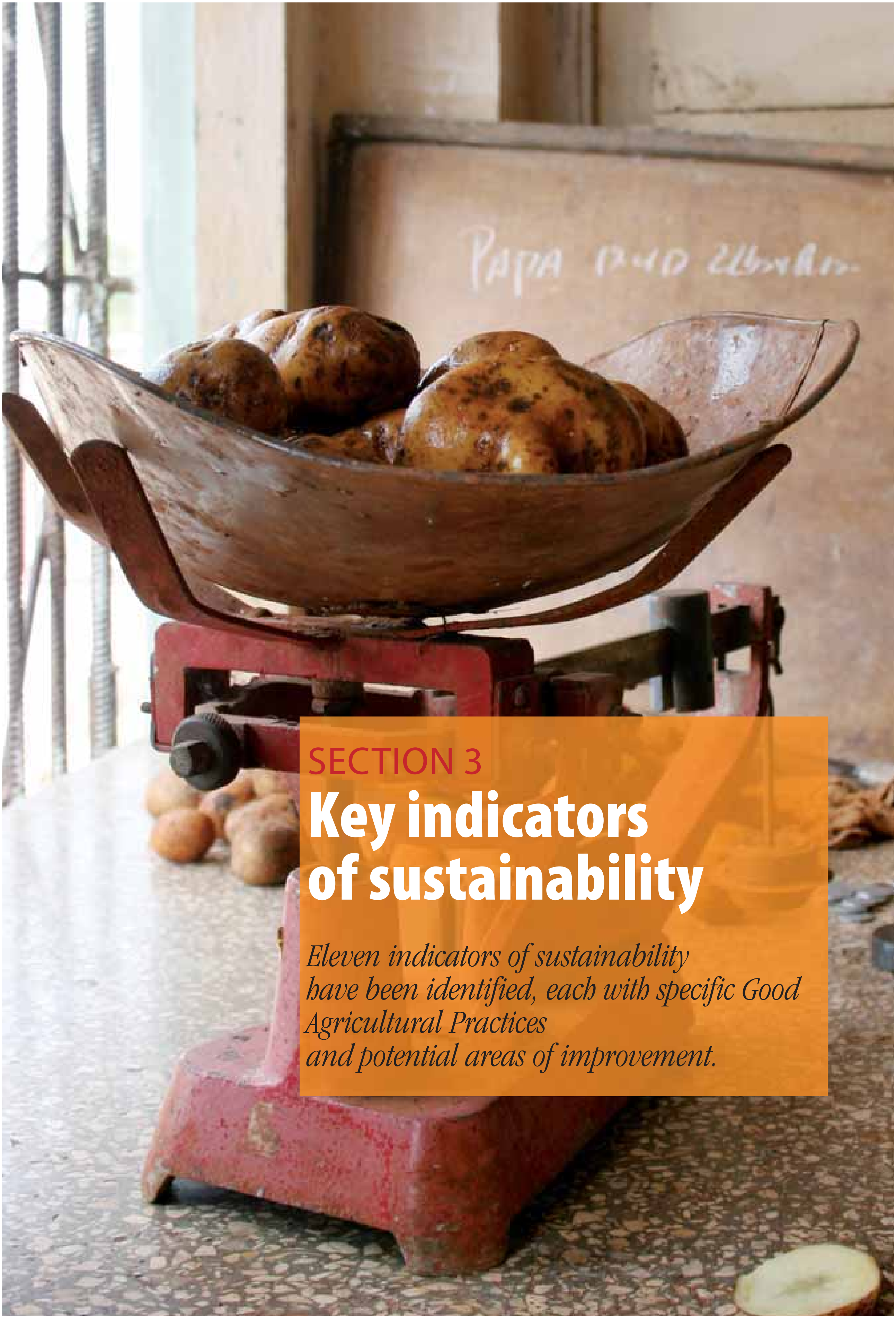


SECTION 3

Key indicators of sustainability

Eleven indicators of sustainability have been identified, each with specific Good Agricultural Practices and potential areas of improvement.

A potato park in the Andes

PAPA HALLAY, PERU
(PHOTO: O.S. BUTRON RIOS)

The 12 000 hectare Potato Park located in the Andes near Cusco is one of the few conservation initiatives in which local communities are managing and protecting their potato genetic resources and traditional knowledge of cultivation, plant protection and breeding. CIP has repatriated to the park hundreds of virus-free varieties of native potatoes which are now in full production and yielding 30 percent more than potatoes that have not been cleaned of viruses. The Potato Park helps preserve indigenous knowledge and ancient technologies, while ensuring that the production of native varieties remains under local control. The approach could serve as a model for other indigenous communities because biological diversity is best rooted in its natural environment and managed by indigenous peoples who know it best.

Biodiversity and varieties

The potato has the richest genetic diversity of any cultivated plant. Potato genetic resources in South American include wild relatives, native cultivar groups, local farmer-developed varieties ("landraces"), and hybrids of cultivated and wild plants. These varieties contain a wealth of valuable traits, such as resistance to insect pests and diseases, nutrition value, taste and adaptation to extreme climatic conditions. To control insect pests and diseases, increase yield and sustain production, especially on marginal lands, today's potato-based agricultural systems need a continuous supply of new, improved varieties, a process that requires access to the entire potato gene pool.

Also at national level in regions outside the Andes, maintenance of and increase in the genetic variability of available potato varieties are needed in order to ensure there is a sufficient broad genetic base for adaptation of the plant to local environmental conditions, such as temperature, day-length, moisture availability, and insect pest and disease pressures.

Good practices

Crop genetic diversity

- Facilitate efforts to conserve and sustainably use potato germplasm.
- Support breeding programmes and ensure conservation of breeding stocks.
- Breed varieties with high yield, high nutritional value, resistance to main diseases and high adaptability to less-favoured conditions.

Choice of potato variety

- Promote varieties adapted to the range of existing climatic conditions to ensure wide adaptability and stable production.
- Abandon varieties with poor storage characteristics and low levels of resistance to major diseases.
- Promote varieties that are already grown in the country and are accepted by farmers and markets.
- Support participatory evaluation of candidate varieties from breeding programmes and other countries for local testing and release.

FROM THE ESSAY, "HARVEST OF NATIVE POTATOES, PERU." (PHOTO: EITAN ABRAMOVICH SAMESAS)

Potential areas of improvement

- More effective national potato breeding programmes.
- Adaptation of breeding objectives and targets based on local expected results and needs.
- Focus breeding programmes on achieving long term benefits, including not only resistance to insect pests and diseases but also high, stable yield, greater resource-use efficiency, nutritional quality, and good storability.
- Disseminate complementary conservation methods, especially the conservation of biodiversity carried out by farmers (in situ/on-farm conservation).
- Reinforce "potato park" initiatives through repatriation of biological diversity to farmers' communities.

