Introduction

There is wide confusion in the use of the term TPS. In the strict sense it refers to the botanical seed produced by crossing two parental potato lines. In some cases it is used as an adjective to describe a crop of potatoes derived from this botanical seed, and sometimes it refers to a potato variety (botanical seed progeny of a cross or in many cases a mixture of desirable clones selected from the tuber progeny of a botanical seed crop). The term ”True Seed Family” is used to describe the botanical seed obtained from a cross of clones that has been made to obtain a population with resistance to certain diseases or pests. This True Seed Family is often used to provide National Agricultural Research Systems (NARS) with the source materials to select new clones (called “varieties”) with certain desirable traits. In this document, authors will use the term “seed” as any propagule used to plant a crop, as in “tuber seed”, or “seed systems”, or “botanical seed” or, indeed, “true potato seed” and “clonal seed”. Clonal seed refers here only to tuber seed, and this usage may need revision when clonal botanical seed is produced by new techniques. The term “tuberlets” is used in this text to denote the small tubers produced in seedbed-like small fields, for future use as TPS derived planting material.

TPS research started at CIP in 1977. The motivation for finding ways to plant the crop with a difficult to manage, very small seed, as opposed to the traditional use of tuber seed, came from the realization that this technology held the potential for circumventing many drawbacks of potato when compared to grain crops. These drawbacks were the high costs of planting material: disease accumulation in seed; disease transfer from generation to clonal generation and the associated tendency to spread soil born diseases; the slowness of the build up of planting materials for new varieties; the slowness of seed multiplication from new healthy (tissue culture derived) seed sources; the high cost of storing seed, the inability to safely store the seed for several years on the farm; and the high cost of transport and handling of the seed.

CIP was not the first to study the use of botanical seed, and this paper will not dwell on its origins, except to say that some believe that centuries ago, Andean farmers may have

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1 This study is dedicated in memory of Dr. Mahesh Upadhya, one of the fathers of TPS, who dedicated much of his professional career to this technique and who developed many of the most used parental lines now used for TPS production. Mahesh contributed substantially to this study through comments and answers to my questions.
2 My thanks go to Mahesh Upadhya, Noel Pallais, Enrique Chujoy, Mohinder Kadian, and Andre Devaux, Rosario Falcon and Rolando Cabello, for their comments and answers to questions.
3 Potato seed is an orthodox seed, that is, it can be dried and stored at freezing temperature. Potato seed stores better when it is dried at about 3.5% to 5% seed moisture. In contrast a recalcitrant seed cannot be dried or stored under freezing temperatures, examples of plant species with recalcitrant seeds are citrus, cocoa, mango, avocado, many tropical trees, etc.
used the technique to regenerate their potato crops and indeed to introduce new varieties. These progenies gave rise to new clones, some of which acquired fame and wide spread use in neighbouring communities and along trade routes in the Andes. Rolando Cabello of CIP also documented in 1981-1982 that 2 families in Chincheros, Cuzco, stored seed berries. The berries were almost petrified. The families claimed that they used the seeds (berries) to renew their potato crop, after emergency situations whenever their potato crop was lost due to frost. The term TPS was coined at CIP, but there were studies in China before CIP’s work on TPS began. One of the fathers of TPS in China was Dr. Song Bofu. TPS use grew out of necessity during the times of the Cultural Revolution. Chinese scientists wanted to find solutions to the severe lack of adequate seed supplies, and alternative to clonal seed was worth pursuing. This also led to a long lasting cooperation with CIP.

This paper will not attempt to attribute exactly the contributions of many to the TPS story at CIP. It will be folkloric about that. In stead, it attempts to focus on an analysis of perceptions held about TPS and about its importance, potential and future merit as a topic of attention for CIP’s research.

**TPS production and variety characteristics.**

CIP’s work showed its usual thoroughness and systematic approach to TPS research. The early planning Conference in 1979 in Manila, laid out many of the potentials and problems of TPS based potato production. In these discussions, TPS was considered a long-term alternative to clonal seed systems. The international potato gurus, such as Peloquin, Hermsen and Sawyer were present, as well as young scientists who would dedicate all or an important part of their career to TPS’s future, such as Upadhya, Sadik and Accatino. The discussion ranged from the pedestrian (germination studies and yield comparisons of TPS to clonal plantings) to the sublime (apomixis, breeding schemes for uniformity, and full fledged TPS based seed systems), and from the day’s reality to futuristic potentials. Few if any concepts of TPS that were pursued in the next 25 years, were absent form this conference’s discussions.

Early TPS was produced from open pollination of parents with desirable traits. As time passed, breeders became more familiar with parental lines that provided greater uniformity in F1 offspring and that produced prolific numbers of berries, a high number of seeds per berry, and high seed weights. Results also showed that Hybrid TPS resulted in more vigorous and more uniform TPS derived tubers, and by the late 80’s most TPS varieties were hybrids.

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4 This is controversial as there is no known direct evidence (literature from colonial times or seeds in archeological sites) that Andean farmers used botanical seed centuries ago. It does, however, provide a ready explanation for the distribution and nature of the large number of native varieties in Andean villages. Today the use of seed appears limited to Andean farmers who learned about the advantages of TPS in modern times, i.e in Ayacucho some farmers keep botanical seed of their native cultivars because an NGO (that collaborates with CIP) promotes storage of seed during drought years.

5 In Vietnam CIP introduced open pollinated TPS in 1985-1988
TPS work had also extended substantially in India, where Mahesh Upadhya led CIP’s program. He proved a strong champion of the approach and a tireless physiologist turned breeder and geneticist. His strong presence created a legacy that by the early 2000’s had led to an effective TPS research and support activity in the strong CPRI research center of in Shimla. In the 90’s CIP’s work began to focus increasingly on the production of TPS parents that would produce hybrids with greater uniformity and higher levels of dry matter and disease resistance. The underlying hypothesis was that TPS could provide planting materials equal to or superior to that available in clonal form for developing country conditions. Mahesh Upadhya was convinced to join the CIP team in Lima where he teamed up with Noel Pallais, crop physiologist, who had dedicated his boundless energy and unbridled creativity to what he at times referred to as “taming the wild botanical seed”. His efforts solved one of the major TPS bottlenecks, that of seed dormancy and unpredictable germination of TPS. At the same time, he solved the dilemma of long-term storage of TPS for strategic reserves in cases of emergencies that had led to a loss of planting material. Upadhya credits Noel’s work with removing an essential bottleneck to the acceptance of TPS. Indeed, where recipients of untreated seed basically played a game of chance with the germination of their seed, materials that were prepared following the Pallais’ methodology of seed treatment, were assured of simultaneous and high levels of germination.

