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Global Potato Research for a Changing World

Manuel Gastelo, Ulrich Kleinwechter and Merideth Bonierbale
International Potato Center (CIP)

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Comments are invited.

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Abstract

The present report provides an overview on newly available technology options for increasing crop yields and improving yield stability in potato production. Biotic and abiotic constraints to crop production are discussed in detail and technologies to address these constraints are presented. As a principal contribution, the report offers a comprehensive overview of technologies available for potato production. With special emphasis on improved varieties, it covers the different types of technologies and approaches, oriented towards yield improvement, yield stabilization as well as aspects of crop quality. Therefore, it not only represents an encompassing exposé of technologies for further use by CIP researchers, but also offers a starting point for prospective analyses of technology impacts.

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Global potato research for a changing world

1. INTRODUCTION

At the beginning of the 21st century, the global food system finds itself exposed to increasing pressures from a broad range of factors. A growing population and changing patterns of food consumption due to globalization, rising income levels and urbanization lead to a higher demand for food products. At the same time, it becomes more difficult to draw additional land into production, while degradation and pressure from alternative uses, such as biofuels, increase. In several regions, surface and ground water is becoming less available and urban and industrial water use is rising. Growing economies require larger amounts of energy, leading to higher energy prices and thus to higher prices of many inputs for agricultural production. This scenario unfolds under conditions of climate change, which through rising temperatures, changing patterns of precipitation and more extreme weather events is likely to negatively affect the conditions for agricultural production in many regions of the world (FAO 2008a).

In these times, the global food system faces complex challenges. On the one hand, the supply required to meet future demands for sufficient, healthful and affordable food must be met. Assuring food security and ending hunger are high on the agenda of the international community (United Nations 2010). On the other hand, greenhouse gas emissions have to be reduced and biodiversity and ecosystem services maintained (The Government Office for Science 2011).

At present, however, there is uncertainty about the ability of the food system to meet these challenges (IAASTD 2009). Model based assessments of global agricultural production, for example, expect grain prices to rise significantly over the next 40 years unless productivity growth rates exceed those observed in recent decades (Nelson et al. 2010). The global food price crisis experienced from 2007-2008 and the new recent rise in food prices are harbingers of these developments and have triggered serious concerns among a broader public and drawn renewed attention to the need for agricultural research (Brown 2011).

An integral part of the strategy to respond to the challenges ahead is represented by new and improved agricultural technologies. Further investments and advances in crop yields and productivity are paramount to raising the availability of food and preparing the global food system for the decades to come. Thereby, potato (*Solanum tuberosum* L.) can make an important contribution.

For a number of reasons, potato stands out among the world's major food crops. Potato plays multiple and important roles in local food systems and for food security. It is well suited for cultivation in environmental conditions where other crops may fail and its short and flexible vegetative cycle makes it well suited for rotation with other major crops, such as wheat, rice, maize or soybeans (FAO 2008b). Thus, potato helps to increase the availability of food, contributing to a better land use ratio by raising the aggregate efficiency of agricultural production systems.

By providing income generation opportunities as a cash crop and generating employment, potato contributes to alleviating poverty (Scott, Rosegrant, and Ringler 2000). Further, potatoes represent an important source of energy, with a high delivery of energy per unit land, water and time, and are a valuable source of minerals and vitamins for the diet (Anderson et al. 2010).

During the food price crisis in 2007/2008, prices of potato were significantly less affected by the price increases in international markets (FAO 2008b). This highlights the contribution the crop can make to a more stable world food system. The fact that potato is grown in regions with high incidences of poverty, undernutrition and food insecurity such as the tropical highlands of Africa, the Andes of South America, or the Indo-Gangetic basin of southern Asia, underlines its particular importance (Bruinsma 2003; Thiele et al. 2010).

In terms of human consumption, potato is the third most important food crop in the world, following only rice and wheat (FAO 2011). In 2009, world production reached 330 million tons (Figure 1), of which 18 million tons were produced in Africa, 16 Million tons in South & Central America, 59 Million tons in South & West Asia, 9 Million tons in Central Asia and the Caucasus and 89 Million tons in East Asia & the Pacific (FAO 2011). The total harvested area was almost 20 million hectares in 2009 (Figure 2). While total production area has declined slightly for the world as a whole, it keeps increasing in developing countries, reflecting a shift in production away from developed countries. This growth in area in developing countries involves a greater diversity of agroecological zones and a greater number of varieties adapted to these conditions. The growth of production in developing countries also reflects the fact that potato is the one commodity in the developing world with consistent increases in quantities consumed per capita (Bruinsma 2003).

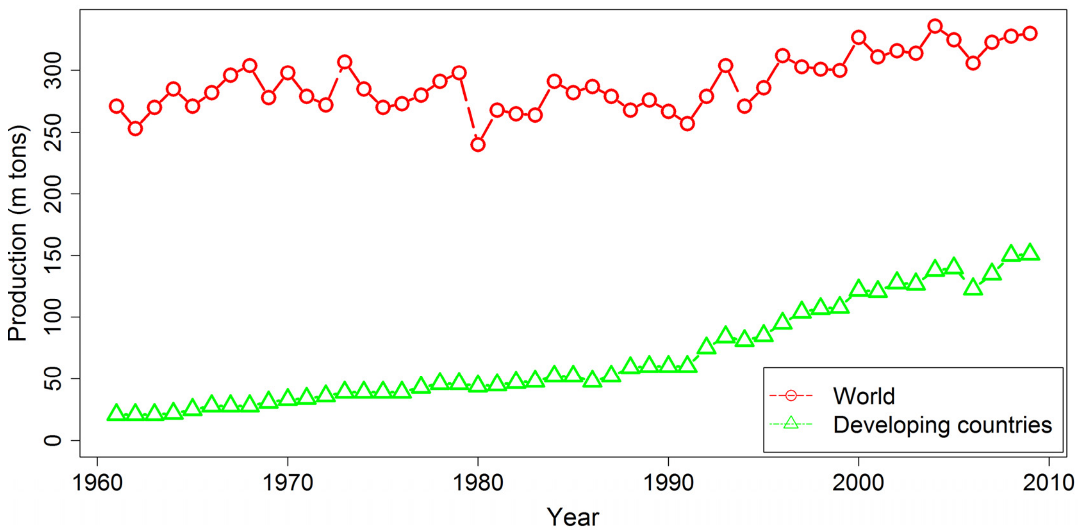


Figure 1.
Potato production, 1961-2009.

Source: FAO (2011).

As the right panel of Figure 2 illustrates, potato yields have grown constantly over the past five decades. Due to the on average comparatively low growth rates – about 0.63% per year in the world as a whole and 0.87% in developing countries, respectively, from 1961 to 2009 – an even larger part of production growth, however, has come from an expansion of the cultivated area.

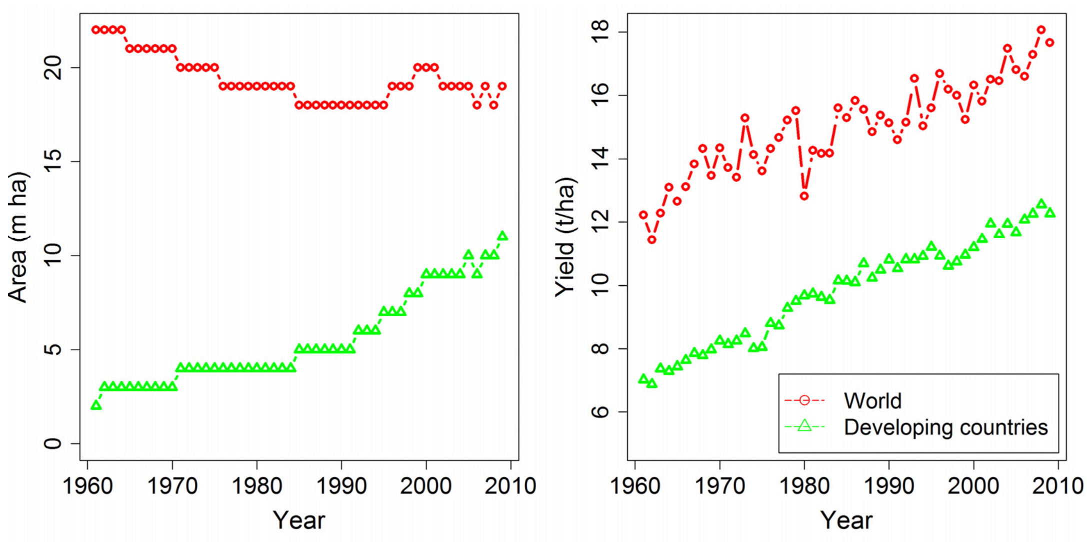


Figure 2. Potato harvested area and yield, 1961-2009.

