PN-ABW-366

ISSN-0256-8748
Social Science Department
Working Paper Series
No. 1994-3

Patterns and Implications of Varietal Change in Potatoes

Thomas S. Walker

INTERNATIONAL POTATO CENTER (CIP)
Address: Apartado 1558 - Lima, Peru. Telex: 25672 PE. Cable: CIPAPA, Lima
Phones: 366920; 354354. FAX: 351570. E-Mail: cip@cgnet.com or cip@cipa.org.pe

The purpose of the Social Science Department Working Paper Series is to encourage debate, exchange of ideas, and advancement of social science knowledge about production and utilization of the potato. The views expressed in the papers are those of the author(s) and do not necessarily reflect the official position of the International Potato Center.

Comments are invited.

Patterns and Implications of Varietal Change in Potatoes

Thomas S. Walker [1]

[1] Economist, Social Science Department, International Potato Center (CIP).

Abstract

Potato varieties, once established in the market, can lay claim to a large chunk of growing area for many decades. The replacement rate of older varieties by newer ones appears to be slower in potatoes than in other arable crops in North America. The durability of popular potato varieties should be a source of concern to crop improvement scientists and to research administrators. The rate of varietal replacement is an important parameter in estimating the economic impact of a plant breeding program.

The adoption performance of public-sector, released potato varieties is analyzed for the U.S. and Canada from the early 1930s to 1990. The historical analysis of varietal change in North America is complemented by comparative case studies for the United Kingdom, the Netherlands, West Germany, East Germany, and Australia.

Increasing specialization and intensification in production and rising preferences for market quality in consumption are associated with a slowing in varietal change. The transition to higher market value is accompanied by a decline in the demand for varietal resistance to diseases and to rustic production conditions. Over time, yield potential and market value acquire increasing importance in determining varietal acceptance among producers and consumers.

If the supply of varieties and seed is forthcoming, the prospects for varietal change are brighter in developing countries, particularly in production environments of lower yield potential and in markets of weaker preferences for quality, than in developed temperate countries with a mature potato industry. The U.S. and other developed country experience also underscores the feasibility and desirability of wide adaptation. Strong national potato breeding programs should be capable of generating spill-over benefits within their own region or within a similar agroecology.

Acknowledgements

I am extremely grateful to J. Brennan, I. W. Buddenhagen, D. Byerlee, C. Crissman, N. Estrada, N. Simmonds, P. Schmiediche, and G. Scott for their extensive comments on an earlier version of this paper. I thank participants at a CIP seminar when this work was presented. I am also grateful to C. Crissman, R. Hijmans, L. Innes, and B. Vrolijk for assistance in coordinating requests for secondary data on certified seed production. B. Trognitz gave unstintingly of his time to discuss potato production in East Germany. R. Chase kindly provided the 1992 version of the North American Potato Variety Inventory. C. Ferreyra provided reference library assistance, V. Suarez and M. Lozano research support, and Z. Vasquez secretarial support. Researching this paper was very much a learning experience, and J. Bryan was a most wise and patient teacher.

Table of Contents

ABSTRACT ii

ACKNOWLEDGEMENTS ii

INTRODUCTION 1

THE U.S. EXPERIENCE: BACKGROUND 2

TRENDS IN CONSUMPTION AND IN PRODUCTION 3
Consumption 3
Regional Specialization in Production 4
Seasonal Specialization 8
Seed Certification 9
Pesticide Use 9
PLANT BREEDING AND HINDSIGHT 9

VARIETAL CHANGE IN THE U.S. AND CANADA 11

PERFORMANCE MEASURES 11
DATA 12
SOURCES OF BIAS 13
PERFORMANCE OVER TIME 14
RUSSET BURBANK 16
PERFORMANCE BY PROGRAM 20
COMPARING WHEAT AND POTATOES 22
CONTROVERSIAL ISSUES 25
Wide versus narrow adaptation 25
The strength of market preferences versus the demand for disease resistance 26

THE EXPERIENCE OF OTHER IMPORTANT POTATO PRODUCING TEMPERATE COUNTRIES 27

THE UNITED KINGDOM 27
THE NETHERLANDS 29
Bintje 29
Starch potatoes 30
WEST GERMANY 31
EAST GERMANY 33
AUSTRALIA 34

SYNTHESIS, IMPLICATIONS, AND REFLECTIONS 37

SYNTHESIS 37
IMPLICATIONS FOR DEVELOPED COUNTRIES 42
Environmental Concern 42
Biotechnology 44
IMPLICATIONS FOR POTATO CROP IMPROVEMENT IN DEVELOPING COUNTRIES 45
Varietal change, the quality of the production environment, and the strength of market preferences 45
Wide Adaptation 48
REFLECTIONS 49

REFERENCES 51

Tables

Table 1. Ranks in 1920 of states which ranked 1-2-3 in 1950 in production of selected commodities 4
Table 2. Fluctuations from year-to year in the price of potatoes by period from 1910-1949 6
Table 3. Potato varieties released by decade in the United States 14
Table 4. Adoption outcomes of released potato varieties from 1932 to 1989 15
Table 5. The importance of North Dakota varieties in 1990 for 11 major producing states in the U.S. 21

Figures

Figure 1. United States per capita consumption, 1870-1989 3
Figure 2. U.S. per capita use of potatoes by major category 4
Figure 3. Movement away from population and toward yields: rank correlation for selected years and states 5
Figure 4. Distribution of potato production in 1899, 1949 and 1990 7
Figure 5. Yield of potatoes in the United States, 1866-1989 8
Figure 6. Proportions sold of U.S. potatoes by season in 1953 and 1989 8
Figure 7. Average adoption performance by decades 15
Figure 8. Average of potato varieties in the U.S. and Canada from 1934-1992 16
Figure 9. Adoption of potato varieties in the United States, 1937-1990, by varietal types 17
Figure 10. Average age of potato varieties in the U.S. and Canada from 1934-1992 without Russet Burbank 17
Figure 11. Average potato yield in Washington State from 1949 to 1989 18
Figure 12. Varietal age and yields in the 11 most important potato producing states in the U.S. in 1990. 19
Figure 13. Performance of public sector breeding programs in the U.S. and Canada 20
Figure 14. Comparing the diffusion curves of important potato varieties in Canada with wheat varieties in the Yaqui valley of Mexico 23
Figure 15. Maincrop varieties—area planted by registered producers 1968-1979 27
Figure 16. Average age of maincrop varieties in the U.K. 27
Figure 17. Evolution of end uses in the utilization of potatoes over time 37
Figure 18. Growth in potato proudction and varietal change 39
Figure 19. The hypothesized relationship between varietal change and the quality of the production and consumption environments. 46

Patterns and Implications of Varietal Change in Potatoes

Thomas S. Walker

Introduction

In 1872, Luther Burbank noted the rare occurrence of a seed ball on a plant of the Early Rose variety in his family's garden in New England[1]. (Burbank was 23 at the time; he was a very keen gardener, but he was not yet a trained horticulturist). During the following summer, he planted 23 seeds from this seed ball. He selected two of those seedlings; one, in particular, appeared to have the potential to give high yields of tubers of an excellent size and shape. After another summer of testing, Burbank sold the rights to this variety to a seed dealer in Massachusetts for $ 150 and 10 potatoes of the variety which he took to California.

In a dealer's seed catalog in 1881, the Burbank variety was described as "Late, immensely productive. Tubers large, long, round; eyes full; skin nearly smooth, white; quality among the best. A good sort for the market" (Frank Ford's seed catalogue, p. 13; cited in Stuart, 1915, p. 18). By the turn of the century, Burbank's seedling had become an important variety in California. Later, sometime before 1914, a grower sowed the Burbank variety and found a plant which produced tubers with a cross-hatched, netted, or russeted skin.

Russet Burbank quickly found a home in Idaho, and, since World War II, it has been the most commercially successful potato variety in the United States. The variety's popularity was enhanced enormously by technological change in the form of microwave ovens and innovations in food processing to produce frozen french fries. Russet Burbank is an excellent baking potato and quickly became industry standard for frozen french fries.

Inspired by his early success, Luther Burbank started a potato breeding program in California. Ironically, none of the 500,000 seedlings from the crosses he made ever became a successful commercial variety. Russet Burbank is sometimes attributed to the improvements in potato breeding made by Luther Burbank (Lucier et al. 1991), but the development of the Burbank potato "called for no understanding of Mendelian law, inasmuch as it was nothing more or less than an amazing stroke of good fortune: the improbable sort of opportunity that proverbially knocks once and disappears forever unless unhesitatingly grasped ... in later years, Burbank was to offer a standing reward for seed balls of the Early Rose potato, but as long as he lived he never saw another (Dreyer 1985, p.61)."

---

[1] Commercially, potatoes are planted from seed tubers which is a form of clonal propagation. New varieties arise from tiny seeds produced from the pollination of the flowers of the plant. The seed ball or berry is the fruit of the plant and is the visible product of sexual reproduction. For multiple reasons, such as absence of flower production or pollen sterility, the formation of berries can be problematic. In his classic taxonomy and description of American potato varieties, Stuart in 1918 describes Early Rose as a variety which flowers freely but which bears no seed balls (p. 27).

The above brief history of Russet Burbank is taken largely from "Russet Burbank: Is it here to stay?" (Zalewski 1992). Typically, this question was put to the readers of a growers' magazine. The fact that potato varieties, once established in the market, can lay claim to a large chunk of growing area for many decades is seldom discussed in specialized scientific journals on potato crop improvement. But it is widely acknowledged and voiced as a concern by potato breeders in workshops and conferences that some very old varieties still command a substantial share of production in several developed countries and that the replacement rate of older varieties by new ones is less rapid in potatoes than in other arable crops (Hermsen and Swiezynski 1986; Thomson 1986).

The durability of commercially established potato varieties should be a source of concern to potato crop improvement scientists and to research administrators. Under some reasonable assumptions, the rate of varietal replacement is a good measure of the economic impact of a plant breeding program (Brennan and Byerlee 1991). The permanence of older varieties erodes the potential for making practical impact.

So the question of whether or not Russet Burbank is here to stay is far from trivial. The substance of this issue transcends the specifics of Russet Burbank and potato production in Idaho. One can generalize by posing the following questions: What has been the pace of varietal change in potato production in the U.S.? How does the rate of varietal change compare with other field crops? How has the rate of varietal replacement varied over time and space? How does the experience in the U.S. compare with other major temperate potato producing countries? And, most importantly, what do the findings on the rate of varietal change in developed countries imply for potato crop improvement in developing countries where potato production is expanding?

The main message emerging from this research is counterintuitive: more specialization and intensification in production and rising preferences for market quality in consumption are associated with a slowing of varietal change. This finding is based on a review of how potato production and consumption have evolved over time and space in the U.S. The review of the evidence on varietal change in the U.S. is by no means exhaustive, but a lengthy treatment in one country is warranted to place in context the comparative evidence which follows for several other major potato-producing temperate countries. In the last part of the study, the experience on varietal change in potatoes is synthesized, implications for potato crop improvement in developing countries are drawn, and directions for further research are charted.