TAKING TIME TO CLEAN HARVESTED POTATOES, THE PHILIPPINES.
(PHOTO: ARTEMIO LAYNO)

Seed production and seed quality

A reliable supply of good quality seed is crucial to the development of the potato subsector. Availability of seed remains one of the main constraints to the large scale adoption of research-bred or research-derived improved varieties.

Good quality seed is essential to high yields and is usually the most costly input to potato cultivation, accounting for 30-50 percent of production costs. The improvement of seed quality will contribute to enhancing farmer efficiency and competitiveness. The most important seed quality characteristics are variety purity, physiological stage, seed size, seed health and physical aspect.

Good practices

Seed production

- Supply seeds that meet strict quantity, timing, and quality-control requirements.
- Grow seed in the best and coolest areas or time of the year in order to avoid insect populations that can transmit diseases.
- Where potatoes can be grown year-round, encourage farmers in a seed production area to include a "potato-free" period in the farming calendar in order to break cycles of insects that act as vector for virus diseases.

Purity of variety

The use of varieties with better quality and greater adaptability to marginal environments will help to enhance potato production and ensure the sustainability and competitiveness of potato-based farming and utilization systems.

- Seed should be of the same variety as that by which it is sold.
- Use varieties that are adapted and stable in term of yields.

Where appropriate and where farmers currently use mixes of different varieties, ensure the added benefits of such mixtures in terms of tolerance to diseases and ensure that farmers have adequate knowledge, infrastructure and guidelines to apply best practices for seed production.

Physiological stage

Physiological development of a seed tuber is categorized as follows:

- Phase I = dormant period;
- Phase II=apical sprouting;
- Phase III=period of normal sprouting;
- Phase IV=period of thin sprouts;
- Phase V= incubated – too old seed tubers.

As the physiology of the seed is a major factor in seed quality, storage systems and storage duration are critical aspects to be considered. To obtain a high yielding crop, seed should be at the correct physiological age and sprouting stage at planting, depending on the purpose of the crop. In principle, seed should be at least three months old before it is planted, and no older than 5-11 months (depending on variety, storage system and temperature).

POTATO HARVESTING IN NEPAL. (PHOTO: G.M. BAKASH)

- Provide a storage area with good air circulation and adjustable lighting.
- Store only seed tubers taken from healthy plants and ensure they are devoid of storage diseases such as late blight, bacterial rot and silver scurf.
- About one month before planting, pre-sprouting of seed potatoes should favour quick emergence at planting time.
- In the tropics, if no refrigerated storage capacity is available, store seed potatoes under diffuse light in order to maintain their sprouting capacity (i.e. help tubers stay physiologically young for longer) and to encourage development of vigorous sprouts.

Direct sunlight on potato seed should be avoided. Therefore:

- For long-term storage, store seed potatoes either at 2-4°C or, when stored at higher temperatures, in diffused light.
- The period between planting and emergence should be kept as short as possible in order to make best use of the available growing season. Therefore, at planting time the seed should be at a physiological stage that allows a quick emergence.
- For planting, the best stage is phase III (robust sprouts having their typical varietal colour), the "normal multi-sprouting" phase.
- Put bulked seed potatoes in trays to stimulate more uniform sprouting.

Seed size

- Use seed of uniform size, ranging from 25 to 50 mm or weighing between 30 to 80 g, depending on tuber size and shape.
- Plant tubers which have little variation in size. Using seed with a wide variation in size will not produce a uniform crop and makes it more difficult to predict the plant density and properly manage the crop.
- Use large tuber seed when soil and weather conditions at planting are unfavourable, the growing season is short, or where there is the risk that during the first part of the growing season, the crop may be damaged by night frost, hail or drought.
- Large tubers may be cut into smaller pieces for planting to reduce seed costs and favour a more uniform crop. This should be done at least two weeks before planting in temperature conditions of between 10 and 22°C to allow wound healing prior to planting. However, precautions are needed to avoid transmission of viruses via the cutting blades.

Seed health

Seed potato is generally the main source of insect pest and disease infection, because most seed-borne diseases are systemic, thus favouring disease transmission to the next tuber generation. Seed treatment with chemicals can never replace the use of high quality seed or proper handling, storage and sprouting. Therefore:

- Use only disease-free seed.
- Produce seed tubers in disease-free areas

FROM THE PHOTO ESSAY, "BELARUS SOLDIERS EAT POTATOES." (PHOTO: VIKTOR DRACHEV) and on land not infested with soil-borne diseases or insect pests.

- Ensure proper sanitation by using clean tools when cutting seed to avoid diseases transmitted mechanically.
- Practice crop rotation and remove potato volunteers when cultivation and weeding are implemented.
- Adopt strict rotation procedures, and never use the same field more than once in a 3-4 year period.
- Rogue out diseased plants, including tubers, stolons and roots, being careful to avoid spilling soil on healthy plants, and bury them in a pit outside the field.
- In the tropics, use storage areas with good air circulation and adjustable lighting.
- Disinfect storage structures every year by spreading lime (use of dangerous chemicals such as formalin is not necessary).
- Clear away potato residues, sacks and other waste, as these can be breeding grounds for potato tuber moths and diseases.
- Remove and destroy seed tubers infected by diseases or insect pests during storage.
- Make routine observations to identify insect pest- and disease-infected tubers in storage.
- Routinely control the temperature in the potato heap (bulk) to ensure that no rotting occurs. Rot processes are likely to emerge when bulk temperature suddenly increases.

Diffuse light storage for seed potato tubers

In tropical areas such as the Central African highlands, where cold storage is unavailable or too costly, smallholder growers store their seeds on the farm. The efficiency of their simple home storage facilities could be dramatically improved with use of diffuse light technology. Diffuse light stores (DLS) are most suitable where temperatures are moderate (no frost or extreme high temperatures) and seed has to be stored for more than four months. By using DLS, farmers are able to store their own seed stocks, instead of buying them from distant suppliers. However, the loading capacity of DLS is limited since all tubers must be exposed to the diffuse light. These stores are suitable generally for small seed units and not for large scale seed production schemes. Seed potatoes stored in diffuse light give a more vigorous crop than seed that has been stored for relatively long periods in the dark at higher temperatures. However, the DLS must be protected against aphids (e.g. with an aphid proof screen) to avoid the risk of infection and transmission of viruses such as potato virus Y and potato leaf roll virus. Since the aphid population increases throughout the storage phase, stringent control measures need to be put in place to reduce seed degeneration.

Capacity-building for seed potato selection

A technique known as "positive selection" was pilot-tested by smallholder potato farmers in the Narok district of Kenya as a way of improving the quality of their seed potatoes. Positive selection involves marking healthy-looking mother plants for later seed collection. More than 100 extension workers and farmer-trainers were trained in all aspects of positive selection, and then assigned to work with some 1 200 farmers organized in 70 farmer groups. A participatory research approach was used, with a demonstration experiment forming the core of the training curriculum. All activities took place in the potato field, and the mode of teaching was "learning by doing". The farmer groups met regularly, learning first how to distinguish between sick and healthy-looking plants in the potato field. Next, a comparative study divided the potato field was into two parts: one where positive selection was used and one where the farmers used their traditional methods. Tubers from the two different selection methods were planted separately the next season, and the group analysed the results. Within the positive selection field, potato yields increased on average by about 30 percent. A survey two years afterwards showed that more than one quarter of the farmers trained had adopted the positive selection method. These farmers reported that their yields had doubled.