Source: FAO (2011).

Technological innovations aimed at increasing productivity can play an important role for enhancing the contribution of potatoes to the future global food system. In fact, past impact evaluation studies have shown the potentially high returns on investments in research on potato technologies (Fuglie and Thiele 2009; Thiele et al. 2008; Walker and Crissman 1996). This reflects a relative underinvestment in roots and tubers research and shows the potentially high impacts these technologies can have on poverty and hunger (Anderson et al. 2010). It is recognized that in particular genetic improvements in potato have so far been an underexploited resource for increasing agricultural yields and production (Alexandratos 1997).

Against the background of its important role and the positive outlook for technological innovations, the present report identifies new and upcoming technologies for potato production. The ultimate objective of the report is to provide a basic overview on technologies we consider to be options for strengthening the contribution of the potato crop to coping with the challenges that lie ahead for the global food system.

The report is part of the work the International Potato Center (CIP) carries out in cooperation with other Centers of the CGIAR and external partners in the scope of the Global Futures for Agriculture and Strategic Foresight (GFSF) Project. GFSF aims at assessing the potential impact of technologies developed by agricultural research for development on crop production, economic welfare and food security, thereby informing program planners, donors and the technology developers themselves as to the merits and the expected impacts of their work and investments.

2. NEW TECHNOLOGIES FOR POTATO PRODUCTION

At the International Potato Center, the development of technological innovations for potato production is oriented towards two sets of goals. Firstly, efforts are directed to increasing or maintaining the productivity of the potato crop under challenging conditions without increments in dependence on expensive external inputs and reducing negative impacts on the environment and human health. Secondly, technological innovations seek to achieve quality improvements related to consumption or market value (Thiele et al. 2008).

As regards the available technological options, three broad groups can be distinguished: varietal technologies, seed technologies and improved management technologies. Variety technologies involve the genetic improvement of the potato crop. Seed technologies are technologies which aim at improving the production, quality and availability of planting material. Improved management technologies are based on an encompassing understanding of potato production systems. In the following, we deal mainly with varietal technologies. Seed technologies and improved management are treated less extensively in this report. Also, in particular in relation to the latter we at times go beyond technologies in a narrow sense and discuss approaches which include technologies as elements, but are more encompassing in the sense that they concern aspects like practices, infrastructure or institutions. We believe that since the improvement of crop production often can benefit from or may even require the application of approaches rather than elementary technologies, their inclusion in a report of this kind is justified.

There is a broad range of factors affecting potato productivity. The potential yield level is determined by a variety's genetic characteristics, including its growth, tuberization and partitioning response to prevailing environmental conditions such as day length, temperature, soil fertility and availability of water. Actual productivity and yield stability are influenced by abiotic factors, such as drought and heat, as well as biotic factors including diseases such as late blight and a number of important viruses (Lutaladio et al. 2009) that can affect yields directly or by reducing seed quality.

Thereby, climate change can be expected to alter the impacts of the different factors. Overall temperature levels are expected to rise and drought and extreme temperatures are likely to occur more frequently (IPCC 2007), thus directly affecting plant growth and yields. At the same time, climate change causes variation in the incidence and intensity of pressure from pests and diseases. In the case of late blight, for example, increasing temperatures and precipitation may be the reason that potato crops in many regions which previously had no presence of this disease have become affected in recent years.

2.1. Shifting the Yield Frontier and Improving Yield Stability

In potato, higher potential yield can in part be achieved by adjusting the genetic response of the variety to the length of the photoperiod. In general terms, the length of the photoperiod plays a highly important role for tuberization, which is generally promoted under short day length conditions. *Solanum tuberosum spp. andígena* has a short critical photoperiod for tuberization; *S. tuberosum spp. tuberosum* has a longer critical photoperiod, and some varieties have neutral response. Genes for photoperiod, however, are variable within as well as among gene pools. Through a process of recurrent selection, clones have been developed from *andígena* populations that similar to *tuberosum* are able to tuberize under long day conditions (Plaisted et al. 1987).

In breeding programs, the development and selection of hybrids of superior quality over parents has resulted in enhanced productivity in many crops. This superior performance of hybrids over parents is known as "heterosis", and can be seen as an increase in biomass, yield, speed of development, fertility, or tolerance to biotic or abiotic stress. Maximum heterosis for these polygenic traits is expected with maximum heterozygosity in polyploids like potato and sweetpotato. Research suggests and breeding has shown that substantial gains in yield can be made upon increasing the genetic distance between parental lines. Maximizing heterosis in potato implies an increase in heterozygosity and number of multi-allelic loci. However, maximum heterozygosity positively influences heterosis expression only when well-adapted genepools are combined (Bonierbale et al., 1993). Thus exotic sources of germplasm should undergo some previous selection for adaptation. A proper balance between heterozygosity and adaptation, mainly to photoperiod, should maximize heterosis for yield in potato (Mendoza and Haynes 1974).

Constraints to crop yield, production stability and profitability include biotic and abiotic stresses that reduce yield and increase production costs. The development of improved varieties aims at genetic and physiological characteristics that contribute to increased resistance or tolerance to these adverse factors, and as a consequence, allow for increased yield stability and higher productivity. Specifically, the most important breeding targets are increased tolerance to drought and heat, resistance to late blight and viruses/ slow degeneration, and the adjustment of the response to photoperiod as a general measure to increase adaptation and yield while maintaining product quality (Moldovan et al. 2011).

The first important abiotic factor affecting potato productivity is drought. Drought has a large influence on productivity. Depending on the genotype, timing and extent of drought, water stress might accelerate or delay flowering and tuberization, or slow down canopy growth and tuber fill or bulking.

The breeding strategy involves the measurement of a range of biological and physical variables. As regards the selection process, it is important to measure differences in earliness between clones in order not to confound drought tolerance and drought escape. Measurement of leaf area is very important because it is related to photosynthesis and transpiration. Size of the root system determines access to soil water. Relative leaf water content measures differences in hydration status of leaf tissue and is an indicator of the capacity of the plant to maintain its water status. Stomatal conductance in connection with leaf area, relative leaf water content and photosynthesis efficiency allows to identify stomatal and non stomatal effects on photosynthetic efficiency under drought. Water use efficiency describes how much water a plant needs per unit of produced biomass or yield. Plants with high water use efficiency are desirable for drought tolerance breeding; however various traits determining water use efficiency such as gas exchange efficiency, carbon allocation, growth regulation and transpiration efficiency are involved (Tournex et al. 2003).

Plant productivity depends on the efficiency of photosynthesis; determination of the status of photosynthesis can be measured by chlorophyll fluorescence to identify genotypes with differences in photosynthetic efficiency under drought (Tournex et al. 2003).

A second important abiotic factor affecting yield stability and productivity of potato is temperature. High temperature affects the rates of photosynthesis and respiration, with the former being reduced and the latter increased. Temperatures of above 20ºC cause reduction of approximately 25% in the rate of photosynthesis and tolerance to high temperatures may be associated more with differences in respiration than in photosynthesis (Levy and Veilleux 2007).

From a production point of view, tuber growth under warm conditions is important. At higher temperatures, typically above 25ºC, tuber initiation and tuber growth are inhibited, the former leading to delays in tuberization. These delays probably result from accelerated metabolism and growth, in particular haulm growth, and from the mentioned specific inhibitory effects of the high temperature on tuber initiation. Increases in either day or night temperature above optimal levels (18ºC–20ºC) reduce tuber yields, with high night temperature being deleterious to tuber bulking and dry matter accumulation. High temperatures also cause physiological disorders such as irregular shape, pre-mature sprouting, cracking and elevated concentrations of glycoalkaloids in tubers, leading to bitter tubers that can be toxic (Levy and Veilleux 2007).