The U.S. Experience: Background

Government-supported potato breeding in the United States started with the United States Department of Agriculture (USDA) program in 1910. It is one of the oldest public-sector

agricultural research programs in North America. Potatoes also enjoy the distinction of being one of the first crops for which the USDA collected production data, as early as 1866 (USDA 1953).

The first products of the breeding program were made available to farmers in the early 1930s. Since that time, more than 200 varieties have been released in North America.

The U.S. experience begins with an overview of potato production and consumption trends in the 20th Century. Then the main elements of the government-supported potato breeding program are described and, with the benefit of hindsight, how changing circumstances influenced the consequences of the program is discussed. The U.S. experience concludes with an analysis of varietal change and with a discussion of the reasons for the results.

This part of the study relies almost entirely on three source materials: (1) a landmark study of the impact of government programs on potato production by Gray et al. (1954), (2) a recent USDA publication (Lucier et al. 1991) providing production and consumption information from 1949-1989, and (3) issues of the American Potato Journal which first appeared as the Potato News Bulletin in November, 1923.

Trends in Consumption and in Production

Consumption

Since 1870, potato use per capita exhibits a non-linear behavior which is divided into three stages in Figure 1. Between 1870 and 1910, a surge in immigration from Europe imparted an upward trend to per capita consumption (Gray et al. 1954). Immigra5nts came from several countries with extraordinarily high levels of potato consumption per person. They did not instantaneously adjust their consumption pattern on arrival in the United States where the diet of the longer term resident population was considerably more diversified.

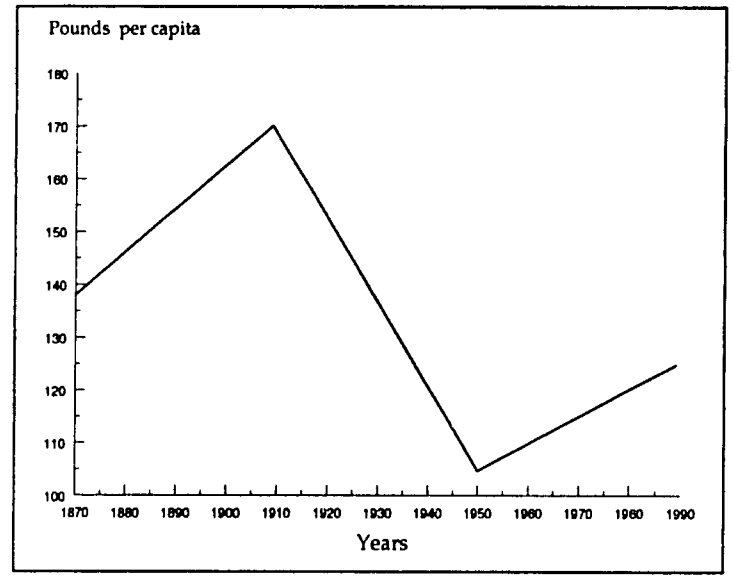


Figure 1. United States per capita consumption, 1870-1989.
Source: Gray et al. 1954, p. 10; Lucier et al. 1991, p.2

The second stage is identified with a long-term declining trend in per capita use. Without the wave of immigration in the late 19th and early 20th Century, this trend would have been visible much sooner (Gray et al. 1954).

The third stage corresponds to gradually rising per person use from about 105 pounds in 1960 to over 130 pounds in 1992 (Lucier 1991 and USDA 1993). This amazing reversal of form was fueled by the demand for fast food, which, in turn, was driven by a rising opportunity cost of time from women's increasing participation in the labor market. Consumption of frozen potatoes, mainly french fries, increased from about 8 pounds per person in 1960 to 50 pounds in 1992 (Figure 2). Consumption of fresh potatoes fell from about 80 pounds to 50 pounds, a level at which it has stabilized (over the past 20 years) thanks largely to microwave ovens (Guenthner et al. 1991).

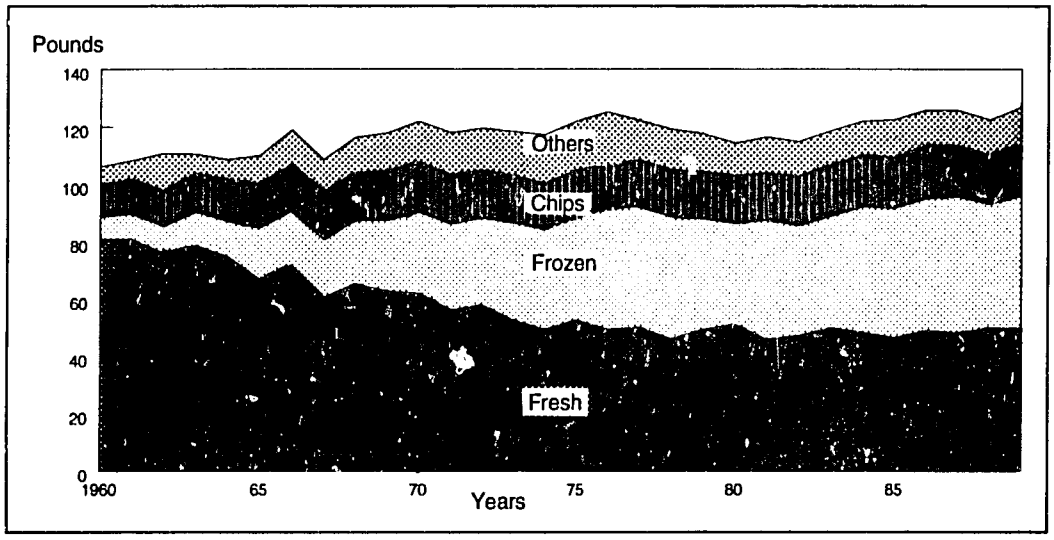


Figure 2. U.S. per capita use of potatoes by major category.
Source: Lucier et al. 1991, p. 2.

Regional Specialization in Production

The spatial distribution of production of many commodities in the United States has not changed appreciably during this century. For example, the states ranked first, second, and third in corn production in 1950 enjoyed the same status in 1920 (Table 1). In contrast, the most important potato producing states in 1950 were ranked sixth, eleventh, and sixteenth in 1920 (Gray et al., 1954).

Table 1. Ranks in 1920 of states which ranked 1-2-3 in 1950 in production of selected commodities

Corn	Tobacco	Apples	Cabbage	Cotton	Wheat	Onions	Potatoes
1	2	2	3	1	1	1	6
2	1	1	2	5	2	18	11
3	3	3	4	3	9	2	16

Source: Gray et al. 1954, p. 31.

The role of potatoes as a staple and its wide adaptation to different growing conditions largely explains why regional specialization occurred later for potatoes than for other crops. Potatoes are bulky and costly to transport; therefore, consuming home-produced potatoes competed favorably with buying them in the market when transportation costs were high. With improvements in the transportation system and marketing infrastructure, semi-subsistence production became a less attractive option to producing other commodities and purchasing potatoes in the market.

Specialization was also driven by the ability of urban consumers to pay price premia for high quality potatoes. This influence of the market is reflected in the following passage by Dean (1933, p.111):

> The growers in the older potato-growing states were not only forced to reduce production but in most cases saw their potatoes discriminated against in the markets of their own cities in favor of potatoes from the newer regions that better met the higher standards in regard to quality and grading.

Gray et al. (1954) succinctly captured the essence of the trend in regional specialization in potatoes with the phrase, "movement away from population and towards yields." In the early decades of this century, production was highly correlated with population, but this positive association rapidly declined over time (Figure 3). Potatoes moved to production environments with higher yield potential.

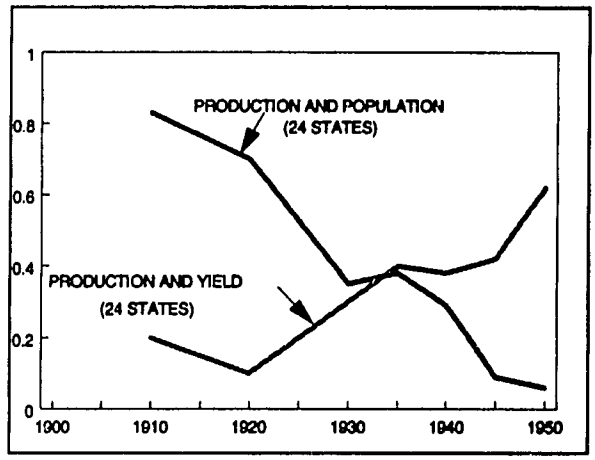


Figure 3. Movement away from population and toward yields: rank correlation for selected years and states.
Source: Gray et al. 1954, p. 28.

Updating the correlations in Figure 3 shows no appreciable changes since 1950. For the 48 continental states, estimated the correlation between production and population was 0.00 in 1990. A comparable estimate for the association between production and yield was 0.60 for the 34 states which produced enough potatoes to merit the listing of production statistics in the USDA report (Lucier et al. 1991).

Before regional specialization occurred, potato production in the United States was synonymous with population density in the northern half of the country (Figure 4, Upper Panel). Where there were people, there were potatoes. By 1949, potato area was halved, and production was concentrated in well-defined, spatially distant, small regions of pronounced comparative advantage (Figure 4, Middle Panel). The trend towards specialization in pockets of high production potential continued during the next 40 years (Figure 4, Lower Panel), but, as the earlier correlations suggest, regional specialization in potatoes had largely sorted itself out by 1950.

The major shifts in the distribution of production took place in the first two stages between 1890 and 1950. In the first thirty years of this period, potato production shifted from the Corn Belt to the Lake states (Gray et al. 1954). During the last thirty years, production moved west, particularly to Idaho and Washington, and to specialist regions of comparative advantage in North Dakota and Maine.

The 1940s were characterized by an acceleration in the trend towards regional specialization. In only one year, potato area in the western and other specialist states expanded by about one-third from 568,000 acres in 1942 to 754,000 acres in 1943 (Gray, et. al. 1954, p. 71). This rapid shift to areas of higher production potential is reflected in a surge in yields in the mid- and late- 1940s when increasing regional specialization was a significant source of economic growth (Figure 5). (Historically, yields in the U.S. in the late 19th and early 20th centuries were substantially lower than those prevailing in Western Europe where production was considerably more labor-intensive in response to greater population pressure). Prominent geographic shifts in production not only took place across states but also within states. For example, Gray et al. (1954) document a significant movement of potatoes from the southern to the northern counties in the lake states during the second stage of regional specialization.

