Zhongqi He · Robert Larkin
Wayne Honeycutt *Editors*

Sustainable Potato Production: Global Case Studies

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Preface

Potato (*Solanum tuberosum* L.) is grown in over 100 countries throughout the world. As a staple food, potato is the fourth most important crop after rice, wheat, and maize, and has historically contributed to food and nutrition security in the world. Global interest in potato increased sharply in 2008 as world food prices soared, threatening the food security and stability of dozens of low-income countries. Unlike major cereals, potato is not a globally traded commodity, and prices are usually determined by local production costs. Thus, potato is increasingly regarded as a vital food-security crop and as a substitute for costly cereal imports. With such importance, we organized this edited collection of global case studies that address the issues of sustainable potato production.

This book begins with an introduction on sustainable potato production and global food security (Chap. 1). This introductory chapter provides the latest updates on geospatial patterns of potato production world-wide and briefly discusses the potential impacts of climatic change, biotechnology and soil resource management on sustainable potato production.

This book presents eight case studies selected globally and covering different issues relevant to sustainable potato production in both developed and developing countries. Part II is a case study on enhancing potato system sustainability in the Northeast USA. Research in this study case was conducted to identify the constraints to potato system sustainability and develop practices and management strategies to overcome or reduce those constraints. For this purpose, five cropping systems were designed and managed as (a) Status Quo, (b) Soil Conserving, (c) Soil Improving, and (d) Disease Suppressive Systems under both irrigated and rainfed management. Four chapters (i.e. Chaps. 2, 3, 4, and 5) in Part II evaluated the five systems for their impacts on soil physical, chemical, and biological properties; plant growth; plant diseases; nutrient availability; and their interactions. Part III focuses on the case studies of sustainable potato production managements for irrigated agriculture in the Western USA. Chapter 6 discusses research conducted in Colorado to evaluate the effect of different cover crops as a management tool in potato cropping systems. Chapter 7 reports mustard green manure use in eastern Washington State. Chapter 8 reviews the field trial experiments of effects of application of commercial humate products on yields of potato and several other crops conducted in the Western USA. Chapter 9 examines the late blight epidemics in the Columbia Basin of south-central Washington and north-central Oregon.

Part IV presents the case studies of rainfed potato production in eastern Canada with the focus on nitrogen management issues. Chapter 10 evaluates a series of N fertilization strategies and recovery of fertilizer N by the potato crop. The subsequent four chapters address the use of soil- and plant-based test systems to improve fertilizer N recommendations (Chap. 11), N management in organic potato production systems (Chap. 12), and N losses to water (Chap. 13) and to the atmosphere (Chap. 14) in potato production systems in eastern Canada. The five chapters in Part V are the case studies of sustaining potato production in the cool-temperate climate of Tasmania, Australia. Chapter 15 briefly describes Tasmania's geography, the farming systems of which potato production is part, and introduces some of the management challenges facing the industry. Chapters 16, 17, 18, and 19 provide more fully-developed descriptions of these challenges and how recent research and development efforts have helped Tasmanian potato growers to meet them.

Sustainable potato production in developing countries may face greater challenges due to resource limits. Part VI present three chapters covering water-saving potato production research for the semi-arid areas of Northern China. Chapters 20 and 21 examine potato growth and yields affected by dripping irrigation and plastic mulch. Chapter 22 reports the case study of enhanced drought and salinity tolerance of transgenic potato plants with a betaine aldehyde dehydrogenase gene from spinach. Some of the efforts towards increasing sustainability of potato production systems in South America are reported in Part VII. Chapter 23 discusses the relationship between potato yield and nitrogen rates obtained by different mathematical models and how the model chose affects plant nitrogen indices under Brazilian conditions. Chapter 24 examines "deep soil loosening" tillage system in two Brazilian potato producing regions, suggesting it as an alternative to improve potato production in compacted areas, and as a tool to promote the recuperation of soils damaged by compaction. Chapter 25 reports experiences and lessons from two distinct potato production systems of Peru in developing integrated pest management for potato.

Four chapters in Part VIII and IX of this book cover the case studies carried out in Mediterranean and tropical African regions. Chapter 26 reviews the role of green manure and amendments application in soil fertility management in organic potato production with a case study in Tuscany (Central Italy). Chapter 27 focuses on effect of humic substances application on potato tubers yield quantity, quality, and nutrients concentration under Egyptian soil conditions. Chapter 28 examines residual pesticides and heavy metals levels in conventionally and organically farmed potato tubers in Egypt. And, finally, Chap. 29 reviews various management techniques for late blight and bacterial wilt diseases highlighted with examples drawn from research conducted in Sub-Saharan Africa.

Chapter contribution was by invitation only. For each chapter to stand alone, there is occasionally some overlap in literature review, and some experiments have been used as examples in more than one chapter. This book is basically the results of the combined efforts of our distinguished group of contributors. We wish to thank all contributors for their timely contributions. Special thanks go to Drs. Bernie Zebarth and Leigh Sparrow for their coordination of the chapter contributions in Part IV and V, respectively. Finally, we would like to thank all reviewers for their many helpful comments and suggestions which certainly improved the quality of this book.

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Contents

Part I
Introduction

Chapter 1
Sustainable Potato Production and Global Food Security

Sherri L. DeFauw, Zhongqi He, Robert P. Larkin, and Sameeh A. Mansour

Abstract The potato (*Solanum* spp.) is currently the leading non-grain commodity in the global food system with production exceeding 329 million metric tonnes in 2009. The extraordinary adaptive range of this species complex combined with ease of cultivation and high nutritional content have promoted steady increases in potato consumption especially in developing countries. Recent uncertainties in world food supply and demand have placed the potato in the upper echelon of recommended food security crops. This introductory chapter provides the latest updates on geo-spatial patterns of potato production world-wide. In addition, the potential impacts of climate change, agrobiodiversity, biotechnology, and soil resource management on sustainable potato production are briefly discussed.