Seed systems

In most developing countries, the vast majority of smallholder farmers use farm-saved seed potato obtained from non-specialized seed growers, owing to the lack of commercial seed production systems or, where they exist, to the high price of certified seed. Farmer-based informal seed systems are generally unable to maintain seed quality or eliminate diseases such as bacterial wilt or viruses. Poor functioning seed systems are consistently ranked by CIP as being among the major constraints to improved potato production.

Good practices

- Train seed growers in seed quality maintenance and managing bacterial wilt and viruses.
- In order to avoid multiplying different categories of seed in the same locality and to sustain the replenishment of quality planting stock, promote a permanent "flush-out" system that prevents multiplication of lower categories of seed.

Potential areas of improvement

Much effort has been made in the past to improve seed potato production in developing countries, usually through specialized seed companies. However, commercially produced seed potatoes remain beyond the reach of many smallholder producers, especially in sub-Saharan Africa, where producers rely on farm-saved seed. Simple, low-cost technologies are therefore needed to help developing countries produce and distribute the healthy and high quality seed tubers needed for sustainable and profitable potato production.

- Develop participatory research and promote appropriate technologies to improve the quality of farm-saved seed in sub-Saharan Africa and other parts of the world.
- Identify localities with low vector pressure and communicate the value of positive and/or negative selection (rouging) practice for the production of potato seed
- Determine the degeneration rate of seed potatoes, by variety and location, so as to determine how much basic seed needs to be produced annually.
- Introduce laboratories for disease diagnostics to identify seed-borne viruses, bacteria and fungi.
- Introduce rapid multiplication techniques and encourage small enterprises to produce healthy material.
- Develop new methods to ensure the production and delivery of high quality potato planting material and improve formal and farmer-based seed systems.
- Develop legislation and accreditation systems for seed certification adapted to local conditions.

FROM THE PHOTO ESSAY, "BELARUS SOLDIERS EAT POTATOES." (PHOTO: VIKTOR DRACHEV)

Soil health and fertility management

Maintaining a high yielding potential in potatoes requires soil health and fertility management. Soil health depends on physical and chemical properties and functions, organic matter and biological activity, which are fundamental to sustaining agricultural production and determine, in their complexity, soil fertility and productivity.

Crop fertilization requirements need to be correctly estimated according to the expected yield, the potential of the variety planted and the intended use of the harvested crop. Before application of fertilizers, farmers should perform, where possible, a soil test to identify soil characteristics, nutrient content and soil contaminants. Soil tests help assess fertility and indicate deficiencies that need to be addressed.

Good practices

Potato should be planted with organic fertilizer, such as farmyard manure where possible and as appropriate. As well as supplying nutrients to the crop, organic fertilizer often increases the efficiency of inorganic fertilizers, improving crop yields substantially, and also improving soil health, which could have a positive effect by helping to reduce soil borne diseases.

Farmyard manure

- Of all field crops, potato has the best response to farmyard manure. Use well-decomposed farmyard manure at a rate of 10 tonnes per hectare or more, if available.
- Precautions should be taken to reduce nitrogen applications by 30 percent, if inorganic fertilizers are applied at the same time.
- Avoid using fresh, incompletely decomposed manure because it will become active too late in the season and may reduce dry matter content, delay maturity and transmit diseases (e.g. *Rhizoctonia solani*).

Fertilizers

- Prior to planting, make a planting bed with some 20 cm of loose soil mixed with fertilizer and/or manure to allow proper rooting and hilling.
- In moist soil, apply fertilizers at the root zone (25-28 cm) where they are most effective.
- To be more effective, place phosphates in the root area because, unlike nitrogen and to some extent potassium, phosphates have limited movement in the soil and within plants.
- Use of fertilizers is advantageous when levels of soil fertility are low.

Potential areas of improvement

- Promote conservation agriculture approaches to soil health and fertility management.
- Support integrated crop, soil health and fertility management programmes.
- Conduct research and development based on adequate use and conservation of natural resources.

notes

Nutrient management

Sustainable nutrient management involves a set of management practices designed to conserve soil resources, maintain or enhance productivity, and help reduce growers' reliance on chemical fertilizers. Due to its relatively poorly developed and shallow root system, the potato demands a high level of soil nutrients. Without balanced fertilization management, growth and development of the crop are poor and both yield and quality of tubers are diminished.

The type and extent of nutrient management depends on the production potential of the area in which potatoes are cultivated and farmers' productivity objectives. Farmers should be advised to perform a soil test before application of fertilizers – fertilization is highly dependent on location and blanket recommendations are not applicable. They should also be aware of the effect of the soil pH on nutrient supply and the type of fertilizer to be used.

Good practices

Crop response to fertilizers varies from field to field. The fertilizer ratio of N-P-K often recommended and practiced is usually 1:1:1. However, high yields and enhanced quality of tubers can only be sustained through the application of optimal nutrient doses in balanced proportions.