The early research results and the desire of Chilean scientists to contribute to the advance of TPS, led to an extensive cooperative research program with INIA in Chile and to the commercial production of TPS in that location. The biological reason for that location was the long day-length, which induces prolific flowering in potato plants, yet it was a location that provided a long growing season. The institutional reason for this close alliance in large measure harks back to the CGIAR’s TAC (Technical Advisory Committee, now Science Council), which frowned upon International Centers taking on a commercialization role for hybrid seed production. Responding to these concerns, while at the same time protecting the public goods nature of the technology proved to be a considerable challenge, until the very enlightened cooperation with Chile was created. CIP’s contribution to this work has been the launching of the initiative, the development of the technology for managing planting of parental lines, emasculation and crossing approaches, the management and harvest of berries and the post harvest separation, cleaning and drying of the TPS. CIP also trained the staff, and provided the early technical and financial support for the operations. Chile now produces TPS under contract for seed companies and other users. A similar role of CIP, led by a determined TPS champion, Mahesh Upadhya, led to a strong capability in India, which now has joined Chile as the world’s major suppliers of TPS for developing country production.

The basics of TPS research, that is; breeding and selection of parental lines, hybridization and management of berry and seed production, post harvest seed physiology; seedbed

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6 Noel’s enthusiasm sometimes combined with his gift for the word, such as in calling TPS “Papas de Amor”, or “Love Potatoes”, referring to their sexual propagation.

7 Before Pallais’ work, TPS was treated with gibberellic acid to break seed dormancy. This treatment was quite predictable in the short term, although the vigor of the seedlings was not always. TPS treated with GA3 also lost viability over time and this was unpredictable.
techniques for transplanting or tuberlet production and the management of botanical seed and tuberlet dormancy, are all nearing completion. True potato seed has been passed on to potato scientists all over the world and had been tested as a highly promising solution of some of potato’s major limitations to effective production in developing countries. Hundreds of scientists and technicians had been trained and major efforts were made for the introduction of this new technology in promising environments. This drive toward adoption of TPS was kept alive by a number of factors:

- The intrinsic attractiveness of the shift to a botanical seed based system.
- The tendency to compare TPS with local, disease ridden planting material, giving it a great advantage, in particular during the first two crops.
- The internalization into the farm enterprise of most of the cost of seed production, costs that often derived from the need to import seed from traders, who imported seed from major seed producing countries such as the Netherlands and Canada. Savings were therefore at the farm and national level.
- The entrepreneurship of seed producers, who found another way to access the lucrative, pretty well sown-up potato seed enterprise.
- The ease of shipment of TPS, at least within a country allowing continuous exposure of new experimenters. Here a caveat was related to the difficulty researchers encountered in gaining phytosanitary credit for the relative disease free nature of TPS.

What then failed in TPS development, and why is TPS adoption (plantings derived from TPS within 4 generations) limited to less than 1 percent of developing country potatoes acreage? Would insight into that question allow us to better predict the future of TPS in developing countries? Would it allow a better definition of what further research CIP may wish to undertake in support of TPS improvement?

- One reason early in the history of TPS has been the poor availability and dependability of TPS seed. Until the mid 1990’s seed was hard to obtain and seed germination was still unpredictable. Several potential users dropped TPS because of it.

- The lack of farmers’ training in the management of seed selection of TPS-derived clonal progenies also influenced TPS acceptance. In Indonesia, where farmers effectively selected for small tubers and thus lower yielding progenies, TPS was rejected. In Nicaragua, however, where farmers selected for desirable haulm and tuber traits associated with high productivity and market appeal, even early introductions of TPS had higher yields in second and third clonal generations, than in the first clonal generation.

- TPS varieties yielded less in regions where the growing season was limited to less than 100 days. In this environment, the delay in canopy closure associated with direct-seeded or even tuberlet-planted TPS reduced the effective growing season of the TPS crop by 10 to 20 days in comparison to the clonal alternative. This is equivalent to a loss of 1/5 to 1/3 of tuber filling and was worsened by the fact that the TPS varieties (mostly Tuberosum x Andigena crosses) generally bulked later
than the locally adapted tuberosum clones. This lateness of TPS varieties limits yields even in TPS tuberlet-derived stands or in subsequent clonal generations in particular where the growing season is limited to 90 days or less.

- The ability of TPS-derived clonal seed to maintain its health and quality had great impact on TPS acceptance in Indonesia, where selection for small tubers, in some locations possibly combined with lower resistance to virus and bacterial wilt, led to a rapid reduction in seed health of TPS-derived subsequent tuber generations.

- The lack of a clearly researched and tested seed system that assures a recurrent influx of new TPS at the start of seed system (be it as transplants or F1C1 tuberlets) also led to a loss of TPS performance and subsequent adoption.

### Conceptual drivers that modified the fate of TPS research.

Four events in the 1990’s added drivers for CIP’s program on TPS research to those listed in the first paragraph above. The first was CIP’s desire to expand potato production into warm climates, including the lowland humid tropics. Tropical conditions would require seed supplies from nearby mountainous areas, or they would need to depend on a costly system of timely imports. TPS based seed systems would be an attractive solution for these regions. Similar concerns apply for lowland subtropical conditions, as exemplified by the Red River Valley of Vietnam, or parts of northwest India. This focus on lowland conditions became a principal objective for the design of TPS technology, so that for years, the common lore at CIP maintained that TPS was not really a choice in highland tropical regions, such as the high Andes or Eastern Africa.

Another additional driver that became operational in the mid 1990’s was the search for ways to manage the worsening threat of Late Blight. Because of their uniformity, clonal crops were found to withstand late blight attacks less than plantings of mixed clones and TPS progenies. The latter maintained a considerable heterozygosis and contained therefore a mixture of several sources and levels of resistance. This provided robust resistance, which behaved much like the multi-gene resistance that the late blight program had been incorporating in its resistant clones. Soon, the TPS breeders began to

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8 This is controversial, as results in other locations (Nicaragua and African sites), did not show this comparatively more rapid phytosanitary degeneration in subsequent generations.

9 This paper employs a nomenclature for TPS generations developed by CIP. F1 refers to the stand directly derived from botanical seed. This stand may be in a direct-seeded field or seedbed. F1C1 refers to the first potato crop planted using tubers (or tuberlets) harvested from the F1 crop. These are in effect a mixture of clones and carry considerable genetic variation. F1C2 is the potato crop planted from tubers of the F1C1 generation. Producer selection will gradually reduce the number of clones in this mixture. Similar terminology applies to the F1C3, F1C4 and subsequent generations. They are referred to as TPS, as long as a mixture of clones continues to constitute the planting material. If a single clone is selected and clonally propagated, the planting ceases to be one of TPS and is referred to as a clonal stand.

10 Although the TPS trials by Lyle Sikka in Uganda in the 1990s demonstrated the high yield potential of hybrid TPS (exceeded 50t/ha in F1C1).
draw on advanced populations from not only the late blight program, but also from the virus resistance work, to build into their parental lines these variable sources of resistance.