1.1 Introduction

The potato (*Solanum* spp.) has helped sustain humanity for centuries, and now ranks as the leading non-grain commodity in the global food system (FAO 2009a), with production exceeding 329 million tonnes in 2009 (FAOSTAT 2011). The extraordinary adaptive range of this plant combined with relative ease of cultivation (Haverkort 1990) and high nutritional content have promoted steady increases in potato consumption

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especially in developing countries which, in turn, account for over half of the total global harvest (FAO 2009a). In fact, the developing world's potato production exceeded that of the developed world for the first time in 2005 (FAO 2010). Millions of farmers depend on potatoes for subsistence and as a local cash crop. Recent uncertainties in world food supply and demand have placed the potato high on the list of recommended food security crops (FAO 2009a, 2010; Lutaladio and Castaldi 2009; Pandey et al. 2005). Potato production potential is exceptionally high as approximately 80% of the plant's biomass constitutes economic yield (Osaki et al. 1996).

Recently, the United Nations (UN) declared the year 2008 as the International Year of the Potato (IYP). The initial resolution, proposed by the Permanent Representative of Peru (at the biennial Conference of the Food and Agriculture Organization (FAO) of the UN convened in November 2005), explained the pivotal role that the potato has served in global diets as well as may serve in achieving international development objectives to further reduce undernourishment. Throughout the celebration of IYP 2008, opportunities were taken to underscore how potatoes could contribute to: (1) improvements in diet and food security; (2) alleviating the income and subsistence challenges for small-scale farming families; and (3) conserving the genetic resources needed to utilize potato biodiversity in order to supply improved varieties in the future (FAO 2009a). In that same year, the Government of Peru created a register of Peruvian native potato varieties (FAO 2009a). The Andes are a center of origin (Vavilov 1992) and diversity for numerous crop species, including the potato (Spooner et al. 2005), with the Huancavelica region of Central Peru recognized as a center of potato genetic diversity (Torres 2001; Huamán 2002; de Haan 2009). Systematic documentation of diversity hotspots such as this one is essential as it deepens our understanding of conservation units (alleles, cultivars, and species mixtures) as well as the socioeconomic scales (at the household-, community-, and regional-levels) associated with improving food security (de Haan et al. 2010).

This introductory chapter highlights the importance of potato production in contributing to global food security and provides maps describing the current geospatial distribution of production areas world-wide. Other inter-related topics briefly reviewed and discussed here as they contribute to strengthening the sustainability of food systems include considerations of the effects climate change, genetic modification of potato, agrobiodiversity reservoirs, and soil conservation strategies. More specific issues on sustainable potato production cultural practices such as control of soilborne pests and pathogens, or improvements in nutrient- and water-use efficiencies that enhance yield are reviewed and discussed in detail in the relevant chapters of the eight case studies.

1.2 The Importance of Potato in Global Food Security

Food webs are central to life, and human-centered food systems are dynamically intertwined with complex changes in the socio-cultural contexts of food production, dispersion of cultures, political alliances, economies and ecosystems

(Eriksen et al. 2009). Increasing demands for food have induced global environmental change (GEC), including soil degradation, loss of biodiversity, rapid proliferation of greenhouse gas emissions, nutrient loading of ground and surface waters, and in some areas critical water shortages. Population and income growth combined with high energy prices, biofuels, science and technology breakthroughs, climate change, globalization, and urbanization are causing drastic changes in food consumption, production, and markets. Adapting to these food security challenges requires integrated food systems approaches (at multiple scales and considering cross-scale dynamics) that engage a broad spectrum of researchers from the social and natural sciences because many other factors, in addition to food production, need to be considered such as food availability, access, utilization and stability (Steffen et al. 2003; Stamoulis and Zezza 2003; Cash et al. 2006; Eriksen et al. 2009). However, further discussion of these highly relevant issues is well beyond the scope of this introductory chapter.

The global agriculture sector is confronting significant challenges within the next four decades. FAO estimates that worldwide agricultural production will need to grow by 70% over an approximated 45-year interval (between 2005–2007 and 2050), and by 100% in developing countries (FAO 2011). By 2050, predictions indicate that the global population will be between 8.0 and 10.4 billion people, with a median estimate of 9.1 billion (Jaggard et al. 2010). Today, more than one in seven people still lack sufficient protein and energy in their diet, and even more have some form of micronutrient malnourishment (FAO 2009b).

Global interest in potato production increased dramatically in 2008 as world food prices soared, creating instabilities in the food security of low-income countries (FAO 2009a, b; Lutaladio and Castaldi 2009). High food prices also tend to worsen poverty and malnutrition (FAO 2011). The nutrient-laden potato yields more food (carbohydrate- and micronutrient-rich, B and C vitamins, protein content comparable to cereal grains, plus dietary antioxidants) (Burlingame et al. 2009) more rapidly on less land than any other major crop as up to 85% of the plant may constitute edible food for humans, compared to only 50% for most cereal grains (FAO 2009a). Potatoes are C3 plants along with wheat, rice, soya, sunflower, oilseed rape, sugar beet and dry bean. Together with key C4 plants that include maize, sugar cane and sorghum, these 11 crops occupy 56% of the world's arable area (Jaggard et al. 2010).

