. Upadhya (1979) reported 70-75% transplant survival when seedlings were transplanted without soil blocks, compared with 90% survival when seedlings were transplanted in soil blocks whereby the roots remained in the substrate in which they were raised. Accatino and Malagamba (1982) also found a significant increase in transplant survival when seedlings were transplanted with their roots in blocks of substrate. Differences in sensitivity to transplanting between TPS-lines have been reported by Accatino (1979). Several other practices including shading by associated crops and the use of a variety of mulches are reported to diminish the stress experienced by the plant resulting from transplanting (Malagamba, 1983 b).

Reported yields of crops from transplanted seedlings vary greatly. Bedi *et al.* (1979) obtained an average yield from 12 lines of 20.6 tons per ha compared with 41.1 tons per ha from a commercial variety. Accatino (1979) reported a mean total yield from 52 lines of 200 g per harvested plant in 90 days. Li (1983) observed that in China several lines yielded similarly to commercial varieties, while in Korea some lines gave a higher total yield than the variety Irish Cobbler, although the marketable yield was lower (Kim *et al.*, 1983). Sadik (1983) re-

ported unpublished results of experiments in Peru carried out by Malagamba, indicating that total yields from the 7 best lines, transplanted during the cooler part of the year, ranged from 12.6 to 44.8 tons per ha. On average 86% of this total yield is reported to be marketable. Kidane-Mariam (unpublished) obtained in Peru a mean marketable yield from 40 lines of 36 tons per ha.

These reports illustrate that very acceptable yields can be obtained from crops derived from transplanted seedlings.

2.4 Planting seedling tubers

This method combines the attributes of potato production from true seed with those of seed tubers (International Potato Center, 1981 a). The sensitivity of direct sowing or transplanting methods to environmental stress has led in China to the use of seedling tubers (Li and Shen, 1979). Seedling tubers were produced from transplanted seedlings in areas traditionally suitable for seed tuber production. The system is reportedly based on clonal and mass selection in plants from seedling tubers, while after several multiplications the tubers are used for ware production. In 1979, 21,660 ha of potatoes were planted with seed tubers derived from TPS, with seedling tubers yielding 29.2% to 155% more than tubers of the standard cultivars. In Russia, seedling tubers were produced from transplanted seedlings and ranged in size from 1 to 15 g (Karlovich *et*

al., 1973). The yields from plants raised from these small tubers were similar to those from plants derived from conventional seed tubers. Kushnareva (1976) also reported trials carried out from 1961-1965 to produce virus free seed tubers from transplanted seedlings. In Kazakhstan (Anonymous, 1976) first generation seedling tubers produced 600-1200 g per plant. Yields from super elite seedling tubers were 36 tons per ha, from first generation super elite tubers 34 tons per ha and from second generation super elite tubers 29 tons per ha.

Besides production of seedling tubers from transplants, production in nursery beds or in field beds has proved to be successful (International Potato Center, 1981 a). In Ethiopia tuber yields per square meter of field bed ranged from 63 to 95 tubers larger than 20 g and from 293 to 440 tubers smaller than 20 g, in a growing period of 117 days after sowing. On the basis of this preliminary trial it was estimated that a 10 square meter field bed could produce sufficient seedling tubers to plant an area of more than 150 square meters.

2.5 Diseases and pests

Virus diseases

None of the viruses infecting the potato crop in the Northern Hemisphere have been shown to be transmitted through TPS, while a limited number of viruses that infect potato in the Andean Region have been reported to pass

through TPS (Jones, 1982). These viruses are potato virus T (PVT), Andean potato calico strain of tobacco ringspot virus (TRSV-Ca) and the oca strain of arracacha virus B (AVB-O). Transmission of Andean potato latent virus (APLV) through TPS has also been reported (Jones and Fribourg, 1977) but could not be confirmed in later tests (Jones, 1982). In addition to these viruses, the viroid potato spindle tuber viroid (PSTV) is transmitted through TPS (Fernow *et al.*, 1970; Singh, 1970). Li (1983) commented on the spread of PSTV in China which possibly resulted from the large scale use of TPS.

Primary infection by virus diseases may be similar in crops derived from TPS to those from seed tubers, except that the chance of virus translocation to the tubers would increase with increasing length of the growing period (Beemster, 1972). Bedi (1978) reported that in 10 TPS-lines an average of 0-59% of the plants derived from TPS showed virus symptoms.

It would thus seem that use of TPS would potentially increase the risk of spreading those viruses that at present only occur in the Andean Region, while similarly it would enhance the spread of PSTV. Furthermore, plants from seedling tubers are subject to secondary infection of any virus, like plants derived from a cultivar or clone.

Pests

Plants from TPS are particularly susceptible to insect attack. Damage by pests such as cutworms, aphids, leaf

beetles, leaf hoppers, leaf miner flies, potato tuber moth etc., can be considerable, although control methods are in development (International Potato Center, 1981 b).

Chemical weed control in crops derived from TPS is risky, since seedlings are extremely sensitive to herbicides, especially after direct sowing and during the period following transplanting. Accatino and Malagamba (1982) obtained best results when Paraquat was applied two days before transplanting or Metobromuron was applied 20 days after transplanting. Application of Metobromuron before 20 days elapsed from the date of transplanting resulted in high seedling mortality.

Soil-borne pathogens

Soil-borne pathogens can cause damage especially during seedling emergence and after transplanting. Elango (1983) reported that *Rhizoctonia* spp. and *Pythium* spp. can cause up to 80% emergence failure and up to 40% plant mortality within 15 days after transplanting. Proposed control measures include fungicidal seed bed treatment, steam sterilization of seed bed substrate and the use of subsoil in seed beds. Accatino and Malagamba (1982) reported good control of *Rhizoctonia solani*, *Sclerotium rolfsii* and *Pythium* spp. from an application of a 0.15% solution of Pentachloro nitrobenzene (PCNB) to the transplanting furrow and a 0.1% solution of Benomyl (Benlate) to the seedling base immediately after transplanting. Furthermore, agronomic practices that reduce soil temperature,

such as mulching and shading are likely to reduce problems due to *Rhizoctonia* and *Pythium* spp. (Elango, 1983).

2.6 Seed management

Seed storage

Several reports indicate that storage of TPS is relatively easy. At room temperature Simmonds (1968) found that seed viability started to decline after 7 to 8 years storage while Wollenweber (1942) and Haig (1952) obtained adequate germination after 13 years. Subramanyan (1971) reported over 70% germination after 10 years storage at temperatures fluctuating between 5-6°C and 42-45°C. With storage in paraffin sealed glass tubes at 5°C, Howard (1969, 1975) obtained 79.6% and 71.5% germination after 15 and 20 years, respectively. For long term storage, Lange *et al.* (1979) recommended drying seed to 5-6% moisture content and storage at -10°C. Storage temperatures ranging from -20°C to 20°C had negligible effects on seed viability after 4 years provided that seed moisture content was low (Hinze *et al.*, 1975). Generally, the longevity of seed may be considerably improved by controlling the storage environment because the increase in longevity with decrease in either temperature or moisture content of the seed is approximately exponential (Cromarty *et al.*, 1982). A simple method of reducing seed moisture, using freshly toasted rice, has been proposed by Sadik and White (1982).

Seed dormancy

The intensity of dormancy may vary with the genetic background of the seed and the stage of fruit development at which seeds were extracted (Simmonds, 1963; Haynes, 1954). An effective method of breaking seed dormancy is to soak seed for 24 hours in a 1500 ppm solution of gibberrellic acid (Fischnick and Grim, 1958; Spicer and Dionne, 1961; Shu-Lock and Erickson, 1966; International Potato Center, 1980).

2.7 True-potato-seed lines

In general hybrid lines are reported to be superior to open pollinated lines, although some selected open pollinated lines can perform equally well as hybrid lines. Bedi (1978), Bedi and Smale (1978) and Kim *et al.* (1983) reported higher yields from hybrid seed than from open pollinated seed, while Bedi *et al.* (1979) found that the highest yielding open pollinated lines yielded similarly to many of the hybrid lines. Bedi *et al.* (1979) reported that none of the hybrid lines produced yields high enough to offset the higher cost of seed production.

At present highly uniform lines seem to be available. Kim *et al.* (1983) indicated that in Korea several lines are sufficiently uniform to be released as a horticultural cultivar while Bedi *et al.* (1979) found ratings for specific gravity and steaming, both in selfed and cross pollinated lines, very close to those of commercial cult-

ivars in New Zealand. Attempts are being made to obtain genetically uniform seedlings by the production of apomictic seed (Hermsen, 1980 b; Irikura, 1981; Iwanaga, 1983).

2.8 Conclusions

The review of literature indicates that TPS research has been performed for several years in various countries. Much of the research has been concentrated on TPS storage and germination, possibly because such information would seem essential for gene banks and breeding institutions. The number of authors that report on methods of TPS use is relatively small. Despite the extensive knowledge of direct sowing methods in other small seeded vegetable crops, few reports indicate successful application of these methods with TPS. At present most authors seem to favour transplanting methods and the use of seedling tubers. Similarly, few authors report on diseases and pests being a problem with transplanting methods, which possibly reflects the small scale on which experiments have been performed. Several authors indicate that although relatively little breeding has been done to produce suitable TPS-lines, several suitable lines are available at this moment for commercial production of consumer potatoes.

Chapter Three
PRODUCTION OF SEEDLING TUBERS IN NURSERIES

3.1 Materials and methods

3.1.1 General

The experiments were performed at one of the Experimental Stations of the International Potato Center during the period 1981-1983. The Experimental Station is located at La Molina, Lima, in the coastal desert of Peru, at an altitude of 240 m above sea level and a latitude of 12° 05'. The climatic conditions at the Station are presented in Appendix 1.

Since the system of production of seedling tubers in nurseries has not been investigated before, several preliminary experiments were performed on various aspects of production. On the basis of these preliminary experiments treatments were chosen for larger trials. The organization of experiments is shown in Fig. 1. First a nursery structure was developed where shade could be applied to lower soil temperature and where seedlings could be grown conveniently. Subsequently a suitable growing medium was identified, as well as adequate rates of fertilizer application and an effective planting system. After having established the basic production techniques, experiments were performed to study optimum plant population, hilling requirements and effects of growth regulators.

In all nursery experiments the substrate was disinfected before seed sowing. A newly prepared substrate was always steam sterilized for 4 hours at 80°C while for

subsequent uses the substrate was treated with Basamid at a rate of 40 g per square meter and then covered with plastic for 1 week. Sowing in a Basamid treated substrate did not take place within 2 weeks after removal of the plastic to avoid damage to emerging seedlings. Before sowing TPS was always treated with gibberellic acid at a concentration of 1500 ppm for 24 hours in order to break dormancy. Fertilisers were applied before sowing and during growth with total rates per square meter ranging from 40-60 g of N, 60-80 g of P_2O_5 and 40-60 g of K_2O, depending on growing conditions. All the phosphate was applied before sowing, while the nitrogen and potash was applied in split doses after seedling emergence. A typical regime of fertiliser application is presented in Appendix 2. Pests and diseases were controlled when required, control measures are given in Appendix 3.

3.1.2 Nursery structure and layout

Beds of 1.1 m width and 25 cm depth were dug out in the ground by removing the top soil and sides covered with formica to avoid caving in. Because of short durability, formica was later on replaced by bricks. The width of 1.1 m was initially chosen because it was thought to facilitate agronomic practices, however a bed width of 1 m was later on found to be more convenient. The beds were filled with a prepared growing medium, referred to as "substrate", to a depth of 20 cm. After

seedling emergence an additional 5 cm of substrate was gradually added to the beds, to substitute for hilling. No barrier was placed on the bottom of the beds in order to allow for drainage. Only the pathways between the beds, 60-65 cm wide, were covered with plastic in order to avoid mud spilling into the beds. Individual experimental plots in the beds were separated by an open space of 20 cm to facilitate harvesting and to avoid mixing tubers of neighbouring plots. Sticks connected with string were placed between plots in order to keep the foliage within the plot boundaries. The foliage, however, was permitted to cover the pathways since these were only intensively used during the initial part of the growing period. The end plots of each bed were bordered by an open space of 20 cm and 3 rows of plants (Fig. 2) spaced at 10 cm. This arrangement resulted in equal border effects for all experimental plots.

Other types of bed used were wooden frames placed above the soil or beds made of cement bricks. The latter type was principally used for experiments on type of substrate and substrate fertility because the bricks formed an effective separation between treatments.

During seed germination and 1-2 weeks afterwards an attempt was made to maintain substrate temperature between 15° and 25°C, to allow adequate germination and rapid plant establishment. To reduce soil temperature in the summer period, shade was applied in the form of a net reducing light intensity on a sunny day to about 50%.

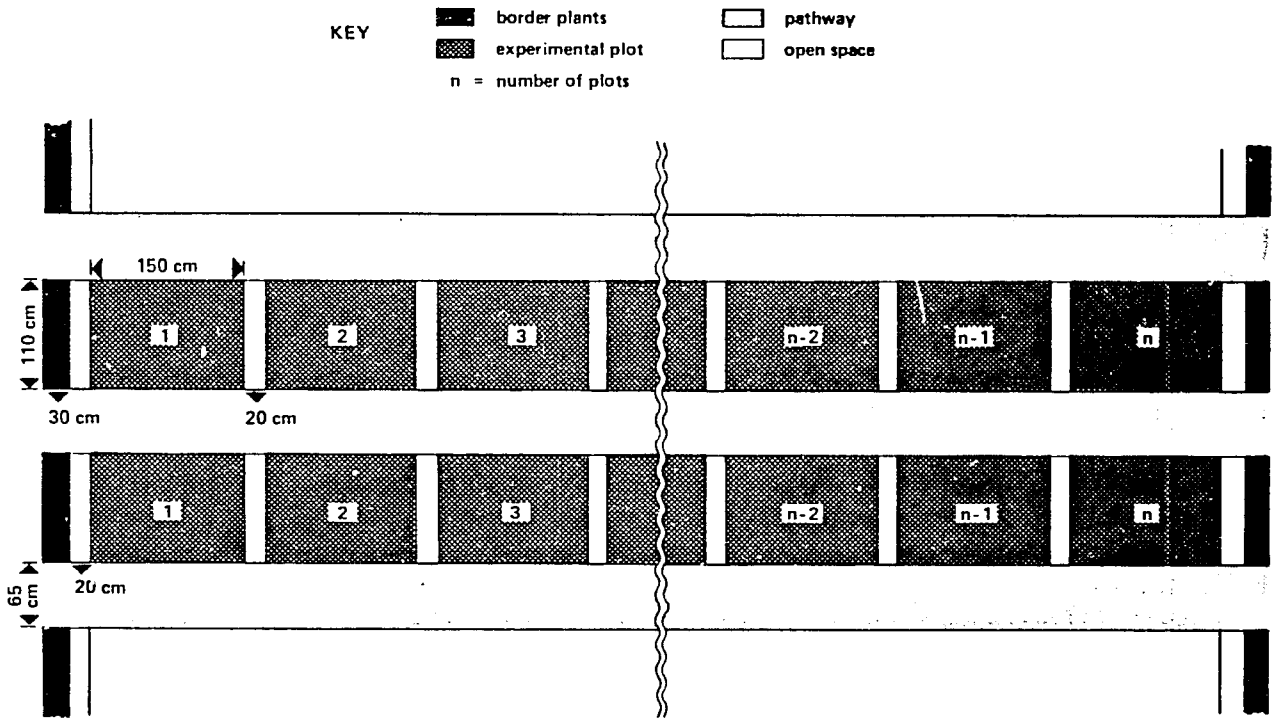

Fig. 2. Nursery layout and border arrangements used in experiments on seedling tuber production in beds.

Irrigation of the beds initially took place by hose and watering-can but later on a mini sprinkler system was installed. This system could be connected with the main field irrigation system receiving water from a well. The sprinklers were spaced 1.50 m apart with connecting hoses placed on the pathways between the beds.

3.1.3 Nursery substrate

The requirements for a nursery substate to produce seedling tubers would seem to be a sufficient water-holding capacity with at the same time adequate drainage and a low proportion of clay to avoid compaction and to facilitate harvesting operations. Substrates with a high proportion of organic material, such as a mix of 50% sand and 50% peatmoss, mixtures of plant compost as well as mixtures of sand and manure, have proved to be suitable to raise potato seedlings (Malagamba, 1983 a; Upadhya, unpublished). It would need to be tested whether such substrates would also be suitable to produce seedling tubers since the total amount of dry matter, produced per unit area is considerably higher when seedling tubers are produced compared with the production of seedlings for transplanting. This would perhaps require different chemical and physical properties of the substrate. In this respect the addition of a small amount of loamy top soil might improve the water and nutrient holding capacity of the substrate. Initial seedling growth however was retarded in substrates with too

much soil (Malagamba, unpublished). For this reason a separate experiment was carried out to determine what proportion of loamy soil in the substrate would be acceptable before negative effects on seedling growth would become apparent. Since detrimental effects of the soil component in the substrate were already noticeable at early stages of growth. it might not be necessary to perform this experiment during a complete growing period. In this experiment seedling growth was therefore evaluated 26 days after sowing rather than at maturity. Because of this short growing period the experiment was carried out using shallow trays. Suitable substrates were subsequently evaluated during a complete growing period in regular nursery beds.

In all substrates 50% river sand was maintained because of its wide availability and low cost.

Procedure

Five sand/peatmoss substrates with respectively 0, 5, 10, 20 and 40% of loamy top soil were compared, while all substrates contained 50% sand. The soil contained 46% sand, 42% silt and 12% clay. All treatments received 800 ppm of P_2O_5 while 0, 50 and 100 ppm each of N and K_2O were applied. The choice of fertilizer levels was based on Accatino and Malagamba (1982) and Malagamba (1983 a) indicating that high P levels were required for vigorous seedling growth. No detrimental effects of P, even at very high levels, had been observed while a N and K_2O

application of 100 ppm was recommended. The treatments were arranged according to a completely randomized design with 3 replications. The substrates were compared in plastic trays of 40 cm length, 28 cm width and 5 cm depth, while maintaining the same volume per tray. Tray bottoms were perforated to allow drainage. The trays were placed on top of an empty tray with the same dimensions but with a closed bottom in order to receive drainage water which was reapplied to the top tray containing the substrate. This procedure was followed to avoid differences in nutrient supply between substrates.

TPS of the line DTO-33 OP was sown in the trays at 150 seeds per tray. After emergence seedlings were thinned to 100 plants per tray in order to distinguish between substrate effects on emergence and those on early seedling growth. At 26 days after sowing, seedlings were cut at soil level and oven dried for 72 hours at 75°C. The substrates were evaluated on the basis of total seedling dry weight per tray.

Based on this experiment it was determined how much soil could be included in the substrates and subsequently various substrates (Table 2) were created to test their suitability for seedling tuber production. The substrates were put in compartments made of bricks with dimensions of 1 m x 0.9 m and 25 cm depth. TPS was sown in these compartments in clusters of 4 seeds with a spacing of 1 cm between seeds to facilitate thinning. Clusters were spaced at 10 x 10 cm. After emergence seedlings were

Table 2. Nursery substrates and their characteristics[1]

Substrate[2]	E C (mmho/cm)	Sand %	Silt %	Clay %	pH	Organic matter %	Total N %	Available P ppm	Available K_2O kg/ha	CEC meq/100g
50% sand, 30% peatmoss, 20% soil	2.2	84	10	6	7.9	3.45	0.150	6.3	310	9.60
50% sand, 50% peatmoss	2.1	90	6	4	6.9	5.10	0.216	7.5	370	10.0
50% sand, 30% compost, 20% soil	3.9	66	28	6	7.6	4.14	0.184	38.2	480	8.60
50% sand, 50% compost	5.0	92	4	4	7.4	7.72	0.330	81.2	850	19.0
50% sand, 30% manure, 20% soil	5.0	84	10	6	7.2	4.14	0.180	27.8	816	10.4
50% sand, 50% manure	9.4	92	4	4	7.4	2.55	0.110	43.5	850	9.4

[1] Substrates analysed by Universidad Nacional Agraria - La Molina, Lima
[2] Percentage based on volume

gradually thinned to one seedling per cluster, resulting in 100 plants per square meter. The substrates were compared during two growing seasons and at 2 levels of nitrogen (Table 3). The levels of nitrogen were based on the estimated total dry matter production per unit area (Villagarcia, personal communication). Because total dry matter production in the first experiment was higher than initially estimated, the levels of N were increased in the second experiment. The total amount of P_2O_5 was applied at sowing while N and K_2O was distributed over 6-10 applications after seedling emergence.

The preparation of substrates included the sieving of soil and river sand over a 2 mm wide mesh, while compost and peatmoss were shredded by machine. River sand and compost were washed to remove salts. To assist their mixing the substrate components were gradually wetted during the mixing process. The substrates were steam sterilized for 4 hours at 80°C.

The treatments were arranged in a completely randomized design with 3 replications. The suitability of a substrate as a growing medium to produce seedling tubers was evaluated on the basis of the number and weight of tubers larger than 1 g, produced per unit area.

3.1.4 Fertilization

Requirements for fertilization of substrates may depend on the fertility level of the substrate components, loss of

Table 3. Details of experiments on type of nursery substrate

	Experiment I	Experiment II
Sowing date	6.1.82	27.7.82
Harvesting date	18.5.82	16.12.82
Growing period (days)	130	140
N-levels (g/m^2)[1]	20,30	40,80
P_2O_5 (g/m^2)[2]	40	80
K_2O (g/m^2)[3]	20	80
MgO (g/m^2)[3]	16	65

[1] Ammonium nitrate (33% N)
[2] Single superphosphate (20% P_2O_5)
[3] Sulphate of potash-magnesia (22% K_2O, 18% MgO)

fertilizer through leaching and the amount of dry matter produced per unit area. Accatino and Malagamba (1982) reported optimum fertilizer levels, to raise seedlings for transplanting purposes, to be 100-300-100 ppm NPK in a mix of 50% sand and 50% peatmoss. This would correspond with 10-30-10 g NPK per square meter nursery since 1 square meter of bed contained approximately 100 kg substrate. Since in the production of seedling tubers considerably more dry matter is produced per unit area than in the production of transplants, fertilizer requirements are likely to be higher. Based on a tuber yield of 6 kg per square meter and a total dry matter production of 2.1 kg per square meter of bed, including tubers, foliage and roots, the total required amount of NPK was estimated at 40-40-30 g per square meter bed or 400-400-300 ppm (Villagarcia and Cabello, 1983). In the calculation of this amount it was assumed that the substrate would not supply any NPK since both sand and peatmoss were characterized by a very low nutrient content. It was also assumed that the subsoil below the beds did not provide nutrients because roots were almost exclusively found in the substrate. A factor fertiliser efficiency was included in the calculation to account for loss of fertiliser through leaching and other reasons.

Application of this high amount of fertilizer at sowing might cause problems due to high salt concentrations. High salt concentrations result in increased osmotic pressure of the substrate which can result in reduced water

uptake by the plant (Bernstein, 1974). In addition high salt concentrations can cause nutritional imbalances or deficiencies and may result in toxic concentrations of ions in the plants (Greenway, 1973; Bernstein, 1974). Since salt concentrations are likely to be more critical during emergence and initial seedling growth than at later growth stages, the experiments concentrated on the study of pre-sowing fertilizer rates rather than on that of optimum fertilizer rates for the total growing period. Fertilizer treatments were therefore evaluated on the basis of early seedling growth.

Since seedlings are reported to respond favourably to P with no detrimental effects of high rates of application (Malagamba, 1983 a) it would seem that the total amount of P required for the entire growing period could be applied before sowing. This would also allow proper distribution of P in the substrate while losses through leaching would most likely be limited since P shows little mobility in the soil. Since most of the P fertilizers are characterized by a low salt index (Table 4), the risk of high salt concentrations caused by these high rates would be low. N and K fertilizers on the other hand are characterized by a higher salt index (Table 4) and the total amount required for the entire growth period would probably require application in split doses to avoid salinity problems.

These considerations formed the basis for several experiments (Table 5) to determine optimum pre-sowing

Table 4. Relative effect of fertilizer materials on the soil solution[1]

Fertiliser material	Analysis (%)[2]	Salt index[3]	Partial salt index per unit of N, P_2O_5 or K_2O
Nitrogen carriers			
Anhydrous ammonia	82.2	47.1	0.572
Ammonium nitrate	35.0	104.7	2.990
Ammonium nitrate-lime Cal-Nitro	20.5	61.1	2.982
Ammonium phosphate	11.0	26.9	2.442
Ammonium sulphate	21.2	69.0	3.253
Calcium cyanamid	21.0	31.0	1.476
Calcium nitrate	11.9	52.5	4.409
Sodium nitrate	16.5	100.0	6.060
Nitrogen solution, 37%	37.0	77.8	2.104
Nitrogen solution, 40%	40.8	70.4	1.724
Potassium nitrate	13.8	73.6	5.336
Urea	46.6	75.4	1.618
Phosphate carriers			
Mono-ammonium phosphate	61.7	29.9	0.485
Diammonium phosphate	53.8	34.2	0.637
Monocalcium phosphate	56.3	15.4	0.274
Superphosphate, 16%	16.0	7.8	0.[illegible]07
Superphosphate, 20%	20.0	7.8	0.390
Superphosphate, 45%	54.0	10.1	0.224
Superphosphate, 48%	48.0	10.1	0.210
Potash carriers			
Kainit, 12.5%	12.5	105.9	8.475
Kainit, 17.5%	17.5	109.4	6.253
Potassium chloride, 50%	50.0	109.4	2.189
Potassium chloride, 60%	60.0	116.3	1.936
Potassium chloride, 63%	63.0	114.3	1.812
Potassium nitrate	46.6	73.6	1.580
Potassium sulfate	54.0	46.1	0.853
Sulfate of potash-magnesia	21.9	43.2	1.971

[1] From Rader *et al.* (1943)
[2] % of N in nitrogen carriers, % of P_2O_5 in phosphate carriers and % of K_2O in potash carriers
[3] Ratio of increase in osmotic pressure produced by fertilizer material to that produced by the same weight of sodium nitrate, based on a salt index of 100

Table 5. Pre-sowing fertilizer treatments in 4 experiments

Experiment	Type of fertilizer[1]	Application levels (ppm)	No. seedlings per tray[2]	Substrate
1	N + K_2O combined	0, 50, 100 of each	100	50% sand and 50% peatmoss
	P_2O_5	800		
2	N + K_2O combined	0, 75, 150 of each	90	50% sand and 50% peatmoss
	P_2O_5	400, 800		
3	N + K_2O combined	0, 100, 200, 400 of each	80	a) 50% sand and 50% peatmoss
	P_2O_5	200, 400, 800		b) 50% sand, 40% peatmoss and 10% top soil
4	N	0, 50, 100, 200, 400	90	50% sand and 50% peatmoss
	P_2O_5	800		
	K_2O	0, 50, 100, 200, 400		

[1] Source of N : Ammonium nitrate (33% N)
Source of P_2O_5 : Single superphosphate (20% P_2O_5)
Source of K_2O : Sulfate of potash-magnesia (22% K_2O)
[2] After thinning

fertilizer application. In these experiments the estimated amount of P_2O_5 required for the total growing period was applied at sowing, while the amounts of N and K_2O applied at sowing represented only a small proportion of the total estimated requirements for these elements. To allow for different yield levels three different rates of P_2O_5 were applied whereby the highest rate of 800 ppm would correspond with a tuber yield of 12 kg per square meter of bed, following calculations by Villagarcia and Caballero (1983).

Procedure

Table 5 shows the fertilizer treatments applied in four experiments, as well as the sources of N, P and K. In experiments 1, 2 and 4 the treatments were arranged according to a completely randomized design while in experiment 3 a split-plot design was used, in which substrate treatments were assigned to mainplots and fertilizer treatments to subplots. In all experiments 3 replications were used.

The experiments were performed in a screenhouse using the double tray system to ensure that fertilizer levels would not be affected by leaching. All procedures were similar to those described in 3.1.3. The number of seedlings per tray (Table 5) varied between experiments due to different germination rates. Within an experiment, however, the number of seedlings per tray was always the same for all treatments. Since effects of fertility were observed to be especially critical during initial seedling

growth, treatments were evaluated on the basis of emergence and total above-ground seedling weight per tray 25-35 days after sowing depending on the rate of growth. In experiments 3 and 4 the electrical conductivity (EC) of the substrate in each tray was determined at seedling harvest as an indication of the total salt concentration. EC values were determined in the soil solution extracted from the substrates which had been brought up to field capacity; a temperature of 25°C was maintained.

3.1.5 Evaluation of planting systems

For the production of seedling tubers in nurseries, two planting systems can be applied. One system would be to raise seedlings in an area outside the seedling tuber nursery for transplanting to the beds. This would allow germination of the seed in places where temperatures might be more easily controlled. Additionally, emerging seedlings could be more easily protected from virus transmitting insects, which might result in tubers of a better health standard. Furthermore the seedling tuber nursery would be occupied for a shorter period of time allowing more intensive use of the nursery space, which is of importance when several crops per year can be grown.

The other system would be to sow TPS direct in the beds for seedling tuber production, followed by thinning. This would probably save labour while problems with plant establishment due to the shock of transplanting are avoided.

Both planting systems were compared to evaluate their suitability for seedling tuber production.

Procedure

Seeds for both treatments, transplanting and direct sowing, were sown at the same date in a mix of 50% sand and 50% peatmoss. Fertilizer application and other growing conditions were the same for both treatments. In both treatments weak seedlings were removed by thinning. In direct sown treatments 100 plants per square meter, spaced at 10 x 10 cm, remained after thinning while the seedlings of the transplanting treatments were transplanted 35 days after sowing at a spacing of 10 x 10 cm between plants.

Since plant establishment after transplanting seems to differ between TPS-lines (Malagamba, unpublished) two contrasting lines were used, these being the vigorous hybrid line Atzimba x 7XY.1 and the open pollinated line DTO-33 OP which usually shows slow plant recovery after transplanting. Treatments were arranged according to a split-plot design with 4 replications. TPS-lines were assigned to mainplots and planting systems to subplots. A growth analysis was performed by harvesting 10 plants in each of 10 sequential harvests. After each harvest a row was left unharvested to function as a border for the next harvest.