In the mid ‘90’s, the strong lowland targeting of TPS technology was broken, because of a climate induced emergency. The El Nino effects had led to serious loss of planting materials in one of the poorest regions of Peru, el Callejon de Conchucos. CIP was approached by Father Ugo de Censi, who pleaded for help in rescuing potato production, the main food stay of the population of Chacas and surrounding communities. The success of what is known as the Chacasina variety became legendary. It showed that TPS could play a unique role in disaster mitigation, and in the rapid introduction of variety change and increase of healthy planting materials. An important contributor to the success of the Chacasina project was the farmer participation in producing TPS botanical seed. TPS production until that time had been considered a complex process demanding highly prepared technical staff. In Chacas, it became a farmers’ enterprise that not only saved their potato industry, but also led to a high paying seed production enterprise that supplied many regions of the Peruvian high Andes.

A third driver of change in CIP’s TPS program during the 1990’s was the realization, that the performance and adaptation of TPS and derived production systems, were spotty. Often, early enthusiasm of research and extension workers petered out with time and in the light of reduced productivity of later generations or their inability to compete with existing clonal seed based production systems. These experiences led to impact related research described below under the heading of “Locational suitability of TPS”. This research was part of the studies on uptake and utilization pathways for new potato technologies and it has contributed greatly to our present understanding of the potential of TPS.

A fourth driver of change was the highly successful work of Noel Pallais in taming the wild type, survivor oriented behaviour of TPS seed. Many TPS initiatives had been hobbled by the unpredictable germination of botanical seed. The difficulty to break the seed’s dormancy was a stumbling block to its effective use. Pallais dedicated his energy, creativity and plant physiological acumen to solving this problem. None the less, the effect of the early dormancy related difficulties was confounded with other reasons for the rejection of TPS, those of low yield, long duration and lack of product uniformity. Often, it was argued that by solving the dormancy problems, the principle barrier to TPS success would be removed. This was unfortunately not the case.

A fifth and recent driver of the place of TPS in CIP’s agenda was the notion that apomixis (as foreshadowed by Hermsen at the 1979 planning conference in Manila) for producing botanical seed would lead to progenies that would outperform existing TPS because of greater uniformity and tuber quality and will fix the genotype and heterosis. This change was also fostered by TAC’s 5th EPMR of CIP, which some 23 years later, recommended that CIP leave further TPS research to national systems, with the exception of advanced research on “biological mechanisms of meiosis in polyploids”. This driver of change may suffer from the typical weakness of internal, science driven activities; a
lack of relevance to or leverage on the factors that actually constrain impact of the targeted technology. This is evident from the experience that tuber uniformity and costs of sexual seed production are really not the problem in many locations, such as Chacas in Peru, Nicaragua, Nagaland in India, Vietnam, and much of Eastern Africa where there is no market demand for uniform quality of potato and that factors such as earliness and virus and late blight resistance will predominate in determining TPS adoption. In these locations, while there may be benefits of crop vigour to be captured from apomixes approaches, these are not likely to be great, given that much of hybrid vigour is already captured in conventional TPS crosses, and they do not address the principle reasons for lack of adoption of TPS in small holder production systems. Apomixis does not only captures tuber yield heterosis, but also will make breeding for other valuable traits easier as compared to conventional TPS crosses. For example, with apomixis we do not need to devote efforts to select for male sterility, extensive time consuming and costly testing of crosses to identify best progenies, selection for plant vigor in F1C1, disease resistance, early tuber bulking (a major bottleneck as you rightly pointed out), plant maturity, plant and tuber quality uniformity. All those traits will be fixed in the apomictic seed. The big question is: can we breed for apomixis in potato? Even though potatoes have several components of apomixis (i.e. parthenogenesis and 2n gametes), apomixis has not been reported yet in Solanum or other Solanaceae species. Genetic engineering may allow us to transfer apomixis genes from other species. However, the genes for apomixis are still to be identified and characterized molecularly.

The politics of TPS

The fate of TPS and its place in research agenda of CIP and NARS has been fraught with influences of groups that have unique interests. TPS scientists have often been overly optimistic about the potential of their technology. This is a natural consequence of being both champions and technology developers. On the other hand, the commercial seed sector is most unlikely to enhance TPS, as clonal seed provides for much greater commercial margins and because commercial benefits from TPS will be hard to capture, as farmers will seed F1C1 and later generations of the initial purchase of TPS. In that sense, TPS suffers from the same drawback as a malaria vaccine; the poor provide no attractive market. It is therefore important that a Center such as CIP, which is dedicated to the reduction of poverty through the development international of public good, be especially cautious about the way it deals with this technology. TPS is pro-poor, and its development will benefit the poor and marginal farm sector.

The impact of commercial seed producers also translates to the level of importers, and regulators of the potato seed sector in countries that have grown dependent on bulk imports of clonal seed. It is against the interests of these individuals and enterprises, to cease importation of costly seed. Their political and economic leverage makes it difficult for even well organized smallholder producers, to become seed producers and to develop a market for their seed. Thus terms of trade and subsidies will continue to favor imported tuber seed.
The real cost of the use of imported clonal seed is hard to assess. This requires a discounting for market inefficiencies, and demands recognition of the shadow costs of foregoing employment generated through domestic TPS based seed systems. Because of their high bulk, clonal seed imports cannot reasonably be expected to be disease free all the time, and the severe impact of disease damage caused by their importation as well as the complex process of certification and phytosanitary approvals carry a high cost.

Different TPS utilization methods.

Of the three ways to use TPS, the production of tuberlets in seedbeds is by far the more common. These tuberlets (F1C1) can then be planted in a subsequent planting season, for ware production or for sale as seed (F1C2). The continued use of this material for seed (F1C3) production is ill advised, except where farmers select carefully for healthy seed and in essentially aphid free areas.

Transplanting of F1 seedlings to the field has the advantage that seedlings can be produced without prior exposure to the fields available for the main potato-growing season, thus adding to the effective growing season length. Some 10 days of this 30-35 day seedling period is, however, lost to transplanting shock, even in the best of conditions.

The use of TPS through tuberlet production requires storage and the breaking of dormancy. While this adds costs to planting materials, the smaller size of tuberlets derived from TPS, typically by a weight based factor of 4-6, makes them much cheaper to store than clonal seed produced conventionally. This may help TPS maintain a market share as seed potato in subtropical lowland regions.

Another observation about TPS adoption derives from its ability to entice researchers and farmers because of the performance of its comparatively disease free early generations (F1 and F1C1). This is because the TPS crops are often compared to local varieties that are disease ridden and that have been in informal seed systems for many crop generations. A more realistic comparison with quality clonal seed would reduce the advantage of TPS in many such trials.