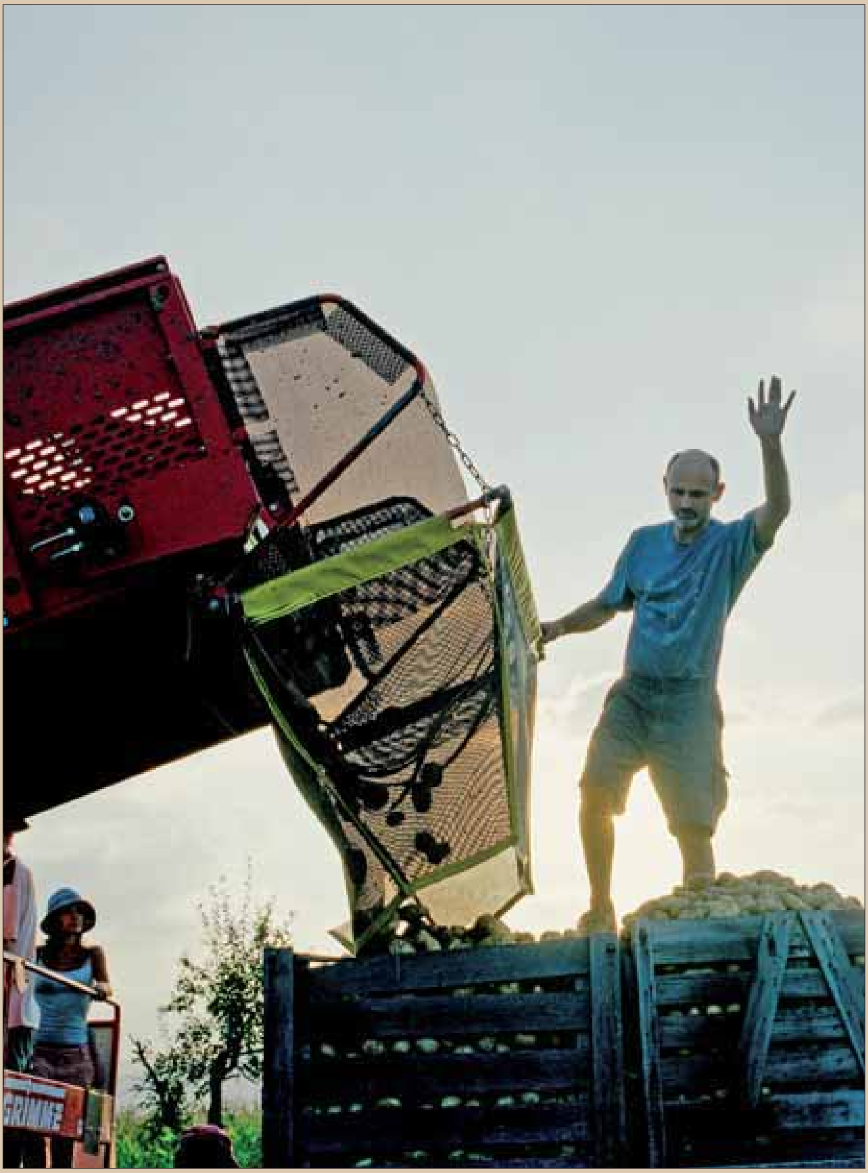
Nitrogen. The amount of nitrogen applied to a potato crop varies from 100 to as much as 300 kg/ha depending on the purpose of the crop and soil characteristics.

- Avoid high or excessive nitrogen dressing as it stimulates haulm growth, delays tuber formation and affects tuber quality (low dry matter content, high reducing sugar content and high protein and nitrate content).
- Apply nitrogen shortly before, or at, planting time. However, if there is a risk of leaching (e.g. with heavy watering on light soils), or if the application of large quantities of fertilizer under dry conditions may cause scorching, a split application may be better. The second nitrogen application should, in general, be given no later than three to five weeks after crop emergence.

Phosphorus. Phosphorus contributes to the early development of the crop and early tuberization. It increases the crop's dry matter content and improves the tuber's storage quality. Often more than 100 kg/ ha is applied, while on phosphorus-fixing soils much higher doses are used.

- Apply the total amount of phosphorus before or during planting.
- Apply phosphorus in the planting furrow in P-fixing soils.

Potassium. Potassium not only improves yields but also improves tuber quality (size, starch content and storability). An adequate supply of potassium can help reduce internal blackening and mechanical damage, and has been



HARVESTED POTATOES BEING LOADED INTO CRATES.
(PHOTO: PASCAL BASTIEN)

associated with increased stress tolerance.

- Apply the total amount of potassium before or during planting.

Magnesium

- Close attention should be paid to magnesium requirements, particularly when potatoes are grown on light acid soils. High rates of potassium, and nitrogen application in the form of ammonium, reduce the uptake of magnesium.

Calcium

- Potatoes are tolerant to soil acidity. Below pH 4.8, however, the crop may fail due to calcium deficiency. Liming may be necessary.
- Seed potatoes, in particular, need to be grown in soils with sufficient calcium. Calcium deficient seed tubers may fail to sprout properly.

Foliar fertilizers

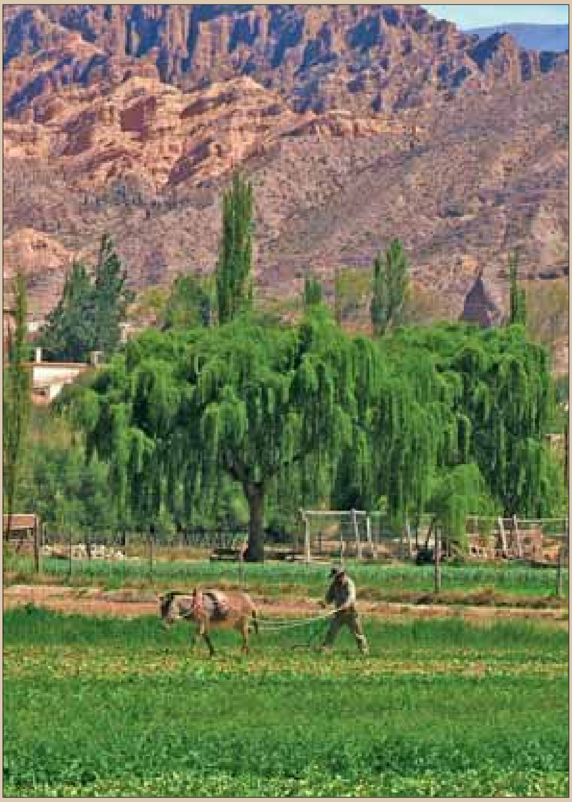
- Foliar fertilizers contain major nutrients and also micronutrients. They are applied to and absorbed by the leaves and have therefore an immediate effect on plant growth. They may help to overcome apparent nutrient deficiencies, especially of micronutrients, and support plant recovery following stress events, such as frost and drought.

Potential areas of improvement

- Promote the establishment of laboratories where soil mineral content can be assessed prior to planting. Laboratories can also verify the claimed concentrations of N-P-K in commercial products.
- Promote the development and use of decision support systems that help growers apply fertilizers according to soil mineral content and crop needs.
- Encourage fertilizer companies to market compound fertilizers with compositions of N, P and K tailored to different soil types.
- Support integrated crop management (ICM) programmes and integrated nutrient management systems for potatoes.
- For the fertilization of crop mixtures that include potato, the Nutrient Supplementation Index (NSI) concept can help estimate the additional percentage of N, P, K and Ca needed to satisfy the needs of a 1:1 row intercrop (e.g. potato-corn). NSI estimates total fertility input needs for the multiple cropping system based on the nutrient uptake of each crop component relative to their monoculture uptake. With NSI, intercrop fertilizer needs can be estimated from established sole crop response curves for the component species. Alternatively, fertilizer needs for the multiple crop system can be estimated for a given planting pattern using the response equations of one or more of the component crops.
- Develop nutrient management practices for potato production under conservation agriculture.

The advantages of conservation agriculture

Conservation agriculture (CA) aims at enhancing natural biological processes both above and below ground. It is based on three principles: minimum mechanical soil disturbance, permanent organic soil cover, and diversified crop rotations for annual crops and plant associations for perennial crops. By minimizing soil disturbance, CA creates a vertical macro-pore structure in the soil, which facilitates the infiltration of excess rainwater into the subsoil, improves the aeration of deeper soil layers, and facilitates root penetration.