Data were taken on the number of nodes, the number of stolons longer than 1 cm that originated directly from

one of the nodes, the length of the longest stolon, the number of tubers larger than 1 g, fresh and dry weights of tubers larger than 1 g and dry weights of leaves and stems.

3.1.6 Plant population experiments

The optimum population density of seedlings in nursery beds was defined as that density whereby a large number of useable tubers are produced but whereby close plant spacing would not hinder agronomic practices. Since preliminary experiments had shown that tubers as small as 1 g could be multiplied successfully, tubers of 1 g and above were considered to be useable.

Because germination and emergence are often erratic due to unpredictable climatic conditions, more seeds have to be sown than the final number of plants desired. For this reason and also to permit removal of deformed and weak plants, over sowing followed by thinning was considered to be an essential practice in seedling tuber production.

Procedure

The effect of plant population was studied in a mix of 50% sand and 50% peatmoss. So as not to confound the effect of density and the effect of spatial arrangement of plants all density treatments were sown in a square pattern. For this purpose TPS was sown in clusters of 4 seeds with the same spacing between rows of clusters as between clusters within the row. The 4 seeds within a

cluster were spaced about 1 cm apart. This space between individual seeds was thought to be necessary in order to avoid root damage due to elimination of neighbouring plants during thinning. After emergence, plants were thinned gradually leaving 1 plant per cluster. During growth, plants were counted at regular intervals.

Individual plots measured 1.5 m x 1.1 m. Because of the close spacing between plants no border plants could be harvested. Each plot was bordered on 2 sides (1.5 m) by the pathway and on the other 2 sides (1.1 m) by a 20 cm space between individual plots (Fig. 2). Foliage was prevented from growing into neighbouring plots by placing sticks connected with string between the plots.

Harvested tubers were divided into six size categories: <1 g, 1-5 g, 5-10 g, 10-20 g, 20-40 g and >40 g. The weight and number of tubers were determined in each category.

Three experiments on plant population were performed (Table 6), whereby the choice of treatments in the next experiment was determined by results of the previous one. In experiment A, plant populations were 50, 100 and 275 plants per square meter, in experiment B 50, 100, 150 and 200 plants per square meter and in experiment C 50, 100 and 150 plants per square meter. In experiment A, treatments were arranged according to a completely randomized design, while in experiments B and C, where plant population was studied together with other factors, a split-plot design was used with plant population assigned to subplots. In

Table 6. Details of experiments* on plant population, hilling and B nine in nursery beds

Experiment	Factors	Sowing date	Harvest date	No. growing days	TPS-line	Factors assigned to: Mainplot	Factors assigned to: Subplot	Harvested area per (sub) plot (m^2)
A	Plant population	7.10.80	5.2.81	120	DTO-33 OP	plant population	-	1.44
B	Hilling Plant population	15.1.82	15.4.82	90	DTO-33 OP	hilling	plant population	1.65
C	TPS-line Plant population	9.6.82 9.6.82 9.6.82	15.10.82 2.11.82 13.11.82	128 145 156	DTO-33 OP Atzimba x 7XY.1 Atzimba x DTO-33	TPS-line	plant population	1.65
D	TPS-line B nine Hilling	28.12.82 28.12.82	19.4.83 19.4.83	112 112	DTO-33 OP Atzimba x DTO-33	TPS-line	B nine, hilling	1.43
E	B nine Hilling	5.7.83	16.11.83	134	Atzimba x DTO-33	B nine	hilling	1.65

* All experiments were replicated three times

experiment B the factor hilling was assigned to mainplots for practical reasons while in experiment C the factor TPS-line was assigned to mainplots to minimize border effects due to large differences in foliage growth between the lines. In all 3 experiments 3 replications were used.

3.1.7 Hilling experiments

In potato crops hilling is usually required to avoid greening of tubers while the resulting ridges facilitate harvesting operations. In addition the formation of ridges may improve conditions for tuber development which may result in a positive effect on yield (Kouwenhoven, 1978). In the production of seedling tubers in nursery beds this practice cannot be followed since the close spacing between plants does not permit the formation of ridges. No hilling at all however would probably limit tuber formation resulting from stolons growing above the soil, especially after direct seed sowing in beds whereby stolons are borne above ground in the axils of the cotyledons. Instead of hilling, additional substrate could be applied after seedling emergence. This gives rise to the question of how many nodes would have to be covered by substrate for optimum stolon formation.

These questions prompted 3 experiments (Table 6) to determine how much "hilling" in the form of additional substrate applied after seedling emergence would be required.

Procedure

TPS was sown direct in a mix of 50% sand and 50% peat-moss, following the cluster system. Hilling treatments included the application of substrate after seedling emergence to a height of 2 to 3 cm and 6 to 7 cm, covering 2-3 and 6 nodes respectively. These treatments were compared with a control where no additional substrate was applied.

The effect of hilling was studied together with other factors in a split-plot design with 3 replications (Table 6).

Hilling operations started when plants were 3-4 cm tall. Substrate was applied in several operations, but hilling was terminated when plants covered the ground completely to avoid plant damage. The height of hilling was measured after one irrigation when the volume of newly added substrate had decreased. Observations at harvest showed a similar difference in height of the substrate between hilling treatments compared with the observations just after hilling.

Depending on the experiment, one or two harvests were performed shortly after tuber initiation to determine the number of stolons longer than 1 cm that originated directly from one of the nodes, the length of the longest stolon, the number of tubers larger than 1 g, the fresh and dry weights of tubers larger than 1 g, and the dry weights of leaves and stems. At each harvest 10 plants were evaluated per plot. At maturity the number of plants, the total tuber weight and the number of tubers in the

various size grades were determined.

3.1.8 Growth regulator experiments

The production of seedling tubers in beds at a high plant population resulted in stem elongation due to mutual plant shading. A considerable amount of the total dry matter was thus used for stem growth. Growth retardants such as Cycocel (CCC) and B nine (N-dimethyl aminosuccinamic acid) are known to reduce stem growth and sometimes to increase tuber yield (Krug, 1963; Bodlaender and Algra, 1966; Humphries and Dyson, 1967; Gunasena and Harris, 1969, 1971). Preliminary experiments with various growth regulators gave excellent results with B nine showing no plant damage or tuber malformation (Sadik, unpublished).

Procedure

In the experiments described, a commercial B9 product from Uniroyal was used, containing 85% of active ingredients by weight. Recommended concentrations ranged from 0.15-1.00% for different crops. A concentration of 0.5% appeared effective on potato seedlings (Sadik, unpublished) and was applied in both experiments (Table 6). The time and rate of application are shown in Table 7. Plants from direct sowing were sprayed to run off. In experiment D (Table 6) destructive harvests were carried out at 50, 59 and 69 days after sowing while in experiment E there was one harvest at 65 days. Attempts to evaluate treatment

Table 7. Details of B nine applications on seedlings grown in nursery beds

	Days after sowing			Plant height (cm)			Application rate (ml/m^2)*		
	Experiment D		Experiment E	Experiment D		Experiment E	Experiment D		Experiment E
	Hybrid line	OP line	Hybrid line	Hybrid line	OP line	Hybrid line	Hybrid line	OP line	Hybrid line
First application	27	34	34	10	10	8	90	90	90
Second application	40	50	42	15	15	12	130	130	120
Third application	-	-	60	-	-	20	-	-	180

* Concentration 5 g/l

effects on stolon development later than 65 days failed due to stolons growing rather long and breaking during harvest. At intermediate and mature harvests, similar data were taken as described under hilling (3.1.7).

In experiment D, B nine treatments were assigned to subplots while in experiment E, where plots were sprayed at a later date, B nine treatments were assigned to main-plots to minimize border effects both due to drift of the chemical and due to subsequent difference in plant height.

3.1.9 True-potato-seed lines used in the experiments

The TPS-lines used in the experiments (Table 6) were selected from the breeding programme as giving good yields and high tuber uniformity. In almost all experiments DTO-33 OP was used as one of the TPS-lines, since it was thought that the method of production of seedling tubers in nursery beds was particularly attractive when OP lines were used because seed of such lines was relatively easy to obtain compared with hybrid lines. Although such lines usually gave lower yields when transplanted; due to slow recovery after transplanting, they often performed well when seedling tubers were used. The open pollinated seed used in the experiments can be considered to be mainly self pollinated seed since the fruits were harvested from a relatively large field planted with the same clone. Fruits were not collected from the border rows of this field, since those might have received pollen from other

clones.

The same TPS-line was used in different experiments to permit a better comparison between experiments.

3.2 Results

3.2.1 Nursery substrates

Increasing amounts of top soil in sand/peatmoss substrates did not affect emergence but affected subsequent seedling growth. Seedling weight 26 days after sowing decreased significantly* when the percentage of soil increased from 20 to 40% while amounts lower than 20% had no effect on seedling growth (Table 8). This suggests that up to 20% of the peatmoss used in this substrate could be replaced by top soil without affecting seedling growth. However, the results of two experiments (Table 9), in which 6 substrates were compared during a complete growing season, showed that tuber yields in substrates containing soil were almost always lower and with smaller average tuber size, than yields obtained in substrates without soil. This indicates that although initial seedling growth was not negatively affected by the soil fraction, this fraction had a negative effect on subsequent seedling tuber production.

Since no significant differences were observed

* A significant difference between treatments refers to significance at the 5% level of probability.

Table 8. Dry weight of 100 seedlings (g) from sand/peatmoss substrates with a different proportion of soil and with three fertilizer rates[1], 26 days after sowing

Substrate			N, K_2O (ppm)			
% sand	% peatmoss	% soil	0	50	100	Mean[3]
50	50	0	.39	.35	.45	.40 a
50	45	5	.40	.43	.43	.42 a
50	40	10	.39	.42	.41	.41 a
50	30	20	.47	.44	.36	.42 a
50	10	40	.35	.33	.28	.32 b
		Mean[2]	.40	.39	.39	

[1] All treatments received 800 ppm of P_2O_5
[2] F-test is not significant (NS)
Coefficient of variation (CV) = 13.9%
[3] Duncan's multiple range test at 5% level - treatment means followed by the same letter are not significantly different
CV = 13.9%

Table 9. Number and weight of seedling tubers produced in different nursery substrates

Substrate	Experiment I			Experiment II			Mean of both experiments		
	Tubers >1g		Mean tuber weight (g)	Tubers >1g		Mean tuber weight (g)	Tubers >1g		Mean tuber weight (g)
	kg/m^2	No./m^2		kg/m^2	No./m^2		kg/m^2	No./m^2	
50% sand, 30% peatmoss, 20% soil	4.17	534	7.8	7.22	890	8.1	5.70	712	8.0
50% sand, 50% peatmoss	6.90	584	11.8	8.77	865	10.1	7.84	725	10.8
50% sand, 30% compost, 20% soil	5.26	685	7.7	6.29	787	8.0	5.78	736	7.9
50% sand, 50% compost	6.49	661	9.8	8.35	1018	8.2	7.42	839	8.8
50% sand, 30% manure, 20% soil	2.95	543	5.4	5.74	828	6.9	4.34	686	6.3
50% sand, 50% manure	2.67	474	5.6	-	-	-	-	-	-
LSD.01	1.40	NS[1]		2.04	NS		1.27	180	
LSD.05	1.03	NS		1.50	NS		0.95	135	
CV (%)	18.3	30.2		17.1	16.9		23.0	22.0	

[1] NS refers to a non-significant F-test in the analysis of variance

between the 2 N levels applied to the substrates, yields are presented as means of both levels of N (Table 9). In the second experiment (Table 9) plots with 50% sand and 50% manure showed poor emergence and retarded growth and were excluded from the experiment. Comparison of peatmoss, compost and manure as organic materials, shows that substrates containing compost gave similar yields to those containing peatmoss while substrates containing cow manure yielded significantly less. Plants in substrates with compost produced a non-significantly* higher number of tubers resulting in a smaller mean tuber size than those in substrates with peatmoss.

From these results it was concluded that substrates containing 50% sand and 50% peatmoss or compost were suitable to produce seedling tubers. Since both river sand and peatmoss were readily available locally, with rather constant physical and chemical characteristics, it was decided to use this substrate in further experiments.

3.2.2 Fertilization

Final seedling emergence was not influenced by pre-sowing application of N, P_2O_5 or K_2O, although the rate of emergence appeared slightly slower when N and K_2O were

* Where the least significant difference (LSD) between treatment means is indicated as not significant (NS) reference is made to a non-significant F-test in the analysis of variance.

applied at a rate of 400 ppm. The main effect of N + K_2O on seedling weight differed greatly from that of P_2O_5; no significant interaction between N + K_2O and P_2O_5 was found. In a substrate of 50% sand and 50% peatmoss, a pre-sowing application of up to 200 ppm of N and K_2O did not significantly affect seedling weight, while at a rate of 400 ppm seedling weight decreased significantly (Fig. 3). On the other hand a pre-sowing application of P_2O_5 as high as 800 ppm did not give a decrease in seedling weight compared with a rate of 200 ppm (Fig. 4). In a substrate of 50% sand, 40% peatmoss and 10% soil a decrease in seedling weight due to N and K_2O application occurred at a rate of 200 ppm. The response to N and K_2O showed a significant interaction with substrate composition, indicating that in substrates with soil high application rates are more critical than in those without soil. Table 8 also shows that the response to N and K_2O application tends to change with increasing proportions of soil in the substrate, however the interaction between fertilizer application and substrate composition was not significant.

The main effects of N and K_2O individually on seedling weight were somewhat different; no significant interaction between both elements was found (Table 10). At application rates of up to 200 ppm, K_2O did not affect seedling weight while at a rate of 400 ppm seedling weight decreased. On the other hand application of up to 100 ppm of N showed a significant increase in seedling weight compared with the control, while at higher application

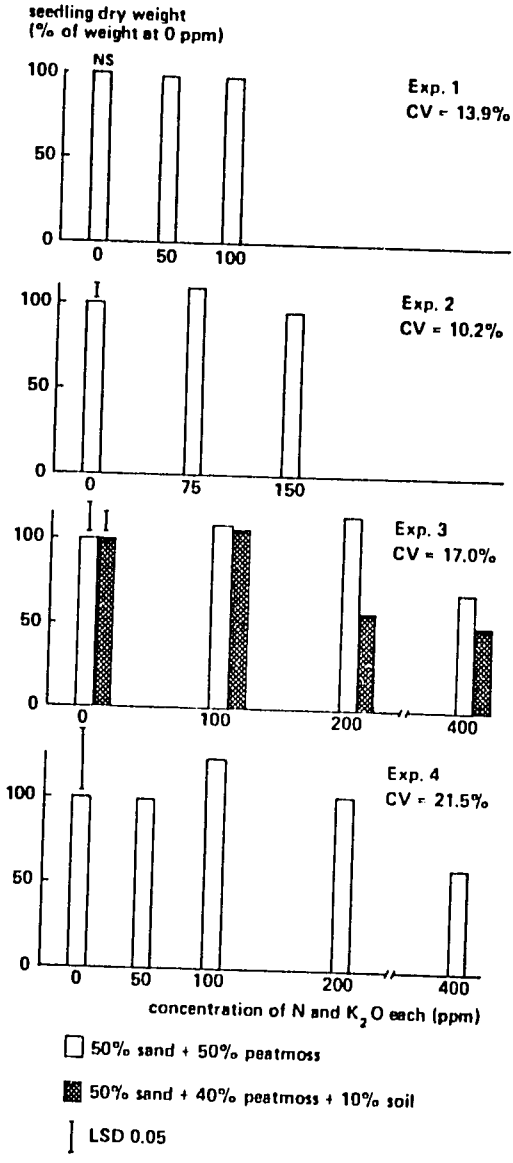

Fig. 3. Effect of pre-sowing application of N and K_2O on seedling dry weight.

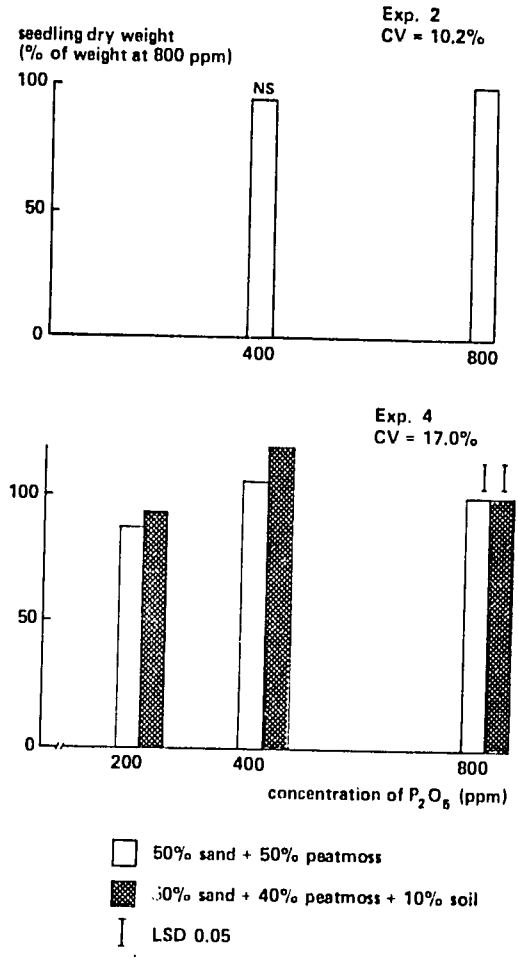

Fig. 4. Effect of pre-sowing application of P_2O_5 on seedling dry weight.

Table 10. Dry weight of 90 seedlings (g) at different rates of N and K_2O, 35 days after sowing - Experiment 4*

Potash (ppm)	Nitrogen (ppm) 0	50	100	200	400	Mean
0	1.66 (2.1)	2.15 (2.2)	2.25 (2.4)	1.72 (2.9)	1.59 (3.4)	1.87 (2.6)
50	1.37 (2.1)	1.64 (2.3)	2.35 (2.4)	2.08 (2.9)	1.00 (3.1)	1.69 (2.6)
100	1.88 (2.2)	2.39 (2.4)	2.06 (2.4)	1.75 (2.9)	1.32 (3.7)	1.88 (2.7)
200	2.00 (2.4)	2.12 (2.3)	2.13 (2.9)	1.70 (2.9)	1.26 (3.3)	1.84 (2.8)
400	1.93 (2.6)	1.28 (2.6)	1.66 (3.0)	1.07 (3.5)	1.01 (3.3)	1.39 (3.0)
Mean	1.77 (2.3)	1.92 (2.4)	2.09 (2.6)	1.67 (3.0)	1.24 (3.4)	

* Between brackets: electrical conductivity of the substrate at seedling harvest

Least significant differences:
- between individual combinations of N and K_2O: LSD .01 = .82
  .05 = .61
- between means of N and K_2O: LSD .01 = .36
  .05 = .27

CV seedling weight = 21.5%

rates, seedling weight decreased significantly. The highest seedling weight was obtained at a rate of 50 ppm of N and 100 ppm of K_2O, while in all treatments 800 ppm of P_2O_5 had been applied.

Both N and K_2O fertilization increased substrate salinity substantially (Tables 10 and 11) while P_2O_5 fertilization had little effect on salinity. The salt concentration was lower in the substrate with soil than in that without soil (Table 12). The EC values of experiments 3 and 4 were plotted against seedling dry weight (Fig. 5) and the results indicate a negative correlation between salt concentration and seedling growth, but it left much of the variation in seedling growth unexplained.

From these results it can be concluded that in the majority of the experiments N application did not promote early seedling growth, while K_2O application never resulted in increased seedling weight. Pre-sowing fertilizer rates above 200 ppm always decreased seedling weight with N and K fertilizers but not with P fertilizers. Based on these results and in order to reduce the risk of salinity problems, a pre-sowing fertilizer rate of 0-800-0 ppm of NPK was used in further experiments.

3.2.3 Planting system

The interaction between planting system and TPS-line was not significant, indicating that the effects of direct

Table 11. Effect of N, K_2O and P_2O_5 fertilization on the electrical conductivity (mmho/cm) in a substrate of 50% sand and 50% peatmoss - Experiment 3

Total concentration of $N+K_2O$ (ppm)	Concentration of P_2O_5 (ppm)			Increase in EC (%) from 200-800 ppm of P_2O_5
	200	400	800	
0	2.1	2.3	2.6	23.8
200	3.0	2.9	3.0	0
400	3.2	3.5	4.0	25.0
800	4.1	4.3	4.8	17.1
Increase in EC (%) from 200-800 ppm of $N+K_2O$	36.6	48.3	60.0	
Mean increase in EC (%):				
- due to 600 ppm of $N+K_2O$		48.3		
- due to 600 ppm of P_2O_5				16.5

Table 12. Effect of N and K_2O application on the electrical conductivity (mmho/cm) in 2 substrates - Experiment 3

Concentration of N and K_2O each (ppm)	SUBSTRATE	
	50% sand + 50% peatmoss	50% sand + 40% peatmoss + 10% soil
0	2.34	2.19
100	2.95	2.63
200	3.56	2.95
400	4.40	3.55
Mean*	3.31	2.83

* LSD 0.01 = 0.75

LSD 0.05 = 0.45

CV(%) = 22.5

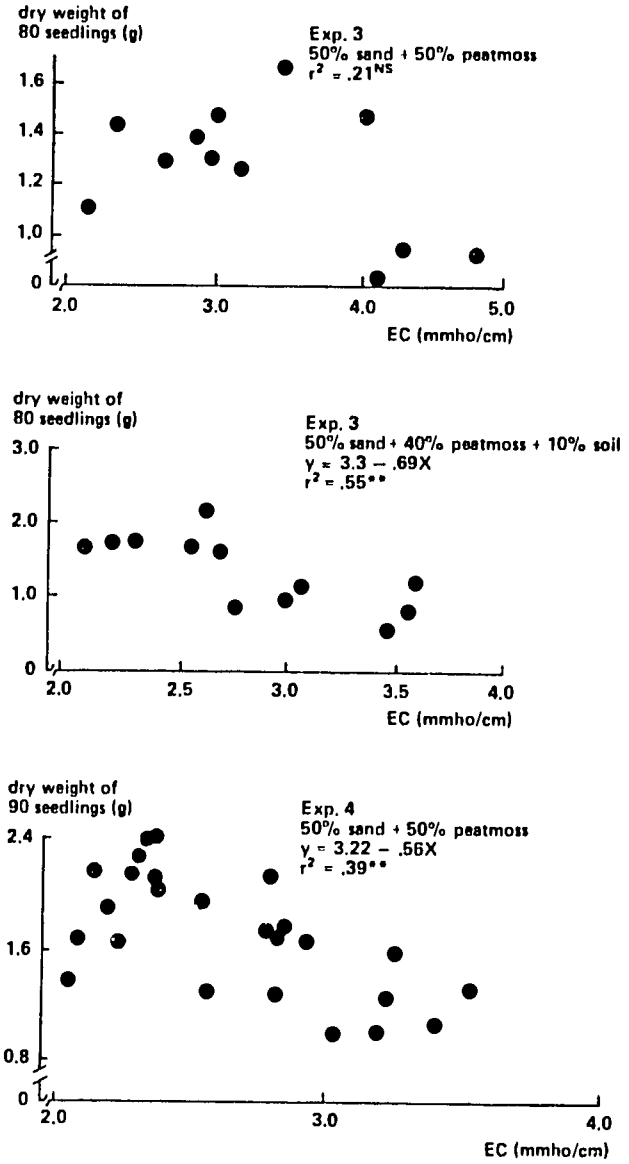

Fig. 5. Relationship between electrical conductivity of the substrate and seedling dry weight. (** = significant at P0.01.)

sowing and transplanting treatments were similar in both TPS-lines. The results are therefore presented as means of both lines.

After transplanting foliage growth was slow (Fig. 6) while tubers were formed immediately after transplanting followed by a temporary lull in the formation of new tubers. Plants from direct sown TPS, on the other hand, showed faster development of foliage (Fig. 6), formation of more and longer stolons (Fig. 7) and later tuber formation (Fig. 6). It would appear that plants from direct sown TPS produced more foliage before tubers were initiated than those from transplants.

A significant difference in total foliage weight between transplanted and direct sown treatments occurred up to 63 days after sowing (Fig. 6) while the difference in total tuber dry weight continued to be significant up to 110 days after sowing (Fig. 8). At 125 days no significant difference in tuber dry weight was found between treatments.

These results indicate that transplanting delayed growth and increased the total growing period from sowing by about 15 days without affecting total yield. Raising seedlings outside the seedling tuber nursery followed by transplanting to the nursery, reduced the total period that the seedling tuber nursery was occupied by (35-15 =) 20 days.

Since direct sown treatments showed less variation

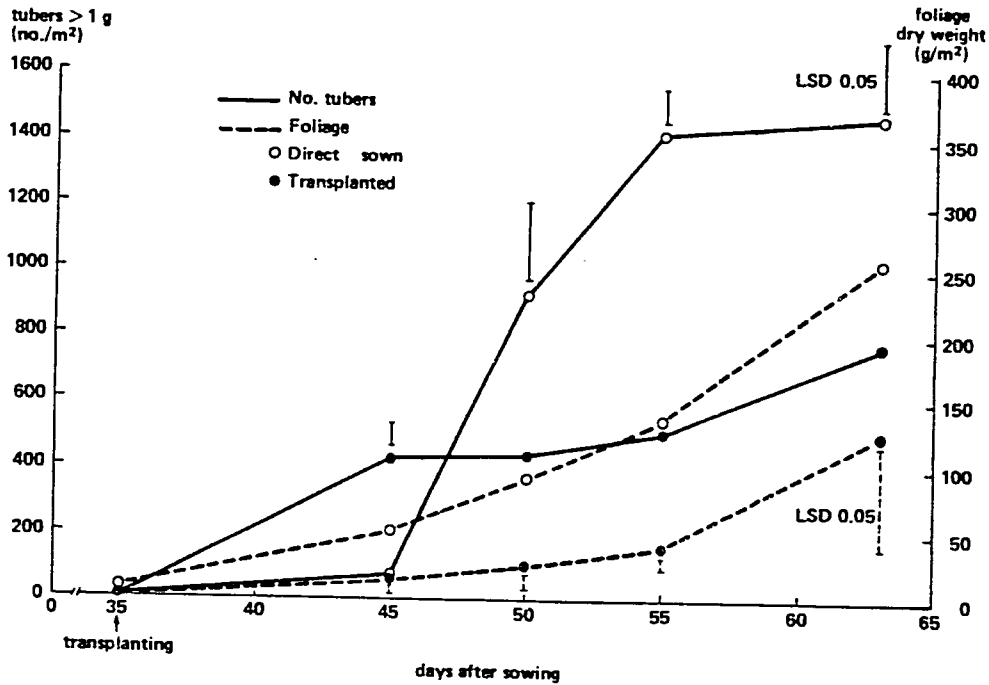

Fig. 6. Effect of planting system on tuber number and total foliage weight (mean of 2 TPS-lines).

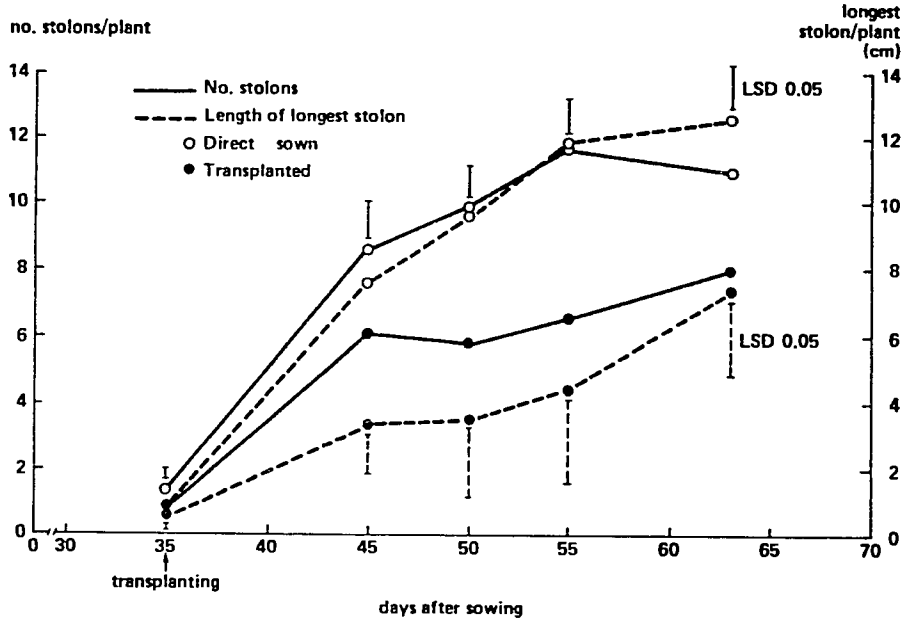

Fig. 7. Effect of planting system on stolon development (mean of 2 TPS-lines).

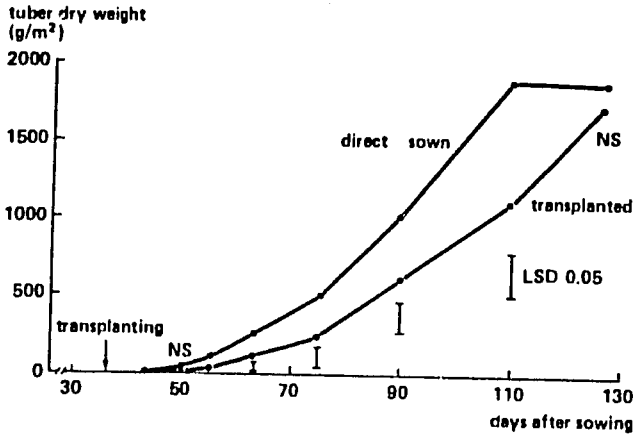

Fig. 8. Effect of planting system on total tuber yield (mean of 2 TPS-lines).

between plants and since temperatures in the seedling tuber nursery did not prohibit seed germination, it was decided to direct sow in further experiments.

3.2.4 Plant population

A plant population of 275 plants per square meter and also that of 200 plants per square meter gave some problems during hilling, because close plant spacing made it more difficult to apply additional substrate, without plant damage.

In experiments B and C no significant interaction was found between plant population and hilling or plant population and TPS-lines, respectively. The results are therefore presented as means of hilling treatments and TPS-lines.