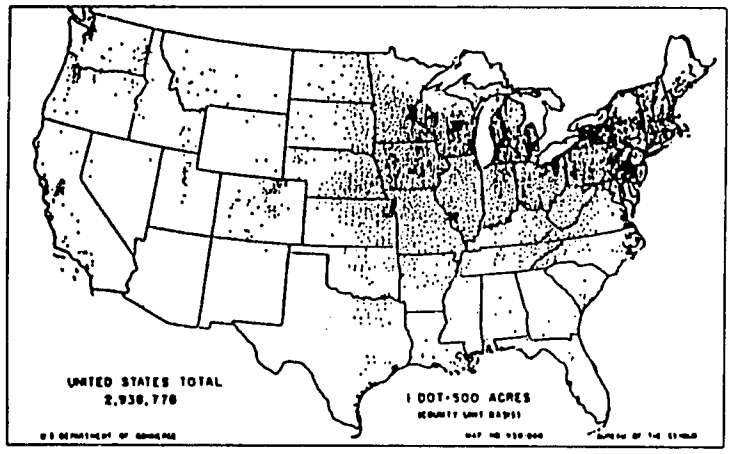
The trend towards regional specialization was stimulated by a government price support program on potatoes in the 1940s. This program was very costly; government purchases of potatoes amounted to about $ 500 million dollars in 1945 prices. Larger, more commercial producers in the specialty regions of production differentially benefited from the program by planting more area in response to increased price stability (Gray et al. 1954). The program substantially reduced exposure to downside price risk (Table 2). The level of price instability declined from 40-50% to about 10% when the program was in force from 1942-49.

Table 2. Fluctuations from year-to year in the price of potatoes by period from 1910-1949

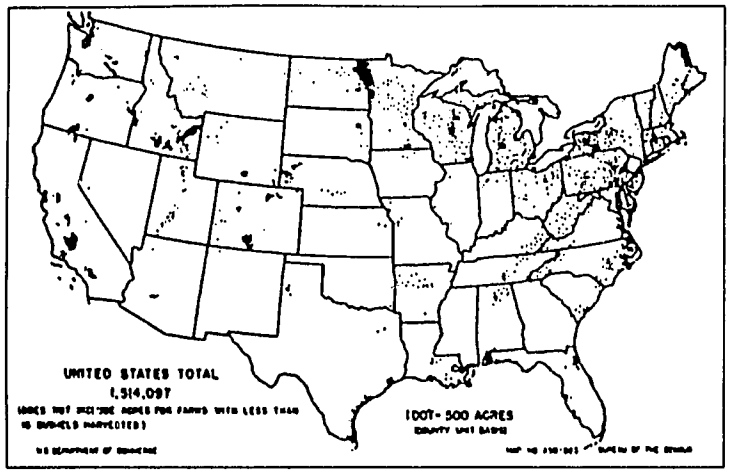
Period	Average Percent fluctuation
1910-17	43.9
1918-25	50.6
1926-33	53.9
1934-41	38.7
1942-49	10.6

Source: Gray, et al. 1954, p. 139.

1899



1949



1990

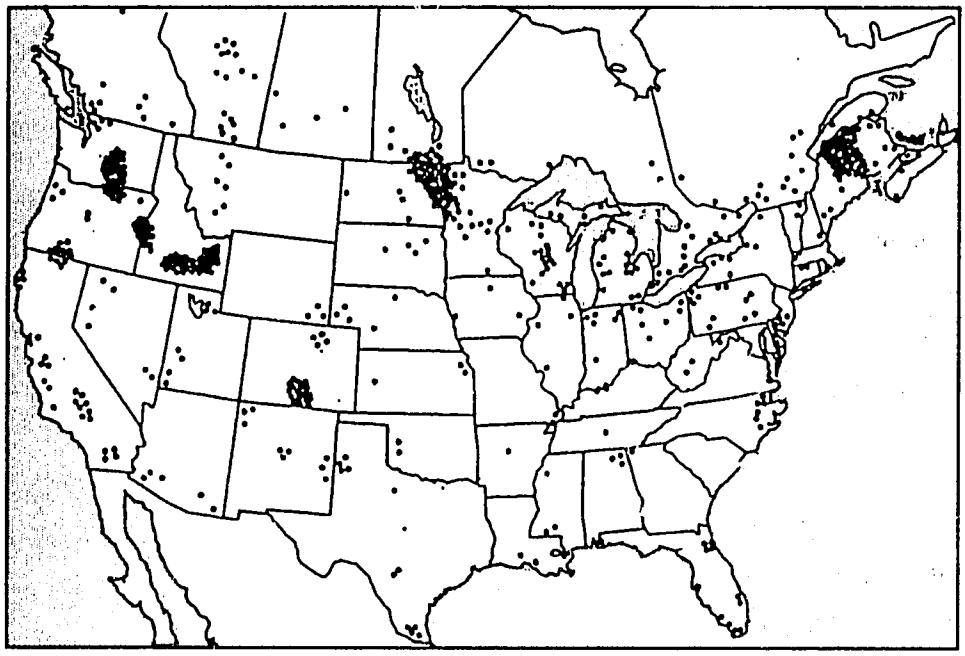


Figure 4. Distribution of potato production in 1899, 1949 and 1990.
Source: Hawkins, A. 1957. Highlights of a half-century in potato production. American Potato Journal, 343(1):25-29; Rowe, R.C. (ed). 1993. Potato Health Management. APS Press. Minnesota, USA.

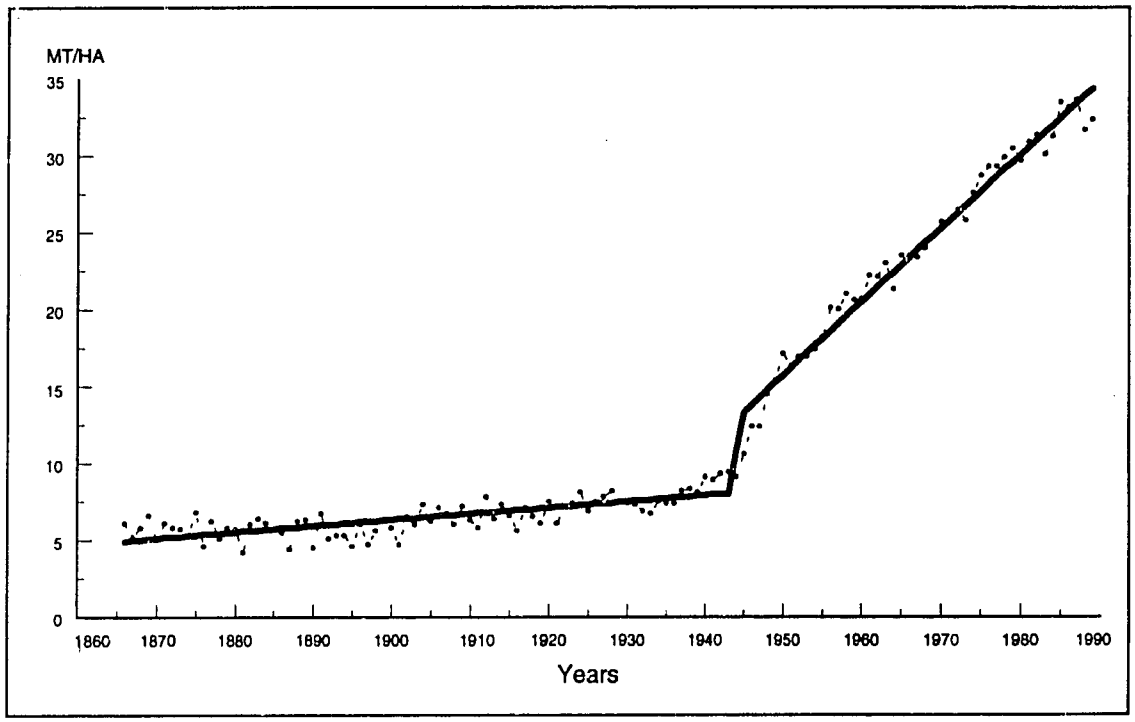


Figure 5. Yield of potatoes in the United States, 1866-1989.
Source: USDA 1953, pp. 5,87; Lucier et al. 1991, p. 11.

Seasonal Specialization

One of the results of regional specialization has been the increasing dominance of production in the higher yielding fall season. The relative importance of production in the summer and spring seasons has declined in the vast majority of states (Figure 6). Cold storage and the increasing importance of frozen french fries has reduced the demand for off-season production in response to price seasonality.

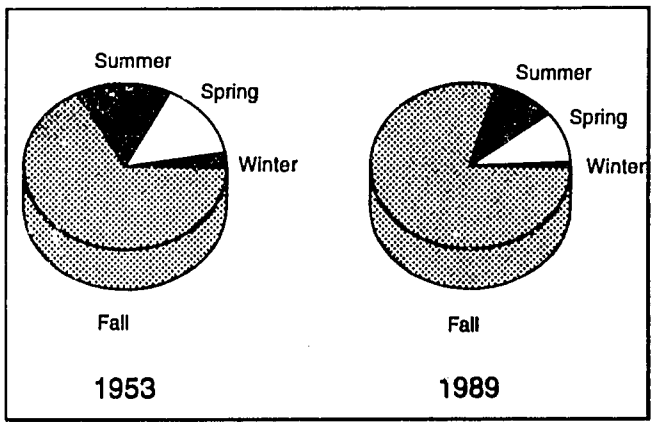


Figure 6. Proportions sold of U.S. potatoes by season in 1953 and 1989.
Source: USDA 1991, p. 6.

Since 1949 spring production in several non-specialist Southern and Southwestern States has become rare; the same trend applies to summer production in several mid-Western and Mountain States. These seasonal trends are largely reflected in the differences in the distribution of potato production between 1949 and 1990 (Figure 4, Middle and Lower Panels). A tendency towards increasing seasonal

specialization has implications, which are discussed later, for the demand for wide vs. narrow adaptation.

Seed Certification

Seed certification rapidly emerged as one of the major success stories in this vegetatively propagated crop which can degenerate rapidly to virus and other seed-borne diseases. Thousands of demonstration plots, comparing certified and farmer's seed of the same clone, were planted between 1915 and 1930. William Stuart, the founder of the American Potato Journal, summarizes the evidence as follows: the average total results in Canada and the United States based on 11,627 reports shows an actual increase of 46.4 bushels per acre. (W. Stuart, 1926, p. 84). In 1926, 40-50 additional bushels per acre were equivalent to a productivity impact of 30-40%.

The uptake of certified seed by potato farmers was most impressive. From 1920 to 1935, certified seed area expanded from about 10,000 to 80,000 acres; the trend in production was even stronger, from about one million bushels in 1920 to sixteen million bushels in 1935 (Tucker 1937). The diffusion of certified seed has profound implications for both the supply of and demand for new potato varieties.

Pesticide Use

Largely because of the crop's high value and because of the effectiveness of pesticides, chemical control loomed large in potato production throughout this century. In the early 1900s, the Bordeaux mixture, based on Copper Sulfate as the active ingredient, was widely used to control late blight. Indicative of this demand, the early volumes of the American Potato Journal were sprinkled with ads for horse-drawn sprayers. The main research issue focused on whether farmers should spray or dust (Fernow 1928). Extensionists expressed their concern for the occupational safety of small growers in applying pesticides in 1924 (American Potato Journal, p. 61). Pesticide use strongly influenced the demand for varietal resistance to insects and diseases.