Potatoes are currently grown on an estimated 20 million ha of farmland spanning the subtropical lowlands of India (near sea level) to the Andean highlands of Peru and Bolivia approaching 4,000 m elevation (FAO 2010). Collectively, the top 20 potato-producing countries (Fig. 1.1) harvested close to 257 million metric tonnes from an estimated 13.7 million ha with a crop valuation of close to 30 billion international dollars in 2008 (data compiled from FAOSTAT 2011). These nations accounted for close to 80% of global production. Under irrigation in temperate climates, yields typically vary between 25 and 45 tonnes ha^{-1} with 120–150 d crops requiring from 500 to 700 mm of water; water deficits in the middle to late stages of the growing season generally have the greatest negative impacts on yield (FAO 2009a; FAOSTAT 2011). Subtropical yields tend to be substantially lower, ranging

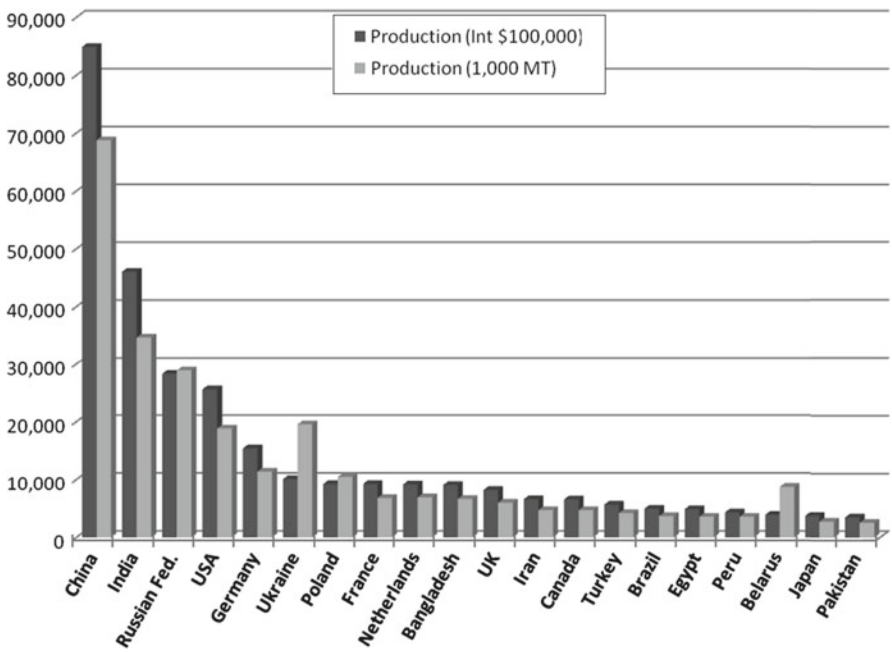

Fig. 1.1 Summary of the top 20 potato-producing nations (2008) comparing valuation in international dollars (Int) with quantity in metric tonnes (MT or Megagrams, Mg) (FAOSTAT 2011)

from 5 to 25 tonnes ha^{-1} (FAO 2009a; FAOSTAT 2011). However, across global landscapes, the versatility of this crop coupled with notable increases in production in most countries over the last two decades is unparalleled. Consumption of fresh potatoes accounts for approximately two-thirds of the harvest, which exceeded 329 million tonnes from an estimated 18.6 million ha in 2009 (FAOSTAT 2011).

Developing countries with high food demands provide case studies on the impact of increased potato production. From 1990 to 2009, 35 countries recorded production increases ranging from approximately 130% to 2,300% (with ten nations profiled in Table 1.1; FAOSTAT 2011). African nations posting some of the largest gains in quantity and harvested areas over this 20-year interval included Angola (2,321%), Nigeria, and Rwanda. Yield averages (for 2009) for these three nations were 8.0, 4.0, and 10.2 Mg ha^{-1}, respectively (FAOSTAT 2011). Other African nations exhibiting substantial growth in potato production (both tonnes and hectares, though not shown in Table 1.1) were Algeria, Cameroon, Mali, Namibia, Niger, Tanzania, and Uganda with average yields (for 2009) ranging from 2.2 to 25.1 Mg ha^{-1} (FAOSTAT 2011). Although consumption is generally rather low for most of these nations (approximately 5–15 kg per capita per year), the potato underpins Rwanda's food security (approximately 125 kg per capita per year; FAO 2009a). Since 1990, the potato has contributed, in part, to reducing the proportion

Table 1.1 Summary of ten selected nations with noteworthy increases in production and harvested area (Based on data compilation from FAOSTAT 2011)

	Production (tonnes)			Harvest (ha)		
Nation	1990	2009	Prod. % diff	1990	2009	Harv% diff
Angola	34,000	823,266	2,321	8,500	103,440	1,117
Bangladesh	1,065,680	5,268,000	394	116,582	395,000	239
China	32,031,189	73,281,890	129	2,829,384	5,083,034	80
Egypt	1,637,810	4,000,000	144	79,663	145,000	82
India	14,770,800	34,391,000	133	940,000	1,828,000	94
Nepal	671,810	2,424,050	261	83,350	181,900	118
Nigeria	54,000	914,778	1,594	7,700	227,519	2,855
Pakistan	830,976	2,941,300	254	79,900	145,000	81
Peru	1,153,980	3,716,700	222	146,435	282,100	93
Rwanda	283,673	1,287,400	354	42,055	126,167	200

of undernourished among the total populations of most of the aforementioned sub-Saharan nations by 33–61% (FAO 2011). Egypt is Africa's top potato producer, and has increased production tonnes by 144% from 1990 to 2009 (Table 1.1; FAOSTAT 2011). Egypt also ranks among the world's top exporters of fresh and frozen potato products directed mostly to European markets (FAO 2009a). In December 2007, a conference was held in Alexandria, Egypt called "Potato, Sweet Potato, and Root Crops Improvement for Facing Poverty and Hunger in Africa", hosted by the African Potato Association. The theme was chosen for the same reason that the UN declared this the International Year of the Potato: "because we realized the food gap problem and we realized that the potato crop can substitute a large quantity of the wheat importation" (Sherk 2008).