Results of the 3 experiments (Tables 13-15) show that the lowest plant population of 50 plants per square meter, always gave the lowest yield, both in total tuber number and weight, while the highest plant population used in each experiment always produced the highest total number and weight of tubers with the exception of experiment 2. In experiment 2 the tuber numbers and weights produced at 100, 150 and 200 plants per square meter did not differ significantly. The positive effect of increasing plant population on the total number of useable tubers (larger than 1 g) was mainly due to an increase in tubers of 1-10 g. The number of tubers larger than 10 g was either not affected by plant

Table 13. Effect of plant population on the yield and size distribution of seedling tubers in nursery beds - Experiment A*

Plants/m^2	Spacing (cm)	Plants surviving till harvest		Tuber yield							Mean tuber weight (g)
				<1 g	1-10g	10-20g	20-40g	>40 g	>1 g	>1 g	
		No/m^2	%	No/m^2	No/m^2	No/m^2	No/m^2	No/m^2	No/m^2	kg/m^2	
50	14 x 14	32	64	74	219	73	46	16	354	4.52	12.8
100	10 x 10	41	41	133	261	82	52	17	412	4.85	11.8
275	6 x 6	47	17	375	467	102	51	10	630	5.87	9.3
LSD 0.01		NS		80	64	NS	NS	NS	128	1.53	
LSD 0.05		NS		53	42	NS	NS	NS	85	1.01	
CV (%)		15.9		13.5	6.7	22.9	15.2	23.3	9.1	9.9	

* TPS-line : DTO-33 OP

Table 14. Effect of plant population on the yield and size distribution of seedling tubers in nursery beds - Experiment B*

Plants/m^2	Spacing (cm)	Plants surviving till harvest		Tuber yield						Mean tuber weight (g)
		No/m^2	%	<1 g No/m^2	1-10g No/m^2	10-20g No/m^2	20-40g No/m^2	>1 g No/m^2	>1 g kg/m^2	
50	14 x 14	43	86	120	287	118	40	445	4.46	10.0
100	10 x 10	63	63	197	441	132	35	608	5.32	8.8
150	8 x 8	78	52	211	433	136	51	620	5.48	8.8
200	7 x 7	85	43	268	462	150	33	645	5.41	8.4
LSD 0.01		11		53	90	NS	NS	110	NS	
LSD 0.05		8		38	64	NS	NS	79	NS	
CV (%)		9.0		15.0	12.5	25.0	30.5	10.8	14.0	

* TPS-line : DTO-33 OP

Table 15. Effect of plant population on the yield and size distribution of seedling tubers in nursery beds - Experiment C*

Plants/m^2	Spacing (cm)	Plants surviving till harvest		Tuber yield							Mean tuber weight (g)
		No/m^2	%	<1 g No/m^2	1-10g No/m^2	10-20g No/m^2	20-40g No/m^2	>40 g No/m^2	>1 g No/m^2	>1 g kg/m^2	
50	14 x 14	36	72	202	496	170	69	23	758	8.00	10.6
100	10 x 10	48	48	318	700	196	81	30	1007	9.59	9.5
150	8 x 8	61	41	478	782	201	89	31	1103	10.08	9.1
LSD 0.01		6		80	131	30	17	NS	127	0.92	
LSD 0.05		4		57	93	21	12	NS	91	0.65	
CV (%)		8.1		16.7	13.8	10.9	15.0	25.0	9.2	6.9	

* Mean of 3 TPS-lines

population (Tables 13 and 14) or showed a small but significant increase (Table 15). In none of the experiments did increased plant population result in a decrease in the number of relatively large size tubers (>20 g).

Because there was no significant interaction between TPS-line and plant population and because the general relationship between plant population and tuber number or weight tended to follow an asymtotic pattern, the data were fitted to the equation: $Y = \frac{1}{a + b/x}$, where Y = tuber number or weight and x = plant population. These fitted curves are presented in Figs. 9 and 10, while the equations of the relationships are given in Table 16. The reciprocal of the a - values in this table represent the maximum tuber number or weight at a theoretical plant population of

In all 3 experiments the percentage of plants that survived until harvest decreased with increasing plant population (Tables 13-15), indicating increased levels of competition between plants. Table 17 shows that plants started to die earlier at high plant populations than at low populations.

These results indicate that increasing population density had a positive effect on tuber yield, both in terms of tuber number and weight. Although mean tuber weight decreased with increasing density, the number of relatively large size tubers (>20 g) did not decrease. It was concluded that a population of 100-150 plants per square meter was adequate for the production of a large

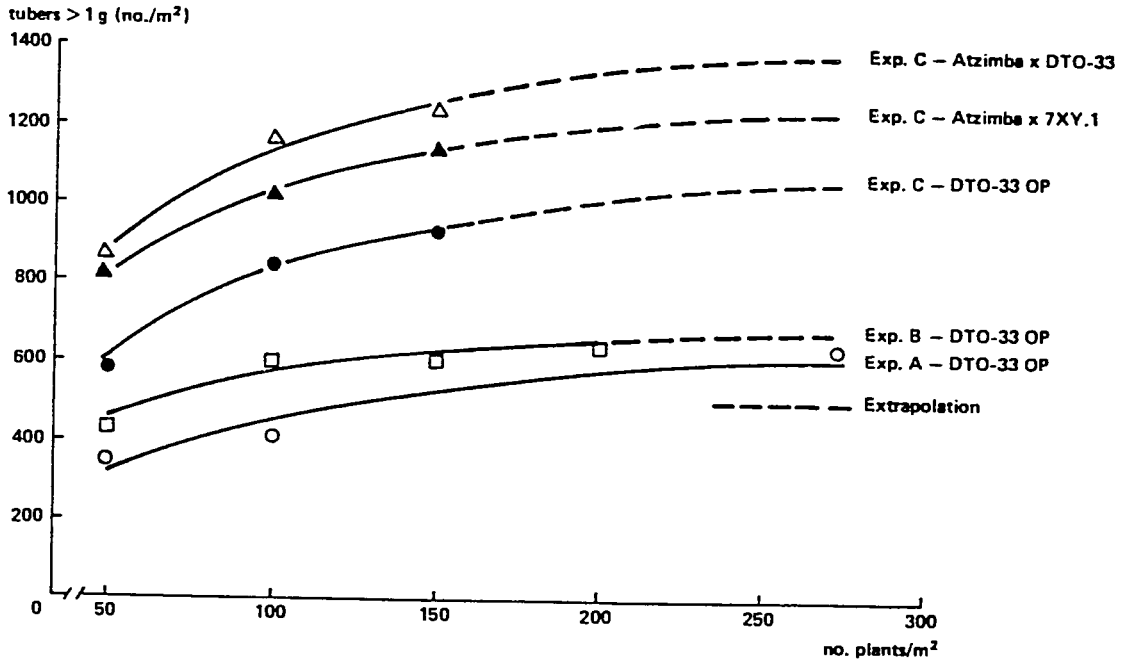

Fig. 9. Fitted curves for the relationship between plant population and total number of tubers larger than 1 g.

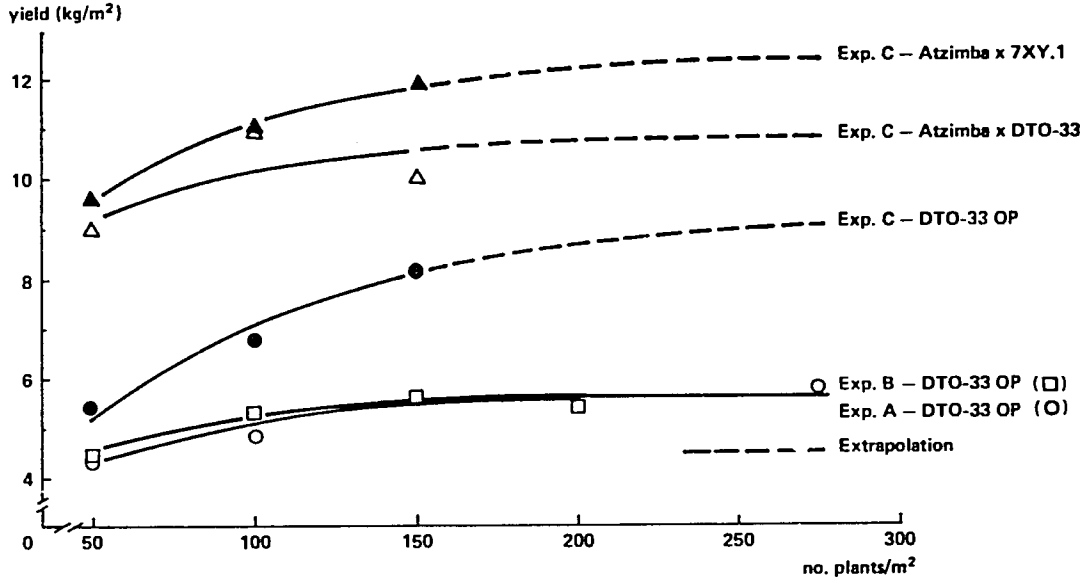

Fig. 10. Fitted curves for the relationship between plant population and total tuber yield.

Table 16. Equations of the relationship between plant population (X) and total number of tubers >1 g (Y_1 - Fig. 9) and between plant population and total tuber weight (Y_2 - Fig. 10)

Experiment	TPS-line*	Tuber number $Y_1 = \frac{1}{a + b/X}$	Tuber weight $Y_2 = \frac{1}{a + b/X}$
A	L_1	$a = 12.93 \times 10^{-4}$	$a = 162.19 \times 10^{-3}$
		$b = 912.35 \times 10^{-4}$	$b = 331.45 \times 10^{-2}$
B	L_1	$a = 130.87 \times 10^{-5}$	$a = 166.52 \times 10^{-3}$
		$b = 430.75 \times 10^{-4}$	$b = 271.09 \times 10^{-2}$
C	L_1	$a = 751.34 \times 10^{-6}$	$a = 903.51 \times 10^{-4}$
		$b = 47.19 \times 10^{-3}$	$b = 498.38 \times 10^{-2}$
	L_2	$a = 62.59 \times 10^{-5}$	$a = 880.98 \times 10^{-4}$
		$b = 25.48 \times 10^{-3}$	$b = 100.77 \times 10^{-2}$
	L_3	$a = 71.36 \times 10^{-5}$	$a = 741.64 \times 10^{-4}$
		$b = 252.87 \times 10^{-4}$	$b = 153.26 \times 10^{-2}$

* L_1 = DTO-33 OP

L_2 = Atzimba x DTO-33

L_3 = Atzimba x 7XY.1

Table 17. Percentage of surviving plants in direct sown nursery beds at different intervals after sowing - Experiment C

Plant population plants/m^2	TPS-line	54 days after sowing	68 days after sowing	At harvest
50	DTO-33 OP	100	96	72
	Atzimba x 7XY.1	100	100	72
	Atzimba x DTO-33	100	100	68
	Mean	100	99	71
100	DTO-33 OP	93	92	52
	Atzimba x 7XY.1	88	85	44
	Atzimba x DTO-33	90	88	47
	Mean	90	88	48
150	DTO-33 OP	80	79	46
	Atzimba x 7XY.1	75	73	33
	Atzimba x DTO-33	77	77	43
	Mean	77	76	41

number of useable tubers; 100 plants per square meter spaced at 10 x 10 cm were used in further experiments for practical reasons.

3.2.5 Hilling

Generally more green or partly green tubers were found in the plots without hilling. Frequently these green tubers were sprouting at the time of harvest. Despite the fact that many tubers were found partly above soil or close to the soil surface, no signs of damage by the potato tuber moth were observed.

Since no significant interaction was found between hilling and plant population, hilling and TPS-line and hilling and B nine, results (Tables 18 and 19) are presented as means of these factors.

Hilling increased the number and length of stolons at 50, 59 and 65 days after sowing (Table 18), while no significant difference was found between 2-3 cm and 6-7 cm hilling. At maturity (Table 19) hilling did not affect the number of surviving plants, while the total tuber weight increased as a result of hilling, although this increase was not significant in experiments B and D. Two-3 cm hilling showed a significant increase in the number of tubers larger than 1 g compared with no hilling. This increase was mainly caused by an increase in the number of tubers weighing 1-20 g. No significant difference in tuber number was found between 2-3 cm and 6-7 cm hilling levels.

Table 18. Effect of different hilling levels on stolon formation in direct sown nursery beds - Experiment D[1]

Height of hilling (cm)	Number of stolons per plant			Longest stolon (cm)		
	50 days[2]	59 days	65 days	50 days	59 days	65 days
0	1.6	3.7	6.0	5.4	8.2	14.2
2-3	6.3	7.7	8.8	8.7	15.2	17.9
6-7	5.8	7.9	8.1	8.8	14.7	21.2
LSD 0.05	1.3	1.0	2.1	NS	5.3	6.9
CV (%)	18.6	10.2	17.5	42.5	26.8	24.8

[1] Mean of 2 TPS-lines and 2 B nine treatments

[2] Days after sowing

Table 19. Effect of hilling on the yield and size distribution of seedling tubers in direct sown nursery beds

	Height of hilling (cm)	Plants at harvest No/m^2	Tuber yield <1 g No/m^2	1-10g No/m^2	10-20g No/m^2	20-40g No/m^2	>40g No/m^2	>1 g No/m^2	>1 g kg/m^2	Mean tuber weight (g)
Experiment B[1]	2-3	70	195	407	131	37	-	575	5.05	8.8
	6-7	64	203	405	137	43	-	585	5.28	9.0
CV (%)		NS 18.5	NS 15.0	NS 10.3	NS 40.1	NS 50.5		NS 13.6	NS 14.4	
Experiment D[2]	0	54	94	198	75	36	10	319	3.62	11.4
	2-3	53	102	245	97	34	9	385	4.07	10.6
	6-7	53	127	269	96	36	8	409	4.21	10.3
LSD 0.01		NS	NS	50	18	NS	NS	60	NS	
LSD 0.05		NS	NS	35	12	NS	NS	42	NS	
CV (%)		17.1	26.1	16.2	15.3	39.7	50.1	12.4	21.7	
Experiment E[3]	0	37	213	396	93	80	38	607	8.74	14.4
	2-3	34	238	515	128	96	33	772	9.74	12.6
	6-7	43	203	429	120	104	39	691	9.92	14.4
LSD 0.01		9	NS	64	24	14	NS	77	1.06	
LSD 0.05		7	NS	47	18	10	NS	56	0.78	
CV (%)		20.0	27.4	12.4	18.4	13.2	20.5	9.6	9.7	

[1] Mean of 4 plant populations
[2] Mean of 2 TPS-lines and 2 B nine treatments
[3] Mean of 2 B nine treatments

Since hilling increased tuber number more than total tuber weight, average tuber weight tended to decrease.

These results indicate that with direct sowing in nursery beds at least 2-3 cm of substrate has to be added to the beds after seedling emergence for adequate seedling tuber production.

3.2.6 Growth regulators

Several days after B nine application, treated plants were darker green than untreated plants.

In experiment D no significant interaction was found between B nine and hilling and between B nine and TPS-line at intermediate and mature harvests; results are therefore presented as means of these factors (Tables 20 and 21). B nine treatment decreased stem length, number and length of stolons but the effect decreased with time (Table 20). The number of nodes was not affected by B nine, indicating similar rates of plant development. At mature harvest (Table 21) no significant effect of B nine was found on tuber number, tuber weight or size distribution.

In experiment E there was a significant interaction between B nine and hilling for the variables stem length and number of stolons (Table 22). At 65 days after sowing stem length was reduced by more than 50% by B nine (mean of hilling treatments), while this reduction in stem length decreased with increasing level of hilling (Table 22). The

Table 20. Effect of B nine application on plant development - Experiment D*

Growth character	B nine application	Days after sowing		
		50	59	65
Stem length (cm)	-	33.7	51.6	67.4
	+	19.3	34.1	53.1
	LSD 0.05	2.8	4.8	6.2
	CV (%)	11.0	11.7	10.6
No. nodes	-	17.8	22.7	26.3
	+	17.8	22.7	27.1
	LSD 0.05	NS	NS	NS
	CV (%)	5.4	4.9	6.8
No. stolons/plant	-	4.9	6.9	7.8
	+	4.2	5.9	7.4
	LSD 0.05	0.8	0.6	NS
	CV (%)	18.6	10.2	17.5
Longest stolon (cm)	-	10.3	15.9	20.2
	+	4.9	9.5	15.3
	LSD 0.05	3.1	3.3	4.3
	CV (%)	42.5	26.8	24.8

* Mean of 2 TPS-lines and 3 hilling treatments

Table 21. Effect of B nine application on the yield and size distribution of seedling tubers in nursery beds

	B nine application	Plants at harvest No/m^2	Tuber yield							
			<1 g No/m^2	1-5 g No/m^2	5-10g No/m^2	10-20g No/m^2	20-40g No/m^2	>40 g No/m^2	>1 g No/m^2	>1 g kg/m^2
Experiment D[1]	-	52	114	148	87	94	33	10	371	3.94
	+	55	101	160	81	84	38	8	370	3.99
	LSD 0.05	NS	NS	NS	NS	NS	NS	NS	NS	NS
	CV (%)	17.0	26.2	19.8	33.7	15.4	39.5	50.1	12.4	21.7
Experiment E[2]	-	43	160	277	136	129	112	44	699	10.79
	+	32	276	362	118	98	75	29	681	8.15
	LSD 0.05	NS	38	56	NS	NS	26	9	NS	2.68
	CV (%)	22.4	12.2	12.2	24.3	27.4	19.2	16.8	13.1	19.7

[1] Mean of 2 TPS-lines and 3 hilling treatments
[2] Mean of 3 hilling treatments

Table 22. Effect of B nine application and hilling on plant development 65 days after sowing - Experiment E*

Variable	B nine application	Hilling (cm) 0	2-3	6-7	Mean	LSD 0.05 between means
Stem length (cm)	-	52.6	47.9	46.3	48.9	13.7
	+	21.2	19.6	24.1	21.6	
	Mean	36.9	33.7	35.2		2.9
No. nodes	-	19.9	18.4	18.0	18.8	NS
	+	19.0	17.5	18.4	18.3	
	Mean	19.4	18.0	18.2		NS
No. stolons per plant	-	6.7	9.6	9.3	8.5	1.9
	+	3.1	6.1	8.5	5.9	
	Mean	4.9	7.8	8.9		1.3
Longest stolon (cm)	-	9.4	12.3	12.1	11.3	NS
	+	3.3	5.9	9.2	6.1	
	Mean	6.4	9.1	10.6		2.4
% deformed tubers	-	18	14	18	17	14
	+	45	40	37	40	
	Mean	32	27	27		5

* The interaction between B nine and hilling is significant for the variables stem length and number of stolons per plant

number and length of stolons was reduced by B nine, although the effect on stolon length was not significant. The effects on stolon formation decreased with increasing hilling level. The percentage of deformed tubers at mature harvest increased significantly with B nine treatment. Tuber malformation was most severe in treated plots without hilling. The number of nodes was not affected by B nine.

In experiment E no interaction was found between the effects of B nine and hilling on the number and weight of tubers at mature harvest, results are therefore presented as means of the hilling treatments (Table 21). B nine treatment increased the number of tubers smaller than 5 g, and decreased the number larger than 20 g. The total tuber number was not affected by B nine while total tuber weight decreased. Maturity tended to be slightly later in treated plots.

These results indicate that although B nine treatment resulted in sturdier seedlings, no positive effects on seedling tuber production could be observed.

3.3 Discussion

3.3.1 Nursery substrate and fertilization

3.3.1.1 Pre-sowing fertilizer application

Results suggest that pre-sowing application of N and

K_2O affect early seedling growth differently than application of P_2O_5 (Figs. 3 and 4). In all experiments a total rate of 800 ppm of N and K_2O combined, decreased seedling weight significantly compared with the control, while the same quantity of P_2O_5 did not decrease seedling weight compared with lower application rates. Similarly, at lower application rates the effect of N and K_2O was in most cases not significantly different from the control, while a rate of 400 ppm of P_2O_5 gave significantly higher seedling weight than a rate of 200 ppm. Malagamba (1983 a) has also reported a positive response of seedling weight to P_2O_5 without negative effects at high application rates. The positive response of seedling growth to P_2O_5 is likely to be associated with the limited root system of potato seedlings and the low mobility of P_2O_5 in the substrate.

The substrates used in the experiments contained apparently sufficient quantities of the more mobile elements N and K_2O since in most cases no significant positive response could be observed. The question remains why seedling growth responded negatively to high rates of N and K_2O and not to high rates of P_2O_5, and the obvious hypothesis is, that this is due to a difference in salt concentration resulting from these fertilizers. The salt concentration of the substrate solution measured by the electrical conductivity (EC) was much more affected by N and K_2O fertilization than by P_2O_5 fertilization (Table 11). Increase in application rate from 200 to 800 ppm resulted with N and K_2O in a 48.3% increase in EC of the substrate

solution while the same increase in the amount of P_2O_5 gave only a 16.5% increase in EC. These results are in agreement with those of Rader *et al.* (1943) indicating that N and K_2O fertilizers usually increase the osmotic pressure of the soil solution considerably more than P_2O_5 fertilizers (Table 4).

The negative correlation between EC and seedling dry weight (Fig. 5) seems to support the hypothesis that an important contribution to the negative response of seedling weight to N and K_2O fertilization at higher application rates is high salt concentration. Papadopoulos and Rendig (1983) also found decreasing shoot weights in tomatoes with increasing EC values of applied nutrient solutions and that of solutions extracted from the soil. Salts increase the osmotic pressure of the soil solution which interferes with water uptake and nutrition of developing plants (Harper, 1955; Bernstein and Hayward, 1958; Cooke, 1967; Bernstein, 1974). In addition to osmotic effects on plant growth, specific ions can cause toxicity or nutritional imbalances or deficiencies (Cooke, 1967; Greenway, 1973; Bernstein, 1974). Since only a limited part of the variation in seedling dry weight is accounted for by the salt concentration (Fig. 5) these specific ion effects are likely to have played an important role.

Generally potato plants from seedlings would seem rather sensitive to salts. Of a total of 40 crops, including forage crops, field crops and vegetable crops, only 9 appear to be more sensitive to salts than the potato crop

derived from tubers (Bernstein, 1974). Potato seedlings are likely to be even more sensitive to salts than plants from tubers.

The effects of salts on plant growth may vary with the growth stage of the plant. Considering the vital role of water inbibition the germination stage is likely to be more salt sensitive than later stages, although seedling stages (up to the 4 leaf stage) of grains such as barley, wheat and rice have been reported to be more salt sensitive than either the germination stage or later growth stages (Ayers *et al.*, 1952; Pearson and Bernstein, 1959). The results suggest that potato seedlings behave similarly to rice, wheat and barley in this respect since at a rate of 400 ppm of N and K_2O seedling emergence was only slightly retarded while early seedling growth was considerably decreased.

Effects of high salt concentrations may be more pronounced when seedlings are grown in trays than when grown in beds. Because of the limited depth of substrate, seedlings in trays are exposed to continuous high salt concentrations, while in beds salts would be washed frequently below the root zone by irrigation. Since the salinity averaged over time should be considered the effective salinity experience by the plant (Shalhevet, 1970; Shalhevet and Yaron, 1973), the effective salinity in the root zone is likely to be higher in trays than in beds. Although the tray method by which pre-sowing application rates were studied may not entirely represent the

situation when seed is direct sown in beds, the conclusion seems justified that potato seedlings are sensitive to salts and that salt increasing fertilizers have to be managed carefully at early growth stages.

3.3.1.2 Type of substrate

The substrates in the nursery gave rise to slower seedling development and lower yields when a certain amount of peatmoss was replaced by field soil (Tables 8 and 9). In addition the negative effect of N and K_2O on early seedling growth occurred at lower application rates in substrates containing soil (Table 8, Fig. 3). The decreased seedling growth due to the soil component in the substrate was not caused by increased salt concentrations since the soil component decreased the salt concentration of the soil solution (Table 12). A possible explanation for the negative effect of the soil fraction on seedling grow could be that the soil contained some type of toxic substance or substances. Since the soil originated from a field that was irrigated for many years by river water it is not unlikely that the deposit of such a substance(s) has taken place especially as waste products are dumped into the river. In the absence of detrimental effects caused by certain substances in the soil, the addition of some soil to a nursery substrate would be expected to have a positive effect on plant growth due to a better water holding capacity. This would normally also lower salt concentrations because of in-

creased water content of the substrate. Good results with field soils as a growing medium for seedlings have been obtained in Rwanda (Haverkort, unpublished) and in Toluca, Mexico (Villareal, unpublished). Personal observations in Toluca on seedling growth in organic soils collected from a forest on different dates and by different persons, indicated large differences in seedling growth due to location and depth from which the soil was collected. Under the circumstances found in Lima it might be better to identify a substrate with a more constant quality and perhaps exclude field soil.

Suitable substrates for seedling tuber production appear to be 50% sand and 50% peatmoss or compost (Table 9). Malaganba (1983 a) has also reported that both substrates are suitable for raising seedlings. The advantage of peatmoss as organic material is its rather constant chemical and physical characteristics while compost is more likely to differ in composition depending on its preparation. Substrates with cow manure gave in Lima significantly lower yields than those with peatmoss and compost although in India good results were obtained with 50% sand and 50% manure (Upadhya, personal communication). The difference is likely to be caused by the type of manure used in these cases. In Lima the manure originated from an intensive cattle feeding programme resulting in high salt concentrations, while in India manure was mixed with straw and soil. Another low salt manure is that from horses and excellent yields have been obtained in mixes of sand and

this type of manure (Wiersema, unpublished).

3.3.1.3 Fertilizer management

The pre-sowing application of fertilizers in beds for seedling tuber production seems to be rather critical. Experience in Turkey, Mexico, Brazil and Peru have shown that many production attempts fail during the first month after sowing, due to an overdose of N and K_2O fertilizers or other salt increasing materials such as certain types of manure. In areas with high evaporation, salt problems are likely to occur at lower application rates due to the concentration of salts near the surface. This may be illustrated by an observation in Lima during the hot summer when a pre-sowing application of 100 ppm of N and K_2O resulted in EC values of over 6 mmho/cm in samples taken at the depth of the seed. Emergence was about 50% of that normally obtained and emerging seedlings showed severely retarded growth. Attempts to leach the salts by heavy irrigation appeared ineffective, while more frequent irrigation caused damping off diseases. The same substrate with 800 ppm of P_2O_5 but without N and K_2O gave a completely normal pattern of emergence and subsequent seedling development. This demonstrates that although shorter intervals of irrigation could possibly minimize the concentrating effect of evapotranspiration on soil salinity (Bernstein and Francois, 1973) the risk of promoting damping off diseases prohibits this practice.

Since the data presented here indicate that only the application of P_2O_5 seems essential for the first weeks of seedling development, a safe practice would be only to apply P_2O_5 before sowing, while N and K_2O application should possibly start a few weeks after sowing depending on seedling growth rate. In experiment 4 (Table 10) where seedling growth was evaluated 35 days after sowing, some signs of N deficiency were apparent, resulting in a significant (P=0.05) positive response to N. This suggests that N application should take place earlier, possibly 15-25 days after sowing.

Failure to obtain a significant difference in yield due to different levels of post-emergence application of N and K_2O suggests that fertilizer application is far less critical at later stages of seedling growth. It should be realized however that N and K_2O fertilizers were applied weekly in small doses. This practice is likely to have minimized any negative effects of salts during later growth stages. To simplify management less frequent applications may be desirable. The salt index from Rader *et al.* (1943) may serve as a practical guide to identify suitable fertilizers that have a limited effect on salt concentrations (Table 4).

3.3.2 Planting system

The results indicate that by transplanting seedlings a similar yield can be obtained as by direct seed sowing in

beds (Fig. 8). However, the growing period with the transplanting system, measured from the time of sowing, appears to be considerably longer than when seed is sown direct. A study of the foliage development of transplanted seedlings (Fig. 6) suggests that this longer growing period is largely caused by a transplanting "shock" expressed as a stagnation of foliage growth immediately after transplanting. Foliage dry weight remained nearly constant for a period of 10 days after transplanting while after this period only a slight increase in weight could be observed for several days. It would appear that the increase in the length of the growing period associated with transplanting (Fig. 8) is similar to the period of stagnating foliage growth following transplanting (Fig 6).

Another expression of the shock of transplanting seems to be the rapid increase in number of tubers immediately after transplanting (Fig.6). This is possibly caused by the sudden stagnation in foliage growth or conversely the extreme tuber production could be the cause of stagnating foliage growth. Accatino and Malagamba (1982) reported the formation of tubers in potato seedlings under stress conditions before transplanting, while Harris (unpublished) found that pruning the foliage can delay tuber formation. It would thus seem that too early formation of tubers is a general problem in seedlings which is perhaps further aggravated by transplanting.

Under field conditions seedlings usually require 10-15 days to fully recover from transplanting (Accatino and

Malagamba, 1982). Although the growing conditions in the nursery were more ideal than those in the field, the transplanting shock appeared to be of a similar duration. Although some difference in transplant survival has been observed in different TPS-lines (Thompson, 1980) the transplant shock seems very much an inherent problem associated with transplanting seedlings that is unlikely to be overcome by selection. Therefore, provided that direct sowing does not present problems in germination and early seedling development, transplanting in nursery beds would generally result in a longer growing period from sowing.

An important criteria when choosing between planting systems is the length of the period that the beds for seedling tuber production would be occupied, especially when several crops can be grown per year. Under conditions in Lima (Fig. 8) the beds were occupied for 110 days following direct sowing, while following the transplanting system, whereby seedlings can be raised outside the beds for seedling tuber production, this period was (125 - 35 =) 90 days. Thus the growing period in the beds was about 20 days less with the transplanting system than with direct sowing. Under field conditions the difference in growing period between transplanting and direct sowing is usually much larger (Accatino and Malagamba, 1983). This is probably due to the less favourable conditions in the field for emergence and early growth (Bedi and Smale, 1978; Bedi *et al.*, 1979; Martin, 1983). It would therefore appear that the merits of transplanting are greater under field

conditions than under nursery conditions. Provided that a 20 day longer growing period in the seedling tuber nursery is not prohibitive, direct sowing in nurseries may have the advantage of reducing labour costs.