Plant Breeding and Hindsight

Looking back from 1993, plant breeders in the early decades of this century faced an opportunity which was fraught with uncertainty. The lag between the time when crosses are first made and new varieties first find a home in farmers' fields is about 10-20 years. Therefore, breeders need to be forward looking in evaluating the demand for new varieties.

What was known when the government-sponsored potato breeding program started in the early 1900s? (The program dates from 1910 when the USDA plant breeding program was

founded and 1930 when the cooperative USDA-state program began). One can conjecture that public-sector breeders at that time were aware of the following: the varieties selected by private breeders in the second half of the 19th century were high yielding, susceptible to disease, and, in many cases, left something to be desired in terms of external appearance (Clark and Stevenson 1935). At that time, the competition was epitomized by Irish Cobbler, a widely adapted, early-maturing, round white variety with medium-deep eyes.

The basis for progress was also known. In general, the hobby breeders of the 19th century selected varieties from naturally fertilized seed balls. Sampling the yield distribution should be much more efficient in a breeding program featuring systematic crosses, large numbers of seedlings for evaluation, and multi-locational testing.

With these considerations in mind, high yields, improved external appearance, and disease resistance became the most important criteria for varietal selection in the crop improvement program (Clark and Stevenson 1935). Initially, emphasis in disease resistance was assigned to late blight, but, with the growing recognition that viruses were seed transmitted, more attention was paid to viruses in resistance screening.

The founders of the program could not have anticipated the nature, magnitude, and timing of production and consumption trends. When breeding started, regional specialization was only beginning to sort itself out. Within 30 years, potatoes changed from a predominantly dryland, semi-subsistence crop, produced mainly by small mixed farms, to a largely irrigated, high value cash crop grown by specialized farms.

The trend towards processing in general and frozen french fries in particular was much slower to emerge. Even in the 1950s, the potential for processing went largely unnoticed. In their classic study in 1954, Gray et al. state that "no important processing industry has developed around potatoes in the United States (the potato chip industry in 1950 used about 5 per cent of the average potato crop) (p.31)." These market-driven changes could not have been forecast in the 1920s.

These and other subsequent events had two profound implications for public-sector breeding. First, the demand for disease resistance was always much stronger in the minds of scientists than in the eyes of farmers. Regional specialization in increasingly concentrated pockets of production enhanced the competitiveness of chemical control. The spatial concentration of production should ultimately have facilitated the availability of chemicals, and, with larger, more commercially-oriented farms, purchases of pesticides were no longer constrained by shortages of liquidity. With economic development, capital also became cheaper over time.

The other alternative to varietal disease resistance was certified seed. The linkage between varietal resistance and certified seed is usually viewed as complementary (Beekman 1987). But seed borne diseases can, in theory, be controlled in two ways: through clean seed or from varietal tolerance, resistance, or immunity. In principle, having both would be optimal, but, in

practice, having one substantially reduces the need for the other. The incipient success of the seed certification program should have been visible in the 1920s, but the implications of this success for varietal change received scant attention in the literature, at least in the American Potato Journal. If the state seed certification programs had started later, the demand for varietal change would have been greater. Other things being equal, it is much easier to compete against a plant which is degenerating than against one which is annually being renewed.

Underestimating the strength of the competition was the second implication flowing from unforeseen trends and events. The local competition was substantially more formidable than expected. In the mid-1930s, when data on certified seed production were first published in the American Potato Journal, Irish Cobbler accounted for about 35% of production (Seed Certification Committee 1936). Green Mountain, a very high-yielding and very disease susceptible late duration clone, was a close second with about 25%. Russet Burbank had a production share of only 4%. Russet Burbank was well-adapted to several of the main regions of specialization, but, more importantly, it was ideally suited to emerging market demand.

Nature was also niggardly to potato breeders, who were not able to draw on fundamental research breakthroughs, i.e. increased harvest index, which led to marked productivity impacts in cereals. Government-supported potato breeders were constrained to sample, albeit much more efficiently, from the same potential yield distribution as the 19th Century hobby breeders. For example, Green Mountain is still hard to beat in terms of yield potential. The absence of effective fundamental technical change made the task of competing with the entrenched 19th Century varieties a more difficult undertaking.

Summing up, government-supported potato breeders in the early decades of the 1900s faced a window of opportunity of only 20-30 years when the major program elements effectively addressed the production and consumption environments. As demonstrated in the next section, they took advantage of that opportunity, but, over time, the window was closing on high returns to investments in breeding.

Varietal Change in the U.S. and Canada

Performance Measures

Three indicators are used to assess the adoption performance of improved potato varieties released in the 20th century. All three share the common time horizon of the date of release of the variety to 1992. The proportion p_{it}, the share of area sown to variety i in year t, is the empirical basis for the three indicators.

The first indicator provides information on the incidence of successful varieties. Varieties are classified into two broad categories: (1) those with a maximum p_t greater than or equal

to .01 indicating that in at least one year since release to 1992 the area sown to the variety of interest exceeded one percent of total area and (2) those with a maximum p_t below .01. The former are called successful; the latter are labeled unsuccessful. The level chosen for a cutoff point of .01 is arbitrary, but clearly a variety that never accounted for more than one percent of total area in any year since its release to 1992 could hardly be called significant in terms of its adoption performance. The successful varieties are further broken down into those with a maximum p_t greater than .05, between .03 and .05, and between .01 and .03. The magnitude of their success is arbitrarily termed as very, moderately, and less successful.

The second indicator conveys information on average adoption performance. For each variety, the annual proportions are summed from the date of release to 1992 and divided by the number of years from release to 1992. This mean share of area planted is useful in comparing adoption outcomes of groups of varieties. Adoption performance by decade and by plant breeding program is analyzed with this measure later in this section.

The third measure is an index of the rate of varietal replacement (Brennan and Byerlee 1991). The weighted average varietal age (WA) describes how old varieties are from the date of release or (for the 19th Century varieties) from when they became commercially available for a given year of interest. WA for year t is calculated below:

$$(WA)_t = \sum_{i=1}^{n} p_{it}$$

Weighted average varietal age describes adoption performance over time. In general, a declining mean age over time suggests higher returns to plant breeding, i.e. newer releases are replacing older varieties.

Data

The process of seed certification provides a rich source of information for the evaluation of varietal adoption. In the U.S., each state seed certification association annually publishes a list of growers with area certified by variety. Since 1934, these lists have been compiled and varietal information has been published annually for the U.S. and Canada by the Potato Association of America and since 1981 by the National Potato Council.

Katahdin was the first public sector release in 1932. From that year to 1992, data were available on certified seed area for 38 of the 60 years for the U.S. and for 42 years for Canada.

Canada is an important source of certified seed for planting in the United States. Varietal data on seed imports are not available; therefore, the analysis below covers varietal change in

both the United States and Canada. Once released, a variety could be grown in either country. Indeed, the most successful varieties are largely the same for both countries.

Sources of Bias

Bias stems from the nature of the data or from the construction of the three indicators of adoption performance. It is assumed that the relative incidence of varieties planted in growers' fields in year t is identical to the relative frequency of area approved as certified seed the same year. This assumption reflects reality if the yield of certified seed does not differ substantially among varieties and among producing regions and if the vast majority of farmers plant certified seed every year. Systematic productivity differences across varieties and seed producing regions most likely exist, but time series information is not available to correct for these sources of variation. Not all potato area is planted with certified seed; even today many farmers in specialty growing areas, such as Idaho, plant "year out" seed (Makus et al. 1992). Hence, adoption of older varieties, for any particular year, will be underestimated and newer varieties overestimated. In spite of these weaknesses, the data on certified seed area should shed enough light on adoption performance to identify the major elements of the story.[2]

From the perspective of the indicators, the most likely source of bias pertains to the max and average p_t which potentially discriminates against later releases, particularly those in the decade of the 1980s, which have not had time to enjoy a full diffusion path. In the case of a few varieties, this bias could be significant because their adoption performance in the years shortly after their release did not presage their popularity in later years. For example, Ontario was released in 1946; it appeared to peak in 1952 at 2.7% of area of certified seed and, subsequently, it experienced a resurgence in the early 1980s when it accounted for as much as 3.5% of area in 1984. But such cases are rare. Moreover, almost all successful varieties account for at least 1.0%

---

[2] One of the anomalies with the data is that no one knows when Russet Burbank became commerically available. The discovery of the Russeted strain of Burbank's seedling is commonly credited to a grower in Colorado in 1914 (Chase 1992). But California Russet, which William Stuart (1918) believed was a synonym for Russet Burbank, was described as "a new variety of great merit ...; unexcelled in quality (Stuart p. 18-19)" in the Dakota's Improved Seed Co.'s catalog in 1908. In the same publication, Stuart (1918) lists Cambridge Russet, which appears in a seed company catalog in 1899, as "similar to California Russet, if not identical with it (p. 19)." In an even earlier work on the classification of popular potato varieties, Fitch in 1914 noted that the quality of the Burbank group was especially fine and that the price of this variety had been for years the government standard in the Chicago market. The illustrations of the Burbank group in Fitch were photos of the russeted sport or mutation. Therefore, the evidence is consistent with dating the commercial availability of Russet Burbank to before 1914, perhaps as early as 1899. This study sticks with convention and uses 1914 as the date when Russet Burbank became commercially available. Staying with 1914 could lead to an underestimate of as much as five years in weighted average varietal age in those years when Russet Burbank was very popular.

of area in a few years after release[3]. Very few of the successful varieties could be characterized as late starters.[4]

Performance over Time

The 1992 version of the North American Potato Variety Inventory lists 287 varieties (Chase 1992). Nineteen 19th century varieties were sufficiently important to include in the inventory. These were mainly selected by farmer hobby breeders and small vegetable seed producers in the 1870s, 1880s, and 1890s. Between 1900 and 1930, there was a lull in private sector breeding. The first products of the public sector breeding program became available in the early 1930s. For the next four decades, on average, about four to six varieties were released each year (Table 3). Over 95% of the 245 varieties released between 1932 and 1989 have originated in government-supported national, state, or provincial plant breeding programs.

Table 3. Potato varieties released by decade in the United States.

Decade	Number
1860 - 1900	21
1900 - 1930	5
1930s	14
1940s	37
1950s	42
1960s	49
1970s	40
1980s	62

Source: Constructed from Chase 1992.

During the last 60 years, the odds were slim that any released variety would ever become popular. Seven of eight varieties, for all intents and purposes, were abandoned by producers after accounting for a few acres of certified seed production for a few years. From Table 4, the odds of releasing a moderately or very successful variety were about 1 in 13.

---

3 Several varieties released since 1990 already satisfy this minimal criterion for success. These include Snowden, Goldrush, and, Ranger Russet.

4 More recent data on the area entered for certified seed production in 1994 also provided more insight on the expected adoption profile of varieties released in the 1980s.

Table 4. Adoption outcomes of released potato varieties from 1932 to 1989

Successful[a]	32
Very[b]	13
Moderately[c]	6
Less[d]	13
Unsuccessful[e]	213
Total	**245**

[a] A successful variety accounted for at least 1% of the area certified for seed in its year of peak adoption since release to 1992 in either the U.S. or Canada.