Davis (1941) found that *Solanum commersonii* had higher tuber yields at 25º C than 14ºC, indicating that certain *Solanum* species may be exploited as sources for breeding for tolerance to high temperatures. Thereby, an important prerequisite to successful breeding is a reliable method of screening to identify genotypes tolerant to high temperatures. Various screening procedures for the selection of heat tolerance have been employed. Ewing et al. (1983) selected clones for heat tolerance according to two important traits: vigor of shoot growth indicating the ability to produce biomass at high temperatures, and tuber formation, indicating the ability to form tubers at high temperatures. Levy et al. (1991), when screening parental material grouped according to maturation, found evidence of a clear association between early maturation and greater tolerance to high temperatures. Stem elongation at high temperatures has also been used as a measure of tolerance to heat. Heat tolerance is dependent on the capacity to maintain growth of both haulm and tubers under high temperatures through balanced partitioning of assimilate.

Among biotic stress factors, late blight (*Phytophthora infestans*) is the most important disease of potato worldwide (Forbes 2008; Hardy, Trognitz, and Forbes 1995; Haverkort 1990). Climate change has led to greater variation in the incidence of this disease in many potato-growing regions in recent years. Increasingly, regions which previously had no presence of this disease are affected (Perez et al. 2010). Therefore, increasing the resistance to this disease in new potato varieties is an important breeding goal.

Field- or quantitative-"rate-reducing" resistance associated with longer latency period, slower rate of lesion growth and reduced sporulation upon infection is generally thought to be more durable against variable pathogen populations than extreme, race-specific resistance conferred by major resistance genes. However, emerging capacity to combine major resistance genes (R genes) by trans- or cisgenics or by conventional breeding may offer new strategies for control of late blight.

The structure of the individual plant and the type of canopy produced may affect the rate of development of the disease. In general, late blight spores require high humidity and water to penetrate the host tissue and to reproduce. Therefore, each characteristic of the plant which affects the availability of water and humidity has an influence on the development of the disease. The canopy and the nature of leaf surface are determinants of the drying of the plant after dew or rain and determine the duration of high humidity. The structure of the individual plant, the leaf shape and its height, the number and density of leaves all affect the distribution of water droplets and, with the canopy affecting the rate of drying, will influence the number of infection sites established by the pathogen.

Breeding for late blight resistance considers features that either completely prevent the pathogen from becoming established, or reduce the rate of disease development in the field. The latent period before infection is established, the growth rate of disease lesions, and capacity of the pathogen to sporulate or reproduce on the host plants contribute to rate-reducing resistance (Thurston 1971). These characteristics are variable in potato germplasm and can be incorporated into new varieties for incorporation into management practices requiring little or no fungicides to control the disease.

Due to their potential for transmission in symptomless seed tubers from generation to generation which causes degeneration of the planting material, virus diseases represent extremely important pathogens of potato (Stevenson et al. 2001). The most important in terms of prevalence and economic effect comprise potato leafroll virus (PLRV) and potato virus Y (PVY), followed by potato virus X (PVX), potato virus M (PVM) and potato virus A (PVA). Symptoms of viruses include chlorosis, mosaic, erectness, leaf rolling, changes in leaf texture and color as well as necrosis on leafs and stems, and tubers can be directly affected by lesions (Salazar 1996). While virus diseases are seldom lethal to the plant, they lead to reductions of plant vigor, quality and yields (Stevenson et al. 2001). Reported effects of virus infections on yields are generally highly variable, but can reach up to 90% (Salazar 1996).

Beside the production of virus free potato seed, a promising method of control is the exploitation of genetic resistance available in the genepool of potato including improved varieties and both wild and cultivated relatives of the crop. The main advantage of genetic resistance is that it is conferred to the crop with no additional need for specialized knowledge of management practices. Resistance is passed from generation to generation as an inherent characteristic of the seed variety. As such, it implies no environmental damage and can enhance productivity from farm-saved seed, thereby conveying a direct benefit to poor farmers (Thiele et al. 2010).

2.2. Genetic improvement of the potato crop and advanced clones and varieties

The International Potato Center (CIP) plays a key role in supplying and developing advanced potato clones and varieties for the tropical, subtropical and temperate agro-ecologies of the developing world (Thiele et al. 2008). The potato breeding program of CIP aims to generate improved populations and clones with resistance or tolerance to biotic and abiotic stresses as candidate varieties that can be easily adopted by farmers to increase production and productivity and avail opportunities for income generation further to their release as varieties in developing countries.

Since its inception, CIP has used wide genetic resources (including wild, landrace and improved germplasm) to develop improved populations adapted to stressful conditions of the tropics. To date, these efforts have resulted in two advanced populations: the Highland-tropics adapted late blight (LB) resistant population (Population B) and the Lowland sub-tropic virus resistant population (Population LTVR) (Figure 3). Recurrent selection of these populations under endemic stresses in the tropical highlands and the subtropical lowlands, respectively, enabled high genetic gains for resistance to the most important diseases, resulting in unique elite gene pools with specific adaptation to most important agro-ecologies of the developing world.

Population B is under improvement for high levels of horizontal resistance to late blight along with economically important traits such as tuber yield, quality for table and industry and adaptation to wide environments and tolerances to other biotic/abiotic stresses as they are present in testing sites. In anticipation of the effects of global warming on potato cultivation in both tropical and subtropical environments, since 2004, efforts have turned to the development of a generation of Population B with improved adaptation to warm environments, resistance to late blight and mid-season maturity (90 day growing period under short day length conditions) denominated LBHT (late blight, heat tolerance). Two groups of clones, the first with resistance to late blight, PVY, heat tolerance and relative earliness that would adapt well to Sub-Saharan Africa and Asia, and the second group without resistance to PVY, but important in highlands for their high resistance to late blight and relative early maturity are available for variety development (Gastelo et al. 2013).

The LTVR population is characterized mainly for its resistance to the most important virus diseases (PVY, PVX and PLRV) of potato, early tuberization in short days, mid-maturity under long days and adaptation to warm, arid environments; the incorporation of late blight resistance was made more explicit in the last few years, though yield under late blight pressure is to some degree afforded by early maturity (escape).