Extreme temperatures are generally considered to prohibit direct sowing. Although germination is inhibited at temperatures above 25°C or below 10°C (Stier and Cordner, 1937; Steinbauer, 1957; Sadik, 1979; White and Sadik, 1983 b), TPS does not loose its viability when exposed to temperatures outside this range (Sadik, 1979). When soil temperatures exceed the 10-25°C range during some hours per day, germination may be somewhat retarded. Several measures such as soil covering, shading and frequent irrigation can be applied to prevent extreme temperatures. In Lima during the summer, with monthly mean maximum air temperatures of 29.5°C, monthly mean minimum air temperatures of 21.8°C and monthly mean day temperatures of 25°C (Appendix 1, January, 1983) germination was only delayed for 2-3 days while the percentage of final emergence was similar to that obtained during the winter period. This demonstrates that with air temperatures of up to 30°C and possibly higher, direct sowing in nurseries can be successfully applied, while data from Sadik (1979) and White and Sadik (1983 b) suggest that the soil temperatures would need to drop below 25°C for a considerable part of the day to permit adequate germination.

3.3.3 Plant population

Increasing plant population in nursery beds decreased the percentage of plants surviving till harvest (Tables 13-15). Considering the high plant population and the usual absence of moisture and fertilizer deficiency, the principal factor causing plant mortality is likely to be competition for light. Light is attenuated rapidly with increasing distance from the top of the leaf canopy. Smaller plants presumably deprived of sufficient light are eventually eliminated. The fact that plants died earlier at increasing plant population (Table 17) also suggests that competition for light was a major factor influencing plant mortality.

Some of the differences in plant survival between experiments may be explained by the different levels of total radiation. In experiment B (Table 14), where plants were grown during the summer with usually no cloud cover, plant survival was higher than in experiment C (Table 15) which was performed during the cloudy winter. In experiment A (Table 13), the limited experience in agronomic practices, rather than the total amount of radiation, caused several plants to die with symptoms of rot at the stem base. An additional factor causing lower plant survival in experiment C may be associated with the longer growing period and the way in which the number of surviving plants was determined. This was done at harvest by counting the total number of plants, including those

with a completely mature stem, thus more plants may have vanished as the growing period increased. This may explain the lower survival rate in experiment C where the average growing period was 53 days longer than in experiment B.

Fitted curves for tuber number (Fig. 9) and tuber weight (Fig. 10) suggest a greater response to plant population in the winter period (experiment C) than in the summer period (experiment B), possibly because of lower plant survival.

At the time when plants have been eliminated through competition (Table 17) they have usually formed tubers (Fig. 6). This may explain why increasing plant population resulted in all experiments in a significant increase in tubers smaller than 10 g. Since the number of tubers larger than 10 g remained fairly constant (Tables 13 and 14) or showed a slight increase with increasing plant population (Table 15), there would seem to be no negative effect of high plant population on tuber size. This would favour a high seed rate since rate of plant survival is often difficult to predict. The upper limit of plant population seems mainly determined by agronomic considerations. When plants were spaced at 6 x 6 cm or at 7 x 7 cm (200 plants/m^2) "hilling" operations became rather difficult and often resulted in plant damage. The results suggest that the lower limit of plant population lies above 50 plants per square meter since in all 3 experiments increasing the plant population from 50 to 100 plants per square meter resulted in an increase in the number and

weight of tubers larger than 1 g. It would thus appear that the optimum plant population lies somewhere between 100 and 150 plants per square méter after thinning. When the plant survival is high, 100 plants per square meter would seem satisfactory, while under less ideal growing conditions with lower survival rates 150 plants per square meter is perhaps more appropriate. These results are in agreement with those obtained in India (Upadhya, unpublished) and the Philippines (Van der Zaag, unpublished) which indicated that the highest plant population usually gave the highest yield.

Prospects for increasing tuber size by manipulating plant population seem poor in this system of seedling tuber production in beds. To increase the number of tubers larger than 10 or 20 g the plant population would have to be lower than 50 plants per square meter. The data suggest that this would result in a lower total tuber yield, both in number and weight, compared with that at 100 plants per square meter. The total nursery area required to produce the same amount of tubers would thus be larger which would offset the advantages of producing seedling tubers in beds due to increased managerial requirements, less effective control of tuber transmitted diseases and higher costs. Since most of the tubers are smaller than 10 g, the potential of the bed system for seedling tuber production seems to lie in the possibility of using such small tubers. Successful use of these tubers would mean that the plant population should be as

high as possible within practical limits.

3.3.4 Hilling

Compared with the control, application of more substrate to the beds after seedling emergence increased the number of tubers larger than 1 g as well as total tuber weight in all experiments, although the increase in tuber weight was not significant in experiments B and D (Table 19). The difference in number and weight of tubers between the two different levels of hilling was generally small and not significant, except in experiment E where 2-3 cm hilling gave more tubers larger than 1 g than 6-7 cm hilling. Similarity between the effect of hilling on the number of tubers (Table 19) and the effect on the number and length of stolons (Table 18) suggests that the effects of hilling on tuber production resulted mainly from differences in stolon formation. This would also explain why both hilling levels, which showed a similar pattern of stolon formation, gave similar tuber yields.

Assuming that the differences in tuber number originated largely from differences in stolon formation, the question arises as to how hilling influences the formation of stolons. Since stolons develop in the axils of the cotyledons, they are borne above ground when no hilling is applied. Table 18 shows that this did not prevent the formation of stolons. The fact that the differences in the number and length of stolons between treat-

ments became smaller with increasing time from sowing, suggests that stolon formation was retarded rather than reduced in the absence of hilling. Therefore it would appear that covering nodes by hilling stimulated the rate of stolon formation.

Since any axillary bud along the axis can develop as a stolon under appropriate conditions (Booth, 1959; Werner, 1954) the highest level of hilling would be expected to result in the highest number of stolons. This however did not occur. A possible explanation for this may be offered from observations on the pattern of stolon formation 72 days after sowing (Fig. 11). These observations showed that most of the stolons originated from the lowest two nodes, despite more nodes being covered. This is in agreement with reports that the first axillary shoots develop from the nodes near the base of the stem and then at progressively higher ones (Taylor, 1953). Since the later a stolon is initiated the slower its rate of growth (Lovell and Booth, 1969) the stolons that developed later than 72 days after sowing are not likely to have had a significant effect on total number of developing tubers. Therefore, it would seem reasonable to assume that the pattern of stolon formation as it was observed at 72 days is largely responsible for the total tuber number at harvest. This would mean that the two lower nodes with more than 70% of the total number of stolons, would be mainly responsible for the number of tubers at harvest. Plaisted (1957) also found that the stolons near the base of the stem play a

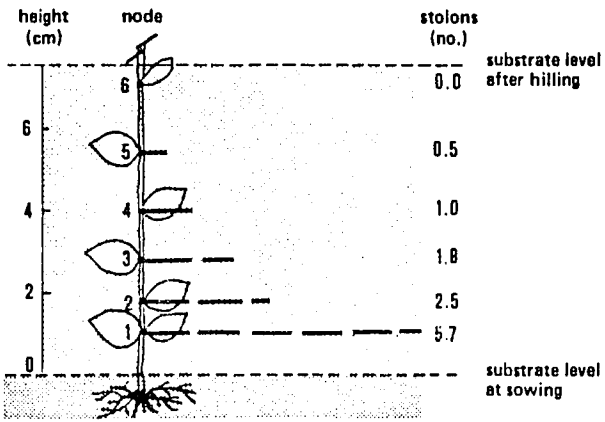

Fig. 11. Number of stolons in different seedling nodes, 72 days after sowing.

dominant role in the formation of tubers. This would seem to explain why 2-3 cm hilling, which covers 2-3 nodes, resulted in maximum tuber production and that covering more nodes by hilling up to 6-7 cm did not further increase total tuber number.

Another potential effect of hilling would be to prevent stolons growing above ground and becoming leafy shoots. A developing stolon can be converted into a leafy shoot depending on the balance between cytokinins, gibberellins and possibly other hormones (Booth, 1959, 1963; Kumar and Wareing, 1972). Light seems to stimulate the formation of leafy shoots (Kumar and Wareing, 1972) and therefore higher hilling levels may be effective in preventing stolons from becoming leafy shoots. However the fact that a large number of stolons and tubers were formed in the absence of hilling (Table 18) suggests that the buds in the lower nodes had a strong tendency to grow diageotropically and form stolons despite being exposed to light. It would thus seem that development of stolons into leafy shoots is more determined by the hormonal balance of the plant than by exposure to light *per se*. It seems therefore unlikely that hilling treatments have greatly influenced the number of leafy shoots, especially since the height of hilling was rather low.

Although leafy shoots were not systematically counted, all treatments showed several stolons growing above ground and developing into leafy shoots. Leafy shoots often developed from branches of stolons which below ground formed

several tubers. It would therefore seem unlikely that shoot formation decreased the number of tubers very much in view of the large number of stolons produced per plant (Tables 18 and 22).

No hilling resulted in an increased proportion of partly green tubers. Although greening of tubers would not prevent their use as planting material, it also resulted in earlier sprouting possibly because of exposure to larger temperature fluctuations than experienced by tubers covered by substrate. No hilling would probably result in increased variability in sprouting behaviour between individual tubers which would be undesirable when tubers of similar physiological condition are required at planting time. Besides insufficient hilling, the rather shallow depth of the beds may also have contributed to greening of the tubers. Scott and Younger (1972) and Ifenkwe (1975) reported tubers being forced through the upper soil surface when a large number of tubers developed in a restricted soil area which resulted in greening.

None of the conventional reasons for hilling under field conditions, such as weed control, insect control, increase of moisture capacity and ease of harvesting seem to apply for the production of seedling tubers in beds. Weeds cause generally no problem because substrate treatment usually killed weed seeds while later on the high plant population prevented weeds from becoming a problem. Although insects such as the potato tuber moth can cause severe damage when tubers are exposed to light under dry

conditions, e.g. tubers in the top of the ridge in a furrow irrigated field, in the beds with frequent overhead irrigation, exposed tubers were not damaged by larvae of the moth. It seems that moths and larvae are repelled by moist conditions. Foot (1974) also reported considerable reduction of tuber infestation by tuber moth under sprinkler irrigation compared with no irrigation. Furthermore drainage in the beds does not require hilling since the water supply can be controlled by the depth of the beds, type of substrate and frequency of irrigation. Therefore, the principal reasons for hilling in beds would be to cover the lower nodes to promote stolon formation and to avoid excessive tuber greening.

The conclusion seems justified that for maximum tuber production at least 2-3 nodes need to be covered by hilling while additional hilling would be needed further to reduce the number of green tubers. In the absence of hilling the number of tubers larger than 1 g may be reduced by 17-20%.

3.3.5 Growth regulators

The results suggest that the effect of B nine on total tuber number and weight is either nil or negative (Table 21). With 2 B nine applications (exp. D) no effects on yield at maturity were obtained, while with 3 applications (exp. E) total tuber yield decreased and tuber malformation occurred. The negative effect of B nine on yield is at variance with results reported by Bodlaender and Algra (1966) indicating

that with plants showing considerable vegetative growth, a positive effect of B nine on yield was obtained. Results, however, are in agreement with Gunasena and Harris (1969, 1971) indicating that reduced stem length due to application of CCC did not result in increased total tuber weight. In beds with a population of 100 plants per square meter of bed the LAI in treated plots reached 8, 65 days after sowing, which is more than sufficient for maximum light interception (Scott and Wilcockson, 1978). The lower yield may be partly explained by the shorter stem length causing increased mutual shading of leaves. Another possible reason for the lower yield in experiment E after B nine treatment may be attributable to the observation that treated plots lodged much later and therefore took advantage of the pathways at a later stage during growth, as it would seem likely that lodging, in a situation with open pathways, would result in increased light interception.

If, in experiment E, tubers smaller than 1 g are included in the total number, B nine increased the number of tubers. Bodlaender and Algra (1966), Humphries and Dyson (1967) and Laycock (1971) also reported similar effects. Treatment with B nine would therefore be inappropriate for increasing tuber size. It would thus seem that after direct sowing, B nine treatment has little potential, even more so because of the risk of tuber malformation. Tuber malformation was also reported by Kunkel and Holstad (1966) and seems associated with the number and the timing of applications. It is not clear what

caused B nine treatment to interact with hilling in experiment E. The greater effect of B nine in plots without hilling may be related to an increased rate of absorption because a greater area of plant tissue that was exposed to the chemical. An additional factor explaining the more pronounced reduction in stolon formation and increased tuber malformation in the absence of hilling may be the direct contact of the chemical with the stolons.

Based on these results it was concluded that although seedlings were sturdier at initial growth stages following B nine treatment, no positive effect on the number or weight of tubers at harvest could be obtained.

3.4 Conclusions

Various types of beds can be used to produce seedling tubers, whereby a width of 1 m is convenient for management practices. Substrates of 50% sand and 50% peatmoss or compost seem to be suitable as a growing medium while mixtures of sand and manure can give variable results depending on type and origin of the manure. Seedlings appeared to be sensitive to high salt concentrations which makes manures such as horse manure in principle more suitable as a substrate component than cow manure from intensive feed lots. Application of nitrogen and potassium before sowing is not essential to promote early seedling growth, while it can reduce growth at higher application rates due to high salt

concentrations. Phosphate fertilizers on the other hand have little effect on salt concentrations and the total amount required for the total growing period can be applied at sowing without negative effects on plant growth. Based on this a pre-sowing application of 0-800-0 ppm of NPK would seem appropriate for a mix of equal proportions of sand and peatmoss.

Total yields obtained after direct sowing were similar to those from transplanted seedlings but the total growing period from sowing was shorter after direct sowing. The period that the beds for seedling tuber production were occupied was about 20 days longer when seed was direct sown into beds. Under temperature levels like those of the summer in Lima high temperatures did not prohibit adequate germination after direct sowing.

High plant populations were instrumental in overcoming slow initial ground cover from seedlings resulting in a positive effect on yields even when plant populations increased over 50 plants per square meter. Plant population did not seem to affect the number of relatively large tubers at populations of 50 plants per square meter and higher. The optimum plant population was between 100 and 150 plants per square meter, whereby the upper limit was mainly determined by constraints of agronomic management.

Application of additional substrate after seedling emergence in direct sown beds increased tuber number through promotion of stolon formation. The amount of substrate applied should cover at least the two lower nodes

since these were mainly responsible for tuber formation. To avoid tuber greening hilling levels would have to be higher.

The application of the growth retardant B nine neither increased tuber weight nor tuber number, while tuber malformation occurred especially when B nine was applied on plots without hilling.

Chapter Four
SEED TUBER QUALITY AND YIELD POTENTIAL

4.1 Materials and methods

4.1.1 Determination of the health status of seedling tubers

The health status of seedling tubers produced in nursery beds is an essential element in the overall evaluation of this system of seedling tuber production, since it would directly affect the yield potential of the seedling tubers.

Since substrates were either steam sterilized or treated with a soil fumigant, the risk of infection with soil-borne diseases was considered low. Infection by virus diseases, especially those transmitted by insects, would probably pose a more important threat.

Infection could potentially occur through transmission by viruliferous aphids from infected crops. Since at the Experimental Station in Lima potatoes are grown all the year round with always a certain incidence of virus infected plants, viruliferous aphids are always present, although their incidence may fluctuate depending on the climatic conditions in the different seasons. Seedling tubers for health evaluation were therefore sampled from experiments grown during different parts of the year. Virus identification concentrated on the viruses PLRV and PVY as these were considered to reduce yield the most (Beemster and Rozendaal, 1972).

The visual identification of virus diseased plants is regarded as an important aspect of seed tuber multi-

plication. This is likely to be more difficult in a crop from seedling tubers since most plants are genetically different and symptoms vary with genotype (Beemster and Rozendaal, 1972). In order to determine the efficiency of roguing practices in a crop from seedling tubers, visual virus identification was compared with results from other identification methods.

Procedure

Tubers were sampled at maturity by harvesting one tuber per plant, weighing approximately 10 g, in randomly selected places in the nursery. These tubers were planted in pots in a screenhouse for visual evaluation of virus symptoms. The plants from these tubers were indexed with ELISA serology to detect PLRV and PVY, while in one sample the plants with visual virus symptoms were, in addition to ELISA, also indexed by mechanical transfer to *Nicotina tabacum* cv Samsum and to *Nicotina clevelandii* for demonstration of PVX, PVS, APLV, APMV and probably others (Hooker, personal communication).

4.1.2 The yield potential of small seedling tubers

Seedling tubers produced in nursery beds were generally smaller than normal seed tubers. Since they were produced from plants of different genotype that were exposed to intense plant competition, selection for certain genotypes may have taken place. The expression of

this selection may take the form of differences in tuber size. This may be defined as the genetic component of the yield potential of a certain size of tubers. Besides this genetic component there would exist a non-genetic component of the yield potential which would be mainly the effect of tuber size *per se*. Both components of the yield potential were studied separately to avoid confounding the genetic and non-genetic effects of tuber size on subsequent yield. In this study it was assumed that smaller tuber size was not associated with virus infection, because tubers were selected from beds with little virus incidence.

The purpose of evaluating the yield potential of seedling tubers was mainly to develop optimum management procedures before and after planting. Information on optimum management would be required for a fair comparison of seedling tubers with alternative planting materials. The scheme on page 104 shows schematically the organisation of experiments that would lead to a fair comparison of seedling tubers with alternative planting materials. The experiments in this scheme are further explained in the following sections. (See also Tables 23 and 24. It should be noted that the experiments are not necessarily presented in chronological sequence.)

4.1.2.1 The genetic component of yield potential

Seedling tuber production in nursery beds takes place at high plant densities resulting in the premature death of

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- genetic component: comparison of progeny tubers to establish whether small seedling tubers represent inferior genotypes
- non-genetic component:
  - characteristics of plant growth from small seedling tubers
  - manipulation of growth by pre-sprouting and spacing
  - a study of causes of slow plant growth

  → optimum management requirements for seedling tubers
- stem population
  - comparison of yield per stem with that of alternative planting materials
  - yield comparison of different stem populations

  → optimum stem population

→ comparison of seedling tubers with alternative planting materials

a large number of plants. Plants that are eliminated by this natural competition will usually have formed some small tubers. The question arises whether these tubers represent inferior genotypes, in which case small tubers would have to be excluded from further multiplication. Another reason why small tubers might have to be eliminated is the fact that they may represent genotypes that are characterized by a large number of tubers per plant. Such genotypes would not be suitable for the production of ware potatoes since a large tuber number per plant is often associated with small tuber size. A third reason why performance of the small seedling tubers would need to be evaluated is that plants eliminated by competition perhaps represent genotypes that show moderate foliage growth. It might be argued on the basis of results from experiments with seed tubers (Burstall, 1983) that early maturing types would be more likely to be eliminated than the later maturing types which usually produce more foliage. This could result in a natural selection for late maturing genotypes since these would more likely grow until maturity and produce larger tubers.

The objective of the following experiment was to find out whether small seedling tubers produced at high plant populations would represent a different group of genotypes than larger seedling tubers produced at the same plant population.

Procedure

Four size grades of seedling tubers were selected at random from the harvest of a direct sown nursery with a plant population of 100 plants per square meter. Each size grade was multiplied in a separate plot under field conditions. During growth, plants with obvious virus symptoms were removed. At harvest tubers of 28-35 mm (about 20-35 g) and 35-45 mm (about 35-60 g) were selected at random from each multiplication plot. Tubers were stored in natural diffuse light at ambient temperature for 3 months. Both tuber sizes selected from each multiplication plot were planted in a split-plot design with 4 replications. The original seedling tuber sizes (Generation 1) were assigned to mainplots and the planted tuber sizes (Generation 2) to subplots. Planting and harvesting dates are given in Table 23.

A plot consisted of 4 rows of 6 m, between-row spacing was 90 cm and within-row spacing 30 cm. During the growing period the number of emerged plants and ground cover were determined at regular intervals. Before the rows closed the number of above-ground stems were counted in the central 2 rows. At harvest the number and weight of tubers were determined in the size grades <28 mm, 28-55 mm and >55 mm. The agronomic practices applied during the experiment were in accordance with standard Experimental Station procedure (Appendix 4).

Table 23. Evaluation of the genetic yield potential of different seedling tuber sizes[1] - Experimental procedures

Production of Generation I in nursery beds			Field multiplication of Generation I to produce Generation II			Yield evaluation of Generation II	
Sowing	Harvest	Selected seedling tuber sizes (g)	Planting	Harvest	Selected tuber sizes (mm)[2]	Planting	Harvest
7.10.80	5.2.81	1-5	19.5.81	16.9.81	28-35; 35-45	22.12.81	31.3.82
		5-10	19.5.81	16.9.81	28-35; 35-45	22.12.81	31.3.82
		10-20	19.5.81	16.9.81	28-35; 35-45	22.12.81	31.3.82
		20-30	19.5.81	16.9.81	28-35; 35-45	22.12.81	31.3.82

[1] DTO-33 OP

[2] 28-35 mm = ± 20-35 g

35-45 mm = ± 35-60 g

4.1.2.2 The non-genetic component of yield potential

The size of seedling tubers produced in the beds appears to be considerably smaller than that of seed tubers normally used for field planting. In preliminary experiments the growth rate of individual stems decreased with decreasing tuber size. This prompted the evaluation of the performance of small seedling tubers.

Since the effects of tuber size are confounded with different stem numbers, the various size tubers should be evaluated with 1 mainstem per tuber at the same spacing between plants or alternatively the tubers could be planted with their natural stem numbers but at different plant spacings in order to reach the same stem population. Since the last alternative would introduce a confounding effect of spatial arrangement, an attempt was made to evaluate the performance of different size seedling tubers with 1 mainstem per tuber.

The detrimental effects of slow growth of plants from small tubers could potentially be limited by increasing the plant population and by planting tubers with more developed sprouts. In a field experiment (Table 24 - Exp IV) various tuber sizes were therefore compared at 2 plant populations and with 2 pre-sprouting periods.

Slow growth of plants from small tubers may be due to lack of available growth substances and/or other intrinsic defects associated with small size such as poorly developed meristems. In order to distinguish between

Table 24. Experimental details of experiments to determine the yield potential of seedling tubers

Experiment	Planting date	Harvesting date	Growing period (days)	Treatments assigned to			Harvested area per (sub)plot or sub-subplot	No. replications
				Mainplots	Subplots	Sub-subplots		
I	28.1.82 (tubers)	6.5.82	99	Mulch	Planting material	-	9 m^2	4
	14.1.82 (seedlings)		113					
II	12.5.82	Several harvests	47 62 83 114	Planting materials	Harvest	-	4.5 m^2	4
III	14.2.83	10.3.83	24	Whole tubers and tuber plugs	Tuber size	-	7 pots	5
IV	19.5.83	17.8.83	90	TPS-line	Tuber size Plant density	Sprouting period	5.6 m^2	3

effects of the amount of substrate and those of other intrinsic defects, a separate experiment in pots was carried out. In this experiment (Exp. III) whole tubers of different sizes were compared with tuber plugs of a standard weight taken from these tubers of different sizes.

Procedure

In experiment III seedling tubers of the TPS-line DTO-33 OP, harvested from a nursery bed, were stored at 4°C. After 3 months storage tubers of 3, 6, 12, 24 and 48 g were selected, allowing a weight deviation of 10%. The tubers were placed for sprouting in diffuse light at ambient temperature and inspected regularly for sprouting. Sprouts other than apical sprouts were removed by means of a sharp, pointed knife. During storage, the date of (apical) sprouting was determined for each individual tuber. Tubers of similar sprouting dates were kept for further experimentation in order to avoid effects of different sprout age. After 30 days storage in natural diffuse light, tuber plugs of approximately 3 g with the apical sprout were cut from the various tuber sizes by means of a bulb-shaped spoon with ground edges.

Tuber plugs were left to suberize by placing the plugs back onto the tuber after cutting. One day after cutting both whole tubers and tuber plugs were planted in pots in a screenhouse. Prior to planting the length of the apical sprouts was determined. The treatments were

planted in a split plot design with 5 replications, whereby tuber cutting was assigned to mainplots and tuber size to subplots. Each subplot treatment represented 7 pots. Twenty four days after planting the dry weights of stems, leaves and underground parts were determined for evaluation of early growth.

In experiment IV, 2.5, 5, 10 and 20 g seedling tubers were selected from three TPS-lines (DTO-33 OP, Atzimba x DTO-33, Atzimba x 7XY.1). The tubers were taken from the cold store (4°C) at respectively 9 and 3 weeks before planting, and placed in diffuse light at ambient temperature. Both batches of tubers were planted at the same time, in order to see whether increased sprout development at planting would promote early plant growth. During storage the same procedure was followed as described above to obtain single-sprout tubers. The tubers were field planted at 12.5 and 25 cm spacing within the row and 70 cm between rows, resulting in 11.4 and 5.7 plants per square meter, respectively. Data were taken on the rate of emergence, the rate of ground cover and the number of above-ground stems. Since the value of these variables might be affected by the depth of planting, an attempt was made to plant all tuber sizes at the same depth, approximately 2 cm below the soil surface measured from the tuber surface at the sprout base. The number of above-ground stems was measured as an indication of the number of tuber-producing units (Allen, 1978). Above-ground stems were defined as the total of mainstems, originating directly from the

mother tuber, and lateral stems that branched from the mainstems below ground, excluding stems arising from stolons. The number of above-ground stems was determined after the first hilling when tubers were covered with about 10 cm of soil. At this growth stage "mainstems" could be easily distinguished from stems arising from stolons. Lateral stems that were covered by soil at a later stage, by the second and third hilling, were not counted as above-ground stems because they were not considered to contribute significantly to yield since they were covered by soil rather late. Ground cover was measured with a grid as described by Burstall and Harris (1983). The individual squares of the grid measured 5 x 5 cm. Plants were harvested prematurely at 90 days because of a severe attack by soil-borne pathogens. At harvest, the number and weight of tubers were determined in the size categories <28 mm, 28-45 mm and >45 mm.

The treatments were planted in a split-plot design with 3 replications. The TPS-lines were assigned to mainplots, the spacing and tuber size to subplots and the pre-sprouting period to sub-subplots.

The experimental details of experiments III and IV, including planting and harvesting dates, are given in Table 24.

4.1.3 Comparison of potato crops from alternative planting materials

With the introduction of TPS the following alternative planting materials could potentially be used to grow potatoes: seedling transplants, different sizes of seedling tubers and seed tubers from a cultivar or clone. The relative performance of these planting materials would clearly depend on growing conditions in the field due to different health status, plant survival and yield potential. Certain growing conditions would favour some planting materials, while other conditions might favour other alternative planting materials. An attempt was therefore made to compare planting materials under growing conditions existing in the coastal desert of Peru, using planting materials adapted to that area.

Ideally the alternative planting materials should be compared at their optimum stem density and optimum spatial arrangement. Since the optimum stem density for seedling tubers was not known, each size of seedling tubers was planted at different weights per unit area (Exp . I). The total weight of seedling tubers planted per unit area will be referred to as "seedling tuber rate". Seedling transplants were planted according to local recommendations using transplanting systems with and without root blocks. Root blocks were used to reduce the shock of transplanting experienced by the plant. Root blocks were cubes of a mix of sand, peatmoss and soil, with dimensions of approximately

4 x 4 cm and a height of 5 cm. TPS was sown direct in these cubes and seedlings were thinned after emergence to two seedlings (Exp. I) or one seedling per cube (Exp. II). At the time of transplanting to the field, the seedlings were planted together with their root blocks. All planting materials were planted at the same row spacing for practical reasons. In order to avoid confounding effects due to different stem population and spatial arrangement these materials were also evaluated with one main stem per unit of planting material, at the same spacing between plants (Exp. II).

In order to minimize differences in genetic yield potential between planting materials, seedling tubers and seedlings for transplanting were obtained from the same TPS-line (DTO-33 OP) while DTO-33 was used as the clone. In one experiment a hybrid line was included in the comparison of planting materials to represent improved TPS-lines with better seedling vigour and supposedly reduced sensitivity to transplanting.

Procedure

In experiment II six different planting materials were planted with one stem (seedlings) or one sprout (tubers) per unit of planting material. These materials were:

seedlings from a hybrid line (Atzimba x DTO-28)

seedlings from an open pollinated line (DTO-33 OP)

5-10 g seedling tubers (DTO-33 OP)

10-20 g seedling tubers (DTO-33 OP)

40-60 g seedling tubers (DTO-33 OP)

40-60 g seed tubers (DTO-33 clone)

The seedlings were raised in a shaded nursery and transplanted 30 days after sowing with their root-blocks. The 5 to 20 g seedling tubers were obtained from direct sown nursery beds and stored for 5 months in diffuse light at ambient temperature, simultaneously with 40-60 g seedling tubers obtained from a field multiplication of first generation seedling tubers and with 40-60 g tubers from low virus clonal stocks. During storage other than apical sprouts were removed when necessary. All treatments were planted at the same time at 90 cm row spacing and 25 cm between plants. Treatments were arranged according to a randomized complete block design with 4 replications. The treatments were evaluated from 4 sequential harvests carried out respectively 47, 62, 83 and 114 days after planting. At each harvest 20 plants were harvested per plot, and the dry weights of stems and leaves were determined, as well as the number and weight of tubers. Counting stems during the growing period presented difficulties since the different treatments showed different rates of foliage development resulting in hilling at different dates. It was therefore decided to determine the number of tuber-producing stems at each sequential harvest, whereby stems with stolons and tubers were counted as "minstems". The stems that produced tubers were either stems originating directly from the mother

tuber or from seed, or lateral stems that branched from this stem at a relatively small distance from the mother tuber or true seed, usually less than 5 cm. All stems within a distance of 5 cm from the mother tuber or from the lowest node (seedlings) were therefore counted as "mainstems".

In experiment I the alternative planting materials were compared with their natural number of stems per unit of planting material and treatments are shown in Table 25. Because of slow sprouting of the tubers and relatively fast development of the seedlings for transplanting, all treatments could not be planted at the same time, resulting in 2 weeks earlier planting of the seedlings. Since the materials were planted in the summer period, a mulch treatment using wheat straw was added to reduce soil temperature (Midmore, 1983). The treatments were planted in a split-plot design with 4 replications, whereby mulch treatments were assigned to main plots and planting materials to sub-plots. As in the previous experiment, the counting of stems during the growing period was rather unsatisfactory due to different levels of hilling in different treatments at a given moment of time. The number of stems was therefore determined at harvest, whereby all stems originating within a distance of 5 cm from the stem base or mother tuber or lowest node (seedlings) were considered as "mainstems".