[b] Very successful is defined as a share of at least 5% of the area certified for seed in either the U.S. or Canada in the year of peak adoption. These varieties include Atlantic, Chippewa, Katahdin, Kennebec, Norchip, Norgold Russet, Norland (including Dark Red Norland), Red La Soda, Red Pontiac, Russet Norkotah, Sebago, Shepody, and Superior.

[c] Moderately successful is defined as a share between 3 to 5% of the area certified for seed in the year of peak adoption since release. Moderately successful varieties include Centennial Russet, Chieftain, FL 657, Monona, Ontario, and Yukon Gold.

[d] Less successful is equated to a share between 1 to 3% of area certified for seed in the year of peak adoption since release. The majority of these varieties were never responsible for more than 2% of the area certified for seed. They include Belrus, Canso, Cherokee, Early Gem, Fundy, Hitlite Russet, Hunter, Keswick, La Rouge, La Soda, Pontiac, Pungo, and Red Warba. Although Canso accounted for about 6.0% of certified seed area in Canada in 1952, its popularity was very short-lived. Its overall adoption performance is inferior to several other varieties in this class.

[e] These varieties never accounted for more than 1.0% of area certified for seed in their year of peak adoption. The vast majority of these never laid claim to more than one-tenth of one percent of certified seed area.

Led by Katahdin, Sebago, and Chippewa, the varieties released in the 1930s were widely adopted by farmers. Their average market share of certified seed area, i.e. their average p_t expressed in percent, approached 1.50% (Figure 7). This performance rating dropped in the 1940s, but the average level of varietal acceptance at about 0.5% per variety was still quite respectable. Adoption performance hit a low point in the 1950s. During the next three decades, the uptake of released varieties improved somewhat, but the level of performance paled in comparison to

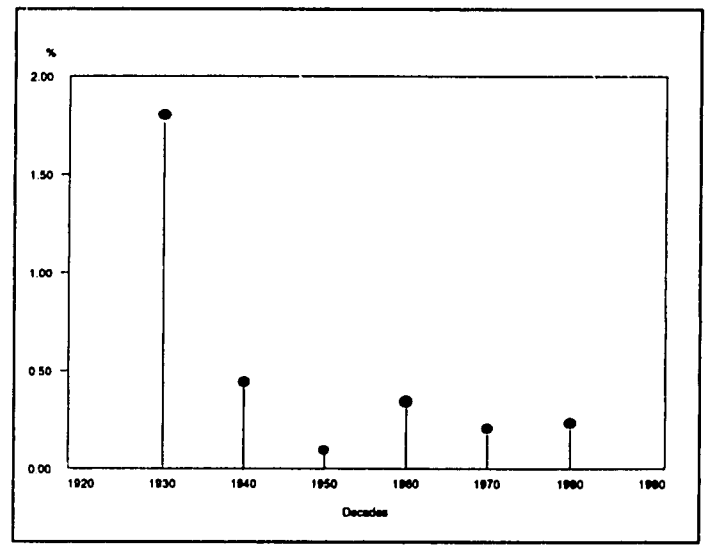


Figure 7. Average adoption performance by decades.

what was achieved in the 1930s. No variety released since Kennebec in 1948 has ever accounted for more than 25% of certified seed area in any given year in either the United States or Canada.

The pattern of falling returns is exemplified by the behavior of the third performance measure, the average age of varieties planted with certified seed (Figure 8). At the release of the "first generation" public sector varieties, all the potato growing area in the United States and Canada was planted to the late 19th Century varieties which were about 50 years old in the early 1930s. The adoption of the varieties released in the 1930s peaked in the late 1950s and early 1960s in the United States and Canada. Average age declined rapidly to about 30 years.

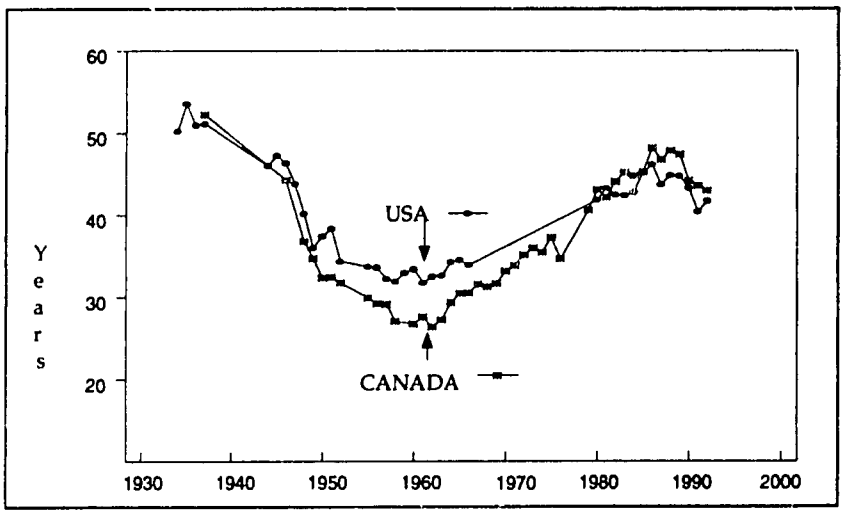


Figure 8. Average age of potato varieties in the U.S. and Canada from 1934-1992.

The decline in varietal age in the 1930s, 1940s, and 1950s is consistent with a scenario of rapid technical change. With the release of about 40 to 60 varieties per decade during the past 40 years, one would have expected this downward trend to continue. Surprisingly, the early 1960s marked a turning point when the rate of varietal replacement slowed to such a degree that average varietal age rose until the late 1980s. By the mid-1980s, the varieties approached the age of those planted in the mid-1930s. In summary, the U-shaped pattern of average age in Figure 8 is synonymous with marked success in the 1930s and 1940s followed by a long period characterized by a slowing in the uptake of released varieties.

Russet Burbank

The amazing story of Russet Burbank explains much of the behavior in Figure 8. From its small base in the 1930s, the diffusion of Russet Burbank gradually increased during the next 50 years (Figure 9). The public sector varieties competed well with Irish Cobbler, Green Mountain, and other 19th Century varieties, but could not penetrate into specialized production areas where Russet Burbank was becoming increasingly popular. By the 1980s, Russet Burbank accounted

for about 35% of certified seed area and about 50% of potato production. By the late 20th Century, Russet Burbank had become the only 19th Century variety of significance (Figure 9).

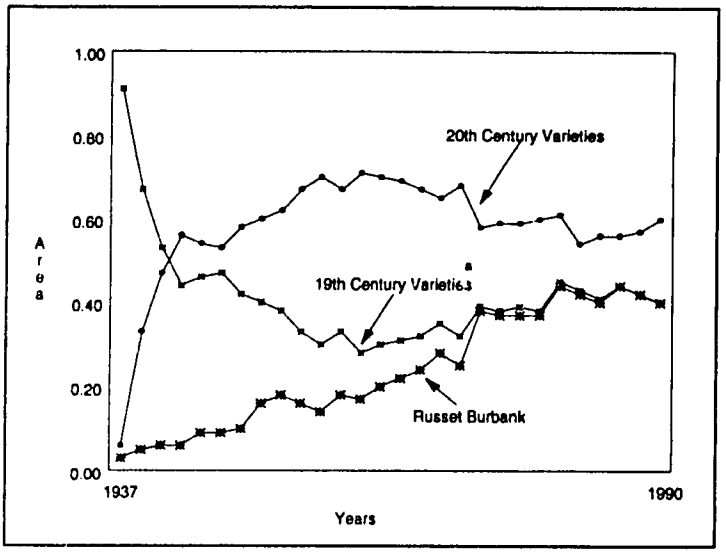


Figure 9. Adoption of potato varieties in the United States, 1937-1990, by varietal types.
[a] Includes the area planted to Russet Burbank

What would have happened to the rate of varietal replacement if Russet Burbank had not experienced such a surge in popularity during the later part of the 20th century? Figure 10 responds to this question. Without the effect of Russet Burbank, the varietal age of the remaining area approved for certified seed declines at a decreasing rate and eventually settles at a level between 10 and 20 years for the U.S. and Canada.

The information summarized in Figure 10 is consistent with expectations for a high value, field crop where the supply of improved varieties has not been constraining and where yield potential and the effective demand for varietal disease resistance have not changed markedly over time. Varietal age fell rapidly as the newly released varieties quickly replaced the 19th Century varieties (Figure 9). Subsequently, the change in varietal age slowed as younger varieties were increasingly replacing older 20th century cultivars.

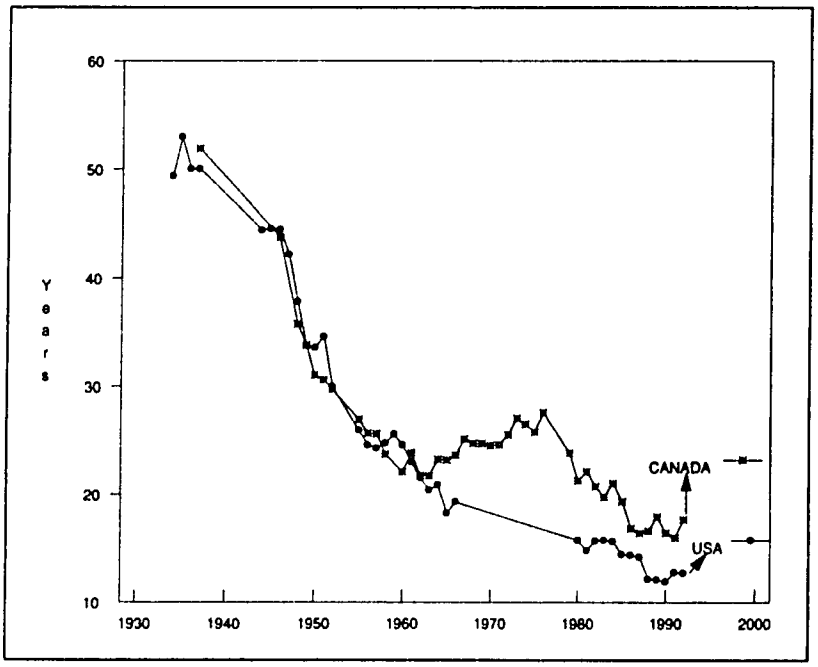


Figure 10. Average age of potato varieties in the U.S. and Canada from 1934-1992 without Russet Burbank.

Combining the information in Figures 9 and 10 leads to a fairly complete picture of why average varietal age behaves as it does in

Figure 8. In particular, the gradual fall in varietal age reached in the late 1980s and early 1990s has more to do with the apparent ceiling level of adoption reached by Russet Burbank at about 35% of certified seed area in Figure 9 than with a quickening of the pace of the remaining or residual varietal change in Figure 10.