Adoption of TPS

Adoption of TPS is actually quite complex to measure. Two indices that have been used are area planted to TPS and the amount of TPS seed sold or traded. The measure of area planted has the complexity that TPS plantings vary widely. They may be plantings of TPS seed, through direct seeding or transplanting. These are F1 stands. They can be stands obtained from planting tuberlets, or from tubers harvested from the F1 generation plants. These stands are F1C1 stands. What about the F1C2 generation and subsequent ones? Are they to be considered TPS areas? What about the selection of clones from the F1 or subsequent clonal generations (which generally are a mixture of clones)? Including
those would further extend the area of TPS adoption, but render the measure less meaningful.

The amount of TPS seed sold or traded would be a measure that should relate closely to area planted to F1 TPS, if all the seed is used as transplants or direct-seeded stands. The proportion of this traded TPS that is used for tuberlet production, which provides for a substantial area multiplication at the F1C1 generation level, will much influence how we convert one kg of botanical seed to area planted. Much of traded TPS may never be planted, or may be confined to experimental use. In the reverse, the assumption that traded TPS is all the TPS that goes into the ground, ignores the increasing capability of farmers to produce TPS, employing TPS parental lines and male sterility of one of the parents. It will be difficult to measure the volume of production and usage of this TPS. In the case of Peru, that informally traded farmer produced TPS (Chacasina, mostly as F1C1tuberlets or later generation tuber seed) now accounts for the largest area planted to TPS.

The definition of TPS has in part been confounded by the desire to measure economic benefits from the approach. Should we continue to attribute benefits to the novel seed system, even if their impact has long since transformed into a benefit associated with variety change through what could be considered TPS-driven participatory selection? This depends on what benefit is being measured. If it is a comparison of TPS based planting and seed systems with the conventional clonal tuber systems, then a narrow definition would be more appropriate. If it concerns a measurement of the overall benefits of TPS research, then the benefits of TPS derived clonal varieties should be included.

Despite and because of these considerations, it may be useful to define a boundary of what is TPS produce, and authors suggest the following can be considered: “TPS ware potatoes are produce of potato crops planted with botanical seed or with derived tuber seed selections of the first to third clonal generations.” TPS ware potatoes therefore include F1C4 tubers, but not F1C5 potatoes.  

There are few complete studies of planted area of TPS by that definition. The authors estimates that the world’s area planted to TPS so defined does not exceed 50,000 ha.

**Locational suitability of TPS**

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11 The restriction to call TPS potatoes only the F1C1-F1C3 would be quite arbitrary. Discussions on TPS confined to these initial cycles will likely favor measure of TPS performance. They will exclude the known yield decline over generations due to small tuber seed selection or health. At present authors prefer to define the limits of TPS in terms of the maintenance of genotypic variability. In practice TPS is not carried more than to F1C5 to F1C8 generations.
Chilver and friends\textsuperscript{12} determined that TPS based production was competitive with clonal seed based production in those locations where the percent ratio of clonal seed cost to value of production is greater than 20.

We also know that the price of good quality tuber seed (Pts) is in most markets a multiple of that of the farm gate price of ware potatoes (Pw). This price ratio (PR) varies greatly among locations, cheaper seed tending to be of lower quality, and more expensive seed tending to be imported or trucked over great distances and after long and costly cold storage.

Therefore Chilver found on the basis of several locations, that TPS is preferred when:

\[
\frac{\text{Clonal Seed Cost}}{\text{Value Product}} > 0.20, \quad (\text{Eq. 1})
\]

or when:

\[
\frac{\text{Clonal Seed Weight} \times \text{Seed Price}}{\text{Yield} \times \text{Ware Price}} > 0.20,
\]

and:

\[
\text{Pts} = \text{PR} \times \text{Pw}
\]

So that:

\[
\frac{\text{CSW} \times (\text{Pw} \times \text{PR})}{(\text{Y} \times \text{Pw})} > 0.20 \quad \text{or} \quad \frac{\text{CSW} \times \text{PR}}{\text{Y}} > 0.20 \quad (\text{Eq. 2})
\]

Assuming that 2000 kg of clonal seed is required per ha (hence CSW=2000), we can calculate the conditions apt for TPS as a function of seed price ratio and the yield. On that basis, TPS would out-compete tuber seed in conditions depicted in the top left-hand part of Figure 1, as determined by the yield and the ratio of seed cost to ware potato cost. The right hand lower part of Figure 1 depicts conditions where clonal seed systems would prevail. For example at yield of 15t/ha, the price ratio SP/WP would need to be only above 1.5. At yields of 25 t/ha this ratio would have to exceed 2.5 and at yields of 35t/ha the ratio would need to be higher than 3.5.\textsuperscript{13}


\textsuperscript{13} Interestingly, if confirmed through time and many locations, this type of relationship between yield potential and tolerable seed costs should provide valuable cost and quality parameters for the design of seed systems, and for seed producers and marketers.
Similar calculations, allow determination of the price ratio that makes TPS suitable as a function of yield (table 1), based on the percent ratio of seed cost to value of production used by Chilver et al.  

Table 1. Percent ratio of seed cost to value product associated with different ratios of the price of clonal seed to the price of ware potatoes (PR), and with different yield (Y) levels.

<table>
<thead>
<tr>
<th>PR</th>
<th>Y=15</th>
<th>Y=20</th>
<th>Y=25</th>
<th>Y=30</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>13</td>
<td>10</td>
<td>8</td>
<td>7</td>
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<td>2</td>
<td>27</td>
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</tr>
<tr>
<td>4</td>
<td>53</td>
<td>40</td>
<td>32</td>
<td>27</td>
</tr>
</tbody>
</table>

The entries in table 1 indicate that TPS would be preferable at high price ratios of clonal seed to ware potatoes as well as at low expected yields. Based on the findings of Chilver et al. (1998), which indicate a breakeven point for the TPS to clonal seed profitability comparison to be when the values in table 1 are at 20, a seed/ware price ratio of 2 would suffice to make TPS preferable at yields of 15 t/ha. This ratio of 2 would mean a preference for clonal planting when yields are expected to be 25 t/ha. At yields as high as 35 t/ha, the seed/ware price ratio would have to be well above 3.5 for TPS to be a profitable alternative.

**TPS in Bolivia**
Antonio Gandarillas of PROINPA, Bolivia, reported yield and price information for potato production in Chullchunqani, Candalaria and Tiraque, all high lying regions. Productivity for these locations was around 7.2 t/ha and ware potatoes fetched prices per kilogram of US$ 0.05 at harvest time and up to US$ 0.27 at the highest price period, averaging an estimated US$ 0.10. Seed potatoes varied from US$ 0.42 for certified seed, down to US$ 0.18/kg for local seed. For these locations TPS would indeed be a technology of interest as the yields are well below 10 times the price ratio of clonal seed to ware potato (see fig. 1), and the break-even point for both seed systems would be at yields of 18 t/ha.