The experimental details of experiments I and II, including planting and harvesting dates, are given in Table 24.

Table 25. Comparison of alternative planting materials derived from the clone DTO-33 - Treatments in Experiment I

Planting material	TPS-line or clone	Spacing between plants[6] (cm)	No. tubers/ transplants per hill	Seed tuber rate (kg/ha)
Normal size transplants[1] without root blocks	DTO-33 OP	20	2	-
Normal size transplants in root blocks	DTO-33 OP	20	2	-
Small transplants[2] in root blocks	DTO-33 OP	20	2	-
1-5 g seedling tubers[3]	DTO-33 OP	20	2	278
1-5 g seedling tubers[3]	DTO-33 OP	10	2	556
1-5 g seedling tubers[3]	DTO-33 OP	7	2	833
5-10 g seedling tubers[3]	DTO-33 OP	20	2	833
5-10 g seedling tubers[3]	DTO-33 OP	10	2	1666
10-20 g seedling tubers[3]	DTO-33 OP	20	1	833
10-20 g seedling tubers[3]	DTO-33 OP	10	1	1666
40-60 g seedling tubers[4]	DTO-33 OP	30	1	1852
40-60 g clonal seed tubers[5]	DTO-33	30	1	1852

[1] Seedlings in 4-5 leaf stage
[2] Seedlings in 3-4 leaf stage
[3] First generation seedling tubers
[4] Second generation seedling tubers
[5] Low virus seed tubers
[6] Row spacing 90 cm

4.2 Results

4.2.1 The health status of seedling tubers

In seedling tubers from an open nursery, the total incidence of PVY, PLRV and both viruses combined, varied from 5.2%-52.1% (Table 26) depending on the period during which they were produced. The highest virus incidence occurred when tubers were produced during the hot summer months when aphid populations are usually high.

A comparison of the visual virus assessment and serological testing shows that from a total of 308 plants, 3.2% (=2.3% + 0.6% + 0.3%) of the apparently healthy plants contained PLRV, PVY or both, according to ELISA serology (Table 26). This suggests that by application or roguing to remove diseased plants, 3.2% of the total number of plants would escape removal. On the other hand, in the 33.2% of the plants that showed visual virus symptoms, only 12.6% (=5.2% + 0.3% + 3.9% + 1.0% + 0.6% + 0.6% + 1.0%) contained PVY, PLRV or both, according to ELISA serology (Table 26). The remaining 20.6% were not necessarily free of virus since these plants were not tested for other viruses in samples II and III. In sample I however, the 32 plants that showed visual virus symptoms but a negative serological reaction were indexed to indicator plants and none of these plants showed a positive reaction to PVX, PVS, APLV or APMV. This suggests that at least a large proportion of the 20.6% of the plants showing

Table 26. Virus incidence in seedling tubers[1] as determined by ELISA serology and visual assessment

Sample no.	Growing period	No. tubers per sample	Elisa reaction to PLRV	Elisa reaction to PVY	No. plants (%)[2]	Visual assessment (no. plants) Healthy	PLRV symptoms	Mosaic symptoms	Other symptoms
I	7.10.80-5.2.81	150	-	-	142(94.7)	110	2	10	20
			+	-	5(3.3)	0	4	0	1
			-	+	2(1.3)	0	0	1	1
			+	+	1(0.6)	0	0	0	1
II	12.8.81-25.10.81	112	-	-	95(84.8)	66	17	2	10
			+	-	11(9.8)	3	8	0	0
			-	+	5(4.5)	1	0	2	2
			+	+	1(0.9)	0	1	0	0
III	5.1.82-15.4.82	46	-	-	22(47.8)	20	0	1	1
			+	-	8(17.4)	4	4	0	0
			-	+	10(21.7)	1	0	9	0
			+	+	6(13.0)	1	1	2	2
			% of total number of plants						
Total of 3 samples		308 (=100%)	-	-	84.1%	63.6%	6.2%	4.2%	10.1%
			+	-	7.8%	2.3%	5.2%	0.0%	0.3%
			-	+	5.5%	0.6%	0.0%	3.9%	1.0%
			+	+	2.6%	0.3%	0.6%	0.6%	1.0%

[1] TPS-line : DTO-33 OP
[2] Between brackets: percentage of total number of plants per sample

symptoms were probably free of the most common viruses.

From these results it can be concluded that although seedling tubers originate from TPS, their rate of infection during one growing season can be considerable. Furthermore, assuming that ELISA is a more accurate method of identifying virus than visual assessment, it can be concluded that visual identification of diseased plants is rather unreliable in a population of mixed genotypes.

4.2.2 Effect of seedling tuber size on yield potential

4.2.2.1 Genetic effects

The four original seedling tuber sizes (Generation I) showed similar rates of emergence and ground cover in Generation II (Table 27) while at harvest, 99 days after planting, all four seedling tuber sizes showed a similar degree of maturity. Since at harvest no significant yield difference was found between the two planted tuber sizes, the subsequent yields from the different original seedling tuber sizes are presented as means of the two planted sizes (Fig. 12). There was no significant difference between the four original tuber sizes either in total tuber yield or in size distribution of the harvested tubers.

These results seem to indicate that all four seedling

Table 27. Effect of the size of first generation seedling tubers on performance of progeny tubers (Generation II)*

Tuber size Generation I	Days to 80% emergence in Generation II			Days to 80% ground cover in Generation II		
	20-35 g	35-60 g	Mean	20-35 g	35-60 g	Mean
1-5 g	21.0	22.4	21.7	48.6	41.7	45.2
5-10 g	22.1	22.7	22.4	61.9	49.2	55.6
10-20 g	21.5	22.1	21.8	51.2	44.7	48.0
20-30 g	22.4	22.1	22.3	55.1	45.2	50.2

* TPS-line : DTO-33 OP

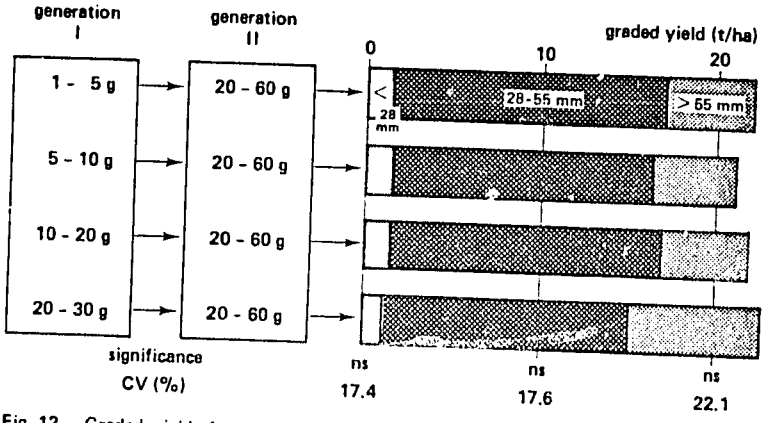


Fig. 12. Graded yields from second generation tubers originating from different sizes of first generation seedling tubers (DTO·33 OP).

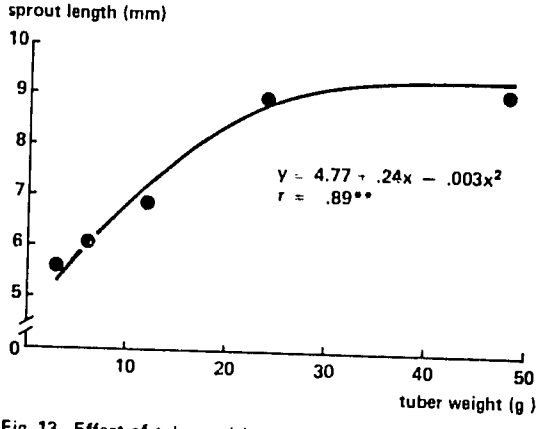


Fig. 13. Effect of tuber weight on sprout length of single-sprout tubers.

tuber sizes in the first generation represented similar groups of genotypes and would be equally suitable for multiplication into seed tubers destined for the production of ware potatoes.

4.2.2.2 Non-genetic effects

In experiment III increasing tuber size had a positive effect on sprout length at planting (Fig. 13), as well as on total plant dry weight 24 days after planting (Fig. 14). There was a significant interaction (P=0.01) between tuber cutting and tuber size indicating that the effect of tuber size on plant dry weight was more pronounced in the whole tubers than in the tuber plugs.

Since sprout length at planting as well as tuber size usually affect early plant growth, both variables were correlated with plant dry weight, individually and combined (Table 28). Tuber size and sprout length combined did not improve the correlation with plant dry weight compared with the separate correlations of tuber size and plant dry weight or sprout length and plant dry weight. Furthermore, significant correlation coefficients were obtained between tuber size and plant dry weight, between sprout length and plant dry weight, and between tuber size plus sprout length and plant dry weight, in the whole tubers but not in the tuber plugs.

These results indicate that although the tuber plugs originated from tubers of different sizes, they showed no

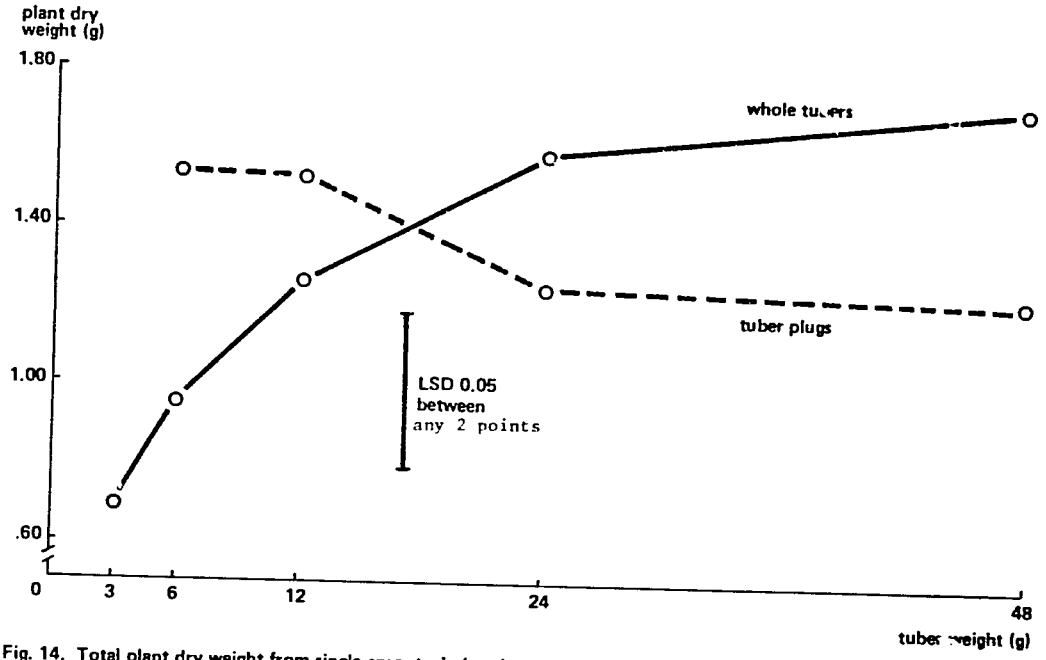


Fig. 14. Total plant dry weight from single-sprout whole tubers and 3 g tuber plugs at 24 days after planting. - Experiment III

Table 28. Correlation coefficients between the variables tuber size, sprout length and plant dry weight in whole tubers and in 3 g tuber plugs - Experiment III

Correlation between	Whole tubers	3 g tuber plugs
Tuber size and plant dry weight	0.82**	0.51 NS
Sprout length and plant dry weight	0.79**	0.50 NS
Tuber size + sprout length and plant dry weight	0.82**	0.53 NS

** P=0.01

NS = Not significant

effect of tuber size on plant dry weight. This would suggest that the amount of reserves or growth substances associated with reserves were largely responsible for differences in plant dry weight rather than other intrinsic defects associated with reduced tuber size.

The results of the analysis of variance of the effects of TPS-line, plant density, tuber size and sprouting period in experiment IV are given in Table 29 while the main effects of treatments on plant emergence, ground-cover, the number of stems and total number and weight of tubers are given in Table 30.

TPS-line

The line Atzimba x 7XY.1 gave a lower percentage of plant emergence, fewer above ground stems, a lower percentage of ground cover and a lower tuber number and weight at maturity than the other lines. Atzimba x DTO-33 produced a non-significantly higher yield than DTO-33 OP.

Plant density

Plant density did not affect plant emergence while 11.4 plants per m^2 produced almost twice the number of above ground stems as 5.7 plants per m^2, indicating that closer plant spacing did not reduce stem number per plant despite more intensive competition between plants. The number of tubers per stem, however, decreased from 4.8 to 3.4 with closer spacing. As a result of increasing the

Table 29. Results of the analysis of variance of the effect of TPS-line, tuber size, plant density and sprouting period on the number of above-ground stems, total tuber weight and total tuber number - Experiment IV

Source of variation	No. above ground stems	Total tuber weight	Total tuber number
TPS-line (L)	XX	X	XX
Tuber size (T)	XX	XX	XX
L x T	XX	XX	XX
Plant density (D)	XX	XX	XX
D x L	X	NS	NS
D x T	NS	NS	NS
D x T x L	X	NS	NS
Sprouting period (S)	XX	X	XX
S x L	NS	NS	NS
S x T	NS	X	NS
S x T x L	NS	NS	X
S x D	XX	X	NS
S x D x L	NS	NS	NS
S x D x T	NS	NS	XX
S x D x T x L	NS	NS	NS
CV - TPS-line (%)	10.9	32.2	19.8
CV - Tuber size (%)	13.6	27.0	22.9
CV - Plant density (%)	13.6	27.0	22.9
CV - Sprouting period (%)	11.4	18.7	14.7

XX : F-test significant at P=0.01

X : F-test significant at P=0.05

NS : F-test not significant

Table 30. The main effects of TPS-line, plant density, tuber size and sprouting period on the field performance of single-sprout seedling tubers - Experiment IV

	Emergence (%)	Above-ground stems (No/plot)	Ground cover* (%)	Total tuber yield			
				kg/plot	No/plot	No/stem	g/stem
TPS-line							
DTO-33 OP	95	72	41	8.37	255	3.5	116
Atzimba x DTO-33	95	67	47	9.65	274	4.1	144
Atzimba x 7XY.1	90	53	30	6.95	206	3.9	131
LSD 0.05	2	4	4	1.52	27		
Plant density							
11.4 plants/m^2	94	84	48	9.30	282	3.4	111
5.7 plants/m^2	93	43	31	7.34	207	4.8	171
LSD 0.05	NS	3	5	0.76	19		
Tuber size							
2.5 g	90	50	24	6.28	205	4.1	126
5 g	93	54	34	7.28	227	4.2	135
10 g	92	62	42	9.32	261	4.2	150
20 g	97	90	59	10.41	285	3.2	116
LSD 0.05	3	4	7	1.07	27		
Sprouting period							
3 weeks	97	68	44	8.66	256	3.8	127
9 weeks	90	60	35	7.98	234	3.9	133
LSD 0.05	2	2	3	0.53	12		

* Mean of observations at 32, 40 and 55 days after planting

number of plants by 100% the total number of tubers per unit area increased only by 36% and total tuber weight by 27%.

Tuber size

Plants from tubers of 2.5 g emerged slightly later and final emergence was lower than in plots with larger tubers, while the highest percentage of emergence was obtained in plots with 20 g tubers. Increasing tuber size had a positive effect on the rate of ground cover (Fig. 15.1), as well as on the number of above-ground stems and the number and weight of tubers (Table 30). Plants from 2.5 g, 5 g and 10 g tubers produced a similar weight and number of tuber per stem while tuber number and weight per stem in plants from 20 g tubers was lower. Increasing tuber size gave an increasing proportion of large tubers at harvest despite a higher number of above-ground stems per unit area (Table 31).

Sprouting period

A sprouting period of 9 weeks reduced plant emergence, stem number, percentage of ground cover and tuber yield compared with a sprouting period of 3 weeks.

Interactions

The interactions between the various factors are given in Table 29. Since the main objective of this experiment was to evaluate growth of plants from the various sizes of seedling tubers, only those interactions involving the

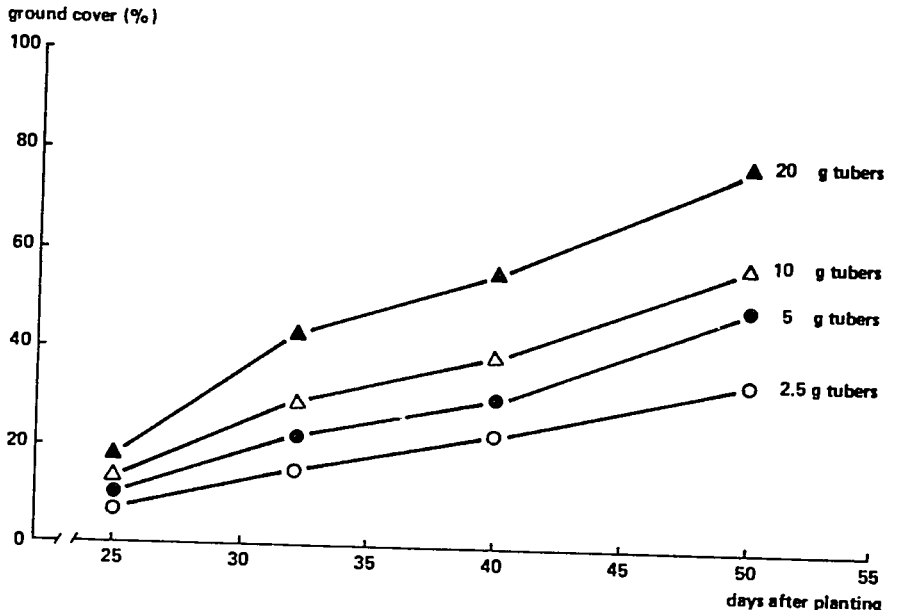


Fig. 15.1 Effect of weight of single-sprout tubers on rate of ground cover - Experiment IV

Table 31. Effect of size of single-sprout seedling tubers on the size distribution of harvested tubers*- Experiment IV

Seedling tuber size (g)	Above ground stems (No/m^2)	Tuber size distribution (%)			Total (%)
		<28 mm	28-45 mm	>45 mm	
2.5	8.9	26.5	41.4	32.0	100
5	9.6	26.3	40.3	33.4	100
10	11.1	21.1	37.3	41.6	100
20	16.1	19.8	36.7	43.5	100

* mean of 3 TPS-lines

factor tuber size are presented. The effect of tuber size on the number (Fig. 15.2) and weight of tubers was more pronounced in the line Atzimba x DTO-33 than in the other lines, mainly because 20 g tubers performed significantly better than 10 g tubers, while this did not occur in the other two lines. The effect of the sprouting period on tuber number (Fig. 15.3) and weight differed between the various tuber sizes, indicating a mean negative effect, over the 3 lines, of the longer sprouting period on the performance of 5, 10 and 20 g tubers but not on that of 2.5 g tubers. Fig. 15.4 shows that the interaction of sprouting period and tuber size did not occur in Atzimba x 7XY.1, while it was particularly pronounced in DTO-33 OP. In this line a positive effect of a longer pre-sprouting period was found with 2.5 g and 20 g tubers but not with 5 and 10 g tubers. In Atzimba x DTO-33 a sprouting period of 3 weeks gave more tubers than a sprouting period of 9 weeks with all tuber sizes except 2.5 g tubers, while in Atzimba x 7XY.1 the shorter sprouting period out-performed the longer one with all tuber sizes.

The results of experiments III and IV indicate that early plant growth, rate of ground cover, tuber yield and proportion of large tubers increased with increasing tuber size. Furthermore, that a shorter sprouting period and closer spacing generally increased total tuber number and weight, although the effect of sprouting period varied with TPS-line and tuber size. It would therefore appear

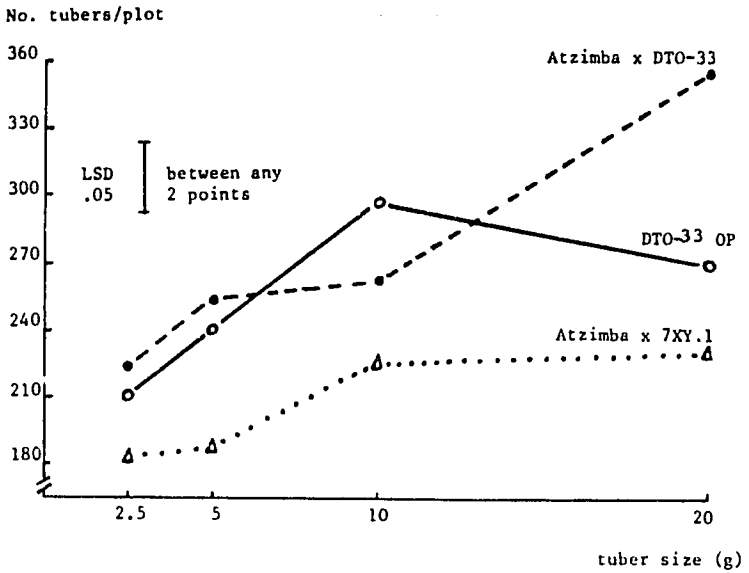


Fig. 15.2 Effect of size of single-sprout seedling tubers on the total number of tubers per plot in three TPS-lines - Experiment IV

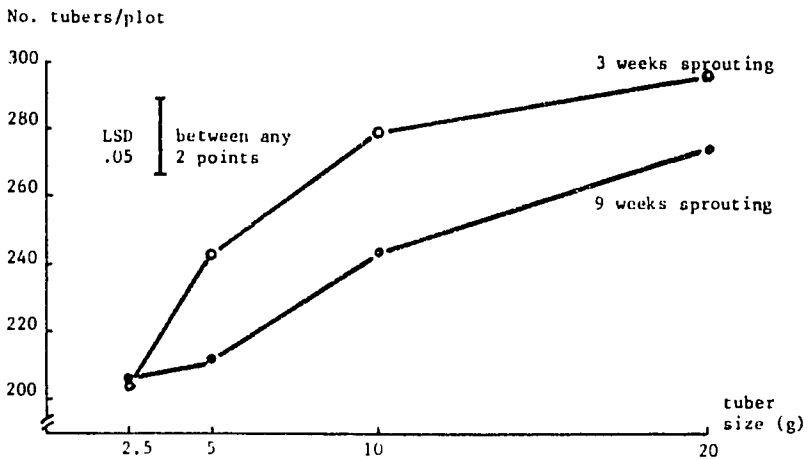


Fig. 15.3 Effect of the length of the sprouting period on the total number of tubers per plot in single-sprout seedling tubers of different size (mean of 4 TPS-lines) - Experiment IV

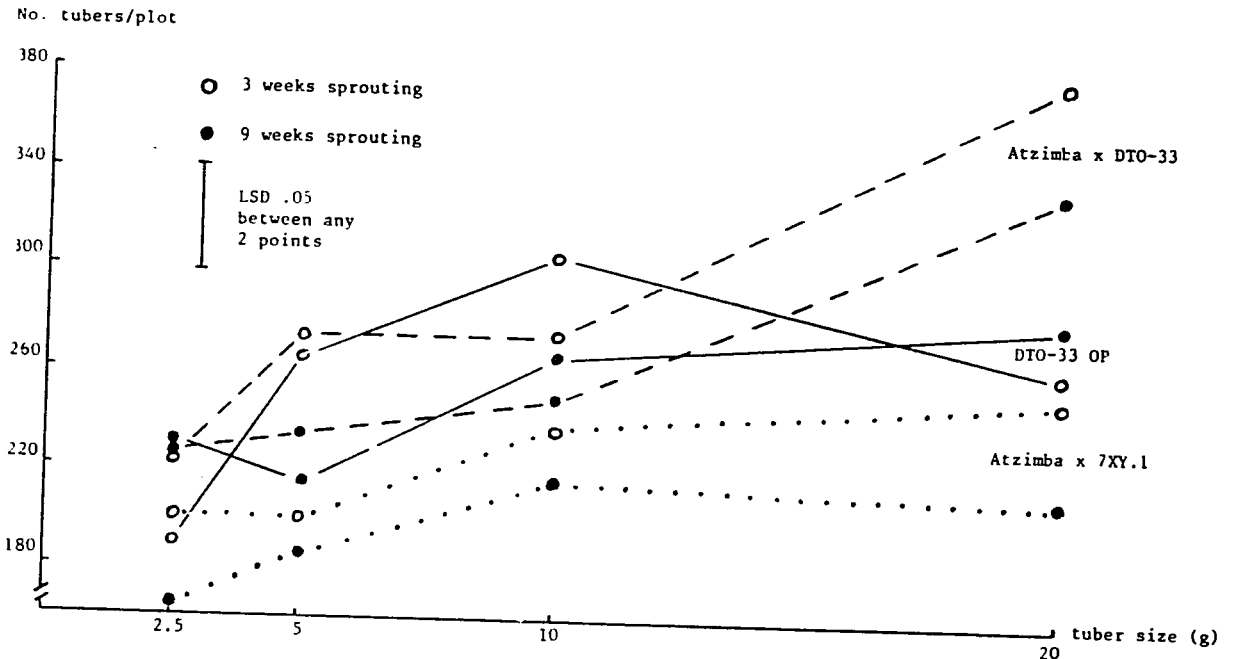


Fig. 15.4 The effect of the length of the sprouting period, the TPS-line and the seedling tuber size on the total number of tubers per plot - Experiment IV

that the management of relatively small seedling tubers should aim at promoting early plant growth by close plant spacing, appropriate pre-sprouting periods, and selection of vigorous TPS-lines.

4.2.3 A comparison of alternative planting materials

The treatments in experiment II did not affect the number of tuber-bearing stems, which will be referred to as "mainstems". The total foliage dry weight per main stem 47 days after planting increased in the following order: seedlings, 5-10 g seedling tubers, 10-20 g seedling tubers, 40-60 g clonal seed tubers and 40-60 g seedling tubers (Table 32).

No significant difference was found between the tuber yield from 5-10 g and 10-20 g seedling tubers and yields per main stem are therefore presented as means of both tuber sizes (= 5-20 g tubers) in Figs. 16 and 17. The yield comparison of the alternative planting materials derived from DTO-33 (Fig. 16) shows that the tuber development per main stem was slowest in seedlings, followed by 5-20 g seedling tubers, 40-60 seedling tubers and finally by 40-60 g seed tubers, while the final yield from 40-60 g seedling tubers and 40-60 g seed tubers was similar. Transplanted, seedlings of the hybrid line showed faster yield development than seedlings of the OP line. The yield of the hybrid was similar to that from the 40-60 g tubers at the final harvest, 114 days after

Table 32. Effect of type of planting material on total foliage dry weight per main stem 47 days after planting - Experiment II

Planting material	Foliage dry weight g/mainstem	Relative weight (%)
Seedlings OP[1] without root blocks	63.0	30
Seedlings OP in root blocks	80.3	38
5-10 g seedling tubers[1]	106.3	50
10-20 g seedling tubers	137.3	65
40-60 g seedling tubers	229.8	108
40-60 g clonal seed tubers[2]	212.8	100
LSD 0.05	48.5	
CV (%)	23.0	

[1] DTO-33 OP

[2] DTO-33 clone

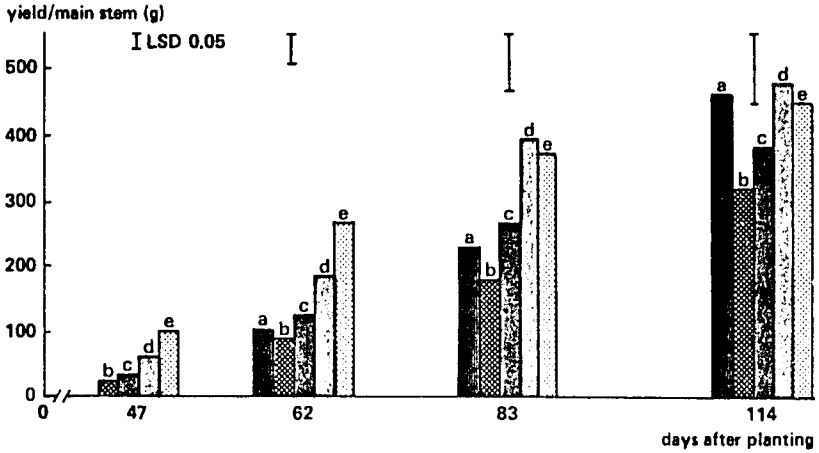


Fig. 16. Effect of planting material on yield per main stem - Experiment II

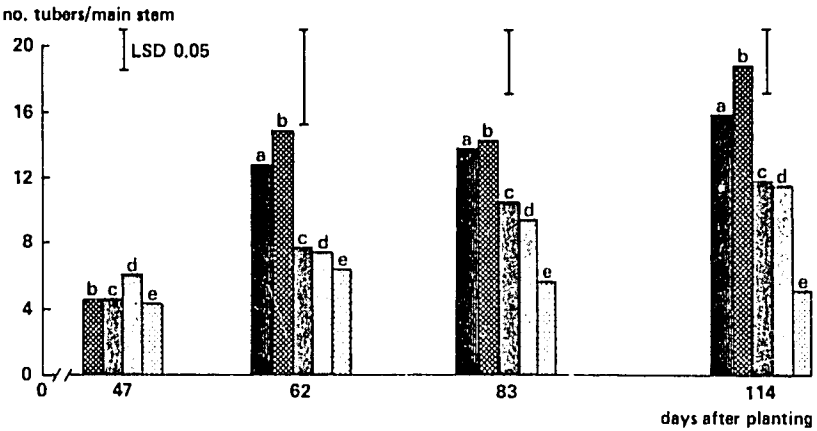


Fig. 17. Effect of planting material on number of tubers per main stem - Experiment II

a : seedlings (Atzimba x DTO-28)
b : seedlings (DTO-33 OP)
c : 5-20 g seedling tubers (DTO-33 OP)
d : 40-60 g seedling tubers (DTO-33 OP)
e : 40-60 g seed tubers (DTO-33 clone)

planting but not at earlier harvests.

The number of tubers per main stem (Fig. 17) was lowest in the clone and increased in the following order: both sizes of seedling tubers, the seedlings of the hybrid line and the seedlings of the OP line.