In the context of technical change, Russet Burbank behaved more as a distinct species than as a variety. In agricultural research, one usually views the environment as given and the technology as variable to accommodate the needs and circumstances of the resource base. Technological change substitutes for the quality of the resource base. But the market-related traits of Russet Burbank were so outstanding that environments of high and stable production potential were implicitly sought where production of the clone could be maximized. Therefore, the production environment became a variable in the quest to produce a variety combining good storability with very desirable traits for both the fresh and processed markets.[5]

Irrigated potato production in Washington is the stellar example of such an environment. The growth and stability of potato yields in Washington has been remarkable (Figure 11). From 1949 to 1989, the linear trend in the average state yield was 8.7% per annum, and the detrended coefficient of variation of production was only 7.0%. The dominant cultivar is Russet Burbank; therefore, varietal change has not been a source of growth. Moreover, in poorer environments or years, Russet Burbank is an unstable yielder compared with several other high-yielding clones. Thus, this most impressive combination of high and stable growth amply attests

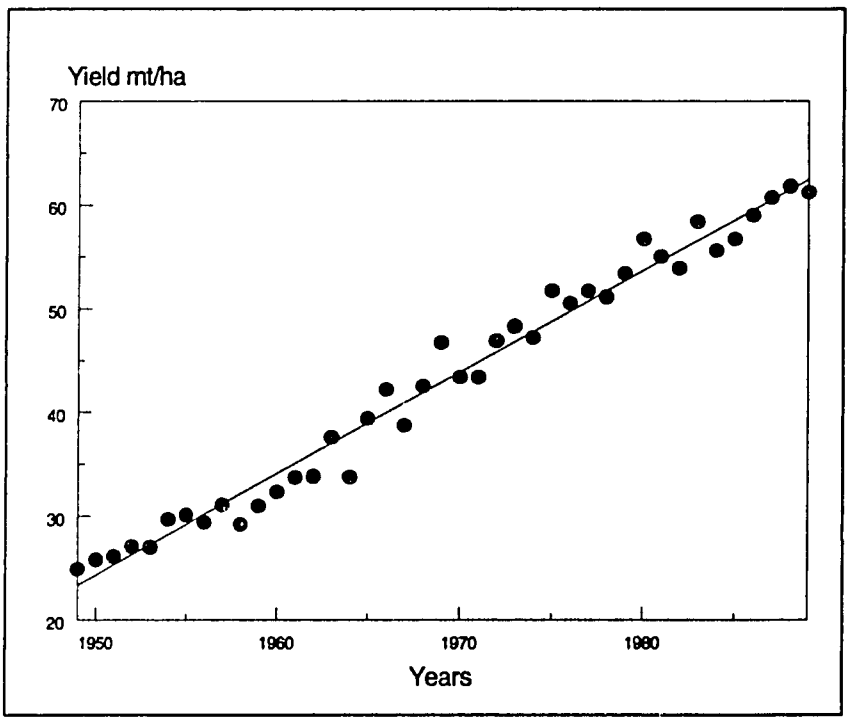


Figure 11. Average potato yield in Washington State from 1949 to 1989.

[5] Price differences between varietal types in the same market for the same time are indicative of quality differences as perceived by buyers. Between 1980 and 1990, the annual average wholesale price for round white potatoes from the Northeast in the Washington, D.C. market was about $10 per cwt (45.45 kgs) (Lucier et al. 1991)). A comparable figure for russeted potatoes from Idaho was around $22.

to the quality of the production environment which, one can say without too much exaggeration, approximates the ideal conditions for the production of Russet Burbank in a growth chamber. Over time the production of Russet Burbank has gravitated to the higher and more stable yielding, irrigated production environments within the specialist growing regions.

One consequence of the Russet Burbank phenomenon is that plant breeders have registered more success in the less well endowed, more rain-fed producing regions. The common criticism of the Green Revolution that varietal change has bypassed the more marginal producing regions could not be leveled at potato breeding in North America. Indeed, the opposite applies: the pace of varietal change has been slower or negligible in the heavier yielding, potato producing states. Based on data from 1990, varietal age and yield were positively correlated in the 11 most important producing states in the United States (Figure 12). In other words, higher yields were associated with less varietal change. Average varietal turnover has been inversely related to the quality of the production environment in the eleven most important potato-producing states.

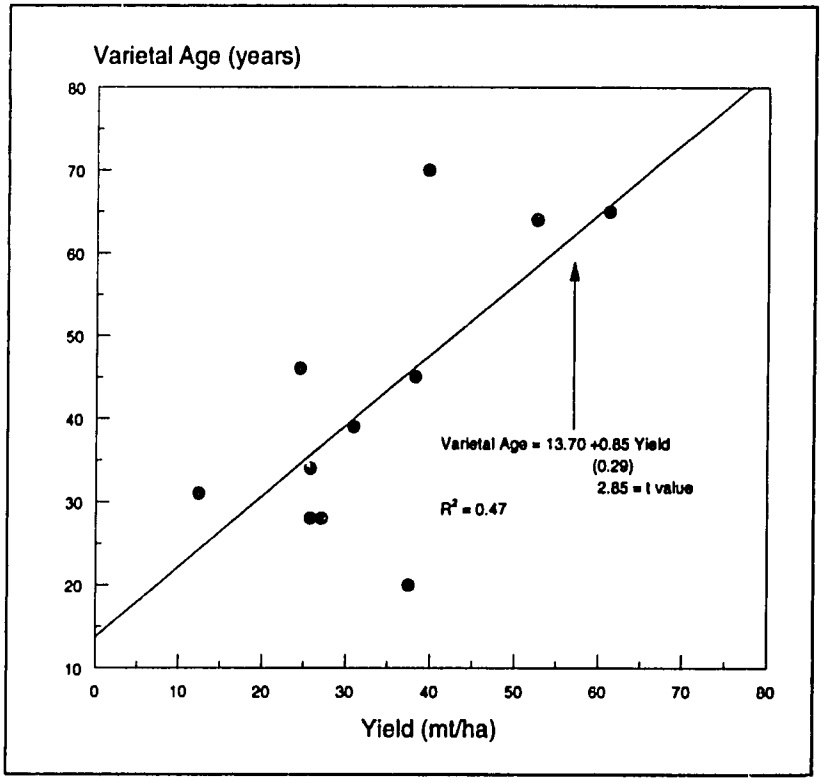


Figure 12. Varietal age and yields in the 11 most important potato producing states in the U.S in 1990.

Public-sector breeders have released several varieties to replace Russet Burbank. Increasingly, one finds more releases of russeted varieties and descriptions in the American Potato Journal of clones which appear to compete favorably with Russet Burbank. For example, the cultivar Butte, released in 1978, gave a 25% yield advantage of U.S. No. 1's over Russet Burbank in multi-locational trials (Pavek et al. 1978). Butte was superior to Russet Burbank on 11 internal quality and disease and grading traits, equal on 10, and inferior on only 1. In spite of this seemingly impressive comparative performance, Butte has not found favor in the market.

Performance by Program

The growing popularity of Russet Burbank greatly reduced the scope for government-supported potato breeding to generate high rates of return during the second half of the 20th century. Nonetheless, not all the public-sector potato breeding programs have been characterized by low rates of diffusion of released cultivars.

The second performance measure, the average share of certified seed area, is charted in Figure 13 for three types of plant breeding programs.[6] In general, the USDA national program, based largely on results obtained from the earlier noted varieties in the 1930s and from Kennebec in 1948, averaged an impressive market share of about 6/10ths of one percent per variety released.

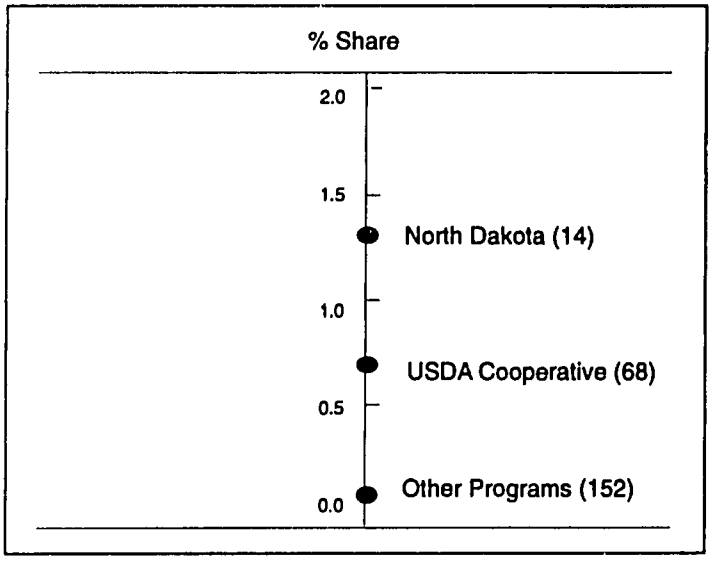


Figure 13. Performance of public sector breeding programs in the U.S. and Canada.
(The number of released varieties by type of program.)

The point estimates of across program performance in Figure 13 support two empirical facts. First, most state programs, i.e. those in the other program category, that were successful in releasing varieties scored very low marks on adoption. This fact reinforces the earlier assertion that the necessary conditions for practical impact in potato breeding were not present during the second half of the 20th Century. If no outliers were present, i.e. no programs with a market share greater than one, we could be reasonably confident that that indeed was the case. But we do have a counterfactual: the North Dakota Program which consistently translated release into adoption since the appearance of its first clone, Norland, in 1956 (Figure 13). Excluding releases where the USDA figured as the main release agency, the 14 releases from the North Dakota State Program accounted for more area in growers' fields in this century than the combined total of the 152 releases from all the other public-sector programs. The truly outstanding performance of the North Dakota Program is the counterfactual observation suggesting that progress could still be made in the 1950s, 1960s, and 1970s when the demand

[6] USDA cooperative refers to releases where the USDA is listed as the first release agency. Joint releases where a state program appeared as the first release agency were placed in the other programs categories.

and supply conditions appeared to be especially unfavorable for the achievement of practical impact from investments in potato breeding.

The varieties of the North Dakota program account for about 15-20% of certified seed area in the U.S. and Canada. They are most popular in the Red River Valley of North Dakota and in the North Central Region, but are not confined to those regions. In 8 of the 11 major potato producing states in the United States, at least one North Dakota variety figured among the top four varieties in 1990 (Table 5). Ranking fourth, third, or even second may not mean that much in some states, such as Idaho, where Russet Burbank accounts for about 90% of cultivated area, but in several states even a fourth place translates into a sizable acreage.

Table 5. The importance of North Dakota varieties in 1990 for 11 major producing states in the U.S.

State	1st	2nd	3rd	4th
Colorado		Russet Norkotah		
Idaho			Russet Norkotah	
Maine				
Michigan				Russet Norkotah
Minnesota		Norchip	Norland	Russet Norkotah
New York				
North Dakota	Norchip		Norland	
Oregon			Russet Norkotah	
Pennsylvania				Norchip
Washington	Russet Norkotah		Norland	
Wisconsin		Russet Norkotah	Norland	

Source: Lucier et al. 1991, p. 98.