For the two locations, of Morochata (high lying) and Comarapa (lower lying) yield were 10 t/ha and seed and ware prices were similar to the other locations. This again indicates that for these regions, the production system favours TPS. Given the cool climate, and growing season, tuberlet based production may be most appropriate. In effect TPS trials conducted by PROINPA of Bolivia using Chacasina, at Lope Mendoza and Chullchunqani showed good results (Gandarillas personal communication).

**TPS in Nicaragua**

The considerations above are results of weight based seed/ware price ratios of clonally derived tuber seed. In the case of TPS derived tuberlets, the number of seed pieces becomes an important factor, as tuberlets weigh in general one-fifth to one-tenth of clonally derived seed pieces, as is shown in the example based on conditions that prevail in Nicaragua (table 2).

<table>
<thead>
<tr>
<th></th>
<th>Clonal</th>
<th>TPS</th>
</tr>
</thead>
<tbody>
<tr>
<td># of seed tubers/ha</td>
<td>30000</td>
<td>43000</td>
</tr>
<tr>
<td>Weight of tuber in g</td>
<td>60</td>
<td>10</td>
</tr>
<tr>
<td>Weight /ha in kg</td>
<td>1800</td>
<td>430</td>
</tr>
<tr>
<td>Seed price $/kg</td>
<td>0.8</td>
<td>0.6</td>
</tr>
<tr>
<td>seed cost, $/ha</td>
<td>1440</td>
<td>258</td>
</tr>
</tbody>
</table>

Source: Noel Pallais, personal communication, 2005

This example makes some assumptions that disadvantage TPS beyond what in fact occurs in Jinoteca, i.e. the number of seed tubers in TPS planting is assumed to be quite high, and the average tuber seed weight of clonally derived material is quite low. Pallais and coworkers estimate TPS derived tuberlets for a hectare planting to cost between 120 and 180 US dollar in Nicaragua, substantially lower than the US$ 258 calculated in table 2. These observations coincide with Chilver *et al* (1998) who concluded that lower seed rates contributed more to savings in seed costs than did lower seed prices.

In effect, the price ratio of around 3 (at ware price of US 30 cts/kg and local seed costs of 100 cts/kg) and production level (at around 25 t/ha), are such that TPS must be an attractive alternative. In addition, reduced disease incidence leads to value products in
Jinoteca that favour TPS derived F1C1 plantings, and certified seed would have to drop considerably in price and improve greatly in quality for it to compete.

The relationship between yields obtained and the suitability of TPS shows that the benefits of tuber-grown crops increase as yields increase. In addition, they increase when the seed to ware price ratio goes down. This explains why TPS use is often discontinued as the potato production improves, or as tuber seed supplies (sometime TPS derived) improve and thus become less costly. The case of Egypt and Vietnam come to mind, where the reduced costs of imported seed replaced or is in the process of replacing TPS based seed systems. Hence a perception that TPS should be considered a temporary seed system until such time when clonal seed propagation is optimized locally.

The dynamics of the introduction of TPS also is such that it leads to a decrease in tuber seed costs for the second and subsequent years to well below those in the year of TPS introduction. This occurs because an increasing quantity of lower cost TPS-derived tuber seed becomes available, which can be produced cheaper and is generally healthier than conventional clonal seed.

Aside from price ratios, the extensive adoption of TPS in Nicaragua has no doubt greatly benefited from the championing by Noel Pallais, who saw the potential and took the steps to make TPS work effectively.

**TPS in Peru**

The potato price regime in Peru (Table 4) shows lower ware prices between March and June. These low prices occur because of the high production in the Andean region, in particular when the total planted Peruvian area exceeds 260,000 ha as was the case in the years 2003 and 2004. The planting period in the Andean region is from September to December. Few potato farmers (less than 1%) use certified seed for the planting. Usually most farmers use their own potato as seed. Sometimes they buy seed from other farmers or in the local market. In this case the cost is no more than $0.15 per kilogram.

The average prices and yields are such that TPS could benefit farmers in the Andean region, above all in areas where yields are below 15 t/ha and yield potential is above 20t/ha. This explains the popularity of Chacasina seed in parts of the Andean region, because local planting material is either very costly or of dismal phytosanitary quality. Much of the benefit associated with Chacasina was attributable to the disease free nature of TPS, which in general replaced potato seed that had been held for “generations”. In the central Andean region: Huánuco, Pasco, Junin, Huancavelica and Ayacucho the average yield reaches 15 t/ha, so that TPS is less attractive in these areas.

Aside from the impact of the Chacasina program, TPS has had little adoption in Peru. The extrapolation domain for Chacasina can be clearly defined for cooperating NGO’s so that the technology can find wider adoption.

<table>
<thead>
<tr>
<th>Location/system</th>
<th>Average yield</th>
<th>Price of ware potatoes / kg ($)</th>
<th>Price of ware potatoes / kg ($)</th>
<th>Price of certified seed potatoes/kg ($)</th>
<th>Price of informal seed potatoes/kg ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perú</td>
<td>t/ha</td>
<td>At harvest</td>
<td>At peak</td>
<td>At planting</td>
<td>At planting</td>
</tr>
<tr>
<td>Andean region</td>
<td>12.2</td>
<td>0.10</td>
<td>0.16</td>
<td>0.5</td>
<td>0.15</td>
</tr>
<tr>
<td>Coast</td>
<td>25.5</td>
<td>0.10</td>
<td>0.16</td>
<td>0.5</td>
<td>0.15</td>
</tr>
</tbody>
</table>

In coastal regions, TPS is unlikely to be useful. At yields of 25t/ha, seed prices would have to be greater than 25 ct/kg, whereas farmers now purchase seed for about 15ct/kg. These farmers also obtain higher product prices, as production is limited in the coast from August to December.

A valid question can be raised about the cost of certified seed production, and a study should be conducted to verify if costs could be lowered. At $0.50 per kg, and ware priced of 10cts, a price ratio of 5 would suggest that cheaper ways of seed production must be possible.

**TPS in Venezuela**

Recent information provided by Laura Niño shows that yields in Pueblo Llano and Santo Domingo average 9 t/ha for the traditional Granola crops, with highest yield reaching 20t/ha and lowest yield (not including the odd crop failure) at 3 t/ha. Ware potato prices at harvest time were US$ 0.26, whereas those at peak demand time were US$ 0.61/kg. Seed prices for imported Granola were US$ 1.26/kg and for locally purchased seed were US$ 0.72. Assuming a product price of US$ 0.35, the price ratio in table 1 would be 2.0 or more. At the yield level of 9 t/ha, these two small holder potato-producing areas would be good candidates for TPS based seed systems. These farm families are familiar with horticultural crop production (carrots, lettuce and cabbage), and late blight is a serious constraint in the region. As there is access to supplemental irrigation, TPS is a distinct possibility and it may even be feasible to consider transplanted TPS, in particular if the growing season is limited. The major issue will be acceptability of the TPS product and any possible market penalty for perceived poor quality.