Potatoes are grown widely in Nepal, and now serve as this nation's second staple food crop (after rice). For smallholder Nepalese farmers in highland areas (1,800–3,000 m ASL), it is more productive than rice or maize and they also produce seed tubers for sale at lower altitudes (FAO 2009a). The potato has also become a significant source of rural income in Pakistan; most production occurs in the Punjab where spring and autumn crops account for 85% of the harvest. Expansion of irrigated Pakistani land has resulted in substantial increases in production output (up 254% from 1990 to 2009) and area under cultivation (Table 1.1). Annual potato intake in Pakistan is estimated at 11 kg per capita (FAO 2009a). Potato is a highly successful winter crop (October–March) in Bangladesh where it is typically grown for cash sale by smallholder farmers; annual consumption was approximately 24 kg per capita in 2005 (FAO 2009a). The bulk of Peru's potato production occurs on smallholder highland farms (most at 2,500–4,500 m ASL) where it has been a staple food for millennia. Peruvian annual consumption is high estimated at 80 kg per capita (FAO 2009a). From the handful of brief national profiles presented here, potato cropping systems help improve resilience especially among smallholder farmers by providing direct access to nutritious food, increasing household incomes, and reducing their vulnerability to food price volatility.

1.3 Potato Production Areas and Yields: A Global Perspective

The most recent production reports from FAO indicated that the 2009 global harvest exceeded 329 million tonnes from an estimated 18.6 million ha (FAOSTAT 2011). Profiling the relative distribution of production areas revealed that four nations grew well over 1 million ha annually with China recording a harvest area of close to 5.1 million ha (Fig. 1.2); the others included the Russian Federation (about 2.2 million ha), India (over 1.8 million ha) and the Ukraine (over 1.4 million ha). Harvests from Belarus, Bangladesh, the United States and Poland ranged from approximately 0.4–0.5 million ha. Additional nations that exceeded 250,000 ha in harvest area extents for 2009 were Peru, Germany, and Romania.

Aggregated yield data reported from 157 nations ranged from 1.2 to 46.3 Mg ha^{-1} in 2009 (FAOSTAT 2011) with a "global" yield of 18.4 ±10.6 Mg ha^{-1} (mean ± SD). Denmark, France, New Zealand, United Kingdom, Germany, Belgium, the Netherlands, Switzerland and the United States had potato yields greater than 40 Mg ha^{-1} in 2009 (Fig. 1.3) with the Netherlands typically achieving world record average yields (FAO 2011). In rather sharp contrast, of the four nations with the largest harvested production areas, India led with a recorded average yield at 18.8 Mg ha^{-1} and Belarus reported a comparable yield of 18.6 Mg ha^{-1}; whereas, China and the Russian Federation reported average yields of 14.4 and 14.3 Mg ha^{-1}, respectively.

Resolving patterns of 2009 potato productivity revealed that China contributed over 22% of the total global production. India, the Russian Federation, Ukraine, and the United States contributed substantially lesser quantities amounting to 10.4%,

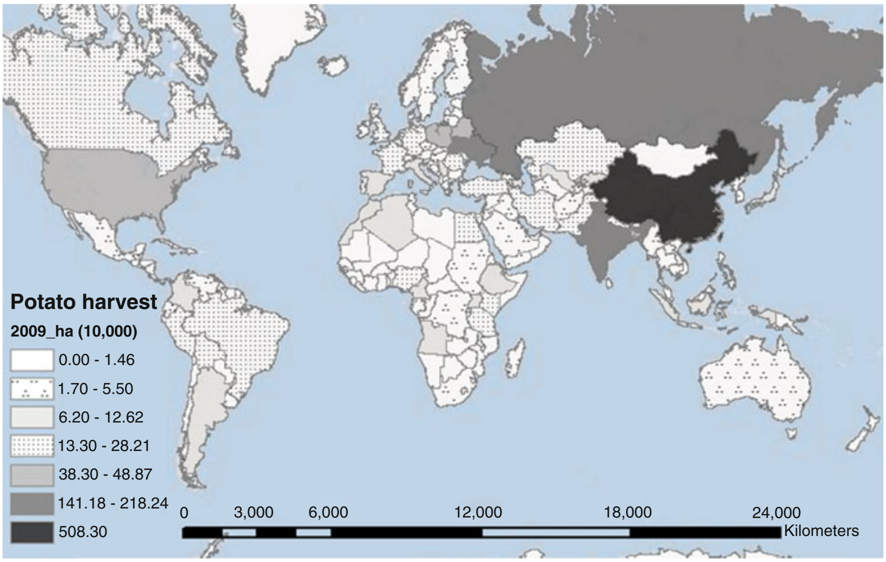

Fig. 1.2 Relative distribution of potato production areas in 2009 with aerial extents reported in 10,000-ha units (Based on data compilation from FAOSTAT 2011)

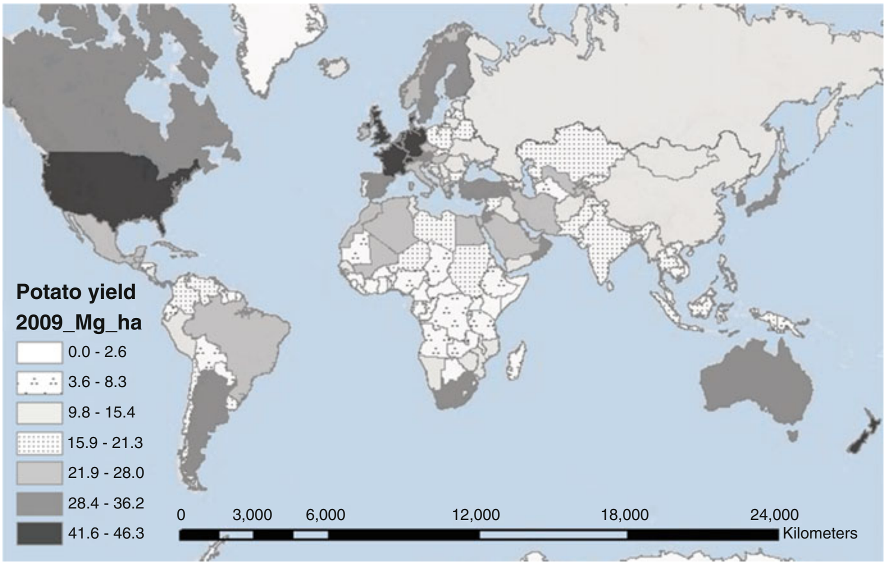

Fig. 1.3 Global distribution of potato yields (Mg ha^{-1}) in 2009 (Based on data compilation from FAOSTAT 2011)