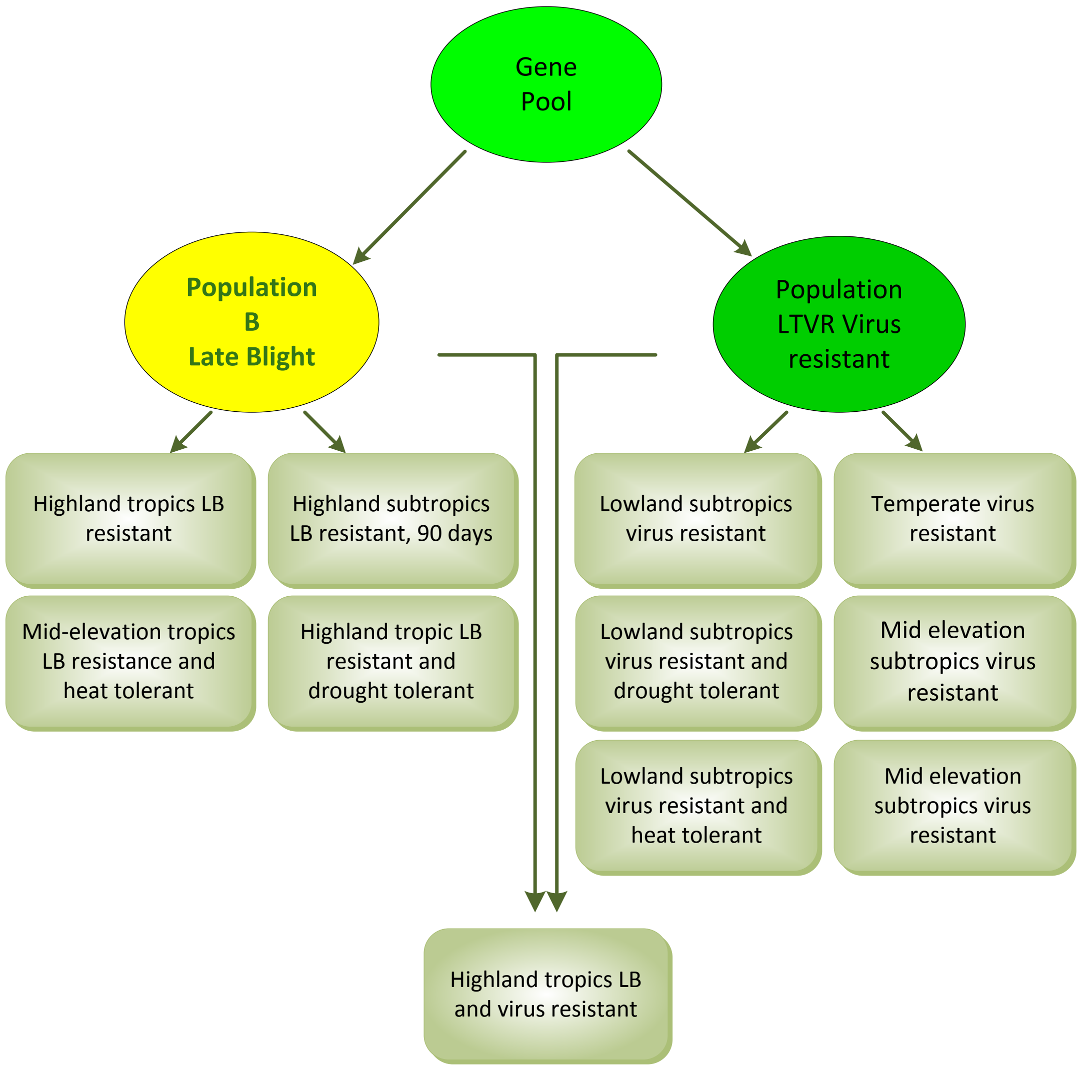


Figure 3. Advanced populations with specific adaptation to the most important agro-ecologies of the tropics.

CIP has recently begun to assess both populations for variability for drought tolerance and water use efficiency. With the international research program HarvestPlus, variability has also been assessed for micronutrient densities (Fe, Zn, and vitamin C) and genetic gains realized from a base population of diploid potatoes. Interploid crosses are used to combine new sources of Fe and Zn concentrations with those present in the advanced tetraploid populations to meet micronutrient breeding goals for impact on the health status of populations at risk of malnutrition.

The location of CIP's headquarters and experimental sites in Peru provides access to a wide range of tropical and subtropical environments, from the warm arid coast, to the cool humid highlands, and the high jungle in between (Table 1 and Figure 4). Each of the environments has homology to production environments throughout Africa, Asia and Latin America.

In locations where more than one cropping season per year is possible the less-favorable one is used, i.e., the one with higher pressure of virus vectors or late blight, higher temperatures, etc., to challenge the populations under selection.

Table 1. Environments in Peru used for evaluation and selection of clones with resistance or tolerance to biotic and abiotic stresses.

#	Place	Environments	Altitude (masl)	Latitude	Planting season
1	La Molina	Cool lowland tropics	300	11° S	Winter, Spring, Summer
2	Huancayo	Cool highland tropics	3300	12° S	Spring - Summer
3	San Ramon	Hot, humid, mid-elevation tropics	900	11° S	Spring
4	Oxapampa	Warm, humid highland	2000	11° S	Spring - Summer
5	Majes	Warm arid lowland tropics	900	16° S	Spring - Summer
6	Tacna	Hot arid lowland tropics	200	18° S	Spring - Summer
7	Nazca	Hot arid lowland tropics	300	14° S	Spring - Summer

Although all of CIP's sites in Peru are in short day environments (the southern-most site is at 18° S), exposure to warm conditions has provided some compensatory effect for longer photoperiods, such that some of the advanced clones representing the LTVR population are not strictly short day adapted. However, some of the characteristics of CIP-bred varieties such as persistent vegetation even after tuber set, are disfavored by scientists and farmers of the temperate regions who prefer *Solanum tuberosum* types of potato that senesce and lose vigor with tuber production. Nevertheless, interactive evaluation in temperate locations of Chile, China, Tajikistan and Uzbekistan, intercrossing and crossing with long day-adapted varieties has rendered this population a good source of varieties for the stressful environments of Central Asia and the Caucasus as well as sub-tropical lowland conditions.

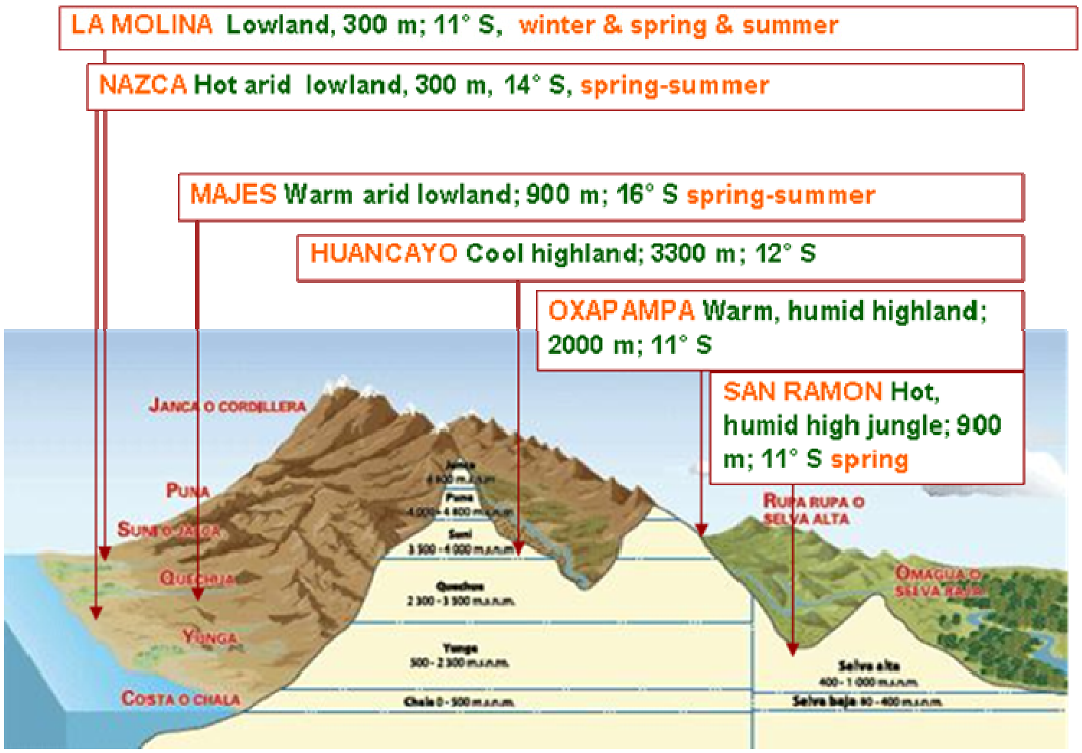


Figure 4.
CIP Peru sites: Diverse environments in relatively close proximity (Pulgar Vidal, 1981).

The breeding efforts described above have resulted in over 300 advanced and elite clones which are described in an on-line catalogue updated each year (https://research.cip.cgiar.org/redlatinpapa/pages/home.php).

To facilitate international exchange and evaluation of CIP's advanced bred clones, 12 sets of clones are offered as nurseries (Table 2). The nurseries offer trait combinations required for productivity under different agro-ecological situations, covering tropical, subtropical and temperate regions of different altitudes and traits of tolerance and resistance to biotic and abiotic constraints as well as agronomic traits (Table 3). All clones are available for distribution from CIP to potato programs of developing countries. The CIP Germplasm Ordering System can be accessed via https://research.cip.cgiar.org/smta/search1.php. More information on the nurseries with a detailed listing of the advanced clones can also be found in appendix to this report.

As Table 2 and Table 3 show, the advanced clones available from the CIP nurseries combine different traits according to the requirements of the different potato agroecologies. For tropical highland environments, resistance to late blight and virus is combined with drought tolerance. Clones for mid-elevation tropics are characterized by late blight resistance and heat tolerance. For subtropical highlands, clones have late blight resistance and a short to medium growth cycle. Clones for mid-elevation areas in subtropical and temperate regions have high resistance to PVY and PVX. For subtropical lowlands, virus tolerance is combined with heat tolerance. Compared to the control variety Desiree, a variety which is heat tolerant but susceptible to late blight, the advanced clones have high tuber yields which reach beyond 20tons/ha without protection by fungicides under high pressure of late blight. All clones have potential to address the effects of warming in the traditional areas of cultivation and new environments to which potato cultivation is increasingly expanding.

Table 2: Nurseries with advanced potato clones.