What accounts for the success, in terms of practical impact, of the North Dakota potato breeding program? Many factors probably contributed to the success of the program[7], but some indications were given when Robert Johansen, the plant breeder responsible for the program, was presented for Honorary Life Membership in the American Potato Association:

---

[7] In an interview on the occasion of his retirement in 1992, Johansen expanded on the reasons for his success:
I take more stock in what growers, processors, and buyers/shippers tell me than what a lot researchers say. I don't mean to be knocking researchers, but when I send out a variety, I'll ask the grower how it did. He won't lie to me because that is his bread and butter. I've had that philosophy for many years. That's why our program may be a little more successful than some of them. We've gotten the varieties out to growers and have gotten either a positive or negative viewpoint of them (Ackerson 1992, p. 6).".
Later in the same article Johansen says that "probably his biggest reward is when he drives down the highway, identifies some of his varieties and knows that those varieties have helped build communities (Ackerson, p. 7).".

> Part of his potato breeding success has been due to the excellent grower relationships he has developed over the years. This has enabled him to get grower input on selections early in their development and also to get adequate seed increases of new releases (Nelson, 1982, p. 441).

The theme of farmer participation is a relatively new one in agricultural research and economic development, but is an old one in potato breeding, particularly in the Netherlands and West Germany.

As alluded to in the above quote by Nelson, close links with growers and with the state seed association have also resulted in a strong supply of seed for new releases. For example, farmers wanting to plant Goldrush, a recent Johansen release in 1992, had access to the production from 339 acres of certified seed grown in the state in 1991 (Valley Potato Grower 1992). By 1993, Goldrush would have already qualified as a successful variety in Table 4 if varieties released after 1990 were included in the analysis.

Comparing Wheat and Potatoes

Based on the work of CIMMYT economists, rates of varietal replacement have been documented for several important and contrasting wheat regions of the world (Brennan and Byerlee 1991). These estimates pertain to the 1970s and early 1980s, and they vary from a weighted average age of 4.6 years in the Yaqui Valley of Mexico to 11.1 years in the Punjab of Pakistan. In Kansas, the mean estimate was 6.7 years.

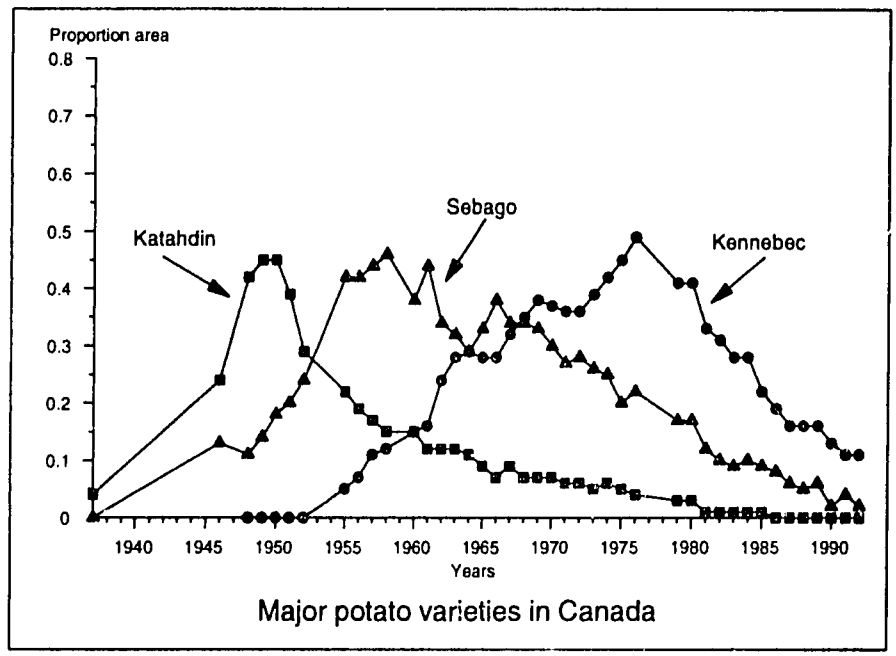
Figure 14 communicates a flavor for the extremes in differences in varietal turnover between wheat and potatoes. Adoption profiles of the three most popular, improved potato varieties in Canada between 1940 and 1990 are compared with the diffusion curves of the dominant modern wheat varieties in the Yaqui valley between 1979 and 1990. This comparison is spurious because it contrasts a large country with a relatively small region. Nonetheless, the figure conveys what a ten fold difference in weighted average age implies for percent adoption.

Turning to longer time series data comparable to those presented in Figure 8, Brennan's work in 1989 on varietal turnover in New South Wales in Australia is insightful. Between 1945 and 1985, the weighted average age of wheat varieties declined from about 15-20 years in the late 1940s and early 1950s and has leveled off at between 5-10 years since the late 1960s.

These comparative results strongly suggest that wheat and potatoes behave like apples and oranges in their rates of varietal replacement. Wheat is characterized by a high rate of varietal turnover. In wheat, genetic resistance to leaf rust continuously breaks down. Varieties have to be replaced periodically to maintain varietal resistance which is very desirable in a low value (per unit area) crop such as wheat.

In the spirit of the analysis of Heisey and Brennan (1991), one could make the case that economically it makes sense to keep the same potato varieties in farmers' fields longer than

similar wheat cultivars. The seed costs of potatoes are much higher than wheat and its multiplication rates are much lower. Still, these considerations do not appear to justify rates of replacement five to ten times faster in wheat than in potatoes. Moreover, the gestation period of varietal generation from crossing to release is roughly the same time lag in wheat and potatoes: 10 to 15 years (D. Byerlee, personal communication, 1993).



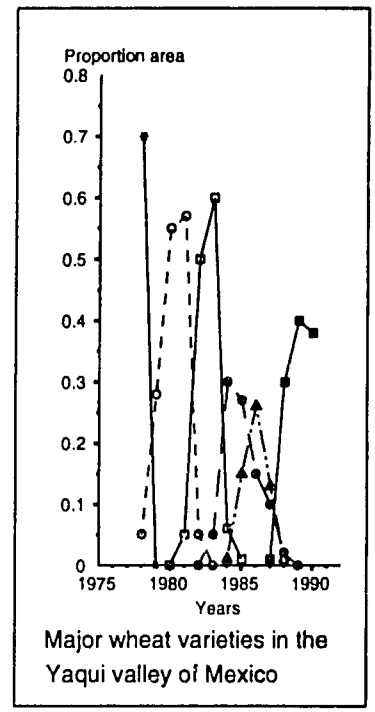


Figure 14. Comparing the diffusion curves of important potato varieties in Canada with wheat varieties in the Yaqui valley of Mexico.

Controversial Issues

To round off the discussion of varietal change in potatoes in North America two historical issues of creative tension need to be addressed. These pertain to the need for wide versus local adaptation and to the desirability of market-related characteristics versus disease-resistant traits. An assessment of the historical evidence on these issues in North America could have important implications for potato improvement programs in developing countries.

Wide versus narrow adaptation

In the 1950s and 1960s, the descriptions of released varieties in the American Potato Journal, suggested that wide adaptation was not possible or that local adaptation was highly desirable. The following quote reflects the view that potatoes are somehow different from other crops in terms of adaptation:

> There need be no fear of too many named varieties. The potato is rather unique among field crops in that varietal adaptation is frequently quite narrowly localized. Certain qualities are particularly prized in a given area, perhaps limited to a few farms (J. R. Livermore, 1951, p. 672).

Several varieties were released for locales or seasons which subsequently went out of production. For example, Merrimack was released in 1954 as "a new variety of potato resistant to late blight and ring rot and adapted to New Hampshire" (Akeley et al. 1955, p.93). The USDA discontinued production estimates in New Hampshire after 1977 when area planted to potatoes fell to 300 acres (Lucier et al. 1991).[8]

The weight of the adoption evidence suggests that potato varieties were more widely adapted than some people thought or that with increasing market integration and production specialization the demand for local adaptation, if, indeed, there ever was a demand, was rapidly declining. If local adaptation had worked, we should have seen better adoption performance for several of the state breeding programs. Varieties narrowly targeted for ecological or seasonal niches did not survive. Again, we encounter one notable exception: Centennial Russet which was released in 1976 and has been the most popular variety in Colorado since the early 1980s. Centennial Russet epitomizes narrow adaptation; it has not spread substantially from the San Luis valley where it is very well-adapted.

In contrast, the evidence that wide adaptation has worked is substantial. Many commercially important cultivars have enjoyed wide adaptation. Atlantic, an outstanding

---

[8] Merrimack has had value as a parent. It is the female parent of Bake-King which, in turn, is the female parent of Shepody, one of the two most commercially important varieties released in the 1980s. Shepody is not prized for its resistance to late blight or to bacterial ring rot; Shepody combines excellent french frying quality in a medium-maturing cultivar.

chipping variety, is a case in point. Katahdin was very widely adapted. Surprisingly enough, Russet Burbank (from the West) was the most important variety in Maine in several years of the 1980s, accounting for about 25% of area (USDA 1991). Varieties, such as Superior, bred in the United States have been widely accepted in Canada. Shepody from Canada is finding a home in some specialist production regions in the U.S. Russet Norkotah, another commercially important variety released the 1980s, has, thus far, amply justified its titular description as "a new russet-skinned potato cultivar with wide adaptation" (Johansen et al. 1988, p. 597).

Since the emergence of well-defined market niches for processed potatoes in the 1960s, the value of narrow or well-targeted adaptation is driven by market demand and not by agronomic adaptation to specific production regions which are becoming increasingly homogeneous over time. Nowadays, the varieties with the best adoption potential would appear to be those that combine wider agronomic adaptation with narrower, i.e. more focused, market adaptation consistent with superior performance in one or more end use sub-market.

The strength of market preferences versus the demand for disease resistance

Although market preferences have ultimately shaped the consequences of potato breeding in North America, some would contend that even more attention could be paid to market demand to enhance the effectiveness of public-sector breeding programs. The following quote illustrates one area of creative tension between preferences for taste and disease resistance:

> At the annual empire state potato club field Day, there have been several requests for new stocks of seedling no. 866 ... Seedling no. 866 was discarded because of the high percentage of leafroll. "That's too bad," one farmer said, "I don't care how much leafroll it had, it was the best quality and finest flavored potato I ever grew." It might be that the potato breeder has already sacrificed too much in culinary quality and flavor in order to produce a high yielding, disease free, smooth, white skinned tuber with eye appeal (J.R. Livermore, 1951, p. 672).

Farmers did not have a monopoly on the sentiment that plant breeding was giving short shrift to taste and quality considerations. Professor Ora Smith, an authority on potato processing, stated, "Practically everything that has been done in the so-called improvement of the potato has either neglected cooking quality or resulted in lowering the cooking quality (Smith 1951, p.733)." In reading the descriptions of varietal releases, mention was often made of cooking quality (Clark and Stevenson 1935). Nonetheless, cooking quality was a secondary objective and one can only speculate on how much more impact plant breeding would have had if quality and taste considerations had loomed larger in selection.

In the literature, one can also find anecdotal evidence to support the assertion that the demand for disease resistance was not strong. For example, Orville Page, reflecting on future

directions for research at the International Potato Center (CIP), said "Back in 1960 while a member of the national potato program in Canada, I was told bluntly that one cannot sell a new variety on disease resistance. That prophecy seems to be true -- at least in developed countries -- even during periods of high oil prices."