In experiment I where the different planting materials derived from DTO-33 were compared at natural stem numbers, no significant effect of the mulch treatment was found. The results (Table 33) are therefore presented as means of both mulch treatments. The lowest yield was obtained from seedlings transplanted without root blocks. The yield of marketable tubers (larger than 28 mm) obtained from seedlings in root blocks, the three planted weights of 1-5 g seedling tubers, the lowest planted weights of 5-10 g and 10-20 g seedling tubers and the marketable yield from the 40-60 g seedling tubers were not significantly different, but tended to increase in this order. The highest yield was obtained from 5-10 g and 10-20 g seedling tubers planted at 1666 kg per ha together with the clonal seed tubers planted at a weight of 1852 kg per ha.

The growing period of the transplanted treatments was 2 weeks longer than that of the tuber treatments. Table 33 shows that at a seed tuber rate of 833 kg per ha, the total yield from 1-5, 5-10 and 10-20 g seedling tubers was almost the same while the proportion of tubers larger than 45 mm decreased with decreasing seedling tuber size

Table 33. Field performance[1] of different types of planting material derived from DTO-33 - Experiment I

	Planted weight kg/ha	No. main stems/m^2 at harvest	Tuber yield (ton/ha)				
			<28 mm	28-45 mm	>45 mm	Total	Marketable[2] yield
Transplants without root blocks	-	5.8	2.0	5.2	3.7	10.9	8.9 c[3]
Transplants in root blocks	-	6.7	3.3	8.9	6.9	19.1	15.8 b
Small transplants in root blocks	-	7.0	2.4	9.0	4.6	16.0	13.6 b
1-5 g seedling tubers	278	10.7	3.0	9.8	5.3	18.1	15.1 b
1-5 g seedling tubers	556	10.8	3.3	11.3	5.6	20.2	16.9 b
1-5 g seedling tubers	833	10.4	3.4	12.2	5.7	21.3	17.9 b
5-10 g seedling tubers	833	8.8	2.7	9.9	8.1	20.7	18.0 b
5-10 g seedling tubers	1666	10.7	3.3	13.8	9.2	26.3	23.0 a
10-20 g seedling tubers	833	9.9	2.2	8.5	9.6	20.3	18.1 b
10-20 g seedling tubers	1666	12.7	2.4	13.1	12.6	28.1	25.7 a
40-60 g seedling tubers	1852	7.7	1.7	7.5	11.3	20.5	18.8 b
40-60 g seed tubers	1852	7.6	0.9	5.0	18.8	24.7	23.8 a
CV (%)		21.6	30.8	26.1	29.9	23.1	23.5
SE		±2.5	±0.1	±0.3	±0.3	±0.6	±0.5

Mean of 2 mulch treatments
Yield of tubers >28 mm
Duncan's multiple range test at 5% level - means followed by the same letter are not significantly different

(Table 34). Increasing seedling tuber rate had a greater effect on the yield from 5-10 g and 10-20 g tubers than on that from 1-5 g tubers. Seedlings and 1-5 g seedling tubers produced a lower yield of tubers larger than 45 mm than the 5-20 g and 40-60 g seedling tubers, while the clonal seed tubers produced the highest yield of tubers larger than 45 mm.

The results from experiments I and II suggest that in plants derived from DTO-33 transplanted seedlings and 1-5 g seedling tubers develop more slowly, mature later and produce a larger proportion of tubers smaller than 45 mm than plants from larger tubers. The tendency to produce small tubers was larger in seedlings of DTO-33 OP than in seedling tubers of DTO-33 OP because of a larger number of tubers per stem in transplanted seedlings. Five-20 g seedling tubers seemed capable of producing relatively high yields at relatively low planted weights. The seedlings of the hybrid line performed considerably better than the seedlings of the open pollinated line.

4.3 Discussion

4.3.1 Health status

Since the substrate used in beds to produce seedling tubers can be disinfected, infection by soil-borne pathogens transmitted by tubers would be of little import-

Table 34. Effect of size of multiple-sprout seedling tubers on the size distribution of harvested tubers* - Experiment I

Seedling tuber size (g)	Planted weight (kg/ha)	Tuber size distribution (%)			Total (%)
		<28 mm	28-45 mm	>45 mm	
1-5	833	16.0	57.2	26.8	100
5-10	833	13.0	47.8	39.1	100
10-20	833	10.8	41.9	47.2	100

* Data from Table 33

ance compared with that of infection by virus diseases. Of all the viruses, PLRV and PVY are probably the most important ones in terms of yield reduction of an infected crop (Beemster and Rozendaal, 1972). Table 26 shows that even in the first generation of tubers from TPS, the incidence of PLRV and PVY can be considerably high. Application of systemic insecticides seemed ineffective in limiting infection by these viruses. This confirms, what is now generally accepted, that systemic insecticides do not prevent the infection of PLRV by viruliferous aphids from surrounding fields (Schepers, 1972), while the spread of stylet-borne viruses such as PVY is little or not reduced by systemic insecticides due to the way they are transmitted. The environment in which the seedling tubers were produced may have been rather extreme, as a result of the presence of infected plants during the whole year combined with high insect populations. Under such conditions isolation of the beds from fields with infected plants, taking into consideration the main wind direction, could possibly offer some level of control. Isolation of the beds is likely to be more effective in controlling PVY than PLRV because of the non-persistent nature of transmission of PVY. Besides aphid transmitted viruses the infection of viruses transmitted by contact such as PVS and PVX need to be considered. Although yield reductions caused by these viruses are much lower than those brought about by PLRV and PVY (Beemster and Rozendaal, 1972) their combination with other viruses can give problems. Although

close plant spacing and intensive contact of hands and implements with plants during hilling would favour rapid spread of contact viruses, there would presumably be no infected plants in the beds. So avoiding the use of contaminated implements from other crops should minimize any problems. This would seem to be confirmed by preliminary observations (Salazar and Wiersema, unpublished) showing that in cases where the incidence of PVY and PLRV together was over 50%, the incidence of PVX and PVS was less than 3%.

Generally the infection of seedlings by viruses would need special attention because there are some indications that seedlings are more susceptible to virus infection than plants grown from tubers (Salazar, personal communication). Tender leaf tissue at the initial growth stages would attract insects, while the longer period of foliage growth would allow more virus to be translocated to the tubers (Beemster, 1972) than in plants grown from tubers.

The symptoms of secondary infected plants appear to be rather confusing (Table 26). Some apparently healthy plants proved to be infected according to ELISA serology and the other way round. Although this would make the effect of negative selection questionable, it can be argued that plants showing severe virus-like symptoms would be of doubtful value as planting material and therefore should be eliminated. It would probably be good practice to concentrate during roguing on plants with severe symptoms of virus infection, whether these were real or apparent.

4.3.2 Effect of seedling tuber size

The effects of seedling tuber size on growth and yield may be due to two different factors. One factor could be some type of natural selection taking place in the nursery beds resulting in genetic differences between seedling tuber sizes. The other factor is seedling tuber size *per se* having a non-genetic effect on growth. The results (Fig. 12) suggest that the various sizes of first generation seedling tubers represented a similar group of genotypes, which would indicate that observed effects of seedling tuber size were largely due to non-genetic causes. This, however, does not exclude the possibility of some type of natural plant selection in nursery beds, but the data suggest that any possible selection for genotypes was not associated with seedling tuber size.

Increasing seedling tuber size resulted in faster plant development, faster ground cover and higher yield (Figs. 14, 15, 16, Table 30). A part of the more rapid ground cover (Fig. 15.1) may be explained by the formation of additional stems. Although all tubers were planted with one sprout per tuber, the number of above ground stems increased with increasing tuber size (Table 30). This indicates that the larger tubers developed more stems below ground than the smaller ones. These stems were either main stems, originating from one of the buds in the eyes, or secondary stems developing from axillary buds. Since both type of stems are capable of producing tubers

(Allen and Wurr, 1973), these additional stems are likely to have contributed to the higher yield. However, when the number of above-ground stems from each of the tuber sizes are plotted against tuber yield, separate yield relationships for 2.5, 5 and 10/20 g tubers are apparent (Fig. 18). On the other hand when seedling tuber rate is plotted against yield, the yield lines for each tuber size tend to merge forming a continuous curve (Fig. 19.1) which gives rise to a close relationship between seedling tuber rate and total yield (Fig. 19.2). This would suggest that, although at equivalent seedling tuber rates the small tubers had a slight advantage, the seedling tuber rate largely accounted for differences in yield, rather than the number of above-ground stems. The small advantage of small seed tubers at equivalent seedling tuber rates is presumably because of either more stems, better spatial arrangement or both. These results do not necessarily conflict with the now generally recognized concept that the growth and yield of individual stems is largely independent of the size of seed tubers (Gray, 1972; Jarvis, 1977; Allen, 1978), since in these reports tubers smaller than 20 g were usually not included. It would thus appear that for seed tubers above 20 g, tuber yield is largely explained by stem number while for tubers of 20 g or below, the seed tuber rate is largely responsible for differences in yield.

Fig. 20 shows that the total tuber yield per unit area from tubers of 20 g or below, increased with an in-

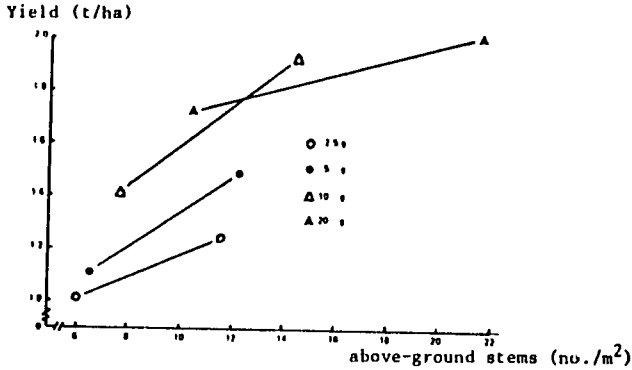


Fig. 18 Relationship between the number of above-ground stems and total tuber yield in seedling tubers of different sizes - Experiment IV

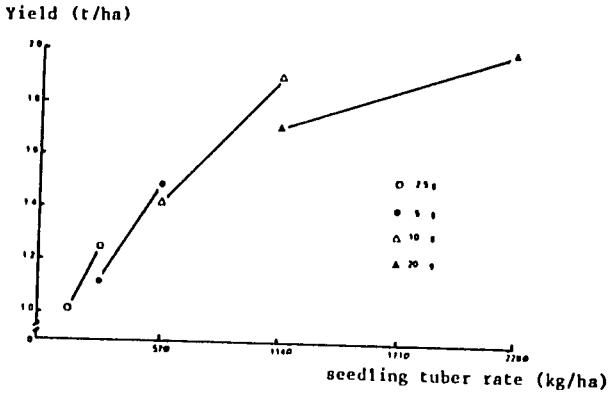


Fig. 19.1 Relationship between seedling tuber rate and total tuber yield in seedling tubers of different sizes - Experiment IV

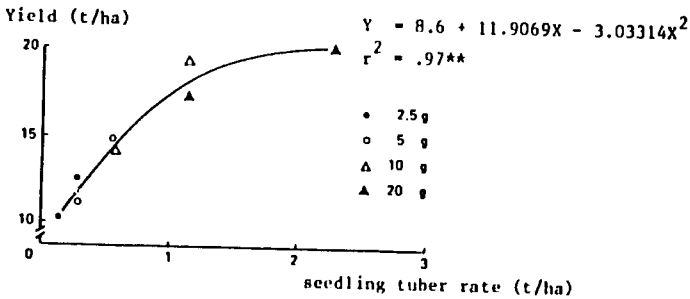


Fig. 19.2 Relationship between seedling tuber rate and total tuber yield in seedling tubers ranging from 2.5-20 g - Experiment IV

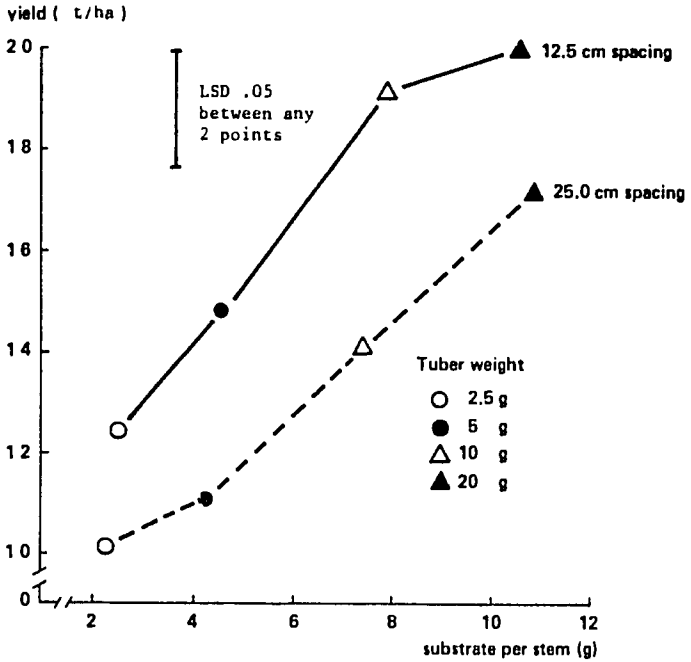


Fig. 20 Effect of the amount of tuber reserves per above-ground stem on total tuber yield per unit area - Experiment IV

creasing amount of substrate per above-ground stem. This suggests that the slow development and low yield of stems from tubers smaller than 20 g is due to a limited amount of reserves. Several researchers have suggested that the amount of reserves per stem affects growth and sometimes yield (Bremner and El Saeed, 1963; Rozier-Vinot, 1971, 1972; Irritani *et al.*, 1972), indicating faster emergence and more rapid shoot growth with an increasing amount of substrate per stem. As pointed out by Allen and Scott (1980) it would seem that with tubers above 20 g differences in growth due to a different amount of substrate per stem are relatively small and not noticeable in the tuber yield at mature harvest. With tubers smaller than 20 g, however, differences in yield due to lack of substrate are apparent throughout the growing period as shown in Fig. 16 where plants from 5-20 g tubers yielded less than those from 40-60 g tubers throughout the growing period. Since these differences seem largely to arise from lack of ground cover during the initial stages of plant growth, it would seem reasonable to assume that stems from small tubers are potentially capable of producing the same total yield as those from larger tubers, provided that their growing period is sufficiently long. Some evidence for this is shown in Fig. 16 where the difference in yield between plants from 5-20 g tubers and plants from 40-60 g tubers was larger at 83 days than at 114 days after planting. The difference in yield potential between the four seedling tuber sizes observed in experiment IV (Table 30), may there-

fore have been magnified due to the somewhat premature harvest.

If tubers were to be planted with their natural number of sprouts, the comparison between tuber sizes may be even more in favour of the larger tubers. In that situation a difference in sprout number between tuber sizes would be expected at planting, while this difference would be further magnified by the tendency of larger tubers to form additional stems below ground. This would seem to be confirmed by Fig. 21 showing that when tubers were planted with their natural sprout number, the relationship between seed tuber rate and yield tends to be linear, with single-sprout tubers this relationship tends to be curvilinear (Fig. 19.2).

It would appear that with tubers larger than 20 g at equivalent seed tuber rates the small seed tubers have an advantage because of a higher stem population per unit area, while with tubers smaller than 20 g the higher stem population from the smaller tubers compensates for the lower yield per stem resulting in a similar total yield from all tuber sizes at the same seed tuber rate; the data plotted in Fig. 21 would seem to support this conclusion.

The effect of decreasing seedling tuber size on the size of harvested tubers would seem to be negative. When different sized tubers were planted at equivalent weights, the smaller tubers produced more stems and more tubers per

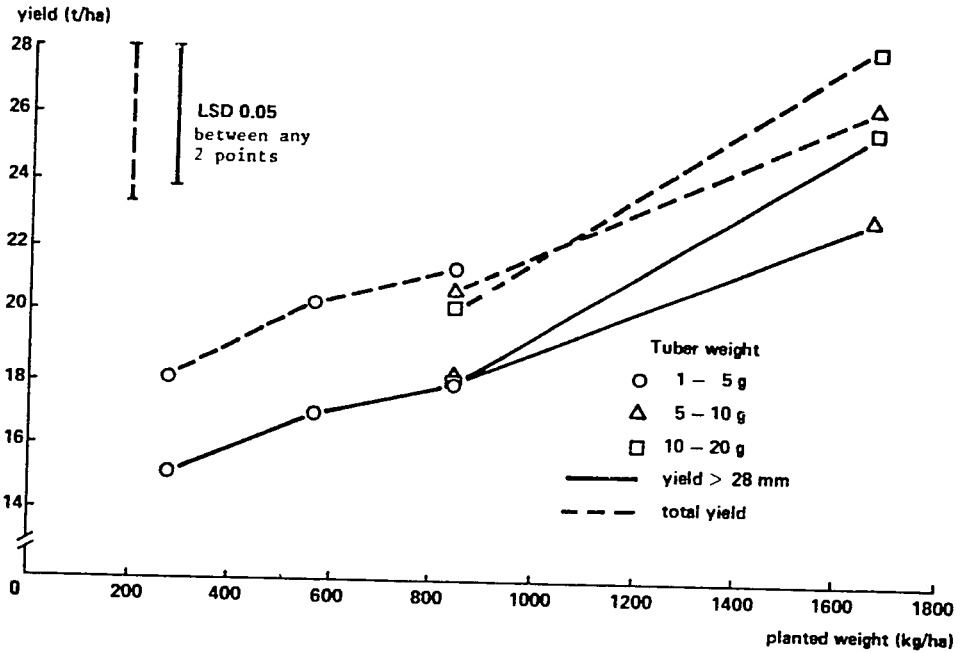


Fig. 21 Effect of seedling tuber rate on total tuber yield in multiple-sprout tubers ranging from 1-20 g (data from Table 33)

unit area resulting in smaller tubers even when total yields were similar to those from larger tubers (Tables 33 and 34). On the other hand if tubers of different size were to be planted at equivalent stem numbers, the number of tubers per unit area might be similar but the yield from the smaller tubers would tend to be lower, resulting again in a smaller average tuber size. A third situation occurred in experiment IV (Table 31) where smaller tubers gave rise to fewer stems per unit area, fewer tubers and a lower yield per unit area (Table 30), but tuber size was reduced because total tuber weight decreased more than total tuber number. The negative effect of decreasing seedling tuber size on the size of harvested tubers would almost certainly increase with decreasing length of the growing period due to the slower initial growth of plants derived from small tubers resulting in a more than proportional yield reduction.

The conclusion seems justified that small tubers tend to produce small tubers, a tendency likely to be more pronounced in a shorter growing period.

The significant effect of tuber size on sprout length (Fig. 13) gives rise to the question whether sprout length could be responsible for some of the effects of tuber size on plant dry weight (Fig. 14). Although in the tuber plugs, the same variation in sprout length existed as in the whole tubers, because the tuber plugs were taken from the whole tubers at planting, no signifi-

cant correlation between sprout length and plant dry weight was found in the tuber plugs (Table 28). This suggests that the variation in plant dry weight due to different sprout lengths was insignificant compared with the variation in plant dry weight due to different tuber sizes. This would mean that the amount of reserves per stem govern initial plant growth and that attempts to increase early plant vigour by planting tubers with longer sprouts, are not likely to be effective, a conclusion supported by the results given in Table 30.

The absence of a significant correlation between tuber size and plant weight in the tuber plugs (Table 28) suggests that besides a limited amount of tuber reserves there was no other intrinsic effect of tuber size on plant growth, suggesting that factors associated with the amount of substrate are causing differences in initial plant growth, while differences in sprout length are merely arising from different amounts of substrate.

Although the total amount of reserves in 6 and 12 g tubers was higher in the whole tubers than in the plugs, the 3 g tuber plugs from these tubers gave rise to higher plant weights 24 days after planting (Fig. 14), possibly because of effects of gibberellins produced by tuber cutting (Rappaport and Sachs, 1967). This would suggest that specific reserves are limiting growth, rather than total reserves. It would seem that cutting can initially overcome the lack of certain growth substances in the smaller tubers while in the larger tubers these substances

seem to become gradually available in sufficient quantities. This would seem to explain why 6 and 12 g tubers could not compete with the tuber plugs taken from them in contrast with larger tubers which did outperform their tuber plugs.

Having established that plants from small tubers tend to grow slowly in the early stages, the question arises concerning the appropriate management of small seed tubers before and after planting. The results given in Table 30 and Fig. 15.3 suggest that too long a sprouting period may exhaust the tuber's limited reserves resulting in poor field performance. The significant interaction between sprouting period, tuber size and TPS-line (Fig. 15.4, Table 29) indicates that in some lines 2.5 g tubers were rather tolerant to a longer sprouting period or gave an even better field performance after a longer sprouting period. The positive effect of a longer sprouting period with 2.5 g seed tubers may be explained by the slower sprout growth in such tubers compared with that in larger tubers (Fig. 13). Assuming that seed tubers would require a minimum level of sprout development at the time of planting, it would seem that in this experiment the tubers larger than 2.5 g had already reached this level in contrast to the 2.5 g tubers which therefore benefitted from a longer sprouting period. It would seem likely that the effect of the length of the sprouting period depends on the rate of sprout development and this may explain why in some lines the 2.5 tubers did not benefit from a longer sprout-

ing period (Fig. 15.4) because they had already reached their optimal level of sprout development.

If relatively small seed tubers were to be stored at ambient temperature in diffuse light, sprout growth would tend to commence later in the smaller tubers (Booth and Wiersema, unpublished), resulting in an even larger difference in sprout length between tuber sizes than was observed in experiment IV where tubers were stored at 4°C and commenced sprouting at similar dates. Therefore in diffuse light storage with larger differences in sprout growth between different sizes of tubers, the optimum storage period or date of planting may well be different for the various sizes of seedling tubers.

Another tool to improve performance of small tubers would be closer plant spacing to promote early ground cover. This resulted in higher tuber yield from all seed tuber sizes (Table 30) with no interaction between tuber size and plant density (Table 29), perhaps resulting from a limited number of stems per plant.

It may be concluded that the small size of seedling tubers produced in beds has not resulted from genotype selection, indicating that the slow growth of plants from such tubers was associated with the amount of tuber reserves rather than with certain genotypes. Management associated with planting small tubers would need to concentrate on the promotion of early growth whereby the length of the sprouting period may be critical and its

optimum length may differ between tuber sizes and TPS-lines. Closer plant spacing was an effective method of improving the performance of small tubers through faster ground cover.

Smaller tubers produced more stems per unit of planted weight which compensated for lower yield per stem and gave rise to a close relationship between yield and seedling tuber rate with seedling tubers between 1 and 20 g. The tendency to produce small tubers increased with decreasing seedling tuber size.

4.3.3 Alternative planting materials

A fair comparison of alternative planting material is difficult for several reasons. Firstly, all treatments were perhaps not planted at their optimum stem population and spatial arrangement. For example the relatively wide row spacing of 90 cm was to the disadvantage of the seedlings and small seedling tubers because slow foliage growth of these materials resulted in poor ground cover at early growth stages. Secondly, although the materials compared in Table 33 were derived from the same clone to minimize differences in genetic background, this was to the disadvantage of the seedlings because seedlings from an open pollinated TPS-line usually require more time to recover from transplanting than hybrid lines resulting in a lower yield (Malagamba, unpublished). This would seem to be confirmed by Fig. 16. Thirdly, not all seedling tubers in Table 33 were from the same generation which is likely to

have resulted in a different health status. The lower yield from the second generation 40-60 g seedling tubers compared with that from the 10-20 g seedling tubers at a similar seedling tuber rate may therefore, in addition to a lower stem number, perhaps be explained by poorer health. Fourthly, there were probably some differences in physiological condition between the various sizes of seedling tubers, resulting from later breaking of dormancy of the smaller tubers and slower sprout growth. This demonstrates that before a valid comparison of alternative planting materials can be made, the factors that determine yield have to be studied separately in each type of material to identify optimum conditions for each type.

Despite these shortcomings in the comparison, some general observations on the performance of alternative planting materials can be made. The 5-20 g seedling tubers outperformed the seedlings of the same TPS-line on a per stem basis, both in terms of early foliage growth (Table 32) and in yield throughout the growing period (Fig. 16), while 1-5 g seedling tubers gave a non-significantly higher yield than seedlings transplanted in root-blocks (Table 33). It would thus seem that transplanted seedlings behaved like very small tubers with slow initial foliage development. Without root blocks the seedlings yielded significantly less than the seedling tubers indicating that the seedlings were rather sensitive to transplanting conditions. It would seem likely that the advantage of small

seedling tubers over seedlings increases with sub-optimum soil and climatic conditions due to sensitivity of seedlings to transplanting conditions. The results also indicate that a more vigorous hybrid line may well compete favourably with seedling tubers, especially when the growing season is sufficiently long (Fig. 16).

Fig. 17 shows that the seedlings produced consistently more tubers per stem than the seedling tubers. The slow foliage growth in the seedlings may have extended the period of tuber formation, although this explanation would not seem to be supported by the fact that plants from 5-20 g seedling tubers produced a similar tuber number per stem compared with plants from 40-60 g seedling tubers (Fig. 17) despite a significant difference in early foliage growth (Table 32). The consequence of these differences in tuber number would be that seedlings are in principle less suitable to produce ware size tubers than seedling tubers because high tuber number is usually associated with small size. In addition, a higher seedling density to promote ground cover would further aggravate the tendency to produce small tubers.

Increasing seedling tuber size increased early foliage growth per stem (Table 32) and gave a higher yield per stem throughout the growing period (Fig. 16), while the yield difference between the different tuber sizes tended to be larger at 83 days than at 114 days after planting. The advantage of large seedling tubers over small ones would thus seem to increase with decreasing length of the growing

period. The advantage of small tubers over larger ones would seem to be their high multiplication rate (Table 35). The high multiplication rate of small tubers and their tendency to produce small tubers (Table 34) would make them particularly suitable for the production of seed potatoes.

The effect of increasing seedling tuber rate on total tuber yield decreased with decreasing tuber size resulting in a non-significant yield increase in plants from 1-5 g seedling tubers as a result of increased seedling tuber rate (Table 33). This coincides with the effect of seedling tuber rate on the number of main stems at harvest. While in plants from 5-10 g and 10-20 g seedling tubers the number of stems increased with increasing seedling tuber rate, it remained fairly constant in those from 1-5 g tubers. It would thus seem that very close plant spacing in 1-5 g tubers resulted in increased stem mortality probably resulting from intensive competition between stems. Increasing the seedling tuber rate by reducing the row spacing, rather than by reducing the spacing between plants within the row, is more likely to result in higher tuber yield.

At a similar seedling tuber rate 5-10 g and 10-20 g seedling tubers produced a similar total marketable yield (>28 mm) to clonal seed tubers while the seedling tubers could not be distinguished from clonal tubers in terms of variation between tubers in their colour, depth of eyes, tuber shape and other external tuber characteristics. This

Table 35. Effect of seedling tuber size on multiplication rate* - Experiment I

Seedling tuber size (g)	Planted weight (kg/ha)	Total tuber yield (ton/ha)	Multplication rate
1-5	278	18.1	65
	556	20.2	36
	833	21.3	26
5-10	833	20.7	25
	1666	26.3	16
10-20	833	20.3	24
	1666	28.1	17

* Data from Table 33

indicates that the quality and yield potential of seedling tubers can be similar to that of a selected clone or cultivar, which supposedly represents a superior genotype. Similar results have been obtained in Sri Lanka* where seed tubers of the cultivar Desiree yielded similarly to selected seedling tubers derived from open pollinated seed of Desiree. Whereas high yielding crops can be obtained with seedling tubers derived from open pollinated seed, crops derived from transplanted seedlings may benefit from hybrid seed because the resulting improvement in seedling vigour and transplant survival usually gives rise to better yields than from open pollinated seed; some evidence for this is shown in Figs. 16 and 17.

The system of seedling tuber production would therefore seem to provide excellent opportunities to utilize open pollinated seed which is almost certainly easier and more economical to produce than hybrid seed.

4.4 Conclusions

Seedling tuber quality and yield potential is largely a function of tuber health and seedling tuber size. The incidence of the insect transmitted viruses PVY and PLRV in first generation seedling tubers was variable but suggest that protective measures are important in areas with infected potato crops and high aphid populations. Visual identification of plants with secondary virus infection was inaccurate, but if all plants with virus or

* Weerasinghe (unpublished)

virus-like symptoms were removed, this might confidently be expected to eliminate most of the poor quality seedling tubers.

Initial plant growth and rate of ground cover decreased with decreasing size of seedling tubers; this mainly resulted from lack of growth substances associated with tuber reserves rather than from any genetic difference associated with tuber size or from any other intrinsic defect of small tubers. With decreasing size of seedling tubers the number of stems per unit of planted weight increased while the yield per stem decreased. The net result of these two processes was a close relationship between total tuber yield and seedling tuber rate over a range of tuber sizes between 1-20 g.

As a general principle closer plant spacing increased early ground cover and yield from small seedling tubers but the effects of the length of the sprouting period was dependent upon tuber size and TPS-line.

In the comparison of alternative planting materials the tendency to slow initial plant growth increased with a decreasing amount of reserves per stem, resulting in the slowest initial growth with transplanted seedlings. The comparison of alternative planting materials was clearly affected by the choice of TPS-line, transplanting method, size of seedling tubers, seedling tuber rate and length of the growing period. In materials derived from DTO-33 transplanted seedlings and 1-5 g seedling tubers tended to produce a large proportion of small tubers and seemed more

suitable for seed rather than ware potato production. Seedling tubers gave rise to similar yields as clonal seed tubers in terms of marketable yield defined as tubers larger than 28 mm, but the mean tuber size was smaller.

With the use of seedling tubers, open pollinated seed can give rise to planting material of equal external quality and yield potential as clonal seed tubers.