**South Asia**

South Asia has been the scene of rapid increase in potato production over the last 25 years. India has become the world’s fifth ranked potato producer, and yield in major production regions have steadily increased. Yet there are producing areas that continue to expand production even though yields are low and access to seed is limited. These are the conditions that lend themselves to TPS plantings. A sampling of yield and potato price ratios of the major potato areas in South Asia shows that West Bengal and
Karnataka in India; Jessore and Rampul in Bangladesh, and Jumla, Kaski and Sunsari in Nepal would all be attractive locations for TPS introduction.

A closer scrutiny of entries in Table 3 shows however some unique conditions of potato production:

- The tuber seed price in West Bengal is very high. This is because access to tuber seed is limited. Indeed, West Bengal’s climate is mild. The aphid population is above threshold levels during crop season and hence this is not a suitable area for seed production and multiplication. The West Bengal potato productivity is the highest (26t/ha) in the country, and farmers import seed from Punjab province (North India) at a distance of about 2000 km. The data in table 3 would lead to the conclusion that West Bengal should be a target area for TPS application, probably as a TPS based tuberlet seed systems. The potato is, however, planted between two rice crops, and gets hardly 80-90 days growing season. Using TPS in place of the tuber seed will take 10-15 days extra for maturity and at conventional yields of 25t/ha in these areas, TPS cannot compete. So far, the

Table 3. Common price ratios in potato production in South Asia, Based on 2005 data provided by Mohinder Kadian and Khalid Farooq.

<table>
<thead>
<tr>
<th>Location/ System</th>
<th>Average yield t/ha</th>
<th>price of ware potatoes (US $ per ton) at harvest</th>
<th>price of ware potatoes (US $ per ton) at peak</th>
<th>price of seed potatoes (US $ per ton) at planting</th>
<th>Price Ratio of seed to ware potato *</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. India</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. West Bengal (Autumn Crop-Lowlands)</td>
<td>26.0</td>
<td>90.91</td>
<td>159.09</td>
<td>409.00</td>
<td>3.27</td>
</tr>
<tr>
<td>b. Uttar Pradesh (Autumn Crop-Lowlands)</td>
<td>24.5</td>
<td>86.36</td>
<td>181.82</td>
<td>227.27</td>
<td>1.69</td>
</tr>
<tr>
<td>c. Karnataka (Spring crop-Plateau Region)</td>
<td>12.4</td>
<td>170.45</td>
<td>198.86</td>
<td>272.73</td>
<td>1.48</td>
</tr>
<tr>
<td>d. Punjab (Autumn-Lowlands)</td>
<td>20.0</td>
<td>90.91</td>
<td>156.14</td>
<td>170.45</td>
<td>1.37</td>
</tr>
<tr>
<td>e. Himachal Pradesh (Spring-Mountains)</td>
<td>12.0</td>
<td>136.36</td>
<td>227.27</td>
<td>159.09</td>
<td>1.0**</td>
</tr>
<tr>
<td><strong>2. Bangladesh,</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Dhaka (Autumn Crop-Lowlands)-Central Bangladesh</td>
<td>20.0</td>
<td>76.92</td>
<td>184.61</td>
<td>230.76</td>
<td>1.76</td>
</tr>
<tr>
<td>b. Jessore (Autumn Crop-Lowlands)-South Bangladesh</td>
<td>12.0</td>
<td>84.61</td>
<td>184.61</td>
<td>246.15</td>
<td>1.83</td>
</tr>
<tr>
<td>c. Rangpur (Autumn Crop-Lowlands)-North Bangladesh</td>
<td>15.0</td>
<td>61.54</td>
<td>169.23</td>
<td>215.38</td>
<td>1.87</td>
</tr>
<tr>
<td><strong>3. Nepal</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Jumla (Spring Crop-Mountains)</td>
<td>8.3</td>
<td>95.89</td>
<td>136.99</td>
<td>164.38</td>
<td>1.41</td>
</tr>
<tr>
<td>b. Kaski (Autumn Crop-Hill)</td>
<td>7.7</td>
<td>82.19</td>
<td>123.29</td>
<td>164.38</td>
<td>1.60</td>
</tr>
<tr>
<td>c. Sunsari (Autumn-Plains)</td>
<td>13.0</td>
<td>61.64</td>
<td>123.29</td>
<td>205.48</td>
<td>2.22</td>
</tr>
</tbody>
</table>
### 4. Bhutan (Spring- Mountains)

<table>
<thead>
<tr>
<th></th>
<th>20</th>
<th>110</th>
<th>200</th>
<th>210</th>
<th>1.35</th>
</tr>
</thead>
</table>

### 5. Pakistan

<table>
<thead>
<tr>
<th>Region</th>
<th>19</th>
<th>148</th>
<th>190</th>
<th>(375) 190</th>
<th>(2.21) 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>a. Autumn Punjab ***</td>
<td>16</td>
<td>185</td>
<td>285</td>
<td>170</td>
<td>&lt; 1.0</td>
</tr>
<tr>
<td>b. Baluchistan (Summer)</td>
<td>9</td>
<td>155</td>
<td>190</td>
<td>190</td>
<td>1.0</td>
</tr>
<tr>
<td>c. Sindh (winter)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- *Ware price calculated as average of harvest and peak prices*
- ** Fixed at 1.0
- *** Values in Parenthesis based on rarely used locally produced certified seed

existing TPS families developed by CIP or NARS do not compete with early maturing Kufri Chandramukhi, Kufri Phukhraj or medium maturing Kufri Jyoti varieties planted in West Bengal (Mahinder Kadian, personal communication).

- The ware potato price in Karnataka is extremely high at harvest time, and the storage-induced differential between it and the price at peak time is quite low. Potato crop in this province is harvested in September/October when there are no fresh potatoes in the North India markets. Until this time the consumers has had to buy the quite old cold stores potatoes. The fresh potato coming to markets fetches much higher prices than cold store potatoes a pattern similar to that encountered in Egypt and the Mahgreb region.

- Finally, the ware price in Himachal Pradesh is very high at its peak. This is because the crop is planted in March/April and harvested in August/September when there are no fresh potatoes available in big markets like Delhi. Secondly, the fresh potatoes produced in Himachal Pradesh are in limited quantity and for short period. Nearly 90% produce of Himachal Pradesh is now used as ware potato. These early, high-priced potatoes are highly quality sensitive and are unlikely to be replaced by TPS derived materials.

- In the case of Pakistan, there appear to be few opportunities for TPS. Still, locally purchased seed from the informal system, will likely depress yields substantially. One can also assume that because of sanitary status the TPS derived tuberlets could be produced at a price per unit well below that of local certified seed, there may be merit into evaluating more carefully the potential for TPS in the autumn Punjab crop.