9.4%, 6.0% and 5.9% of the global total, respectively. It is noteworthy that production output in China has more than doubled since 1990 (Table 1.1) and it is becoming a prominent global supplier. Chinese farmers in mountainous areas now rely on potato sales for approximately one-half of their household earnings. In addition, major expansion of potato cultivation is underway in the dry areas which account for approximately 60% of China's arable land (FAO 2009a). Production output in India has also more than doubled from 1990 to 2009 (Table 1.1). There the potato serves as a rural staple as well as a cash crop with production concentrated on the Indo-Gangetic Plain from October through March and some year-round production occurring at higher altitudes in the south. Annual per capita consumption in India is approaching 20 kg (FAO 2009a). The Russian Federation and the Ukraine have very high annual potato intakes compared to other nations; these are estimated at 130–136 kg/year, respectively, although pest and disease pressures result in annual losses of approximately several million tonnes (FAO 2009a). In the USA, over 90% of annual output is for human consumption with approximately 60% processed into frozen products, 33% consumed fresh, and the remainder reserved for seed (FAO 2009a). Other countries commonly ranking in the top 20 of 2009 production output (Fig. 1.1, though Belgium exceeded Pakistan in that year) contributed from 1.0% to 3.5% of global production.

Tracking yields for the top 20 potato-producing nations (shown in Fig. 1.1) for 1990–2009 reveals greater details concerning yield "stability" from year-to-year. Also highlighted are those countries that have experienced rather steady and substantial yield increases over this time interval; in particular, Belarus, Brazil,

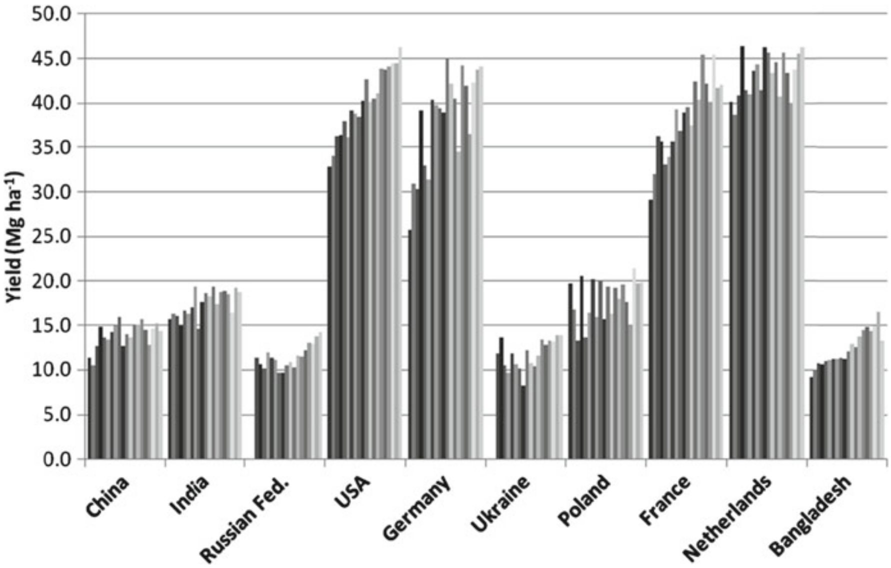

Fig. 1.4 Variations in yield (Mg ha^{-1}) for the past 20 years (1990–2009) for "tier 1" potato-producing nations (Based on data compilation from FAOSTAT 2011)

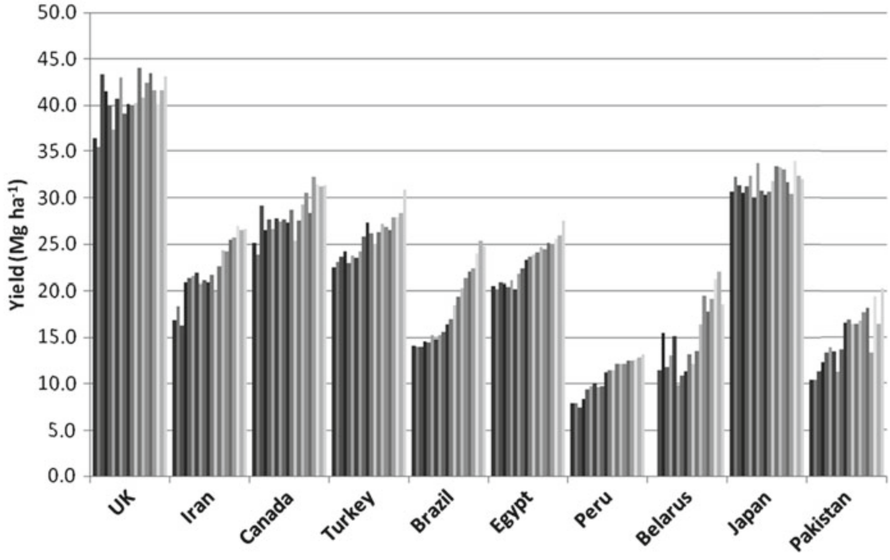

Fig. 1.5 Variations in yield (Mg ha^{-1}) for the past 20 years (1990–2009) for "tier 2" potato-producing nations (Based on data compilation from FAOSTAT 2011)