#	Description	No. of clones
1	Potato Lowland Subtropics Virus Resistant Nursery	16
2	Potato Lowland Subtropics Virus Resistant and Drought Tolerant Nursery	24
3	Potato Lowland Subtropics Virus Resistant and Heat Tolerant Nursery	25
4	Potato Temperate Virus Resistant Nursery	23
5	Potato Mid-elevation Tropics Late Blight Resistant and Heat Tolerant Nursery	18
6	Potato Mid-elevation Subtropics Virus Resistant Nursery	14
7	Potato Mid-elevation Temperate Virus Resistant Nursery	29
8	Potato Highland Late Blight Resistant Nursery	34
9	Potato Highland Tropics Late Blight Resistant and Drought Tolerant Nursery	21
10	Potato Highland Tropics Late Blight Resistant and Virus Resistant Nursery	17
11	Potato Highland Bacterial Wilt Resistant Nursery	14
12	Potato Highlands Subtropics, Short-medium Growth Cycle Nursery (90 days from planting to harvest)	20

Table 3: Trait combinations by agro-ecology as available in CIP nurseries of advanced clones.

	Tropical	**Subtropical**	**Temperate**
Highlands	LB, virus resistance, drought tolerance	LB resistance, short – medium growth cycle	
Mid-elevation	LB resistance, heat tolerance	Virus	Virus
Lowlands		Virus resistance, drought and heat tolerance	

Identification of homologous selection and target environments using the Stability Analysis Model (AMMI) and Geographic Information System (GIS) (Salas et al., 2010)

The identification of homologous environments to support decisions on the dissemination of advanced clones and varieties requires the study and interpretation of genotype by environment interaction. To this end, several statistical methods are available, among them the additive main effects and multiplicative interaction model (AMMI). CIP has developed a method to couple GIS with the AMMI model to predict potential areas of adaptation of advanced clones. This method consists of three parts:

1. Exploratory analysis.
2. Phenotypic stability analysis (yield trial).
3. Prediction of adaptation environments.

1. **Exploratory analysis. -** Exploratory analysis requires information for each locality of interest, consisting of altitude, latitude, longitude, and planting and harvest dates. Next, climate information is extracted for each locality with the DIVA-GIS or ArcGis systems. Then, a multivariate test is performed, using SAS and R statistical software. The exploratory analysis allows the breeder to characterize selection and target sites and observe the spatial relationship between these localities and climate variables for studies of phenotypic stability in advanced potato clones.
2. **Phenotypic stability analysis (yield trial). -** Phenotypic stability experiments are performed for advanced clones in several divergent localities selected with help of the exploratory analysis. Climatic variables (temperature, rainfall, relative humidity, photosynthetically active radiation, wind speed) are obtained from weather stations at each locality. Furthermore, soil data is used to characterize the site. The data is analyzed with the AMMI and partial least square models, which show the spatial relationships of genotypes and environments and help to identify genotypes with specific adaptation or broad adaptation.
3. **Prediction of suitable environments.-** Environmental characteristics and clonal performance data are related using MAXENT (Phillips et al., 2006). MAXENT is a recent implementation of the maximum entropy model for analyzing climate data (minimum and maximum temperature, rainfall) from the WorldClim Global Climate GIS Database is used. MAXENT is used to identify environments similar to those in the stability analysis to which the experimental clones have been shown to have either specific or broad adaptation.

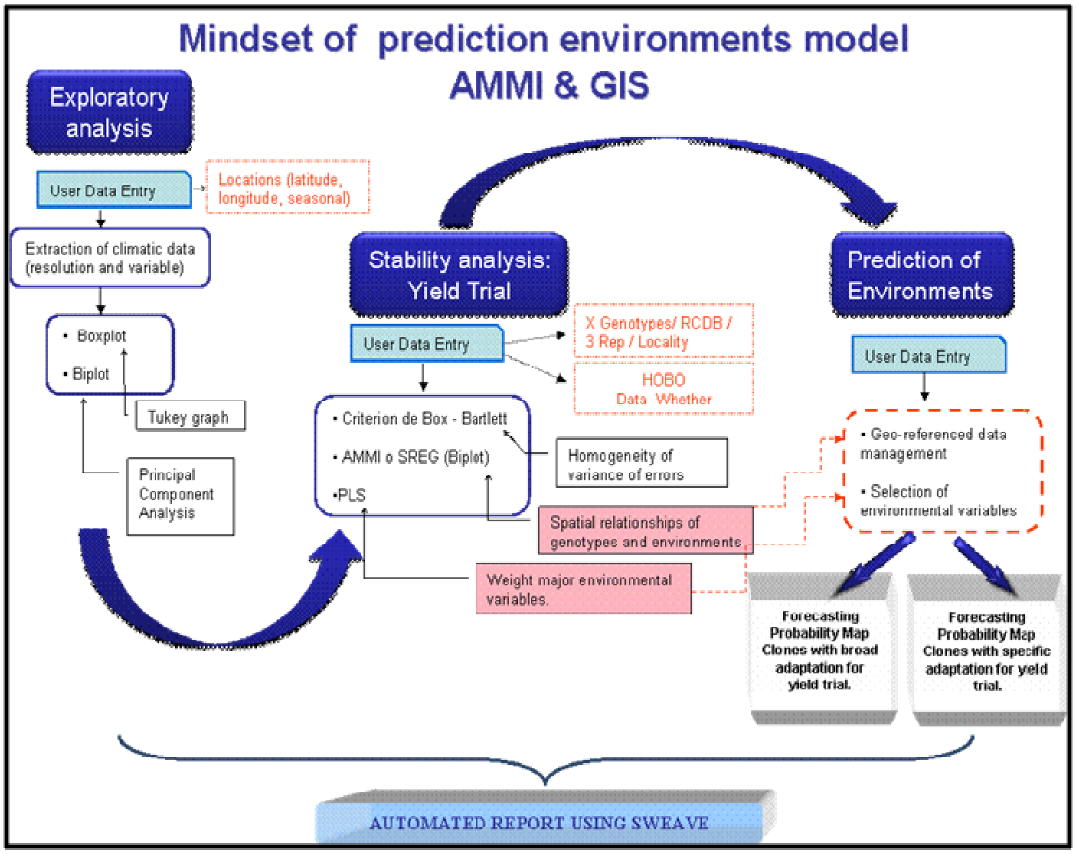


Figure 5. Mindset of prediction environments model, AMMI and GIS.

Source: Stability analysis models and definition of environments with GIS. Source: Presentation in training course: Enhanced food and income security in SWCA through potato varieties with improved tolerance to abiotic stress. 9-13 August 2010 CPRI Shimla, India.

2.3. Seed technologies

Low seed potato quality is a major constraint of potato production in developing countries (Gildemacher, Kaguongo, et al. 2009). Since potato is a vegetatively propagated crop, planting material is subject to degeneration over time, caused by the build-up of virus diseases and other degenerating factors that are transfered from one generation to the next. The use of planting material of low quality leads to reduction in quality and yields and is responsible for yield reductions on over 5 million hectares of potato in the developing world. Accordingly, and as a complement to the use of virus-resistant varieties, the access to and use of disease-free and quality seed material is considered to be highly promising for improving potato production and reducing poverty in these regions (Fuglie 2007a; Fuglie 2007b).

The degeneration of seed material takes place in a setting in which farmers either use their own seeds retained from the previous harvest or rely on informal production and trade of “seed” potatoes (Gildemacher, Demo, et al. 2009). The underlying reasons are the limited development of (formal) seed systems and the high cost which gives farmers little incentive to invest in quality seeds (Fuglie 2007b). This makes it evident that when talking about seeds, a broader perspective on “technologies” which involves the entire seed system has to be taken.

Thereby, solutions can be of purely technological nature. Examples include technologies for the production of better and cheaper quality planting material, such as aeroponics and tissue culture, or the varietal technologies mentioned above, namely breeding for virus resistance (Low et al. 2007). Any purely technological effort, however, will have to be accompanied by a broader, systemic approach aimed at the general improvement of the seed system in a particular region. Efforts can be directed to the establishment and strengthening of formal and informal seed systems, building on cooperation between the public and private sector or the establishment of seed multiplication programs adapted to local conditions (Zaag and Horton 1983; Low et al. 2007). The improvement of farmer seed management also contributes to solving the problem of low-quality seeds (Fuglie 2007b), giving an important role to training and extension directed towards seed production technologies, such as Positive Selection on special small plots (Low et al. 2007). Not least the linkage of the two directions of work – public and private sector seed production and on-farm multiplication initiatives – can prove promising (CIP 2012a).