#### Expansion of the adaptation domain for TPS

The research by Chilver, Walker and Fuglie, essentially defined the extrapolation domain of TPS derived potato production systems. The sensitivity of the ratios employed is however quite substantial, in particular where seed costs are a steep function of seed quality as required to achieve high yields. Seed costs for materials that allow yields below 15t/ha are very close to the costs of ware potatoes (Ps/Pw ≤ 1.8), whereas this ratio can approximate 3.0 if the seed is to yield more that 30t/ha. It simply costs more to bring high quality seed to market. Deviations from this relationship between seed cost and yield potential are indicative of unique product pricing problems or opportunities related to early product markets or extremely high seed delivery costs, as shown in the south Asian examples above. The study of these factors and the feasibility to accommodate
TPS in the local cropping system should be encouraged in areas where TPS is likely to compete well against existing seed sources and which could become the object of TPS introduction programs.

The argument that smaller TPS derived seed units (tuberlets), can be produced cheaper than clonal tuber seed of similar quality, while correct, also merits careful analysis. A TPS-derived tuberlet that weighs less than 25% of the weight of clonal seed, will give rise to a ware crop that likely has about 10 days less of tuber filling than the crop of a similar clone.\(^{14}\) This means that while the planting material is cheaper, it is likely to yield 10% less if the total growing season is limited to less than 100 days and 20% less if the growing season is 80 days or less; the shorter the growing season, the greater the edge for tuber seed production. This underlines the importance of developing early bulking TPS varieties, which thereby compensate for their slow start. Canopy closure should also be obtained as close as possible to the time bulking starts, either by rapid growth or by higher density planting (at an added seed costs). Earliness is by far the most effective way to expand the area of suitability for TPS based production.

Low input systems will favor TPS based production, as lower investment for seed and higher pest tolerance will reduce the need to use high levels of fertilizer and pest control measures to minimize production risk of costly plantings from clonal seed. TPS will therefore be more readily adopted in areas where inputs are scarce and costly.

Improved resistance to diseases may favor TPS. There are two components to this; the benefits from reduced disease losses in the ware potato crop, as may be achieved through resistance to late blight and common viruses; and the effect of virus resistance on the maintenance of seed quality in second and third clonal generations of the TPS derived planting material. It is likely that the benefits from virus resistance in TPS will parallel those from resistance in conventional varieties, while the late blight, and maybe future bacterial wilt resistance will give a unique advantage to TPS with its genetically variability. Benefits in terms of yield and costs of production are likely in the range of 10% and do not appear to compensate for the yield loss caused by reduced effective growing season, and thus may not have a great deal of leverage to expand the extrapolation domain for TPS based production systems.

Transplanting TPS seedlings should lower the growing season requirement of the crop. Some 40 days of early crop growth will take place outside the main field on small seedbeds, after which seedlings are transplanted. When comparing this transplanted crop to a tuber seeded crop, 10 of the 40 days head start are lost to seedling shock, giving TPS transplants still a sizeable advantage in canopy closure and leaf area duration over those of the tuber planted crop. Unfortunately, most TPS varieties are late bulking, so that 20

\[^{14}\text{This is less a matter of the starting time of tuber bulking, which is determined by the variety’s phenology and the seed’s physiological maturity. It is more a question of the growth area duration from which the crop benefits. Assuming that the dry matter contribution from planting material to the ware crop is 80\% of the seed dry mater, the ware crop would take about 10 days to pass through the growth lag-phase of total plant dry matter accumulation from 80 to 360 kg/ha.}\]
of the remainder of the 30 days advantage are normally lost. In terms of adoption of the seedling approach to crop establishment for TPS, it is important to note that cash requirements will be lower, but labor requirements will be much greater than those for tuber seeded crops. Finally, it is well known that transplanted TPS makes extremely high demands on farmers’ skills and quality of irrigation. In addition, tuber size distribution is poor compared to production from conventional clonal seed.

Chilver and colleagues argue that reduction of crop establishment costs does not greatly drive TPS adoption. This analysis is based on the greater cost associated with yield losses than the savings from crop planting. A 30% reduction of planting costs may render as much as $1000/ha, whereas a reduction of as little as 10% in yield, will reduce net incomes by close to $2000/ha. This analysis, however, needs further scrutiny. There are three factors that mitigate in favor of TPS seed systems. First is of course the lower total cost of crop establishment. Secondly, the costs associated with planting are for the greater part shifted from those of purchases from external suppliers to internal costs, mostly of family labor. External may mean, the village, the region, or even the country, so that internalizing these costs to the farm unit or to the local community may have a considerable benefit stream. Third, the costs are shifted from what are cash requirements (that demand access to credit) to labor costs (which can be met on the farm or locally). In the authors’ experience, farmers like to optimize returns to cash, their most limiting factor of production, and also wish to reduce their risks associated with high, early season outlays of cash obtained through costly credit. This would greatly favor adoption of TPS, specially in cash strapped low input regions. It also questions Chilver’s suggestion that reduced crop establishment costs do not greatly leverage TPS adoption.

Transplanting TPS seedlings also virtually eliminates seed (tuberlets or tubers) storage costs, which may well be a factor that should be considered more carefully in the analysis for the most suitable TPS establishment approach.

Getting around the problem of transplanting shock, an old research area in rice production, is an attractive option. As a rule of thumb, the percentage of growing season lost to transplanting shock translates to twice that percentage in reduction of tuber filling, and hence yield. Direct seeding avoids the need to transplant, but it is virtually impossible to get a good stand over a large area. The use of direct seeding pelleted seed has been researched in New Zealand and the USA, but despite considerable promotion, there has not been a large area under this type of crop. This is because direct seeding of TPS can be recommended only under very stringent conditions of light textured soil, low wind and rainfall right after seeding, low incidence of damping-off, long (>110 days) growing season, and reliable irrigation. Under these conditions, farmers are likely to have high yield expectations and will thus favor the use of very high quality tuber seed. In addition, the extra 15-20 days that the TPS crop will take to reach its full rate of bulking (because of low intergenerational dry matter transfer), will reduce tuber-filling, and hence yield, by 20 - 25%. For direct seeding of pelleted seed, varieties must satisfy more stringent earliness requirements than for TPS F1C1 tuberlet-based production, which again are more demanding of earliness than varieties used for transplanted crops.
An important way to expand adoption of TPS may be to create a longer potato growing season. This can be done in multiple cropping systems of subtropical regions, and in South and Southeast Asia. In these locations, potatoes are generally squeezed in between two cereal crops, and are limited to 70 or 90 days duration. Reducing the rice crop duration by 10 days through varietal choice, or the use of older seedlings or double transplanting, may lead to higher net returns for the total cropping pattern. This would accommodate TPS better, but unless the growing season for potatoes can be extended to 110 or more days, TPS will still be at a disadvantage. In addition, expanding the potato growing season works only in irrigated areas, and these areas have good infrastructure and access to reasonable quality tuber seed at reasonable prices.