POTATO FARMING IN ARGENTINA.
(PHOTO: H.C. CUEVAS)

Soil conservation

Soil erosion on tillage-based cultivated lands is a problem that continues to threaten the sustainability of both subsistence and commercial agriculture in potato growing areas around the world. Potato cultivation usually involves intensive soil tillage throughout the cropping period, which often leads to soil degradation, erosion and leaching of nitrates. During soil preparation, the entire topsoil is loosened and – particularly on sticky clay soils – pulverized into small aggregates to avoid the formation of clods in the potato beds. Mechanical weeding and mechanized harvesting also entail intensive soil disturbance.

Good practices

The use of mulch at planting and the "no-till" land preparation method are recommended to reduce soil degradation, erosion and nitrate pollution and to restore degraded soils and achieve good potato yields with reduced need for fertilizer. The mulch protects the soil from erosion during the first weeks of the crop.

A green manure crop can be seeded towards the end of the crop, as the potato plants are drying off. The cover crop will help to dry out the potato beds, contributing to healthier tubers with reduced risk of damage during harvest. Nevertheless, while mulch planting of potatoes reduces the risk of erosion and nitrate leaching, it may have some disadvantages (e.g. excessive moisture and reduced soil temperature leading to retarded plant emergence). Hence it should not be a blanket recommendation.

The "no-till" potato is pressed into the soil surface, and then covered with a thick layer of mulch, preferably straw, which is fairly stable and does not rot quickly. The young potato tubers form under the mulch but above the soil surface. In some cases – for example in dry areas under drip irrigation – black plastic sheets can also be used as mulch. Holes are punched in the plastic to allow the potato plant to grow through it. During harvesting, the sheets are removed and the potatoes are simply "collected". Currently, the "no-till" potato is only grown in small fields using manual labour.

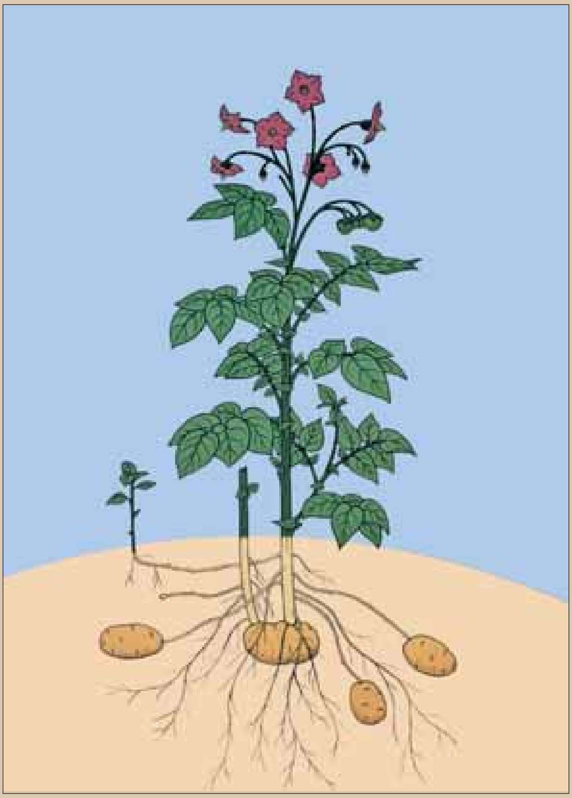
Potential areas of improvement

- Promote conservation agriculture approaches as a resource-saving crop production system.

Principles of potato plant health management

Incorporation of the following practices into the production scheme should result in optimal health of the potato crop:

- Plant healthy seed tubers from reliable sources.
- Select and prepare planting site, and choose cultivars, planting and harvest dates with disease and insect pest management in mind.
- Handle and plant seed potatoes to ensure rapid emergence, and protect foliage using a holistic crop protection approach or integrated production and pest management.
- Minimize tuber infection by timely killing or removal of vines before harvest; avoid tuber injury and cure tubers before long term storage.
- Manage storage conditions to minimize post-harvest deterioration.



POTATO PLANT
(CIP)

Pest management

Potato diseases are spread by insect vectors, seed and wind, running water, soil, sacks and implements. Seed is generally the main source of infection. Combating insect pests, diseases and weeds with intensive use of insecticides, fungicides and herbicides can harm the environment and pose a serious threat to the health of producers and consumers.

Regular field monitoring for pests and the broader agro-ecosystem is the basis for ecological-based plant protection and pest management. For example, aphid monitoring and consequent adjustment of planting and harvest dates would deserve special attention as a feasible knowledge-based practice in the context of insect pest management. However, the management of potato late blight is difficult without fungicides. Therefore, the use of biocides is acceptable, and often considered as a component of integrated insect pest and disease management schemes.

Good practices

- To increase potato production while protecting producers, consumers and the environment, use insect pest and disease management strategies that encourage biological control of insect pests, varieties with insect pest and/or disease resistance, planting of healthy seed potatoes, the growing of potatoes in rotation with other crops, and organic composting to improve soil quality.
- Whenever possible, use rotations that reduce insect pest and disease problems and avoid those that may increase them. In general, avoid solanaceous crops as rotation choices.
- Control volunteer potato plants and weeds in the rotation crop.
- Avoid build up of weed seeds in the soil by removing weeds before they flower and set seeds.
- Reduce or eliminate weed seeds in soil through conservation agriculture approaches to weed management.

Fighting potato late blight

In developing countries, farmers generally lack knowledge of late blight (LB) control measures, and have limited or no access to resistant varieties and agricultural inputs needed to control potato LB effectively. CIP is working on different fronts to develop alternatives to control LB. In recent decades, its breeding programme has developed LB-resistant varieties adapted to smallholder farming conditions in tropical environments. Some of these varieties are already being cultivated in several countries in Latin America (Bolivia, Colombia, Ecuador, Peru), in Africa (Ethiopia, Uganda, Rwanda, Tanzania) and in Asia (China, India). CIP has also developed technical principles for optimizing fungicide use, and for designing and adapting participatory research and training methods to deal with the complexities of LB management. The experience in LB management accumulated so far has shown that returns on investment in controlling the disease are high, with marginal rates of return ranging from 260 percent to 1360 percent. These are especially significant for resource-poor farmers for whom potato cultivation represents an important coping strategy. Support is needed to help optimize this impact by scaling up and out the technologies and methodologies developed by CIP.

Pesticides and the environment

Improper use of pesticides in potato cultivation is a major environmental concern. The most widespread and intensive use of pesticides in developing countries is for control of late blight (LB) potato disease. Farmers in some countries spray their potato fields more than 10 times during a single growing season of 4 to 6 months to combat this disease. Biocides are a health risk to farm families and farm workers engaged in potato production. With the emergence of new and more virulent strains of LB, even more frequent (and increasingly ineffective) applications of pesticides are being made, raising the risk to human health and the environment. The spread of pesticides or fertilizer residues into water supplies through irrigation systems or field run-off contribute to water pollution that damages plants, insects and livestock, and poses a serious threat to drinking water and to water used for post-harvest activities. Concern over environmental and health impacts, combined with the better appreciation of the damage different diseases and insects cause to the potato, have led to the development and diffusion of alternative technologies including disease-resistant varieties and integrated management (IDM/IPM) techniques.