Chapter Five
GENERAL DISCUSSION

5.1 Production of seedling tubers

5.1.1 Alternative methods

Seedling tubers can be produced in nursery beds, in field beds or in normal field rows. When field conditions are suitable for transplanting seedlings or direct seed sowing, seedling tubers might be produced in the field in beds or rows. However, under such conditions there would seem to be no need to produce seedling tubers, since consumer potatoes could almost certainly be produced at lower cost from direct field sowing or transplanting methods. Nevertheless, farmers are likely to keep small tubers from crops derived from transplants for planting in the next season, which is a traditional practice in normal systems of potato production. The quality of such seedling tubers would depend on the rate of infection of tuber-borne diseases during the growing season and on storage conditions. Better quality seedling tubers might be produced when a crop from transplanted seedlings is specially managed for the purpose of producing seed tubers. An example of this has been reported by Li and Shen (1979) in China, where in areas with low levels of virus infection, crops derived from transplanted seedlings were subjected to field selection, including clonal and mass selection. The degree of selection that is required in crops from seedlings would depend on the desired quality of seed tubers. China would seem to be rather a special case in

this respect, because their growing conditions apparently permitted several seed tuber multiplications which would justify the intensive selection methods in order to produce high quality seed tubers in the initial stages of multiplication. In other areas with less suitable conditions for the production of seed tubers and fewer seed tuber multiplications, simple selection methods, such as removal of plants with severe virus-type symptoms together with tuber selection at harvest, would perhaps be adequate for the production of seed tubers.

The choice between production of seedling tubers in the field in beds or in rows would depend on the desired yield level and tuber size. Production in rows is likely to give lower total yield and larger tubers compared with production in field beds because in beds a higher plant population can be obtained and it has been shown that high plant populations are required for high yield, although this was associated with relatively small tubers. Production techniques for field beds might be rather similar to those described for the nursery beds. In addition to flat field beds, multiple row beds as described by Jarvis and Shotton (1968) could be used or alternatively normal rows at closer spacing than is usually practised for ware production (e.g. 40-50 cm between rows). When growing conditions, particularly soil conditions, length of the growing period and infection rate of tuber-borne diseases, prohibit the production of healthy seedling tubers in the field, production in a protected nursery would seem appropriate. This

would also make production of seedling tubers relatively independent of regular field season(s) which may permit several crops per year. The risks of producing healthy tubers from TPS are likely to be lower in nurseries since growing conditions can be better controlled. Generally it would seem that the potential for production of seedling tubers in nursery beds, with a prepared growing medium, would increase with decreasing length of the field season, poor soil conditions, absence of field irrigation, high rates of field infection with tuber-borne diseases and temperatures during the off-season that are favourable for potato production.

5.1.2 Production techniques in nursery beds

Perhaps the most crucial factor of this production system is the identification of a suitable substrate. Substrates for the production of seedling tubers appear to require a high proportion of organic material and low salt levels. The non-organic component of a substrate might consist of river sand, available in most parts of the world. Peatmoss as the source of organic material proved to be ideal because of an absence of toxic elements, but is not likely to be commonly available. Different types of manure are more widely available, but would require careful selection. Chicken manure and cattle manure from intensive feed lots would generally seem more risky than manures with low salt concentrations such as horse manure.

Whereas substrates with cow manure resulted in reduced yields, the same amount of horse manure has given yields similar to those in substrates with peatmoss (Wiersema, unpublished). Although some loamy field soil is likely to increase the water-holding capacity of substrates, it also introduces the possibility of damage from toxic elements and salts, especially in dry areas. Since the beds can be irrigated easily, better water-holding capacity would be of relatively little importance. In many instances substrates without field soil would therefore be less risky.

The careful selection and preparation of appropriate substrates may be worthwhile undertaking because a substrate can be used for several growing seasons. Although disinfection of the substrate by chemicals or high temperatures may not always be required, it probably increases plant survival, especially after direct sowing. Application of chemicals such as Basamid would seem easier than steam treatment since with the latter, the substrate would have to be removed from the beds. Nevertheless, heat treatment is likely to be cheaper especially when the oil drum method is applied. In this method oil drums are cut lengthwise and partly filled with bricks and water while the substrate is put on top of the bricks. A fire underneath the drum heats the water and the escaping steam penetrates the substrate.

Fertilizer requirements for crops from TPS would seem rather different from those derived from seed tubers. The present evidence suggests that young seedlings are sensitive

to high salt concentrations while the positive response to P is dramatic. Especially after direct sowing it would seem risky to apply the total required amount of N and K in one or two applications as usually occurs in crops grown from tubers. The bed system would seem to provide excellent opportunities to deal with problems related to fertilization. P can conveniently be mixed with the substrate before sowing while N and K can be supplied with the irrigation water throughout the growing period, in amounts appropriate for each stage of crop development. This method of fertilizer application may also offer opportunities to manipulate tuber number by different regimes of application of N and perhaps K (Gunasena and Harris, 1968, 1969). Furthermore, the application of fertilizer throughout the growing period is likely to increase fertilizer efficiency through lower leaching losses. Although the total amount of fertilizer applied in the beds was rather high, this would not necessarily be prohibitive for farmers in developing countries since with the use of suitable manures the fertilizer rates could be considerably reduced.

Population thinning after direct sowing probably increases the proportion of vigorous plants and therefore tuber yield, but it is doubtful whether this would result in any major genetic improvement of the population. The correlation between seedling vigour and genotypic yield capacity has been found to be negligible (Thompson, personal communication), which would make the elimination of poor genotypes by population thinning difficult. Reports

from Korea (Kim, unpublished), indicating an absence of correlation between yields from individual seedlings and yields from seedling tubers derived from these seedlings, would seem to support this. Nevertheless it would seem likely that thinning reduces the heterozygozity of the population, especially in open pollinated lines. Similarly it is not clear whether the competition caused by close plant spacing results in specific selection for certain genotypes or causes plants to die merely at random. Initially, early maturing types would have an advantage over later ones because of faster foliage development while later in the growing period the later maturing types probably dominate the earlier maturing ones. Since most of the plants appear to die during the later part of the season (Table 17) they would possibly mainly represent the earlier maturing types. However, since most plants have formed tubers when they die, it would seem that all genotypes are able to form tubers. Because early types have probably more tubers at earlier dates, the number of tubers at harvest that represent early types may be similar to that representing later maturing types. Whether or not genotype selection takes place, evidence has been presented that this was not associated with tuber size at mature harvest (Fig. 12).

The application of growth retardants would seem to have some potential for raising seedlings for transplanting purposes which might result in sturdier plants with better prospects for survival after transplanting. After direct

sowing however, application of growth retardants would seem an ineffective way of increasing yields, possibly because shorter internodes may result in increased intra-plant shading. Prospects for CCC application on seedlings may be better than that for B nine because of a reduced tendency to increase tuber number and the absence of tuber malformation.

The bed system permits the imposition of very high plant populations, which would seem one way of overcoming problems associated with the slow initial growth of plants from TPS. Because of this slow initial growth, particularly after direct sowing, seedlings continue to respond favourably to higher plant populations even at very high levels. This is illustrated by the fact that in all experiments 50 plants per square meter yielded less than 100 plants per square meter. Thus, high plant populations are required to maximize total yield, which carries the penalty of small tuber size, but prospects of manipulating tuber size seem to be limited in the bed system. The size of tubers could potentially be increased by increasing total tuber yield and/or by reducing tuber number. The highest mean yield of a treatment obtained was close to 12 kg per square meter of nursery bed (Fig. 10). Since pathways were eventually also covered by foliage, the yield should perhaps be expressed in tuber weight per unit of total nursery area rather than per unit of bed area. The highest yield then becomes 7.1 kg per square meter of total nursery area or 71 tons per ha. Since this yield probably approaches

the potential yield of a potato crop in the Coast of Peru during the winter season (Moreno, personal communication), it would seem difficult to obtain any further increase in total tuber yield per unit area. The other possibility of increasing tuber size by reducing tuber number, could be achieved by reducing plant population and/or the number of stolons per plant and/or decreasing the number of tubers per stolon. A lower plant population would reduce total tuber yield and thus increase the requirements for nursery space resulting in higher production costs for the same quantity of tubers. However, when instead of nursery beds, field beds are used with lower production costs per unit of land area, this might be a possibility. In that case plant populations would need to be lower than 50 plants per square meter since above this population the number of relatively large size tubers was little affected by plant population (Tables 13-15).

Manipulation of the number of tubers per stolon and the number of stolons per plant may also offer potential for increasing tuber size. Several researchers have discussed the role of plant growth regulators in processes associated with stolon and tuber formation (Palmer and Smith, 1969; Cutter, 1978; Sattelmacher and Marschner, 1978 a, 1978 b; Mauk and Langille, 1978; Wareing and Jennings, 1980) but reliable methods of manipulating tuber number are so far not available. Application of growth retardants such as CCC and B nine would seem to offer little potential to increase tuber size since tuber number

tends to increase with these chemicals rather than decrease. Since these chemicals are not likely to increase yields in beds, their effect on tuber size is negative. Although, at present, most synthetic plant growth regulators applied to potato plants have been shown to favour tuber formation (Table 36), there would seem to be potential for the manipulation of the crop at various stages in its development (Wareing, 1982) which might result in lower tuber numbers.

Another possibility of reducing tuber number might be through the N application regime, for example delayed application of N may decrease tuber number (Gunasena and Harris, 1968, 1969). However, since the delay of N application in seedlings may further aggravate the tendency to slow initial foliage growth and perhaps reduce tuber yield, the potential of this method may be limited for increasing tuber size.

5.1.3 Seedling tuber size

The seedling tubers produced in beds appear to be rather small (Tables 13-15) but probably in only two situations should this be considered a problem. The first situation occurs when poor soil conditions and a short growing season would not permit planting small tubers and thus prohibit the multiplication of small seedling tubers into larger seed tubers. The second situation is associated with consumer preference and occurs when small con-

Table 36. Effects of some plant growth regulators on stolon and tuber formation*

Growth regulator	Effect on stolon formation	Effect on tuber formation
Gibberellins	+	-
Cytokinins	-	+
Abscisic acid	No information	No effect
Indoleacetic acid	+	+
Cycocel, B nine	No information	+
Coumarin	No information	+

* Based on Humphries and Dyson (1967), Gifford and Moorby (1967), Tizio (1969, 1971), Palmer and Smith (1969), Woolley and Wareing (1972), Kumar and Wareing (1972), Cutter (1978), Moorby (1978), Wareing and Jennings (1980), Mauromicale (1982), Stallknecht and Farnsworth (1982), Wareing (1983)

sumer potatoes are not acceptable. The second situation results from the fact that small seedling tubers have to be planted at high stem populations to compensate for slow ground cover, which carries the penalty of small tubers at harvest as an undesirable consequence. Therefore, the size of harvested tubers rather than total yield poses a potential problem when small tubers are planted for the production of consumer potatoes.

The reasons for slow growth of plants from small tubers seem rather complex. Evidence has been presented that the amount of substrate per sprout or stem affects early growth, particularly with tubers smaller than 20 g. Similar results were reported by Headford (1962) indicating a linear relationship between sprout growth and the amount of tuber substrate per sprout over a range of tuber pieces varying from 1 to 64 g. Cutting stimulated early plant growth (Fig. 14) whereby the performance of a 3 g tuber plug was similar to that of an uncut tuber of about 12 g. This would suggest that certain specific growth substances, rather than the absolute amount of reserves, are limiting growth, while the process of wounding the tuber, seems to play a significant role in making available such growth substances. It would seem reasonable to assume that gibberellins, produced by wounding the tuber (Rappaport and Sachs, 1967), play a role in promoting growth, especially since several reports indicate that gibberellins can stimulate initial growth and break sprout dormancy (Rappaport *et al.*, 1957; Slomnicki and Rylski, 1964;

Bruinsma *et al.*, 1967; Holmes *et al.*, 1970). Other plant hormones are likely to play a role in stimulating early sprout and stem growth, but their interactions and functions are insufficiently understood. For a better understanding of early plant growth it would be necessary to quantify the effect of the mother tuber after the stem has emerged. At present it is not clear how much of the slower growth of plants from small tubers is due to a smaller root system and a limited leaf area and how much to a limited supply of growth substances from the mother tuber.

Whereas it may not be clear at this stage how tuber size could be increased effectively, or how plant growth from small tubers might be improved, there are several possibilities for improving the performance of small tubers. An obvious way of advancing the time when ground cover is complete is to plant in close rows or beds. An added advantage of closer row spacing at a specific plant density is less intra-plant shading before ground cover is complete. Optimum soil conditions and adequate fertility levels would further enhance initial foliage growth. Planting tubers of increased physiological age by longer storage periods would seem to offer limited prospects to promote early growth and might be counterproductive because excessive sprout growth may well exhaust the tuber's limited reserves.

It would appear that very small tubers (1-5 g) should perhaps be multiplied to produce large seed tubers, while tubers larger than 5 g might be directly used for the pro-

duction of consumer potatoes, particularly in areas where farmers have experience with planting small tubers.

5.1.4 Tuber health and multiplication

Virus infection would seem to pose a potential threat to the system of seedling tuber production. Although insect populations are usually high in many tropical countries, ecological niches with low aphid populations can often be identified. Isolation from infected fields would generally seem an effective way of reducing infection, while the same effect can be obtained by protecting the beds with an aphid-proof screen. The required level of protection would depend on the tolerances for the various virus diseases in first generation seedling tubers, while this in turn would depend on the anticipated number of tuber multiplications. The tolerances for virus diseases and other tuber-borne diseases should be in proportion to the yield reduction caused by these diseases at different levels of infection. Data from Reestman (1970) have shown that significant yield reductions due to virus diseases only occur at rather high infection levels.

The presence of high insect populations may prohibit more than one or two tuber multiplications in order to produce seed tubers of a reasonable health standard. Since TPS will supposedly be available in sufficient quantities there would seem to be no reason to multiply seedling tubers more than once or twice. Table 37 shows that one multi-

Table 37. Nursery area required to produce 1 ton of seed tubers

Yield in nursery (kg m^{-2} bed)	Number of multiplications*	Nursery-bed area (m^2)	Relative nursery area (%)
2	0	500	100
	1	33	6.6
	2	4.4	0.9
4	0	250	100
	1	16.6	6.6
	2	2.2	0.9
6	0	167	100
	1	11.1	6.6
	2	1.5	0.9
8	0	125	100
	1	8.3	6.6
	2	1.1	0.9
10	0	100	100
	1	6.7	6.6
	2	0.9	0.9

* Assumed multiplication rates:
- first generation seedling tubers: 15
- second generation seedling tubers: 7.5

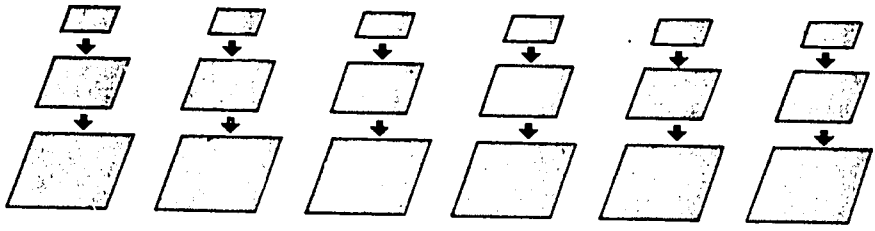
plication reduces considerably the required nursery area resulting in lower costs and less managerial requirements for the production of first generation seedling tubers. One multiplication would also satisfy the need to increase the size of first generation seedling tubers. High multiplication rates (Table 35) of first generation seedling tubers would be another factor in favour of at least one multiplication. During multiplication the seed tuber stocks may be somewhat improved by roguing, although roguing intensity should be in proportion to the number of multiplications. With only one tuber multiplication roguing of plants with severe virus-like symptoms would perhaps be sufficient.

5.1.5 Organizational considerations

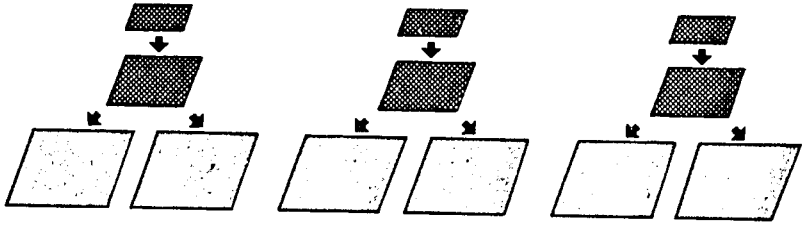
The system of seed tuber production from TPS may consist of 3 major stages: the nursery stage in which seedling tubers are produced, the multiplication stage and the last stage in which consumer potatoes are produced. It would seem that the nursery stage involves the highest amount of skill and management, followed by the multiplication and ware production stages.

The production of seedling tubers could be organized in 3 alternative ways (Fig. 22). In alternative 1, individual farmers would apply the whole system including the production of seedling tubers in nurseries, the multiplication of these tubers and their use for ware production.

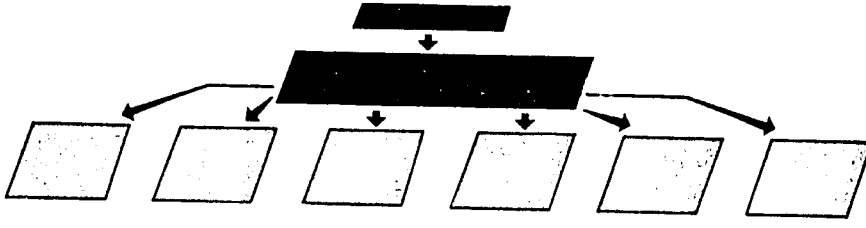
Alternative 1 – Completely decentralized production; no distribution of seedling tubers is required.



Alternative 2 – Partly decentralized production; limited distribution of seedling tubers is required.



Alternative 3 – Centralized production; extensive distribution of seedling tubers is required.



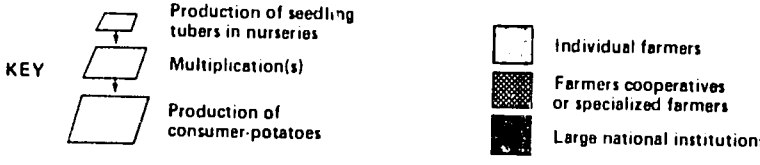


Fig. 22. Three alternative systems of production and distribution of seedling tubers.

In alternative 2 the production and multiplication of these tubers would be handled by specialized farmers of farmers cooperatives. The production of planting material by specialized farmers is not uncommon in some vegetable growing areas. Producers of consumer potatoes would then buy their seed tubers directly from such specialized farmers or cooperatives. An example of this alternative is presented in Fig. 23. This alternative might provide producers of consumer potatoes with a rather reliable source of good quality seed tubers, while the production of seed tubers is sufficiently decentralized to avoid problems associated with transport and distribution. In alternative 3 large national institutions would be involved in the production and multiplication of seedling tubers. This alternative may be effective in places where some kind of national seed tuber production and distribution scheme is in operation. Instead of producing basic or certified seed tubers from cultivars seed tubers could be produced from TPS of selected lines. Although cultivars supposedly represent a superior genotype, evidence has been presented that the yield potential of seedling tubers was similar to that of a clone or cultivar.

From alternatives 1 to 3 the way seedling tuber production is organized changes from completely decentralized to rather centralized. In alternative 1 farmers are self sufficient in the supply of planting material, but need to acquire a considerable amount of skill that is more usually associated with horticultural enterprises. The

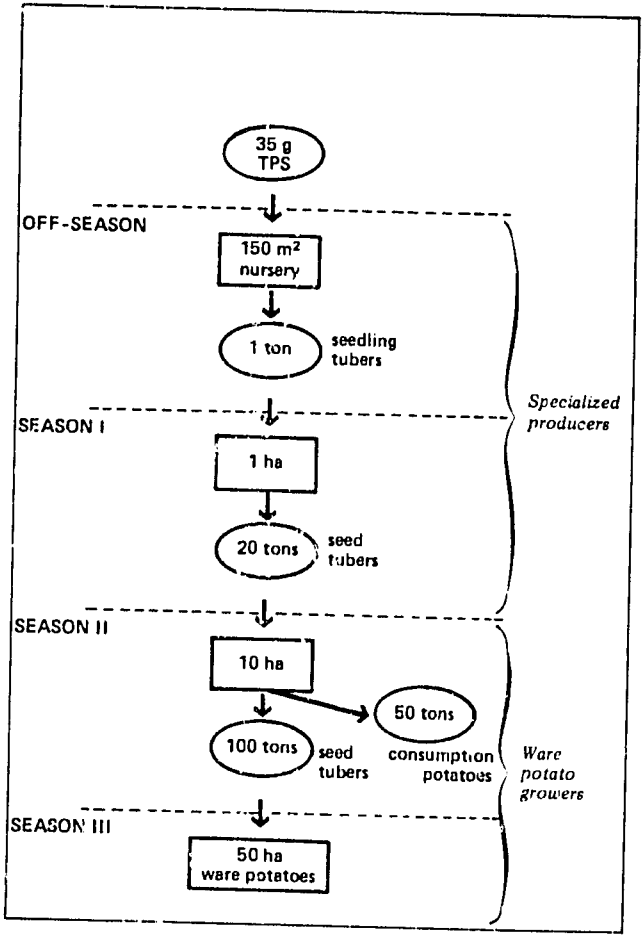


Fig. 23. Example of a production scheme based on seedling tubers.

limitations of a more centralized way of producing seedling tubers such as alternative 3, are associated with transport and distribution of seed tubers. An intermediate system such as alternative 2 might be an effective compromise.

5.1.6 The implementation of a seedling tuber production system

Although the procedures for implementing a seedling tuber programme may vary with local conditions, some general observations can be made. Assuming that one has been given the task to produce seedling tubers for a certain area of ware potatoes, it would seem that the first question to be answered is, how many square meters of nursery or field bed is required to produce first generation seedling tubers. To answer this question the following information is needed:

- the yield per squaremeter bed
- the number of possible multiplications
- the multiplication rate of first generation tubers
- the multiplication rate of subsequent generations
- the number of nursery crops per year.

With the following procedure this information could be available in a relatively short time. After the identification of a suitable substrate for the seed beds, beds may be sown in different locations on a monthly basis. This would provide information on suitable production areas

and periods as well as average yield levels. Subsequently the first generation seedling tubers might be planted at different rates to obtain information on average multiplication rates. Simultaneously, the health status of the tubers may be determined after each multiplication in order to determine the rate of health degeneration and the number of possible multiplications. With this information the total bed area required can be calculated using the following formula:

$$X = \frac{Q}{M1 \times M2 \times \ldots\ldots Mn \times Y \times C}$$

where:

X = Nursery area (square meter of bed)

Q = Total quantity of seed tubers required to produce consumer potatoes (kg)

M = Multiplication rate of each generation

n = Number of possible multiplications

Y = Yield of first generation seedling tubers in nurseries (kg per square meter of bed)

C = Number of nursery crops per year

Table 38 shows the nursery area required to produce seed tubers for 10,000 ha of ware potatoes, assuming different yields in nurseries, a different number of multiplications and a different number of nursery crops per year. In this table it is assumed that the farmers would buy new seed tubers every year, which is perhaps a somewhat extreme

Table 38. Nursery and TPS requirements to produce seed tubers for 10.000 ha of ware potatoes*

Yield in nursery (kg m^{-2} bed)	No. multi-plications	No. nursery crops $year^{-1}$	Nursery bed area (m^2 x 1000)		TPS (kg)	
			M_L	M_H	M_L	M_H
4	1	1	333.3	250	77.8	58.3
		2	166.7	125	38.9	29.2
		3	111.1	83.3	25.9	19.4
	2	1	44.4	25.0	10.4	5.8
		2	22.2	12.5	5.2	2.9
		3	14.8	8.3	3.5	1.9
	3	1	5.9	2.5	1.4	0.6
		2	3.0	1.3	0.7	0.3
		3	2.0	0.8	0.5	0.2
6	1	1	222.2	166.7	51.8	38.9
		2	111.1	83.3	25.9	19.4
		3	74.1	55.6	17.3	13.0
	2	1	29.6	16.7	6.9	3.9
		2	14.8	8.3	3.5	1.9
		3	9.9	5.6	2.3	1.3
	3	1	4.0	1.7	0.9	0.4
		2	2.0	0.8	0.5	0.2
		3	1.3	0.6	0.3	0.1

* Assumptions:
- Seed tuber rate for ware production: 2 tons per ha
- Multiplication rates (M):
  M_{Low}: multiplication rate of first generation tubers = 15
  multiplication rate of subsequent generations = 7.5
  M_{High}: multiplication rate of first generation tubers = 20
  multiplication rate of subsequent generations = 10
- TPS sowing rate is 3 times more than the number of plants required
- No. plants per m^2 nursery bed after thinning = 100

situation. The assumed yield levels of 4 and 6 kg per square meter of bed correspond with respectively 33% and 50% of the maximum yield obtained at the experimental station in Peru and could perhaps realistically be obtained under less ideal conditions. Two different multiplication rates have been assumed, both for first and second generation tubers. The high multiplication rates (M_H - Table 38) are similar to those obtained at the experimental station at CIP, while the lower multiplication rates (M_L) are 25% lower. Because of smaller tubers in the first generation than in the second, the multiplication rate of the first generation has been assumed higher than that of the second. Table 38 shows that with a yield level of 4 kg per square meter of bed, 2 nursery crops per year and 2 multiplications at the higher multiplication rate a total bed area of 12,500 square meters is required to produce 20,000 tons of seed tubers. This would mean 12.5 units of 1,000 square meters, 125 units of 100 square meters or 1250 units of 10 square meters. With a reasonable transport and distribution system 12.5 units of 1000 square meters would initially perhaps be easier to manage. In a later stage of the programme when more farmers would be familiar with TPS, an increasing number of smaller units might be introduced.

Table 38 also points to the fact that in case only 1 field multiplication is possible, an attempt should be made to produce seedling tubers in nurseries on an almost continuous basis, in order to limit the total nursery area

requirements. Table 38 illustrates that the total amount o TPS required is relatively small, especially when seedling tubers can be multiplied more than once. With one multiplication, a yield of 6 kg per square meter of bed, 2 nursery crops per year and a multiplication rate of 20, 19 kg of TPS would be required to produce first generation seedling tubers for an area of 10,000 ha of ware potatoes.

5.2 Potential areas for adoption of alternative systems of producing planting material

Some criteria to locate areas where the bed system to produce seedling tubers might have potential would seem useful in order to identify areas where the prototype system described here might be tested and further adapted to local conditions. Although a description of potential areas of adoption would be more accurate when results of the adapted prototype system in different environments become available, some general characteristics of suitable areas could be usefully identified, even before such results are available. For this discussion a method of evaluation is suggested whereby the merits of several alternative systems of producing potato planting material is considered over a range of production factors. It would seem essential to include alternative systems of producing planting material since the potential for the adoption of the seedling tuber system would depend on other systems and their efficiency in the area under consideration.

The following alternative systems of producing planting material have been considered:

S1: The production of seedlings for transplanting to the field

S2: The production of seedling tubers in beds

S3: The production of clonal seed tubers by means of simple methods such as the seed plot technique (Bryan, 1981 a). These methods would generally involve a limited number of multiplications

S4: The production of clonal seed tubers by means of more sophisticated schemes such as those based on *in vitro* mass tuberization (Wang and Hu, 1982), clonal selection (Bryan, 1981 b) and rapid multiplication techniques (Bryan *et al.*, 1981 c).

These schemes are characterized by several multiplications.

Although other alternative systems, such as direct field sowing, can be thought of, only those systems are considered here which are at present technically sufficiently developed for application on a relatively large scale.

The method attempts to quantify how several production factors may influence the potential for adoption of each alternative system of producing planting material, using a scoring method. For each production factor 5 different levels are assumed corresponding to standard scores of 1-5 (Table 39). In each system an optimum score is assigned to each production factor, which indicates the level of that factor at which a production system would have the

Table 39. Standard scores for different production factors and optimum scores in 4 production systems*

Production factor	Standard scores 1-5					Optimum scores in each production system			
	1	2	3	4	5	S1	S2	S3	S4
1. Seed tuber costs (% of total production costs)	<20	20-30	30-40	40-50	>50	5	4	1	1
2. Consumer preference	unimportant				important	1	2	4	5
3. Health degeneration (no. of possible multiplications)	0	1	2	3	>3	1	2/3	3/4	5
4. Storage period for seed tubers (months)	2	2-4	4-5	5-6	>6	1/5	2	3/4	3/4
5. Mean storage temperature (°C)	<10	10-15	15-20	20-25	>25	5	2	2/3	1
6. Water supply (rainfall or irrigation frequency in days)	1-3	3-5	5-7	7-9	>9	1/2	3/4	4/5	4/5
7. Available growing period (months)	<3	3-3.5	3.5-4	4-4.5	>4.5	4/5	3	2	1
8. Soil type	light textured, high organic matter				heavy textured, low organic matter	1/2	2/3	4/5	4/5
9. Farmers experience	vegetable grower				traditional potato grower	1	3	4	5
10. Farm size (hectares)	<1	1-5	5-10	10-20	>20	1	2	4	5
11. Labour	cheap				expensive	1	2	4	5

* See text on page 186

least competition from the other systems and therefore have the highest potential for adoption. For a specific area, each production factor is given an actual score representing the estimated level of that factor in the area. The absolute difference between optimum and actual scores results in "penalty points". The system with the lowest total number of penalty points, over all the production factors, would have the highest potential for adoption in that area.

The application of this scoring method is demonstrated with an example, using the production factor "seed tuber costs". It is assumed that the costs of seed tubers can represent <20%, 20-30%, 30-40%, 40-50% or >50% of the total production costs, respectively. These values correspond to standard scores 1-5 (Table 39). When seed tuber costs are as low as 20% of the production costs (standard score of 1), the use of seed tubers (S_3 and S_4) would be attractive and would experience little competition from seedling transplants (S_1). Therefore with a score of 1 S_3 and S_4 would have the highest potential for adoption and this results for these systems in an optimum score of 1 for the factor "seed tuber costs". On the other hand when seed tuber costs are >50% of the production costs (standard score of 5), there would be a strong tendency to change to cheaper planting material such as seedling transplants (S_1); this results in a high potential for adoption of S_1 and therefore the optimum score in S_1 for

the factor seed tuber costs is 5.

In a production area where the costs of seed tubers represent 20-30% of the total production costs (actual score of 2), S_1 would receive (5-2 =) 3 penalty points and S_4 would receive (1-2 =) -1 penalty point. Since the method is based on the deviation of the actual from the optimum score, absolute values for penalty points are used, so S_4 receives 1 penalty point. From this example it is concluded that for the factor "seed tuber costs" S_4, with fewer penalty points, has a higher potential for adoption than S_1.

In the following, the optimum scores for the various production factors (Table 39) are discussed.