CIP has generated a set of technologies and approaches, which includes Positive Selection and 3G. Positive Selection is a simple and effective technique to improve seed quality especially for small producers and consists of marking the best looking plants (healthy and appropriate to the variety in production), then harvesting these plants separately, store and multiply in the following season in isolated areas applying the recommended management for seed production and management techniques. So far, this technology has substantially improved crop yields in the Andean countries of Bolivia, Ecuador and Peru (Alvarez, 1988; Bryan, 1983) and in Sub-Saharan Africa (Gildemacher et al., 2011).

The three-generation (3G) seed multiplication strategy is another approach that helps to substantially improve the quality of the seed. However, it requires availability of a certain infrastructure such as laboratory and greenhouses for mass production of plantlets in vitro and of mini tubers and it needs a skilled partner in the field multiplication. The concept of 3G is to reduce the number of multiplications from in vitro plantlets to seed available to farmers to prevent contamination with diseases and viruses transmitted by vectors.

2.4. Management technologies for pests and diseases

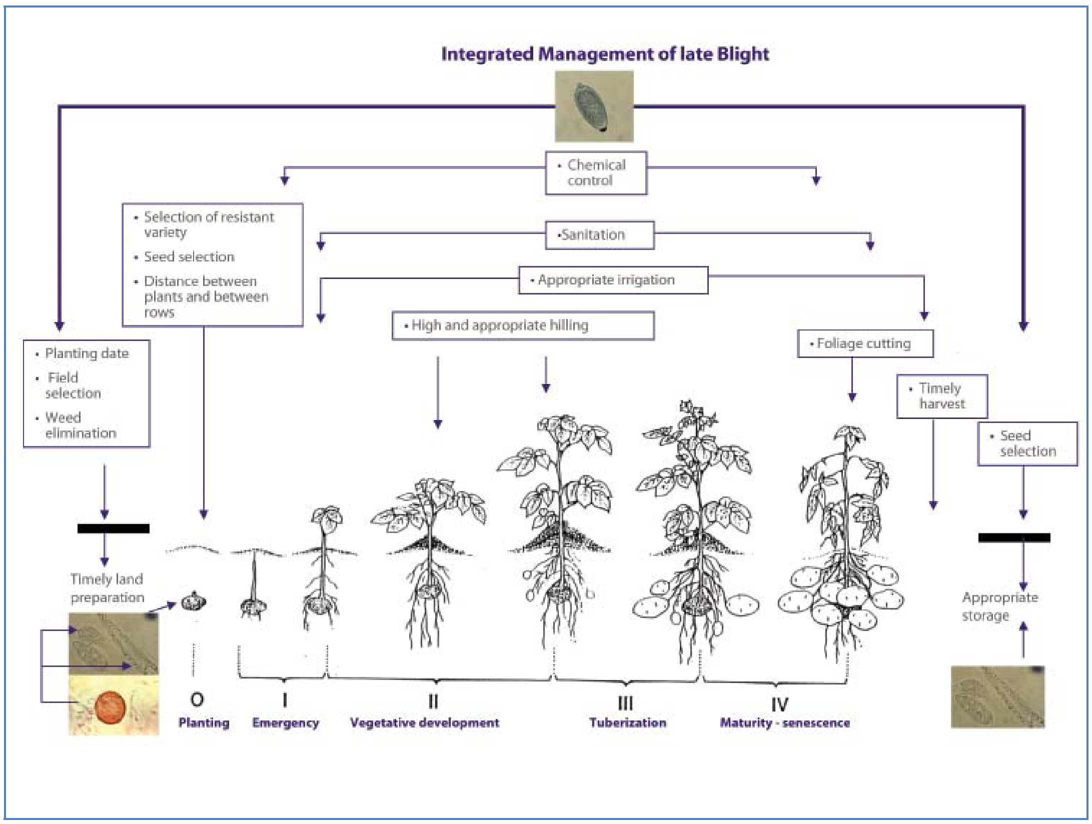
As a first set of technologies related to the management of the potato crop, integrated pest management (IPM) has great potential to contribute to prepare the global food system for the future by increasing food production, counteracting the impact of climate change on the distribution of pests and their damage potential, reducing contaminants in the food chain and increasing the resilience of agro-ecosystems (CGIAR 2011). The direct goal of IPM is to maintain pest populations at acceptable levels and keep pesticides and other interventions at levels which are economically reasonable and safe for the environment and human health (FAO 1967).

IPM for potato production systems offers several options which are ready for implementation. These options comprise inoculative biological control and technologies to replace insecticide interventions. Inoculative biological control offers the possibility to increase the resilience of potato agroecosystems to pest outbreaks by controlling for invasive species. For this purpose, a number of parasitoids are maintained at CIP and available for distribution to national programs. Examples include *Copidosoma koehleri*, *Orgilus lepidus*, *Apanteles subandinus* for potato tuber moth control and *Halticoptera arduine*, *Chrysocharis flacilla* and *Phaedrotoma scabriventris* for the leafminer fly (CIP 2012b).

Innovative and simple technologies can be used to replace insecticide interventions. Plastic barriers can effectively prevent infestation of migrating Andean potato weevils (*Premnotrypes sp.*). Since in the Andean region potato weevils are the main pests for which farmers apply pesticides, this technology can contribute to reduce pesticide applications in potato (Miethbauer 2012; Kroschel, Alcazar, and Pomar 2009). To protect potatoes in stores, commercial *Bacillus thuringiensis subsp. kurstaki* (Btk) products can be reformulated with talcum to obtain a cost-effective product. Sexual pheromones and insecticides can be co-formulated to control *P. operculella* and *S. tangolias* in both field and storage. In fields tests in different potato agroecologies, the application of 2500 droplets (100µl) have shown >90% reduction in the male population up to 60 days following the application. Damage to stored tubers has decreased by few droplets by up to 90% (Kroschel and Zegarra 2012).

CIP has developed an integrated management program for late blight control. As Figure 5 illustrates, this program is composed of different elements, including genetic, chemical, agronomic and biological control, which in their conjunction allow a successful control of the disease and help to reduce or avoid losses.

Figure 6. Scheme of integrated management of potato late blight (Pérez and Forbes, 2010).



A further promising management technology is partial root zone drying (PRD). PRD is an irrigation management technique aimed at improving the water use efficiency of the potato crop. With this technique, the two halves of the potato rootstock are irrigated alternately. This treatment causes the stomata of the plant to close further as a response to the perceived water stress. It has been shown that PRD greatly increases the water use efficiency of the plant. In spite of lower yields, the yield obtained per unit of irrigation water increases (Posadas et al. 2008), making PRD a promising option for production regions facing water constraints.

3. CONCLUSIONS

The present report provides an overview on newly available technology options for increasing crop yields and improving yield stability in potato production. Biotic and abiotic constraints to crop production are discussed in detail and technologies to address these constraints are presented.

For the potato crop, breeding efforts aimed at the development of improved varieties have resulted in the availability of a large number of advanced clones with resistances and tolerances to some of the most pressing biotic and abiotic production constraints in the different potato agroecologies of the developing world, such as late-blight, virus diseases, heat or drought. At the same time, the advanced clones are characterized by improved agronomic and quality traits, such as shorter growth cycles or suitability for processing. Since the advanced clones are readily available for delivery, they represent an important potential to improve potato productivity in the short and middle run.

Seed technologies aim at addressing productivity problems associated with low quality of planting materials caused by seed degeneration. Thereby, seed technologies combine technological solutions in the narrow sense with aspects of infrastructure, management and institutions. New technologies in this area are Positive Selection or 3G.

A high potential can also be seen in improved management technologies. For the potato crop, several promising technology options are available, for example partial root zone drying or integrated pest management through biological control, plastic barriers, pheromone products or CIP's integrated management program for late blight control. As in the case of seed technologies, improved management technologies often take a more systemic approach which goes beyond a single technology in a narrow sense.

As a principal contribution, this report offers a comprehensive overview of technologies available for potato production. It covers the different types of technologies and approaches, oriented towards yield improvement, yield stabilization as well as aspects of crop quality. Therefore, it not only represents an encompassing exposé of technologies for further use by

CIP researchers, but also offers a starting point for prospective analyses of technology impacts, such as envisaged and carried out by CIP's Social and Health Sciences Global Program. In that context, this report is a first step towards providing program planners and researchers with information about the likely merits and impacts of the different technologies. At the same time, we are aware that a further important area of breeding, namely breeding for processing characteristics, is not explicitly dealt with by this report, although advanced clones' selection at CIP encompasses these characteristics as well. We believe that leaving this area aside is justified, since the selected technologies relate to crop system productivity rather than characteristics that influence market acceptance and final adoption.