Potential areas of improvement

- Develop approaches that are specific to the target pests and have the least harmful effect on other organisms, human health or the environment.
- Develop decision support systems that assess disease or insect pest pressure and identify the most appropriate timing and dosage of chemical interventions.
- Ensure that when there is a need to apply pesticides, appropriate equipment is used and measures are taken to reduce risks during handling of the pesticides.
- Establish laboratories to verify compounds and concentration of the active ingredients in pesticides.
- Support facilitation of CIP's integrated pest/disease management (IPM/IDM) programme, FAO's IPM and any other IPPM approach through Farmer Field Schools or other formal or informal extension programmes.
- Always aim for reduced use of pesticides by applying IPM practices. If pesticides must be applied, use only products registered in the country, give preference to comparatively less toxic pesticides strictly follow usage recommendations and ensure that farmers and farm workers use properly functioning protective equipment.
- Promote conservation agriculture approaches to crop health management.

AN IRRIGATED POTATO FIELD IN CAPE VERDE.
(PHOTO: MARZIO MARZOT)

Water management

In potato production, shortages of water are usually one of the most important constraints to higher yields. Achieving better yields requires an adequate water supply from planting until maturity. The main effect of drought or water stress on potato is yield and size reduction.

Frequent irrigation reduces the occurrence of tuber malformation. For the potato, the critical period for water deficit is during tuber development. Water deficit in the early phase of yield formation increases the occurrence of spindled tubers (more noticeable in oval than in round tuber varieties) and, when followed by irrigation, may result in tuber cracking or tubers with "hollow hearts". Therefore, water supply and scheduling have important impacts on potato growth, yield and tuber quality.

Good practices

- Match water application to the potato crop's water requirements and maintain adequate soil moisture to maximize yield. For best yields, a 120 to 150 day crop requires from 500 to 700 mm (20 to 27.5 inches) of water.
- Avoid water deficits in the middle to late part of the growing period – deficits during stolonization, tuber initiation and bulking tend to reduce yield.
- Allow higher depletion toward the ripening period (a practice that may also hasten maturity and increase dry matter content).
- Where water supply is limited and salinity might become a problem, use of a technique known as "partial root-zone drying" increases water use efficiency. Potatoes are planted in furrows so that one side can be irrigated and the other kept dry in one watering cycle; the opposite furrows are watered in the following cycle.
- Use no-till and soil cover to minimize soil evaporation.

Potential areas of improvement

- Support research aiming at developing drought tolerant and resistant varieties.
- Improve irrigation and fertilization techniques using conservation agriculture approaches.

notes

Post-harvest management

Since harvested tubers are living tissues and therefore subject to deterioration, proper storage is essential, both to prevent post-harvest losses of potatoes destined for fresh consumption or processing, and to guarantee an adequate supply of seed tubers. The storage of potatoes is intended:

- to preserve them in first class condition for consumption by the grower and customers;
- to add value and increase profit through off-season sales or during the more lucrative high-price season;
- to preserve tubers for planting in the next season.

For ware and processing potatoes, storage aims at preventing "greening" and losses in weight and quality. In potato storage, the two critical environmental factors are temperature and humidity. Adequate and unrestricted air movement is necessary to maintain constant temperature and humidity throughout the storage pile, and to prevent excessive shrinkage from moisture loss and decay. The storage temperature affects curing and wound healing processes, the spread and severity of disease, sugar-starch balances, and respiration. Respiration, in turn, influences dormancy or sprouting, and weight loss. High humidity is essential for optimum wound healing during the curing period.

It is also essential throughout the storage period in order to minimize tuber weight loss – weight loss rapidly increases at relative humidity levels below 90 percent.

Depending on variety and conditions during growth, at 10-13°C and 93 percent humidity, potatoes store for 1-3 months; at 8-10°C
and 93 percent humidity for 2-5 months; at 5-8°C and 93 percent for 4-8 months; at 2-5°C and 93 percent humidity for 7 months.

Good practices

- Store well cured potatoes that were harvested when ripe (2 weeks after foliage death) in a well-ventilated, dark, cool place at about 4°C (where refrigeration is an option) with humidity around 90 percent. The potatoes will store for roughly three to six months.
- Store only tubers that are mature and free of diseases, insect pest and physical damage such as bruising. Research has demonstrated that potatoes from healthy plants are much more resistant to storage decay than potatoes from plants that have been weakened from physiological stresses.
- Handle the tubers carefully throughout the harvesting and pre-storage operations in order to minimize bruising, skinning and cutting. Ideally, the harvest should be carried out in temperatures of between 10-18°C. Do not harvest when tuber pulp temperature is less than 8°C or more than 20°C.
- Remove soil and plant residues before placing potatoes in storage.
- A wound healing or curing period is

COLLECTING POTATOES IN DIENG PLATEAU, INDONESIA. (PHOTO: HARJONO DJOYOBISONO) necessary to prevent the entry of rot organisms and to reduce water loss. Wound healing occurs most rapidly at 15-18°C, with 95 percent humidity, and requires 5-20 days.

- Pile potatoes without refrigeration in several small piles rather than in one large heap. Large amounts tend to heat because ventilation cannot reach the centre of the pile, thus lowering quality and shortening storage life.
- Never store potatoes in close proximity to fruit – hormones produced by ripening fruits will cause the potatoes to sprout or rot prematurely.
- Storing ware potatoes at a temperature of less than 6°C stimulates the conversion of starch into sugars, giving the tubers an unnaturally sweet taste. Moreover, sugars will interact with free amino acids during frying, producing dark products with poor taste.

Potential areas of improvement

- Promote improvements in harvest technologies to minimize bruising, improve tuber quality and storability.
- Develop and promote low-cost storage technologies suitable to small-scale farms in the tropics and subtropics.
- Carry out ex-ante cost-benefit studies on small or large scale refrigerated storage capacity.

Adding value in East Africa

A study was conducted recently across the East African region to estimate the potential size of the market for fresh and processed potato in selected cities in Burundi, Ethiopia, Kenya, Rwanda, Tanzania and Uganda. Findings show that establishment of a viable industry for processed potato hinges on improvements in quality standards and packaging and premium prices for quality produce. The study said that expanded potato processing would increase employment opportunities in city areas. With half of East Africans expected to live in urban areas by 2015, the boom in demand for potato chips and French fries looks set to continue.