There appears to be an opportunity to improve TPS competitiveness by further improving tuber quality of its produce. This may be tuber uniformity because TPS that produces uniform red or purple skinned tubers is hard to find. There has, however been considerable progress in the development of TPS varieties that produce more uniform tubers since the late 90’s. It may also relate to dry matter and taste considerations. The most costly quality parameter is, however the poor tuber size distribution, where TPS plants in particular F1 and F1C1 generations, tend to have few large sized tubers (>150g) and show a large number of small tubers. Unfortunately, there are few studies that establish the price reduction associated with present TPS materials compared to the conventional clonal varieties. From comments among students of TPS, the price punishment for F1 (transplanted) and F1C1 (from tuberlets) averages in the neighborhood of 15%, but is unevenly distributed. This loss is composed of a reduction in market price and in percent marketable tubers.

There is an opportunity for TPS area expansion any time disasters such a drought, floods, earthquakes or strife, lead to the loss of planting materials. CIP has seen this happen in 4 locations in the past 15 years. A strategic reserve of 500 kg TPS seed should be prepared for the three major producing environments; short day length highland tropics, sub tropical short day length winter crop, and long day length crops at higher latitudes. The 500 kg can seed more than 6000 ha and can be stored for many years and stand by in case a disaster strikes.

Summarizing, TPS plantings will be competitive with clonal tuber seed, when the yield and cost ratios are as depicted in figure 1, based on work by Chilver et al. In addition, if transplanted, present TPS varieties will require a growing season of at least 100 days and the availability of irrigation. Within this generalized adaptation domain, transplanting TPS is the best means to overcome the drawback associated with late bulking of TPS varieties and the loss of growing season due to slow early crop growth of direct-seeded TPS or low weight F1C1 tuberlets. As mentioned above, transplanting TPS often leads to low product quality because of poor tuber size distribution. For this reason it may be best to aim for ware potato production from F1C2 and F1C3 planting materials.

Areas of research
It is evident that the major constraint to TPS-based potato production is not botanical seed production. The existing methods for hybrid seed production, the techniques for seed extraction and pretreatment, and for their subsequent storage and handling, are well developed and adequate. Much insight has been gained in planting methods and crop management of TPS stands, and any further work of that nature can best be done in situ by local technicians.

The major research effort should be directed to getting early bulking TPS varieties. It is by far the greatest determinant of TPS adoption. CIP’s TPS work has moved in that direction since 1992, but it is still only one of too many objectives in TPS. Beyond this dominant factor, TPS breeding should draw on progress made in late blight and virus resistance work at CIP, to increase resistance to these important diseases.

The uniformity of tuber produce from TPS is a constraint in some market sensitive locations, but appears less important than other tuber quality factors. Changing consumer habits from red skin colored potatoes to white or cream colored ones, is difficult. Still, CIP does not have a single red skin TPS variety, and this trait is important for competing in the local markets with clonal varieties in Nepal, Bangladesh and parts of India. The same applies to differences in flesh color. Fortunately, today CIP has a wider range of TPS varieties (whites to yellows) and has now 24 elite TPS varieties and several of them quite good in terms of tuber uniformity. More important than uniformity as a quality parameter, tuber size distribution may be a worthy target for improving TPS acceptance.

There may be long-term benefits in the study of asexual reproduction in potato such as apomixis. This may greatly benefit achieving earliness, resistance and quality goals that will expand the adaptation domain of TPS. It should be noted that most of the benefits of apomixes based improvements also apply to tuber-seeded plantings, and that this research should not be considered as part of TPS activities. The authors consider that the issue of TPS variability is a weak justification for such work.15

TPS performs well in about a dozen locations, averaging 5,000 ha in size. It may well be that further study of the adaptation domain will lead to additional TPS locations. More entrepreneurial and market approaches may lead to a tipping point for rapid expansion of TPS based potato production in marginal areas. Associating future TPS varieties with

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15 The role of apomictic TPS will be in the seed system. Apomictic TPS has the potential to greatly change how tuber seeds are produced, it will:

1. replace the invitro plantlets and related cost in the seed system
2. reduce the number of years needed to propagate large quantities of tuber seed: rather than 4 years to produce 4,000 tons, only one year with apomictic seed
3. reduce cost for producing tuber seed: it will cost about 1/2 to 1/3 (because a lower number of years required)
4. improve the phytosanitary quality and reduce associated health costs (because a lower number of years- lower health risk)
5. reduce tuber seed imports by developing countries: they will import both tuber and apomictic seed. The latter will be used for local production of tuber seed at about 1/3 of the cost of imported seed.
novel traits (high nutritional value, high anthocyanin, iron, zinc or vitamin A), may lead to more champions of TPS driving such an expansion.

Finally, a continued study, using crop production models that focus on early growth rates, combined with simulation of leaf area duration, and information on costs of alternative seed, its yield potential and the price of produce, can deliver clear specification of the adaptation domain for TPS. These specifications of the adaptation domain for TPS should also differentiate between transplanted TPS and tuberlet based seed systems. Often, the adaptation domains of TPS will be small pockets of producers, who are marginal to the market system, and the impact of TPS will therefore initially not extend to large areas. In addition, TPS’s impact of raising average yields will eventually lead to a greater capacity of farmers to use clonal seed efficiently, thus reducing future markets for TPS technology. This may happen as highly adapted clonal seed is selected from TPS progenies, or through new sources of imported tuber seed that respond to a new market demands. These effects should be considered in the modeling of adaptation domains of TPS. The better specification of these domains will allow clearer judgments as to the locations where research and implementation efforts will contribute to millennium development goals through improved production. In this regard, it is important to remember that TPS has the advantage where yields are low, inputs are hard to get to, and farmers are poor. That is exactly where CIP’s target population lives.

**Conclusions**

True Potato Seed has made an important contribution to the most marginal of potato producers. It has become adopted in the poorest areas with little access to production inputs, especially seed, and with very low average yields (below 15t/ha in general). In these locations it has outperformed disease ridden and disease susceptible local materials by a substantial margin, at times doubling yield.

CIP should limit its investment into further TPS research, and focus in particular on the development of very early bulking materials for inclusion into multiple cropping systems.

Research on apomixes should continue in the broader context of developing seed systems that are easily managed and that allow rapid changeover of varieties. This will have benefits for control of late blight and viruses in developing country potato crops.

As is, we estimate that TPS is now benefiting a quarter of a million poor households in a wide range of highly marginal locations. Further studies of the adaptation domains of TPS and a more active marketing approach may lead to a more general adoption of TPS based seed systems in developing countries.