France, Iran and Pakistan (all experiencing 10+ Mg ha^{-1} increases within a 20-year span) (Figs. 1.4 and 1.5). In addition, these time-series comparisons begin to underscore the interactions of biogeographical and environmental phenomena as well as socioeconomic factors that influence the growth, yield and quality of this drought sensitive crop. France is Europe's leading exporter of fresh potatoes and dedicates approximately 10% of its production area to growing seedlings (FAO 2009a). Belarus ranks 8th among the world potato-producing countries (Fig. 1.1) and exports both fresh and seed potato. Belarusians consume more potatoes per capita than any other country, an estimated 180 kg $year^{-1}$ (FAO 2009a). Iran is the third largest potato producer in Asia (after China and India). This nation is steadily increasing its irrigated lands, and the potato is one of Iran's leading agricultural exports (FAO 2009a). These 20-year yield "snapshots" (Figs. 1.4 and 1.5) may also serve as tracers for potential yield declines resulting from global environmental change (GEC). According to model simulations on the effect of climate change on global potato production presented by Hijmans (2003), Bangladesh, Brazil and the Ukraine were predicted to experience potential yield decreases in excess of 20% for the interval 2040–2069.

1.4 Global Climate Change and Potato Production

The ecology of potato cropping systems in relation to climate as affected by latitude and altitude was reviewed by Haverkort (1990). This author reaffirmed that the potato is a versatile commodity adapted to a wide range of environmental conditions while underscoring the plant's sensitivity to drought stress (dependent on cultivar rooting depth) along with preferences for tuberizing under short-day conditions and best performances in cool temperate climates (Haverkort 1977, 1990). Higher temperatures, for example, promote foliar development, delay tuberization and influence potato quality characteristics such as higher numbers of smaller tubers per plant, and lower specific gravity which is indicative of lower dry matter contents (Haverkort 1988). In addition, water stresses (i.e., either waterlogging or drought conditions) occur to varying degrees dependent on site-specific heterogeneity of soils, complexity of field-scale topography, soil resource management by the farmer, and availability of water for irrigation. Drought events occurring early in the growing season reduce the number of tubers per plant (Haverkort et al. 1990). Furthermore, a single, short-term drought event during tuber bulking can inhibit future bulking of those potatoes set and result in initiation of new tubers; these plant responses not only decrease potato grade (i.e., tuber size and quality) but lower overall yield. High soil moisture conditions prior to harvest are known to negatively affect tuber specific gravity, whereas other in season stressors influence the development of disorders such as internal heat necrosis and hollow heart (Hiller et al. 1985).

Models that couple the biology of crop growth with the physics of climate change help policy-makers and scientists envision these potential changes in patterns of production and galvanize research efforts to mitigate their effects on future food supply. Hijmans (2003) assessed the effect of climate change on global potato production using a simulation model linking temperature and solar radiation datasets (with plant performance based on radiation use efficiency (RUE) algorithms). Climate data inputs included "current climate" (i.e., monthly averages for 1961–1990) as well as 7 scenarios from 5 climate models (CGCM1, CSIRO-Mk2, ECHAM4, GFDL-RI5 and HadCM2); these inputs were used to create two sets of projected climate surfaces for 2010–2039 and 2040–2069. Model runs for each grid cell (1° by 1° in size) included 12 planting times, 5 maturity classes (early to late senescence), and non-heat tolerant versus heat-tolerant potato. Mapped results (for countries with > 100,000 ha of potato area) permitted comparison of average change in potential potato yield (by country) due to climate change with and without adaptation (adaptation was defined as changes in planting month or cultivar maturity class). Climate scenarios for 2040–2069 predicted the increase in global average temperature will be between 2.1°C and 3.2°C, although the predicted temperature increase was smaller (between 1.0°C and 1.4°C) when weighted by the potato area and adaptation of planting time and cultivar choice were allowed. For the 2040–2069 interval, global potential potato yields were forecasted to decrease by 18% to 32% 'without adaptation', and by 9% to 18% 'with adaptation'. In addition, when adaptation was considered for the 2040–2069 scenario, Bangladesh, Brazil, Colombia and the Ukraine were predicted to experience the largest decrease in potential yield (>20%). Argentina, Canada, China, Japan, Peru, the Russian Federation, Spain, the UK, and USA were listed as notable examples where adaptation could mitigate much of the negative effects of global warming – particularly by shifting the location of production with existing potato growing regions. In general, the strongest negative impacts to potato production were predicted for the tropical and subtropical lowlands though these impacts could be ameliorated by the development of heat-tolerant cultivars (Hijmans 2003).

Higher resolution crop modeling entails systematically structuring biotic and abiotic spatiotemporal factors that influence crop development, growth and yield (i.e., genotype*environment*management (g*e*m)). Detailed models permit the potato industry to perform agro-ecological zoning by estimating timing (from planting to crop maturity), yields, hazards, and water-use efficiency (Haverkort 2007). These models also help serve as decision support systems for farmers (for irrigation as well as timing and dosing of nutrients and crop-protection inputs), help guide procurement strategies and aid in price policy establishment (MacKerron and Haverkort 2004). SPUDSIM, for example, is a new explanatory-type potato crop model that upgrades the RUE ('big-leaf') approach with a more detailed biochemical leaf-level model system that better depicts canopy architecture (for both shaded and sunlit leaves), and assimilate allocation to branches, roots and tubers (Fleisher et al. 2010). Comparison of SPUDSIM predictions versus gas exchange and dry mass data indicated the model predicted plant growth accurately (with high indices of agreement (≥0.80)) over a broad range of temperatures (12.6–32.3°C, on a 24-h average basis) except for the 34/29 case study. The model will be suitable for a variety of applications (i.e., farmscape to regional-scales) that involve complex soil-plant-atmosphere-water relationships (Fleisher et al. 2010).