The road ahead for future efforts on the identification and description of new and upcoming technologies would be to base the work on more thorough expert consultations, involving a broader group of experts and going beyond the organization CIP, in particular its Genetics and Crop Improvement Global Program, which was the primary source of information for this report.

Furthermore, the report should be considered as representing a snapshot of the technologies available during the time of the realization of the work. Constraints to agricultural production, however, evolve and change in a dynamic manner, which is reflected in a continuous adjustment of the focus of agricultural research and in the characteristics of promising technologies. It is therefore indicated to carry out regular updates of the content of the report.

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5. APPENDIX 1: CIP NURSERIES FOR ADVANCED POTATO CLONES

Table A1: Potato lowland subtropics virus resistant nursery.

#	Clone	Pedigree	Observations
1	388615.22	B-71-240.2 X XY.16	
2	388676.1	378015.18 X PVY-BK	Maria Bonita*
3	388972.22	XY.20 X 377964.5	
4	390478.9	SERRANA X XY.4	Tacna*
5	392745.7	88.078 X XY-20	
6	395193.6	C91.612 X C92-030	
7	392797.22	387521.3 X APHRODITE	Unica*
8	390663.8	SERRANA X XY.14	
9	392820.1	MONALISA X YY-5	
10	393708.31	PW-31 X DXY.10	
11	397073.16	LR93.120 X C93.154	
12	395434.1	C91.612 X N93.067	
13	396311.1	C93.059 X N93.020	
14	397016.7	92.119 X 88.108	
15	397036.7	LR93.160 X 92.187	
16	397077.16	LR93.221 X C93.154	

*Name under which clone has been released as variety in Peru.

Table A2: Potato lowland subtropics virus resistant and drought tolerant nursery.

#	Clone	Pedigree	Observations
1	392781.1	B71-74-49.12 x XY.13	Primavera
2	392797.22	387521.3 x APHRODITE	Unica
3	397073.7	LR93.120 x C93.154	
4	393708.31	PW-31 x DXY.10	
5	399101.1	391213.1 x 388972.22	
6	391402.5	B-71-74-49.12 x XY.14	
7	392780.1	SEDAFIN x YY.3	Basadre
8	397079.6	Maria Tambeña x C93.154	
9	395436.8	C93.059 x N93.020	
10	397006.18	92.119 x 88.052	
11	397036.7	LR93.160 x 92.187	
12	397077.16	LR93.221 x C93.154	
13	303381.3	C91.612 x I-1039	
14	304350.1	CHIEFTAIN x C93.154	
15	304350.118	CHIEFTAIN x C93.154	
16	304350.18	CHIEFTAIN x C93.154	
17	304366.46	LR93.120 x I-1039	
18	304369.22	MARIELA x I-1039	
19	304371.2	MONALISA x 92.187	
20	304371.67	MONALISA x 92.187	
21	304372.7	MONALISA x I-1039	
22	302476.108	TITIA x 92.187	
23	304405.42	WA.018 x I-1039	
24	304406.31	WA.077 x I-1039	

Table A3: Potato lowland subtropics virus resistant and heat tolerant nursery.

#	Clone	Pedigree	Observations
1	388615.22	B-71-240.2 x XY.16	
2	388676.1	378015.18 x PVY-BK	Maria Bonita*
3	388972.22	XY.20 x 377964.5	
4	390478.9	SERRANA x XY.4	Tacna*
5	392745.7	88.078 x XY-20	
6	303381.106	388611.22 x 676008	
7	304345.102	388615.22 x 676008	
8	304349.8	CHIEFTAIN x 92.187	
9	304350.100	CHIEFTAIN x 392820.1	
10	304350.118	CHIEFTAIN x 392820.1	
11	304350.95	CHIEFTAIN x 392820.1	
12	304368.46	391846.5 x 676008	
13	302428.20	MARIELA x 392745.7	
14	304371.20	MONALISA x 92.187	
15	304371.67	MONALISA x 92.187	
16	304383.41	800824 x 92. 187	
17	304383.80	800824 x 92.187	
18	304387.17	REINHORT x 92.187	
19	304387.39	REINHORT x 92.187	
20	304394.56	SHEPODY x 391207.2	
21	302476.108	TITIA x 392745.7	
22	304405.47	WA.018 x 676008	
23	304406.31	WA.077 x 76008	
24	302499.24	720139 x 392820.1	
25	302499.30	720139 x 392820.1	

Table A4: Potato temperate virus resistant nursery.

#	Clone	Pedigree	Observations
1	388611.22	REICHE (MEX-32 x XY.9)	
2	392797.22	UNICA (387521.3 x APHRODITE)	
3	392759.1	Y84.027 x Pentland Crown	
4	392820.1	MONALISA x YY-5	
5	397035.26	LR93.120 x 92.187	
6	397065.2	C90.266 x C93.154	
7	397069.11	C92.140 x C93.154	
8	303381.106	388611.22 x 676008	
9	304350.1	CHIEFTAIN x 392820.1	
10	302428.2	MARIELA x 392745.7	
11	304371.2	MONALISA x 92.187	
12	304371.67	MONALISA x 92.187	
13	304387.17	REINHORT x 92.187	
14	304394.56	SHEPODY x 391207.2	
15	302476.108	TITIA x 392745.7	
16	304405.47	WA.018 x 676008	
17	304406.31	WA.077 x 676008	
18	397073.16	LR93.120 x C93.154	
19	397077.16	LR93.221 x C93.154	
20	304347.6	C93.154 x I-1039	
21	304351.109	CHIEFTAIN x I-1039	
22	304366.46	LR93.120 x I-1039	
23	304369.22	MARIELA x I-1039	
24	304399.15	SNOWDEN x 92.187	

Table A5: Potato mid-elevation tropics late blight resistant and heat tolerant nursery.

#	Clone	Pedigree	Observations
1	391002.6	386209.1x 386206.4	
2	398098.119	393371.58 x 392639.31	
3	398098.205	393371.58 x 392639.31	
4	398180.144	392657.171 x 392633.64	
5	398180.253	392657.171 x 392633.64	
6	398180.292	392657.171 x 392633.64	
7	398190.200	393077.54 x 392639.2	
8	398190.404	393077.54 x 392639.2	
9	398190.530	393077.54 x 392639.2	
10	398190.605	393077.54 x 392639.2	
11	398190.735	393077.54 x 392639.2	
12	398192.41	393077.54 x 392633.54	
13	398192.592	393077.54 x 392633.54	
14	398193.650	393077.54 x 392633.64	
15	398201.510	393242.5 x 392633.64	
16	398208.620	393371.58 x 392633.64	
17	398208.670	393371.58 x 392633.64	
18	398208.704	393371.58 x 392633.64	

Table A6: Potato mid-elevation subtropics virus resistant nursery.

#	Clone	Pedigree	Observations
1	390478.9	SERRANA x XY.4	Tacna
2	395195.7	C91.612 x C92.167	
3	397065.28	C90.266 x C93.154	
4	390663.8	SERRANA x XY.14	
5	397073.7	LR93.120 x C93.154	
6	395434.1	C91.612 x N93.067	
7	396311.1	C93.059 x N93.020	
8	397006.18	92.119 x 88.052	
9	397012.22	LR93.309 x 88.052	
10	397014.2	92.062 x 88.108	
11	397055.2	88.052 x C93.154	
12	397067.2	C91.628 x C93.154	
13	397073.15	LR93.120 x C93.154	
14	397196.8	C92.140 x C91.612	

Table A7: Potato mid-elevation temperate virus resistant nursery.