1. Seed tuber costs (% of total production costs)

As pointed out by Van der Zaag and Horton (1983) it would be difficult to reduce the proportion of seed tuber costs below 17% of the total production costs. Therefore, with a score of 1 the production systems 3 and 4 (S_3 and S_4) would experience little competition from the other systems, while with a score of 5, S_1 would offer the greatest opportunities to reduce seed tuber costs. The optimum score for S_1 is therefore 5 and that for S_3 and S_4 one. S_2 receives an optimum score of 4 because the reduction in costs of planting material may be less with the use of seedling tubers than with the use of seedling transplants.

2. *Consumer preference*

Consumer preference may include factors such as skin colour, depth of eyes, tuber shape, homogeneity and size of tubers. When consumer preference is not important, S_1 is highly attractive while in the opposite situation S_4 would seem more appropriate. S_3 may be less effective in producing high quality seed tubers than S_4 (e.g. mixing of varieties) and receives therefore an optimum score of 4. S_2 can produce better quality seed tubers than S_1 because of more opportunities for tuber selection, resulting in an optimum score of 2.

3. *Health degeneration (number of possible multiplications)*

With extremely high degeneration rates (score 1) S_1 is attractive since no seed tubers are involved, while with more than 3 multiplications S_4 becomes feasible. S_2 requires at least one multiplication to increase the size and quantity of first generation seedling tubers, resulting in an optimum score of 2 or 3. S_3 requires fewer multiplications than S_4 but perhaps more than S_2, and therefore receives an optimum score of 3 or 4.

4. *Storage period for seed tubers*

Seed tuber storage for less than 2 months presents problems because of dormant tubers, as well as storage for more than 6 months because of increased physiological age and moisture loss. Therefore under these conditions S_1

would receive little competition from the other systems. This results in an optimum score for S_1 of 1 or 5. Intermediate storage periods of 4-6 months are not prohibitive for S_3 and S_4 while S_2 would be more appropriate when storage periods are shorter because smaller tubers may have a somewhat lower storability. The optimum score for S_2 is therefore 2 and that for S_3 and S_4, 3 or 4.

5. *Mean storage temperature*

At mean temperatures over 25°C, seed tuber storage may present problems which would favour S_1, while below 20°C simple storage methods using diffuse light could be applied in S_3. S_2 requires lower storage temperatures than S_3 because of smaller tubers. In S_4 the amount of tubers to be stored might be larger because of a more centralized type of production, which may prohibit the use of diffuse light. Bulk storage with forced ventilation would require low temperatures, therefore, S_4 would epxerience the least competition from the other systems with an optimum score of 1.

6. *Water supply (rainfall or irrigation frequency)*

S_1 requires a supply of water at least once in 5 days especially during the period following transplanting, although this may vary with soil type and temperature. S_3 and S_4 can be applied in any condition where the frequency of water supply permits potato production, while it is arguable that S_2 with smaller tubers occupies an intermediate position.

7. *Available growing period*

Crops from transplanted seedlings require at least 3 months to mature under hot conditions and perhaps at least 4 months under cooler conditions, although this may vary with TPS-lines. Since with an increasing growing period the potential yield from transplants increases, S_1 would experience the least competition with scores 4 and 5. S_4 that produces the highest quality seed tubers, is possibly the only system that could produce seed tubers that would yield acceptably in a growing period of less than 3 months, while S3 with lower seed tuber quality may need a somewhat longer growing period. S_2 with smaller tubers would require a longer growing period than S_3 but not as long as S_1.

8. *Soil type*

S_1 is likely to have more potential on light soils and on soils with a high level of organic matter (scores 1 and 2) because of better transplant survival, while with scores 4 and 5 the systems S_3 and S_4 would experience little competition from the other systems. S_2 with smaller tubers would occupy an intermediate position.

9. *Farmers experience*

S_1 requires experience with vegetable growing, while S_3 and S_4 would seem to be more appropriate for traditional potato growers that are only familiar with planting tubers.

In S_3 the individual farmer may require some additional skills in seed tuber production and receives therefore an optimum score of 4. For the adoption of S_2, only some farmers would require experience in vegetable growing and this system therefore receives an optimum score of 3.

10. Farm size

Because of high management requirements S_1 would seem more appropriate for small farms while S_2 may be applied on somewhat larger farms. Large farmers may benefit most from an organized seed tuber multiplication scheme (S_4) while S_3 would seem more appropriate for medium size farms.

11. Labour

S_1 is rather labour intensive and requires cheap labour, while when labour is expensive S_4 may be more attractive, because large production schemes would allow mechanization. S_3 would require more labour than S_4 but less than S_2.

The application of this evaluation method is illustrated with two examples. The characteristics of the production areas under consideration are presented in Table 40, while the results of the evaluation method for each area are presented in Tables 41 and 42, respectively. The actual scores in Tables 41 and 42 correspond with the description of the area while the optimum scores for each production factor in each production system are the same

Table 40. Characteristics of 2 potato production areas considered for the evaluation of the adoption potential for different production systems

Production factor	AREA I	AREA II
1. Seed tuber costs	more than 50% of the total production costs	same as I
2. Consumer preference	unimportant	same as I
3. Health degeneration	permits 1 multiplication	same as I
4. Storage period	2-4 months	same as I
5. Storage temperature	20-25°C (mean)	same as I
6. Water supply	irregular, weekly irrigation available	irrigation available every 2-3 days
7. Available growing period	3.5-4 months	same as I
8. Soil type	medium textured, medium levels of organic matter	light-medium textured with high levels of organic matter
9. Farmers experience	traditional potato grower	vegetable grower
10. Farm size	1-5 ha	same as I
11. Labour	abundantly available and cheap	same as I

Table 41. Example of a method to evaluate the adoption potential for different production systems in production area I (Table 40)

Production factor[2]	Production system[1]											
	S_1			S_2			S_3			S_4		
	O[3]	A[4]	P[5]	O	A	P	O	A	P	O	A	P
1	5	5	0	4	5	1	1	5	4	1	5	4
2	1	1	0	2	1	1	4	1	3	5	1	4
3	1	2	1	2/3	2	0	3/4	2	1	5	2	3
4	1/5	2	1	2	2	0	3/4	2	1	3/4	2	1
5	5	4	1	2	4	2	2/3	4	1	1	4	3
6	1/2	3	1	3/4	3	0	4/5	3	1	4/5	3	1
7	4/5	3	1	3	3	0	2	3	1	1	3	2
8	1/2	3	1	2/3	3	0	4/5	3	1	4/5	3	1
9	1	5	4	3	5	2	4	5	1	5	5	0
10	1	2	1	2	2	0	4	2	2	5	2	3
11	1	1	0	2	1	1	4	1	3	5	1	4
Total number of penalty points			11			7			19			26
Ranking of adoption potential			2			1			3			4

[1] See text on page 186
[2] See Table 39
[3] Optimum score (see Table 39)
[4] Actual score based on Table 40
[5] Penalty points

Table 42. Example of a method to evaluate the adoption potential for different production systems in production area II (Table 40)

Production factor[2]	Production system[1]											
	S_1			S_2			S_3			S_4		
	O[3]	A[4]	P[5]	O	A	P	O	A	P	O	A	P
1	5	5	0	4	5	1	1	5	4	1	5	4
2	1	1	0	2	1	1	4	1	3	5	1	4
3	1	2	1	2/3	2	0	3/4	2	1	5	2	3
4	1/5	2	1	2	2	0	3/4	2	1	3/4	2	1
5	5	4	1	2	4	2	2/3	4	1	1	4	3
6	1/2	1	0	3/4	1	2	4/5	1	3	4/5	1	3
7	4/5	3	1	3	3	0	2	3	1	1	3	2
8	1/2	2	0	2/3	2	0	4/5	2	2	4/5	2	2
9	1	1	0	3	1	2	4	1	3	5	1	4
10	1	2	1	2	2	0	4	2	2	5	2	3
11	1	1	0	2	1	1	4	1	3	5	1	4
Total number of penalty points			5			9			24			33
Ranking of adoption potential			1			2			3			4

1 See text on page 186
2 See Table 39
3 Optimum score (see Table 39)
4 Actual score based on Table 40
5 Penalty points

as those given in Table 39. The number of penalty points results from the difference between actual and optimum scores or from the smallest difference between these scores, in cases where 2 different optimum scores are given. The accumulated number of penalty points for each production system would indicate the potential for adoption of each system. Table 41 shows that System 2 has the lowest number of penalty points followed by Systems 1, 3 and finally 4 in an area with the following characteristics: seed tuber costs represent more than 50% of the total production costs, consumer preference is unimportant, the health degeneration allows one tuber multiplication, the tuber storage period is 2-4 months with a mean temperature of 20-25°C, rainfall is irregular with irrigation available on a weekly basis, the growing period is 3.5-4 months, the soil is medium textured with medium levels of organic matter, farmers are traditional potato growers with farms of 1-5 ha and labour is cheap. Therefore, in this area the production of seedling tubers in beds would have the highest potential for adoption, followed by transplanting seedlings, simple seed tuber production techniques and finally by more sophisticated seed tuber programmes. When the frequency of water supply increases, soils are better and farmers are trained in transplanting methods (Table 40, area II), the transplanting of seedlings would have the highest potential for adoption followed by the production of seedling tubers in beds, simple seed tuber production techniques and finally by more sophisticated seed tuber programmes.

This method would seem informative about how a range of different production conditions, including soil, climatic, economic and social factors, affect the adoption potential for each system of producing planting material. After experience with this method, more production factors might be considered, while the values assigned to the scores 1 to 5 (Table 39) may be modified. Several factors such as "farmer's attitude to new technologies" are rather difficult to put on a scale and were not included in this method, but are likely to play a role in the process of adoption. Similarly, certain factors may be more important than others and may need more weight assigned to them. For example, the frequency of water supply may be more critical than the soil type.

Further perfection of this method of evaluation would require empirical data from areas where the system of seedling tuber production actually has been adopted by farmers or where the technology for the production and utilization of seedling tubers has been evaluated and compared with alternative planting materials. A format for such a technology evaluation and for the recording of agronomic data has been proposed by Wiersema (1982). Such agronomic data together with information about environmental conditions and socio-economic data, from various areas, would be essential for the development of a model that may predict the adoption potential for the seedling tuber system. In such a model factors such as the availability of hybrid seed, and opportunities to produce seed-

ling tubers during the off season should also be considered.

5.3 Production of consumer potatoes in beds

The production of consumer potatoes from transplanted seedlings would seem to be hampered by poor plant establishment, slow rates of ground cover and a rather long growing period. These factors may prohibit field production of consumer potatoes especially in areas where potatoes are a minor crop and where the length of the season and availability of labour for the potato crop is mainly determined by requirements of other more important crops. Although the production of seedling tubers in beds may offer a solution for such areas, farmers may not be inclined to grow a crop during its complete life cycle just to produce planting material. In such a situation direct production of consumer potatoes in beds may be attractive, especially in areas where tuber size is of minor consumer importance. Evidence has been presented that in beds total tuber yields can be very high (Fig. 10), while management is restricted to a very small area. A long growing period would not be prohibitive since the beds can be located in a way that they can be managed independently from the field. The bed system would further provide opportunities to reduce storage problems by sequential planting. Assuming a total yield of 2.5 kg per square meter of bed in a period of 120 days after sowing, an average family of 5 in the Philippines would need, at the present rate of consumption, only 10

square meters of bed to supply potatoes for a year's requirement. Assuming two crops per year, only 5 square meters of bed would be permanently required to produce consumer potatoes. Such a system would seem attractive for smallholdings where land is scarce, vegetable growing is common and compost and manures are available. Under such conditions potatoes could possibly be produced at very low costs and with a minimum amount of risk. The bed system would therefore seem to offer excellent opportunities to make the potato a low cost food rather than an expensive vegetable. A pre-requisite for these prospects to become reality would be the availability of TPS on a scale similar to that of other vegetable crops.

5.4 Further research and development

The development of a system to produce seed tubers from TPS has given rise to several areas requiring further research.

Manipulation of the size of seedling tubers produced in beds

The easiest method of manipulating tuber size is perhaps by means of plant population. The present evidence suggests that in order to increase tuber size the plant population should be lower than 50 plants per square meter. It would seem useful to study how plant populations lower than those required for maximum yield would affect total

yield, number of tubers and tuber size in order to quantify the yield penalty associated with the production of larger tubers. Such a study would be especially relevant to the possibility of producing consumer potatoes in beds.

Alternative approaches to increasing tuber size would include the selection of TPS-lines with a lower tuber number per stem and the application of growth regulators to control stolon formation and tuber initiation. The development of a practical method to control tuber size by growth regulators is perhaps complicated by the apparent antagonism between stolon development and tuberization. Tuber initiation involves a change in the pattern of growth of the stolon apex from one of marked internode elongation involving highly polarized cell divisions to one in which there is unpolarized division in the sub-apical region (Cutter, 1978). It may therefore not be surprising to find that desired effects on tuberization by a growth regulator can be offset by stimulation of stolon growth, illustrated by the fact that high gibberellin levels inhibit tuberization but promote stolon development (Wareing, 1982). The same author, however, argues that since the potato plant is particularly responsive to applied growth regulators at each of the main stages of its development, opportunities for regulating stolon and tuber formation would be available especially with the continuous discovery of new plant growth regulators. Despite this rather optimistic view point, it would not seem clear at present which growth regulators

would have more potential to increase tuber size, since with the exception of gibberellins, the well known growth regulators seem to favour tuber formation (Table 36) and would therefore tend to decrease tuber size. Perhaps more important than the effects of individual growth regulators are the interactions between them as well as the effects of concentration and time of application. A better understanding of developmental processes and their control by plant growth regulators would seem required before a practical method to control tuber number and size can be developed.

Stimulation of early plant growth from small tubers

Small tubers seem to be lacking some type(s) of growth substance associated with the mobilization of tuber reserves. Identification of these substances would seem necessary for the development of a method whereby these substances can be applied externally by spraying or dipping the tubers. Application of GA may offer some potential to promote initial growth, although the break of bud dormancy may be an undesirable consequence, since this would increase the number of sprouts per tuber which would further reduce the amount of substrate available per sprout or stem.

At this stage a logical approach to increase early vigour would seem to be the reduction of the number of sprouts per tuber resulting in a larger amount of substrate

per stem. It would seem useful in this respect to determine the optimum number of sprouts per tuber for various size grades of tubers.

Agronomy of planting small tubers

Before methods which stimulate early growth become available, attempts should be made to optimize the management of the crop to take the maximum advantage of small tubers. This research might concentrate on methods of increasing early ground cover such as a more ideal spatial arrangement of plants through closer row spacing and increased fertilizer uptake by several applications of relatively small amounts of fertilizer.

Storage behaviour of small tubers

Although theoretically small tubers would loose more weight during storage because of a larger skin surface per unit weight, evidence of lower storability compared with larger tubers is lacking. The effects of larger skin surface on water loss in small tubers might to some extent be compensated by a longer dormancy and slower sprout growth which reduces sprout length and associated water loss. Since seed tuber storage in diffuse light at ambient temperature has proved to be a suitable, low cost method (Booth *et al.*, 1983) experiments should preferably be performed under such conditions. Treatments might include

different ambient temperatures, relative humidities, tuber sizes and storage periods. In addition to the effect of storage conditions on tuber weight loss in various size grades, the effects on sprout development and sprout condition would require evaluation. In particular further study would be required to determine optimum levels of sprout development for each size grade.

Adaptation of the system of seedling tuber production to local conditions

The principles of seed tuber production from TPS have been outlined and these principles now have to be applied to specific local conditions. This would involve the identification of suitable local substrates and bed structures to produce seedling tubers, as well as identification of suitable areas within a country where first generation tubers can be produced. Similarly, appropriate farmers and institutions would need to be selected for the adoption of certain parts of the production chain. Once the system has been adapted to local conditions a socio-economic analysis would seem required to see whether the system competes favourably with other systems of producing planting material. Similarly, a socio-economic analysis would seem a useful tool to identify certain production problems that require further improvement. With socio-economic data available from different areas a more general model could perhaps be developed to predict where the seed-

ling tuber system would have high potential for adoption.

Production of good quality TPS

Although it has been assumed that TPS is relatively easy to produce, it would seem that at present the supply of good quality TPS is rather limited. Efficient methods of producing good quality TPS are required. Before such methods can be developed more information is needed on several aspects of TPS-production such as factors affecting flowering, fruit set, outcrossing rates (for hybrid seed production) and seed quality, as well as on seed processing techniques such as seed extraction, seed drying and separation of seed sizes.

Chapter Six
SUMMARY AND CONCLUSIONS

Problems associated with the use of seed tubers are high costs of healthy seed tubers, low availability of suitable seed tubers and rapid degeneration of seed tuber stocks due to pathological and physiological reasons. True potato seed (TPS) can potentially overcome these problems because of easy storage and transport while transmission of virus diseases by TPS is limited to 3 or 4 viruses, of perhaps minor importance, and one viroid.

Methods of TPS use include direct field sowing, transplanting seedlings and planting seed tuber derived from TPS (seedling tubers); good results have been reported with the last 2 methods. Sensitivity of transplanted seedlings to environmental conditions has led to the investigation of a system to produce seed tubers from TPS, whereby seedling tubers are produced in a nursery protected from diseases. Beds of 1 meter width and 25 cm depth filled with a substrate of sand and peatmoss or sand andcompost, mixed in equal proportions, were found to be suitable for the production of seedling tubers by direct sowing methods. Seedlings seemed to be sensitive to salts which would explain why low yields were obtained when concentrated cow manure was used as source of organic material instead of peatmoss. For the same reason generally no positive effect of pre-sowing application of N and K_2O on early seedling growth was obtained while at application rates of 200 ppm and above, seedling weight was significantly lower than the control. On the other hand the positive response of early seedling growth to pre-

sowing application of P_2O_5 is reported to be dramatic and experiments showed that in a substrate of 50% sand and 50% peatmoss a total amount of 800 ppm, which is estimated to be sufficient for a tuber yield of 12 kg per square meter of bed, could be applied at sowing without detrimental effects on seedling growth. Based on these results it is suggested to apply only P at sowing while N and K might be applied in split doses after seedling emergence. Direct sowing in beds gave similar yields to transplanted seedlings and reduced the total growing period from sowing by 15 days. Direct sowing followed by thinning of seedlings after emergence would seem an attractive labour saving method, provided that substrate temperatures permit adequate germination. The optimum plant population seemed to be between 100 and 150 plants per square meter of bed after thinning with a total tuber weight of up to 11.97 kg per square meter of bed and a total number of useable tubers (>1 g) of up to 1242 per square meter of bed. The length of the growing period normally varied from 110-150 days after sowing, depending on TPS-line and season. Increasing plant population had a positive effect on the number of tubers of 1-10 g while the number of larger tubers remained fairly constant.

The application of additional substrate in direct sown plots after seedling emergence, to substitute for hilling, increased the number and length of stolons as well as tuber number. The lowest two nodes would seem mainly responsible for stolon and tuber formation, and

covering more than 2-3 nodes did not further increase tuber number. The application of B nine resulted in sturdier seedlirgs at early growth stages but had no positive effect on the number or weight of useable tubers. Tuber malformation occurred especially when B nine was applied on seedlings which did not receive additional substrate after seedling emergence.

The incidence of the insect transmitted viruses PVY and PLRV in seedling tubers produced in beds varied considerably between seasons but indicated that isolation of beds from infected potato fields, or protection by an aphid proof screen would be impcrtant for the production of healthy seed tubers. The infection by contact viruses would seem relatively unimportant.

Due to the high plant population the seedling tubers produced in beds were relatively small but all size grades represented a similar group of genotypes, suggesting that a possible expression of the natural selection due to plant competition did not take the form of differences in tuber size. All tuber sizes were therefore equally suitable for multiplication into seed tuber stocks, while differences in growth between plants from different sized tubers were largely due to non-genetic rather than to genetic causes. In single-sprout tubers of 20 g and below, increasing tuber size increased early foliage growth and ground cover, the number of above ground stems, the total tuber yield and the proportion of large tubers. Slow

growth of plants from small tubers was mainly due to lack of growth substances associated with tuber reserves rather than to other intrinsic defects. Both in single-sprout and multiple-sprout tubers of 20 g and below, the total tuber yield was related to seedling tuber rate rather than to the number of mainstems or above-ground stems. This would indicate that the higher stem number per unit of planted weight, generally arising from smaller tubers, compensated for the lower yield per stem. Thus, small tubers require a high stem density to promote early ground cover which gives a large number of tubers per unit area and this results in small tubers. This property of small seedling tubers, in addition to their high multiplication rate, would make them more suitable for the production of seed tubers rather than for the production of ware sized tubers.

Closer plant spacing increased early ground cover and yield from small seedling tubers but the effects of the length of the sprouting period was dependent upon tuber size and TPS-line.

Comparison of alternative planting materials derived from the clone DTO-33 on a per mainstem basis showed that early foliage growth and yield at several intermediate harvests decreased with decreasing tuber size while transplanted seedlings behaved like very small tubers with the lowest final yield. Tuber number per stem was consistently higher in seedlings which would make

them principally more suitable for seed rather than ware potato production. The comparison of alternative planting materials was influenced by the TPS-line, the transplanting method, the length of the growing period, the size of seedling tubers and the seedling tuber rate. Seedling tubers derived from open pollinated seed of the clone DTO-33 gave a similar marketable yield to seed tubers of the clone DTO-33.

The system of seedling tuber production may show high potential for adoption in areas where the use of TPS is attractive because of factors such as high costs of healthy seed tubers and absence of consumer preference for certain tuber qualities, while growing conditions such as heavy soils, irregular water supply, a short length of the growing season and the presence of potato growers that lack experience in vegetable growing, would not permit potato production from transplanted seedlings. An effective way of organizing the production of seedling tubers may be the use of specialized farmers or farmers cooperatives for the production of first generation seedling tubers and possibly for the first multiplication of these tubers; this system would provide a reliable source of good quality seed tubers while the production of seed tubers may be sufficiently decentralized to avoid problems associated with tuber transport and distribution.

The bed system would seem to be an attractive method

of producing potatoes from TPS, both for planting and for direct consumption, because this system permits a high plant population which compensates for slow initial foliage growth and can result in high yields per unit area. In addition the bed system may permit several crops per year since growing conditions can be easily controlled.

Areas of further research for the future development of the production and use of seedling tubers include the manipulation of the size of seedling tuber produced in beds, the stimulation of early plant growth from small tubers, the storage behaviour of small tubers, the adaptation of the system of seedling tuber production to specific local conditions and the production of good quality TPS.

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APPENDICES

Appendix 1. Climatic conditions at CIP Experimental Station in La Molina, Lima, Peru*

Period	Total radiation (gcal cm^{-2} day^{-1})	Temperatures (°C)			Rel. humidity(%)		Vapour pressure (ml)
		Mean of 24 hours	Max.	Min.	Max.	Min.	
January 1981	7155	20.9	25.5	17.3	95	61	19.6
February 1981	7029	23.1	28.0	19.5	94	56	21.8
March 1981	7923	22.9	28.3	19.4	95	56	21.9
April 1981	6971	20.5	26.1	17.0	96	59	19.8
May 1981	5390	17.5	22.6	14.0	97	64	16.9
June 1981	4294	15.7	19.9	12.8	96	69	15.4
July 1981	3898	15.0	18.8	12.5	97	74	15.1
August 1981	4177	15.3	19.0	13.4	96	73	15.3
September 1981	4951	15.6	20.0	13.0	97	69	15.6
October 1981	6125	16.5	21.0	13.9	96	69	16.2
November 1981	6340	17.7	22.5	14.9	96	68	17.5
December 1981	7128	19.5	25.3	16.6	97	63	18.8
January 1982	7781	21.0	26.9	17.9	97	59	20.3
February 1982	6873	22.5	28.0	19.4	95	56	21.5
March 1982	7400	21.7	27.6	18.0	95	52	20.3
April 1982	6992	20.0	25.7	16.1	95	58	19.0
May 1982	5783	17.9	23.3	14.5	98	64	17.7
June 1982	4070	16.6	20.6	13.3	96	71	16.4
July 1982	3941	16.2	19.4	14.1	96	72	16.0
August 1982	3588	15.6	18.6	13.8	97	78	16.0
September 1982	4655	16.6	20.5	14.2	98	71	16.8
October 1982	5781	18.1	22.0	15.5	98	69	17.4
November 1982	4414	20.3	23.6	17.7	98	67	20.6
December 1982	6546	23.1	27.7	19.9	98	62	23.5
January 1983	7197	25.0	29.5	21.8	98	63	27.2
February 1983	6646	25.5	30.5	22.1	99	63	27.3
March 1983	7085	25.8	30.6	22.3	98	58	26.7
April 1983	5482	24.9	29.2	21.8	95	64	25.7
May 1983	4915	23.6	27.2	21.0	92	64	23.6
June 1983	4474	22.3	25.5	19.9	93	66	22.1
July 1983	3766	19.1	22.2	16.6	95	68	18.8
August 1983	3883	17.7	20.9	15.3	93	71	17.0
September 1983	4314	16.8	20.2	14.6	96	73	16.9
October 1983	6064	17.8	21.9	15.1	95	68	17.3
November 1983	3077	18.8	23.1	15.7	95	65	17.8
December 1983	6936	21.2	25.3	17.9	95	63	20.7

* Data from meterological station "Alexander Von Humboldt" located at 0.5 km from CIP

Appendix 2. A typical regime of fertilizer application in nursery beds for the production of seedling tubers[1]

Weeks after sowing	Ammonium nitrate (33% N) g/m^2	Single super phosphate (20% P_2O_5) g/m^2	Sulphate of potash-magnesia (22% K_2O, 18% MgO) g/m^2
0[2]	0	400	0
1	0	0	0
2	0	0	0
3	5	0	5
4	10	0	10
5	15	0	20
6	20	0	30
7	25	0	35
8	25	0	35
9	20	0	35
10	15	0	30
11	10	0	25
12	5	0	0
Total	150 N: 50	400 P_2O_5: 80	230 K_2O: 50

[1] Nursery substrate: 50% sand and 50% peatmoss
[2] Before sowing

Seedlings emerged about 7 days after sowing

Appendix 3. Pest and disease control during production of seedling tubers in nursery beds

Type of application[2]	Doses	Number of applications	Control of[1]
I. Insecticides			
Decis	1-2 ml/l	3-5	1, 2, 3, 6
Ripcord	1-2 ml/l	3-5	1, 2, 3, 6
Belmark	1-2 ml/l	2-4	1, 2, 3, 4
Tamaron	1-3 ml/l	2-3	3, 4
Lannate	1-2 g/l	2-4	1, 3
Vydate	1-2 ml/l	4-6	1, 2, 3
Parathion	1-2 ml/l	1-2	3, 6
Morestan	2-4 g/l	2-4	9
II. Fungicides			
Benlate	1-2 g/l	4-8	8, 10, 11
PCNB	1-2 g/l	1	8, 10, 11
Antracol	2-4 g/l	2-4	5
Ridomil	1.5-3 g/l	1-3	5
Basamid[3]	40 g/m^2	1	7, 8, 10, 11
III. Nematicides[3]			
Temik	2.5-3 g/m^2	1-2	2, 4, 7
Nemacur	3-4 g/m^2	1	7
Curater	3-4 g/m^2	1	7

[1] 1. *Phytorimaea operculella*
2. *Liriomyza huidobrensi*
3. *Scrobipalpula absoluta*
4. *Myzus persicae*
5. *Phythophtora infestans*
6. *Prodiplosis* sp.
7. *Meloidogyne* spp.
8. *Rhynoctonia solani*
9. *Polyphagotarsonemus latus*
10. *Verticillium albostrum*
11. *Pythium* spp.

[2] This list indicates all chemicals applied during the experimental period 1981-83; fewer chemicals were used in individual experiments

[3] Before sowing

Appendix 4. Field conditions and crop management at CIP Experimental Station, La Molina, Lima, Peru

1. Soil characteristics

Sandy loam soil: 50% sand, 30% silt, 20% clay
pH: 7.8
EC: 2.18 mmho/cm
Organic matter: 1.14%
Available nutrients: Nitrogen 0.020-0.072%
Phosphorus 4.3-17.3 ppm
Potassium 136-620 kg/ha
CEC: 8.60-13.80 meq/100 g

2. Crop rotation

Crop	Season
Potato	Autumn/Winter
Maize*	Spring
Potato	Spring/Summer
Maize*	Summer

* Incorporated in the soil before flowering (50-60 days after sowing)

3. Fertilizer application kg/ha

	N	P_2O_5	K_2O	MgO
a) Before planting				
Single superphosphate 1500 kg/ha	0	300	0	0
Sulfate of potash-magnesia 600 kg/ha	0	0	132	108
b) At planting				
Urea 200 kg/ha	90	0	0	0
Single superphosphate 400 kg/ha	0	80	0	0
Sulfate of potash-magnesia 400 kg/ha	0	0	88	72
c) At hilling				
Urea 200 kg/ha	90	0	0	0
Total fertilizer application	180	380	220	180

4. Cultural practices during growth of the crop

Weed control	: Herbicides/manual
Hilling	: Manual (two or three times)
Irrigation	: Furrow irrigation (till April 1983) and sprinkler irrigation (from April 1983)
Application of pesticides	: Manual application by spraying every 15 days
Harvesting	: Manual

5. Disease and pest control

Time of application	Product	Doses	Control of:
At planting	Temik	23 kg/ha	Nematodes, aphids, leaf miner fly
	Benlate	2 g/l	*Rhyzoctonia solani*
	PCNB	2 g/l	*Rhizoctonia*
	Sevin 5%	10 kg/ha	Cut worms
During growth	Belmark	2 ml/l	Tuber moth, leaf miner fly
	Ripcord	1.5-2 ml/l	Tuber moth, leaf miner fly
	Decis	1.5-2 ml/l	Tuber moth, leaf miner fly
	Vydate	1.5-2 ml/l	Tuber moth, leaf miner fly, root knot nematode
	Lannate	1.5 g/l	Aphids, leaf miner fly
	Tamaron or Monitor	2 ml/l	Leaf miner fly, aphids, thrips
	Morestan	2 g/l	Mites
	Dithane M 45	2 g/l	Late blight, early blight
	Ridomil	1.5 g/l	Late blight
Post harvest (seed tubers)	Texto 60	3 g/l	Fungi
	Decis	2 ml/l	Tuber moth