Enhancing the value chain and markets

Learning to innovate and engage with markets, and to become more competitive are main challenges facing small-scale farmers. However, in many low-income developing countries, potatoes are typically marketed through fragmented chains with little coordination and poor information flows, giving rise to high supply risks and high transaction costs. Average yields remain far too low to enable small-scale potato growers to produce a marketable surplus, preventing them from increasing their participation in potato marketing systems. In addition, limited storage and transport facilities can adversely affect the quality of tubers after harvest. Efforts to enhance the value chain will only be successful provided there are substantial levels of public and private investment in the subsector, such as in breeding programmes, infrastructural improvements and initiatives to support and coordinate activities along the chain. Policy-makers should increase support to the subsector, by – for example – extending to the potato sub-sector policies and resources traditionally focused on cereals and on cash crops for export.

The Participatory Market Chain Approach

The Participatory Market Chain Approach (PMCA) was developed by the Papa Andina Regional Initiative conducted in Bolivia, Ecuador and Peru by the International Potato Center (CIP). The aim of Papa Andina is to improve the competitiveness of potato market chains and small potato producers. PMCA has proven effective in strengthening innovation capacity and developing market chain innovations that benefit small farmers as well as processors and distributors. Valuable capacities for innovation have been developed, particularly in the realms of knowledge, attitudes, skills, and social capital. These new capacities are potentially valuable assets for stimulating future innovations in market chains. The benefits of the PMCA have stimulated considerable interest in the approach among R&D organizations, policy makers and market chain actors.

Value addition and markets

With its adaptability to a wide range of uses, the potato has a potentially important role to play in the food systems of developing countries. In fact, in many countries, growth in urban populations, rising incomes and dietary diversification have led to rapidly increasing demand for potatoes from the fresh market, fast food, snack and convenience food industries. The structural transformation of agriculture-based economies into more urbanized societies opens up new market opportunities for potato growers and to their trading and processing partners in the value chain. In order to tap such potential, an efficient value chain for potato needs to be established.

Often potatoes are purchased in the countryside by traders from cities, with very limited negotiation and with prices decided at the farm gate, resulting in an uneven distribution of income along the value creation chain. This leads to insufficient buying power among potato growers and the draining away of capital that could be invested in rural areas to build infrastructure such as roads and improve education.

Good practices

- Carry out consumer surveys to identify growing market segments and types of products likely to be in demand in the near future.
- Develop and select cultivars that are preferred by consumers, processing industries or local exporters.
- Use appropriate post-harvest practices and storage facilities to keep tubers in their most edible and marketable condition.
- To increase value, provide high quality ware potatoes or potato products to consumers.
- Use simple market-oriented technologies that transform potato tubers into stable high quality products.
- Encourage farmer participation in producer groups and organizations in order to increase their market competitiveness and bargaining capacity and strengthen their position within the potato value chain.

Potential areas of improvement

- Support participatory market chain approaches for potato (see box).
- Develop innovative marketing and utilization techniques linking small scale potato producers to new market opportunities.
- Promote mechanisms and approaches to link technology suppliers with farmers' needs, based on opportunities identified within a market chain framework.
- Organize growers in cooperatives for joint purchase of inputs such as fertilizers and for joint processing and trading so that a greater proportion of the potato value chain remains in the hands of producers.

POTATO HARVESTING.
(PHOTO: FAO)

Farmers' health, safety and welfare

The health, safety and welfare of farmers and consumers are vital assets for the sustainable development of the potato subsector and agriculture throughout the world. Particular attention must be paid to reducing risks associated with the use of pesticides, tools and machinery, and to ensuring that potatoes are produced and handled in a manner that does not harm the environment and the health, and safety of farmers and consumers.

Good practices

- Creating awareness of food safety and environmental issues should be part of community education programmes in rural areas.
- Train farmers in the efficient and safe use of pesticides, fertilizers, tools and machinery
- Encourage them to invest in potato farming, and in improving their living standards.
- Use decision support tools to reduce the amounts of biocides used in potato production and thus reduce the risks of dangerous levels of residues in harvested or stored produce.
- Ensure that medical doctors and hospitals in rural areas are able to recognize symptoms of agrochemical poisoning and treat it.

Potential areas of improvement

- Farmers groups should consider developing partnerships with public sector and development organizations to address health and safety issues.
- Create services that collect pesticide packing material and unused redundant stocks for centrally organized destruction.
- Inform farmers and households about proper pesticide labelling and the designation of containers used to mix pesticides, and the use of properly functioning protective equipment and clothing.
- Establish a list of chemicals that are generally safe for various crops and a "black list" of chemicals that are dangerous and are forbidden.
- Set maximum residue levels for agrochemicals that are permitted for use in the country.
- Organize farmers groups in cooperatives to promote their interests and call for positive marketing regulations, lower duties and taxes on imported tools and equipment, and better access to credit to improve their self-reliance and welfare.

SECTION 4

Implications for policy and research

Potato production in the developing world grew from 85 million tonnes in 1991 to 165 million tonnes in 2007. To sustain that exceptional growth, policy and research must shift from the traditional focus on raising production to a broader approach aimed improving rural incomes, livelihoods, nutrition and health, while conserving the natural resource base.

"Papa pan", a pro-potato policy solution

Although the potato has been a staple food for Andean peoples for millennia, many modern Peruvians prefer rice or bread made from imported wheat. To support domestic potato production, the Government of Peru has offered low-income potato farmers emergency credit to maintain production and encourages Peruvians to eat a greater proportion of potatoes, thus boosting demand and prices. The government is also promoting the use of potatoes to make bread. A government-run food company produces each day more than 12 000 loaves made from one-third boiled and mashed potatoes and two-thirds wheat flour. Replacing a third of the wheat flour with mashed potatoes or potato flour results in a soft, tasty bread that keeps well, and is more nutritious and cheaper than bread made from wheat only. Since January 2008, Peru's prisons and many public schools have been serving potato bread (papa pan). It is also sold by Plaza Vea, a Peruvian supermarket chain. More recently, the chief of Peru's Sierra Exportadora, which supports farmer co-operatives, has called on Ministers to approve the construction of 100 potato flour production plants to supply small and medium bakeries and even to export potato flour to Europe, Japan and the USA.

POTATO STARCH.
(PHOTO: JANGSU CORP.)

Building support at policy level

Globally, potato production is growing at a rate of 2 percent annually while in developing countries, growth is estimated at around 5 percent. Sustaining the exceptional growth in potato production of the past two decades – from 268 million tonnes in the early 1990s to 325 million tonnes in 2007 – and the expansion of potato domestic trading in developing countries depends on choosing the right policy and research options for development of the agricultural sector and potato-based farming systems. The policy and research agenda is expected to shift from the traditional focus on raising productivity to a broader approach that makes a real contribution to the fight against hunger, poverty and environmental degradation by improving rural income, livelihoods, nutrition, health, and conserves the natural resource base.

Policy reforms are a needed if developing countries wish to develop and promote a sustainable potato industry and agricultural sector. This implies overcoming current trade barriers, including the lack of harmonized transit charges and customs documentation. It also implies overcoming current barriers to sustainable production intensification based on good agricultural practices.