Potato productivity and production in India was estimated under future climate change scenarios (Singh and Lal 2009). The authors concluded that without adaptations potato production under the impact of climate change and global warming may decline by 3% and 14% in the years 2020 and 2050, respectively. Possible adaptations like change in planting time, breeding heat tolerant varieties, efficient agronomic and water management and shifting cultivation to new and suitable agro-climatic zones can significantly arrest the decline in the production.

The "SUBSTOR" model is a mechanistic, process-oriented model for simulating tuber yield and crop development, and was employed to simulate physiological processes and yield of potato production in Egypt (Abdrabbo et al. 2010). Actual measurements of potato production were used to compare present and predicted. The climate change data was used from two general circulation models (GCMs), CSIRO and HadCM3, for the A1 greenhouse gas scenario to 2050 (Pearman 1988). The results of the work indicated that the potato yield in 2050 may be decreased by 11% to 13% compared to 2005/2006. Irrigation at 100% gave the highest tuber yield for different cultivars with the two climate change GCM models.

1.5 Agrobiodiversity and Biotechnology Considerations

The widely-cultivated potato, *Solanum tuberosum* L., along with six other cultivated species grown only in the Andes (Walker et al. 1999) collectively constitute one of the world's principal food crops. Results from recent molecular research indicate that the widest grown species retains but a portion of the actual range of genetic diversity found among the key recognized species, and they are divided into two cultivar groups based on adaptation to day length conditions. The 'Chilotanum' group (also referred to as the *"European"* potato) is now cultivated around the world, whereas the 'Andigenum' group (adapted to short-day conditions) is still primarily grown in the Andes (FAO 2009a). However, breeders in Europe and North American have produced many of the cultivars in current use by drawing on potato germplasm from Chile (Lutaladio and Castaldi 2009).

Farmers in the high Andes recognize potatoes not only by species and variety, but also by the microenvironmental niche where the tubers grow best; in fact, it is customary to find 8–20 cultivars per field at altitudes varying from 3,550 to 4,250 m in Huancavelica where weather extremes are frequent occurrences (de Haan et al. 2010). Natural potato pollination sustains the diversity of Andean farmer-developed, locally-adapted varieties. The systems perspective on planting levels and emergent properties of potato biodiversity documented by de Haan et al. (2010) in this central Peruvian highlands region (latitude 11°59′94″S to 14°7′48″S and longitude −74°16′11″W to −75°48′38″W) is of great importance for ongoing crop conservation efforts that will, in turn, contribute to future global germplasm enhancement. Of all the major crops, potato is arguably one of the most important species groups sustaining mountain agriculture, for the highest levels of genetic diversity are maintained by farmer communities at altitudes well above 3,000 m (Zimmerer 1991). An individual farm household may retain as many as 160 unique cultivars based on long-established culinary preferences as well as intimate site-specific knowledge of the deployment of cultivar diversity to ensure a reasonable harvest return; therefore, food system interventions designed to enhance food security should encourage participant growers to emulate these high altitude farmers by building on agrobiodiversity (de Haan 2009; de Haan et al. 2010).

Genetic modification (GM) technologies and the on-going debate over their acceptance has become highly politicized and polarized, particularly in Europe. Although biotechnology tools (genomics and bioinformatics) are likely to be of pivotal importance (Phillips 2010) in contributing to some rapid advances (i.e., single transgene events that could dramatically alter plant performance), broader-based concerns expressed by agronomists indicate that diverting resources and focus from conventional breeding could slow the rate of yield increases required to feed a rapidly expanding world population (Jaggard et al. 2010). Leading researchers on global food and farming futures (e.g., Godfray et al. 2010, pp 815–816) agree that "genetic modification is a potentially valuable technology whose advantages and disadvantages need to be considered rigorously on an evidential, inclusive, case-by-case basis." These authors also affirm that this technology needs to garner greater public trust and acceptance "before it can be considered as one among a set of technologies that may contribute to improved global food security." Furthermore, new technologies (both GM and non-GM) must be community-directed; those efforts meant to benefit the poorest nations will require innovative alliances of civilians, governments, and businesses (Godfray et al. 2010). As mentioned in the previous section of this chapter, in general, the strongest negative impacts to potato production have been predicted for the heavily-populated subtropical and tropical lowlands (Hijmans 2003); these impacts could be ameliorated, in part, by the development of a broader spectrum of stress-tolerant cultivars. Si and colleagues (Chap. 22 of this volume; Zhang et al. 2011) have developed transgenic potato plants that are resistant to drought and salinity stresses; however, these plants have yet to be grown commercially. Performance trials and biosafety assessments are underway.

Biotechnology has provided a fast alternative for potato crop improvement in the areas of resistance to insects and viruses. Genetic transformation of potato by *Agrobacterium tumefaciens* has been most successful and this method has been particularly efficient in introducing several useful genes into various potato genomes (Kumar et al. 1995). It is well known and documented that the choice of cultivar, type and physiological status of the explants tissue, transformation vector and the *Agrobacterium* strain utilized are major variables in any attempted transformation system (Badr et al. 1998). Potato tuber moth (PTM), *Phthorimaea operrculella,* is a caterpillar insect pest that attacks potato plants in field and storage causing great damage to foliage and tubers. Derivation of genetically modified and PTM-resistant potato using *Bacillus thuringiensis* (Bt) toxin genes is the most suitable way to control PTM and avoid the negative impacts of chemical insecticides. An Egyptian Bt isolate produces a potent Cry1Aa7 toxin that kills the larval stages of PTM more efficiently than other standard Bt toxins (Ibrahim et al. 2001). The transformed tubers were challenged by releasing PTM larvae (1st instar) and emerged adults were scored. The authors' results revealed that the transformed tubers resisted insect attack 30–40% better than their non-transformed counterparts. The benefits of Bt transgenic plants, however, are still the subject of much debate between supporters and opponents of genetic modification (IUPAC 2004; EPA 2004).