#	Clone	Pedigree	Observations
1	392820.1	MONALISA x YY-5	
2	397006.18	92.119 x 88.052	
3	397069.11	C92.140 x C93.154	
4	303381.106	388611.22 x 676008	
5	304350.1	CHIEFTAIN x 392820.1	
6	302428.2	MARIELA x 392745.7	
7	304371.2	MONALISA x 92.187	
8	304371.67	MONALISA x 92.187	
9	304387.17	REINHORT x 92.187	
10	304394.56	SHEPODY x 391207.2	
11	302476.108	TITIA x 392745.7	
12	304405.47	WA.018 x 676008	
13	304406.31	WA.077 x 676008	
14	397073.16	LR93.120 x C93.154	
15	397077.16	LR93.221 x C93.154	
16	397079.6	Maria Tambeña x C93.154	
17	397099.4	LR93.073 x LR93.050	
18	303381.3	C91.612 x I-1039	
19	303381.61	C91.612 x I-1039	
20	304347.6	C93.154 x I-1039	
21	304351.109	CHIEFTAIN x I-1039	
22	304351.31	CHIEFTAIN x I-1040	
23	304366.46	LR93.120 x I-1039	
24	304369.22	MARIELA x I-1039	
25	304372.7	MONALISA x I-1039	
26	304387.92	REINHORT x 92.187	
27	304399.15	SNOWDEN x 92.187	
28	304405.42	WA.018 x I-1039	
29	302498.7	YAGANA x C90.266	

Table A8: Potato highland tropics late blight resistant nursery.

#	Clone	Pedigree	Observations
1	389746.2	381379.9 x 386614.16	
2	391002.6	386209.1 x 386206.4	
3	391011.17	387041.12 x 386206.4	Good for French fries, chips
4	391046.14	386209.1 x 387338.3	Good for French fries, chips
5	391691.96	381381.9 x LB-CUZ.1	Serranita, Gold Purple, good for chips
6	393077.54	387348.2 x 389746.2	Good for chips
7	393085.5	387348.2 x 390357.4	Good for French fries, chips
8	393280.57	387015.3 x 386316.14	
9	393371.159	387170.16 x 389746.2	
10	393371.164	387170.16 x 389746.2	Good for French fries, chips
11	393371.58	387170.16 x 389746.2	Chugmarina, Kenya MPYA, good for French fries and table
12	393382.44	387205.5 x 387338.3	Good for French fries, chips
13	395015.6	393083.2 x 391679.12	
14	395037.107	391004.4 x 391679.12	Good for French fries, chips
15	395112.19	391686.15 x 393079.4	
16	396012.266	391004.1 x 393280.58	Good for French fries, chips
17	396034.103	393042.5 x 393280.64	Good for French fries, chips
18	396038.105	393077.54 x 393280.64	Good for French fries, chips
19	384866.5	376724.1 x Bulk Precoz	Amarilis – INIA*
20	377744.1	M-1266-14 Mex x 374035.1	Kori – INIA*
21	387164.4	382171.1 x 575049	
22	399049.22	395262.2x 395273.1	
23	399051.1	395273.2 x 395257.6	
24	399053.15	395230.1 x 395322.11	
25	399062.108	395285.5 x 395282.3	
26	399062.115	395285.5 x 395282.3	
27	399062.118	395285.5 x 395282.3	
28	399076.12	395266.2 x 395235.8	
29	399094.25	395322.3 x 395256.1	
30	399085.30	395296.2 x 395256.1	Altiplano - INIA*
31	392637.10	387143.22 x 387170.9	Good for French fries
32	385524.9	380475.4 x Bulk-1 (85LB54.11)	
33	399075.7	395266.2 x 395282.3	Puca Llicla*
34	399085.23	395296.2 x 395256.1	Pallayponcho*

*Name under which clone has been released as variety in Peru.

Table A9: Potato highland tropics late blight resistant and drought tolerant nursery.

#	Clone	Pedigree	Observations
1	380496.6	INDIA-1058 B x XY BULK	Chagllina-INIA
2	391002.6	386209.1 x 386206.4	
3	391011.17	387041.12 x 386206.4	Good for French fries, chips
4	391046.14	386209.1 x 387338.3	Good for French fries, chips
5	391058.175	387170.16 x 387338.3	Good for French fries, chips
6	391137.7	387181.5 x 387338.3	
7	392633.64	387132.2 x 387334.5	
8	392657.171	387341.1 x 387170.9	Good for French fries, chips
9	393073.179	387015.13 x 389746.2	
10	393220.54	381400.22 x 387170.9	Good for French fries, chips
11	393371.159	387170.16 x 389746.2	
12	396034.103	393042.5 x 393280.64	Good for French fries, chips
13	396034.268	393042.5 x 393280.64	
14	396038.101	393077.54 x 393280.64	
15	396038.105	393077.54 x 393280.64	
16	396029.250	392633.54 x 393382.64	
17	398180.289	392657.171 x 392633.64	
18	398190.404	393077.54 x 392639.2	Perricholi*
19	398190.571	393077.54 x 392639.2	
20	398193.553	391686.15 x 393079.4	
21	398193.553	393077.54 x 392633.64	

*Name under which clone has been released as variety in Peru.

Table A10: Potato highland tropics late blight resistant and virus resistant nursery.

#	Clone	Pedigree	Observations
1	393385.39	387231.7 x 387170.9	LB, PVX, PVY
2	391691.96	381381.9 x LB-CUZ.1	Serranita, LB, PVX, PVY, PLRV, good for chips
3	391580.30	387002.2 x 387214.9	LB, PVX, PVY, PLRV
4	393073.179	387015.13 x 389746.2	LB, PVX, PVY
5	393077.159	387348.2 x 389746.2	LB, PVX, PVY, PLRV
6	393079.24	387004.13 x 390357.4	LB, PVX, PVY
7	393079.4	387004.13 x 390357.4	LB, PVX, PVY, PLRV
8	393280.82	387015.3 x 386316.14	LB, PVX, PVY
9	393371.159	387170.16 x 389746.2	LB, PVX, PVY
10	393371.164	387170.16 x 389746.2	LB, PVX, PVY, good for French fries, chips
11	393382.44	387205.5 x 387338.3	LB, PVX, PVY, good for French fries, chips+E149
12	300046.22	392973.48 x 393613.2	LB, PVX, PVY
13	300056.33	95.071 x 387170.9	LB, PVX, PVY
14	394611.112	780280 x 676008	LB, PVX, PVY
15	397060.19	392739.4 x 392820.1	LB, PVX, PVY
16	397196.3	392797.22 x 388611.22	LB, PVX, PVY
17	385524.9	380475.4 x BULK-1	LB, PVX, PVY

Table A11: Potato highland tropics bacterial wilt resistant nursery.

#	Clone	Pedigree	Observations
1	391002.6	386209.1 x 386206.4	BW, LB, PVY
2	392657.8	387341.1 x 387170.9	BW, LB, PVY, PVX
3	395193.6	388611.22 x C92.030	BW, PVY, PVX
4	395446.1	BWH-87.446R x 393613.2	BW, PVY, PVX
5	395438.1	BWH-87.344R x 393617.1	BW, PVY, PVX
6	394904.20	720118.1 x C90.205	BW, LB, PVX
7	394895.7	BWH-87.230R x C90.205	BW, LB, PVX
8	392285.72	36.14 x 382157.3	BW, LB, PVY, PVX
9	394904.17	720118.1 x C90.205	BW, LB, PVX
10	392661.18	389743.1 x 390357.4	BW, LB, PLRV
11	396285.1	393617.1 x 104.12 LB	BW, PVY, PVX, PLRV
12	395443.103	BWH-87.289 x 385280.1	BW, LB, PVX
13	394199.2	C-282LM87B x 385305.1	BW, LB, PVY, PVX
14	394223.17	XY.13 x C-282LM87B	BW, LB, PVY, PVX

Table A12: Potato highland subtropics, short-medium growth cycle nursery (90 days from planting to harvest).

#	Clone	Pedigree	Observations
1	393371.58	387170.16 x 389746.2	
2	395037.107	391004.4 x 391679.12	
3	391046.14	386209.1 x 387338.3	
4	392637.10	387143.22 x 387170.9	
5	391002.6	386209.1 x 386206.4	
6	393077.54	387348.2 x 389746.2	
7	393371.159	387170.16 x 389746.2	
8	393371.164	387170.16 x 389746.2	
9	396012.266	391004.10 x 393280.58	
10	395109.29	391589.26 x 393079.4	
11	395111.13	391686.5 x 393079.4	
12	396038.107	393077.54 x 393280.64	
13	396033.102	392639.53 x 393382.64	
14	392633.54	387132.2 x 387334.5	
15	396034.103	393042.50 x 393280.64	
16	393248.55	387002.11 x XY.16	
17	396038.105	393077.54 x 393280.64	
18	396004.263	391002.6 x 393382.64	
19	396244.17	391580.3 x 392633.10	
20	391011.17	387041.12 x 386206.4	

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