Policy makers need to be more aware of the contribution that the potato is already making to development and food security, and of its importance as a staple food and cash crop in developing countries. In the process of revising poverty reduction strategy papers (PRSPs), and in formulating strategies for agricultural development, they should take into account the needs and potentials of the potato subsector and support its more active engagement in the development process.

One important policy aim in developing countries should be to enhance the value of potato production by establishing links between farmers and food processors, improving credit availability, and fostering public-private partnerships for technology innovation. By engaging interested partners from the public and private sectors and civil society, policy can facilitate the development of focused country-level programmes, projects and activities to support a sustainable potato subsector.

Policy should also create a regulatory environment conducive to sustainable potato development through support for knowledge enhancement and research, application of best management practices, and sharing and promotion of proven and advanced potato technologies through education, extension and training.

Policy should address constraints on potato-based production systems by favouring the introduction of good quality planting material and potato varieties more resistant to insect pests, diseases, water scarcity and climate change, farming systems that can make optimum use of natural resources, seed certification schemes and soil testing laboratories.

Policy will also have to secure financial commitments from national governments, donors and the private sector to invest in potato-based systems and value chains. In doing so, policy makers should encourage a stronger commitment by the potato community to potato subsector development.

IN VITRO PLANTS OF POTATO. (PHOTO: YOAV FRIDLANDER)

Research for development agenda

Accelerated and sustainable development of the potato subsector in developing countries requires increases in the productivity, profitability and sustainability of potato-based farming systems. This implies a new and vigorous research for development agenda.

The way forward for potato research in developing countries will include a number of priority areas. First, the lack of adequate quantities of clean seed is a major bottleneck to improved productivity. Promising results have been obtained through extension efforts that promote the use of "positive selection" and small-scale seed plots. Other research work aimed at improving the quality of farmers' seed through novel technologies such as aeroponic production of clean seed tubers has yielded positive results. Strong consideration should be given to fostering public-private sector partnerships as a strategy for getting potato seed systems moving in developing countries. Also recommended are ex-ante assessments of the potential return on investments by calculating the impact of new adapted varieties and cleaner seed.

In many countries, investments are needed in laboratories for the diagnosis of potato diseases, for measuring mineral concentrations in soils, manure and fertilizers, and for determining the composition and concentration of active compounds in herbicides, pesticides, fungicides and nematicides.

Legislation is needed in many countries to set quality standards for seed and to introduce or enforce mechanisms for certification through accredited laboratories. Legislation may also be needed to protect potato breeders' rights.

The potential effects of climate change pose a threat to the levels and stability of potato yields. Heat and drought resistance should be considered in breeding programmes along with other key traits such as late-blight resistance, virus resistance, earliness and culinary qualities. Hence, research needs to provide a broader range of genetic material that meets site-specific criteria, is adaptable to changing environments, and meets new demands from emerging markets for processed food products, non-food ingredients and starch for industry. The growing demand for potato with specific characteristics for a particular processed product must be taken into consideration, but should only be pursued after a careful analysis of market prospects.

The potato subsector faces a growing challenge from more aggressive strains of late blight and many developing countries have a limited capacity to control the disease through fungicide application. Continued research on resistance breeding and integrated management strategies is essential, while support is needed for scaling up LB control technologies and methodologies developed by CIP.

It is unlikely that resistance to latent bacterial wilt infection will be available through conventional breeding in the near

FROM THE ESSAY, "HARVEST OF NATIVE POTATOES, PERU." (PHOTO: EITAN ABRAMOVICH SAMESAS) future. Research on integrated management to control bacterial wilt needs to focus on designing improved detection technologies, developing recommendations that farmers are willing and able to adopt, and exploring options for suppressing the disease through improved soil fertility and health management (e.g. sanitation measures and clean seed). Participatory approaches to farmer empowerment and learning, such as Farmers' Field Schools (FFS) for IPM and IDM, are required in order to reach a significant number of potato growers. Progress in the sequencing of the bacterial wilt genome might lead to new ways of controlling the disease in the long term.

The development of conservation agriculture technologies and practices for potato-based systems presents opportunities for both public and private sector research. All aspects require increased research support.

Finally, improving the incomes of small-scale potato growers depends on increasing demand-driven opportunities and developing value-chains which include all market chain actors, from input suppliers to consumers. Linking farmers to markets, especially high-value supermarkets and restaurant chains, can substantially increase the profitability of the potato cultivation. This requires technological innovation at many points in the value chain, including introduction of improved varieties and more efficient post-harvest processes, as well as technical assistance to ensure timely production and supply of adequate quantities of high quality potato products.

Challenge of a better functioning value chain

Potato seed producers arguably constitute the most critical link in the potato chain. For it is their role to ensure that the chain has access to sufficient quantities and qualities of planting material to meet the needs of potato growers, processors and traders. In order for this group to successfully participate in the value chain, they need yield-improving and input-saving technologies to help close the persistent potato "yield gap" and to reduce per tonne production costs. Production initiatives can be strengthened greatly by germplasm research focused on specific end uses, tissue culture, rapid multiplication of planting material, insect pest and disease resistance (including enhancing resistance to prevalent diseases such as late blight by combining conventional plant breeding techniques with biotechnology) and the formation of producer groups to share expertise and to strengthen bargaining power. The continuous generation and diffusion of improved varieties is important if the potato subsector is to flourish. The expansion of potato cultivation will also be facilitated by improved irrigation supply, chemical fertilizers, cold storage facilities, and transport infrastructure. In addition, the market price of potato is often subject to very limited negotiation and is often decided at the farm gate. Inefficient and unfair pricing often results in producers failing to respond to market incentives, stifling efforts to increase productivity and undermining the necessary on-farm investments in production.

ASSEMBLING THE POTATO HARVEST, INDONESIA. (PHOTO: FERNADIE LILI)

Partnerships for policy and research

Extending the benefits of potato subsector in developing countries requires action on a wider front. The best strategy for achieving this is to engage the international community in agricultural development that benefits small-scale farmers, who make up the majority of the world's most poor and hungry. Such commitment will make a strong contribution to achievement of the first of the United Nations Millennium Development Goals, to half the proportion of those living in extreme poverty and hunger.

As a lead UN agency for agriculture and rural development, FAO will be a key partner in that process, by advising on policies and strategies to modernize the potato subsector, sharing its extensive knowledge of potato farming systems, promoting appropriate technology for sustainable intensification of production, and forging links among decision makers, producers, processors and marketing chains.

CIP will play a key role through its campaign for a new research for development agenda that puts potato science at the service of the poor. The new agenda seeks to boost potato yields in developing countries by working with them to provide higher quality planting material, better varieties drawn from a broader base of potato genetic resources (including the rich storehouse of Andean varieties), and improved crop management practices. CIP is calling for a renewed sense of responsibility for conservation of the potato gene pool and take concrete steps to ensure that developing countries acquire the capacity to utilize it in a sustainable manner.