More serious than the PTM insect are the Potyviruses which belong to one of the largest plant virus groups**.** Potyvirus Y (PVY), the most important pathogen of cultivated potato, is responsible for substantial damage to potato production throughout the world and can reduce yield by up to 80%. Saker (2003) reported for the first time the development of transgenic potato plants harboring potato virus Y coat protein gene (CP-PVY), which confers recipient plant resistance against PVY without the use of antibiotic resistance gene as a selectable marker gene. This avoids theoretical environmental risks of horizontal gene flow of antibiotic resistance genes from transgenic plants to enteric bacteria. The obtained results indicated that it is possible to avoid the use of antibiotic and herbicide resistance genes as selectable markers and consequently avoid environmental risks. Moreover, this system may be useful for the transformation of crops known to be recalcitrant for *in vitro* regeneration, as the omitting of antibiotics from the regeneration medium enhances the percentage of shoot recovery. Further studies have to be undertaken to evaluate the efficacy of the transgenic potato clone for resistance to potato virus Y isolates.

1.6 Soil Resource Assessments and Management Strategies

Soil erosion is a major cause of soil degradation in arable landscapes, adversely impacting hydropedologic dynamics (such as infiltration, patterns of subsurface flow, and shallow aquifer recharge) as well as farmscape- to watershed- and regional-level processes including redistribution of nutrients, pesticides and emission of greenhouse gases (e.g., Pennock and Corre 2001; Lin 2003; MacLauchlan 2006). Potato is in the top tier of crops with the highest erosion risk; in some production settings, harvest erosion rates were of the same order of magnitude (almost 10 Mg ha^{-1} year^{-1}) as water and tillage erosion on sloping land (Auerswald et al. 2006; Ruysschaert et al. 2006). Tiessen et al. (2007a, b, c) demonstrated that the tillage erosivity of commercial potato production systems in Atlantic Canada (due to primary, secondary and tertiary tillage operations – especially the latter which included planting, hilling and harvesting) was greater than that for the other major cropping systems in Canada. Soil losses varying between 20 and 100 Mg^{-1} ha year^{-1} have been reported from convex landscape positions with the significance of these observations linked to reductions in crop yield (up to 40%); rolling agricultural terrains have been estimated to range between 15% and 30% of arable landscapes (Tiessen et al. 2007d). Investigations that detail crop yields in topographic contexts and assess soil resource risks at finer-scales (preferably from the farmscape-assemblage to watershed or sub-regional levels) for key cropping systems such as potato using geographic information systems (GIS) based approaches are urgently needed for most production areas.

High-resolution GIS-based investigations have been conducted on rainfed commercial potato cropping systems in Prince Edward Island and Québec, Canada (DeHaan et al. 1999; Cambouris et al. 2006). These datasets show that potato production constraints related to soil degradation have developed over decades, and when combined with annual variability in a multitude of environmental factors, the apparent results are five to ten-fold differences in yield at the field- scale. Geospatial integration of extrinsic (temperature and rainfall) as well as intrinsic field-specific (e.g., soil heterogeneity, topography, surficial and subsurface drainage patterns) datasets in potato production settings could help growers resolve field- to farm-scape-level complexities in order to better manage soil and water resources as well as evaluate pest- and pathogen-related risks.

Increasing awareness of the adverse influences of soil degradation and the role of conventional agriculture in potentially accelerating erosion rates an average of 1–2 orders of magnitude greater than rates of soil production (e.g., Montgomery 2007) prompted GIS-based assessments of the soils sustaining potato production systems in Maine (using farmland and erodibility classifiers) in order to help producers, communities, and policy makers gauge future food systems security risks (DeFauw et al. 2011). In addition, DeFauw et al. (2011) examined crop sequences and detected rotational patterns based on 3 years of Cropland Data Layer (CDL 2008–2010) classified imagery released by the USDA, National Agricultural Statistics Service. The 3-year potato production footprint covered approximately 62,000 ha. Zonal assessments of agri-environmental indicators that combined farmland and erodibility classifiers showed that close to 85% of potato production soils in Maine (over 52,000 ha) were either "potentially highly erodible" (PHEL) or "highly erodible" (HEL), therefore, requiring the highest standards in soil conservation practices. These geospatial frameworks help resolve patterns and trends in production environments (at multiple scales) that may, in turn, facilitate the wider adoption of adaptive management strategies which enhance yield, increase whole-farm profitability, and foster sustainable land use (DeFauw et al. 2011). Future refinements to the Maine potato systems geodatabase will include derived layers based on topographic and climatic datasets that will, in turn, facilitate higher resolution modeling (i.e., local- to regional-scales at 30 m resolution) of erosion potential as well as crop yields using SPUDSIM, a new process-level model that has the ability to accurately predict plant growth and yield for different potato varieties (Fleisher et al. 2010).

1.7 Conclusion

The widely-cultivated potato, *S. tuberosum* L., along with six other cultivated species grown only in the Andes collectively constitute one of the world's principal food crops; it ranks fourth after rice, maize and wheat. The global agriculture sector is confronting significant challenges within the next four decades as predictions indicate that the global population will be between 8.0 and 10.4 billion people, with a median estimate of 9.1 billion. Recently released studies estimate that worldwide agricultural production will need to grow by 70% over an approximated 45-year interval (between 2005–2007 and 2050), and by 100% in developing countries.