A salient example of disease resistance being subordinated to market preference occurred in the early 1920s in an intensive potato growing county in New Jersey (Douglas 1927). Until 1923 about 90 percent of the varieties grown in Monmouth County were long types, particularly American Giant which was resistant to scab, an endemic problem on more alkaline soils. Within two years and in response to more stringent market preferences, round whites, such as Irish Cobbler, accounted for 90 percent of production. With improved grading standards and with the arrival of post-war prosperity, urban consumers refused to pay for the inferior quality American Giant (Dean 1933). As Douglas noted, "smaller yields of high quality potatoes proved to be worth more in the long run than a larger yield of the Giants variety (p.122)." Fields with high scab infestation were planted to other crops, and soil amendments were applied to reduce scab incidence.

The Experience of Other Important Potato Producing Temperate Countries

To what extent do the findings on varietal change in the U.S. and Canada apply to other developed countries, which are important producers of potatoes? More specifically, does the inverse relationship between varietal change and the quality of the production and market environments hold in other developed countries? Because varietal information has not been systematically canvassed in other developed countries, the country-specific evidence presented below is necessarily fragmentary. Nonetheless, the available snapshots, taken at different points in time, are sufficiently informative to piece together a picture of how the production and consumption environments affect varietal change when the supply of varieties is not constraining. Before presenting that picture, the country case studies of varietal change are discussed below.

The United Kingdom

Varieties released in the U.K. from the two State Plant Breeding Stations (SPBS) in Cambridge, England and Pentlandfield, Scotland in the 1960s and 1970s were rapidly adopted by potato growers. The Maris (from Cambridge) and Pentland varieties largely replaced the 19th Century varieties, especially Majestic, which enjoyed widespread popularity until 1965 (Figure 15). Indicative of speedy diffusion, average varietal age fell rapidly from 40 to 25 years between 1965 and 1975 (Figure 16).

Figures 15 and 16 refer to the maincrop varieties which comprise about two/thirds of area planted by registered producers. Dynamic varietal change also took place in the production early varieties in the 1970s as such traditional favorites as Arran's Pilot, Home Guard, and Red Craig's Royal rapidly lost ground to other Maris and Pentland varieties and to introduced Dutch varieties.

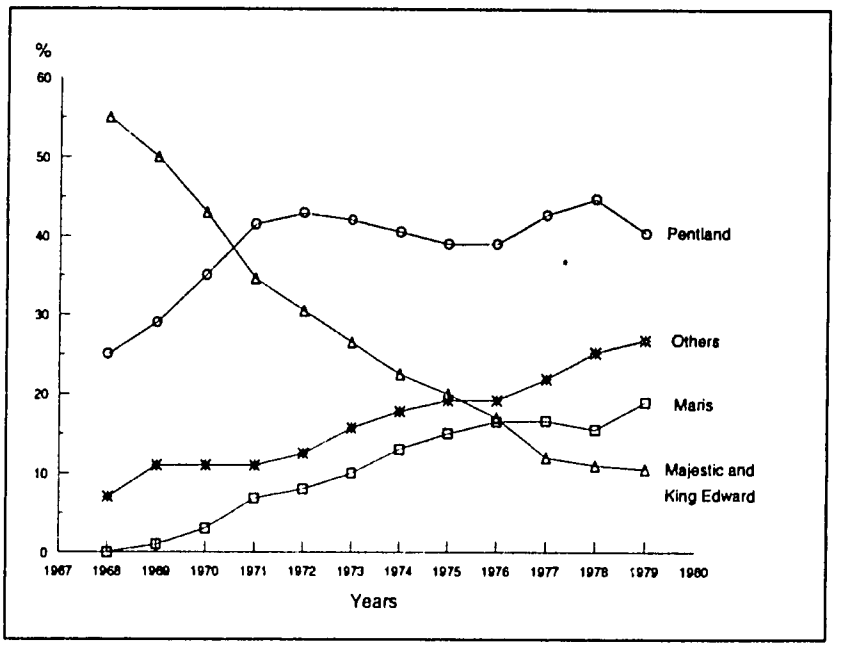


Figure 15. Maincrop varieties—area planted by registered producers 1968-1979.
Source: Graph based on Potato Marketing Board data.

This impressive performance is clearly one of the major success stories in the plant breeding of potatoes. It is noteworthy for other reasons. Several of the released varieties are resistant to a widely occurring pathotype of potato cyst nematode or eelworm which is often viewed as the second most important yield reducer after late blight in the U.K. Not only do these varieties yield well under conditions of infestation, but they also depress eelworm populations to such an extent that the yield of following potato crops of susceptible varieties is improved (NSDO 1976, p. 21). This is probably the outstanding example where breeding for pest resistance has translated into practical impact.

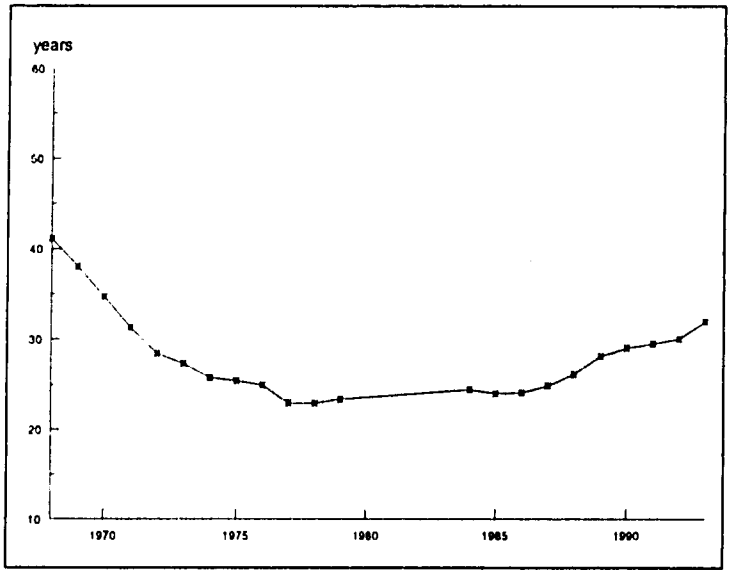


Figure 16. Average age of maincrop varieties in the U.K.
Source: Constructed from NSDO 1980, p. 10.

In the late 1980s, the most widely grown main crop variety, accounting for between 10-15% of total planted area (Potato Marketing Board 1990), was Maris Piper which was prized not only for its eelworm resistance but also for its quality. Indeed, "in a Potato Marketing Board Consumer Acceptability Survey (1974) Maris Piper was by

far the most acceptable variety of those tested (NSDO, p. 21)." Because of its high consumer acceptability, Maris Piper is also grown where eelworm infestations are not a problem.

Although not as pronounced, the trend in varietal age for the abbreviated period of 1968-93 in Figure 16 is vaguely reminiscent of the trends in Figure 8 for the U.S. and Canada: steeply falling varietal age followed a rising trend. Estimated varietal age reached a low point of 23 years in 1978 and for the last 15 years has gradually increased to 31 years. In contrast to the U.S. case, this rise is not derived from a surge in popularity of a 19th century variety, but rather stems from the ageing of the "first-generation" improved varieties which have not been replaced by newer releases in growers' fields.

The Netherlands

The Dutch dominate world potato trade, and their organizational efficiency in breeding, production, and marketing is well-known (Young 1977 and 1990). Potatoes are grown mainly for human consumption (ware), seed, or starch. The pace of varietal change differs markedly among these three generalized end uses. Below, we discuss the extremes: ware potatoes with the remarkable dominance of Bintje and starch potatoes with a more conventional record of practical impact from plant breeding.

Bintje

Although Russet Burbank is well-known, it has not been the most extensively cultivated potato variety in the 20th Century. That title belongs to Bintje, a Dutch variety bred by K.L. de Vries, a Frisian schoolmaster, who named Bintje after one of his pupils. Bintje was selected from a cross made in 1904, was first marketed in 1910, and was "re-discovered" in 1923 (Stevenson 1966).

The durability and dominance of Bintje in the marketplace is suggested by the title of the Dutch paper from which Stevenson's account in the American Potato Journal is taken - "Fifty years Bintje" by H. Zingstra. Similar to Russet Burbank, Bintje had a rather inauspicious beginning. Bintje was high-yielding and soon acquired the name of Rijkmaker (Richmaker), but it was not sufficiently floury to be highly regarded in the ware market for human consumption. The lion's share of its production was destined for pig feed. Nonetheless, its area continued to expand during World War I when the quantity of production was at a premium during years of shortage. After the war, the importance of quality returned to the marketplace and the area of Bintje planted for domestic consumption declined.

Meanwhile, the export market for seed of Bintje, then known by other names, was steadily increasing to several other countries, particularly to France where Bintje had acquired a reputation for making excellent french fries. Bintje continued to be grown mainly for its export trade in seed potatoes until about 1930 when Dutch housewives "began to show a preference" for this variety (Stevenson, p. 459). Stevenson does not elaborate on why this shift in

preferences occurred, but, apparently, Bintje's other outstanding external and internal quality traits must have assumed more importance over time than its perceived lack of mealiness.

Fifty years after it was introduced, Bintje occupied about one-half of the potato area of continental Western Europe excluding West Germany. By 1975, Bintje accounted for 70% of the area grown for human consumption in the Netherlands and for 30% of the total potato area for fresh consumption and for starch (Young 1977). During the 1970s and 1980s, Bintje's share of area for potatoes grown for fresh consumption and for starch gradually climbed to 40% (IVO 1993, p. 293).

Bintje's market dominance stems from its good to excellent performance for multiple end uses. Bintje may not be the optimal variety for each end use, but it more than meets "the minimum specifications for home sales, export sales and the crisp, par-fried and dehydrated potato manufactures (Young, p. 55)." Similar to Russet Burbank, Bintje is a difficult variety to grow, but it is extremely easy to market. Bintje does not satisfy the demands of several market niches, including more floury types, early processing material, and small specialized export requirements, but it is more than adequate for the bulk of the market.

Based on the most recent data in 1989, the estimated average age of varieties grown for human consumption was about 60 years which has been increasing with Bintje's gradually rising market share. Varietal age may no longer be increasing and may even be falling somewhat. In 1980, Bintje accounted for 31% of the area certified for seed in the Netherlands (Young 1981). Most recently, from 1989 to 1992, Bintje's contribution to total certified seed production has declined to 19 percent (IVO 1993, p. 239). Varieties, such as Agria, released in the 1980s, may finally be responsible for ushering in a period of varietal change in the ware potato market in the Netherlands, but new releases are unlikely to replace Bintje as the dominant cultivar in the 1990s.

Starch potatoes

Varietal change in the market for starch has been much more dynamic than in the market for fresh consumption. The production of starch potatoes is restricted to sandy, peaty soils in the northeast of the country (Vos 1992). In spite of severe cyst nematode infestations, high and sustainable yields are produced with the very heavy use of nematicides in only a two-crop rotation, i.e. potatoes followed by one break-crop (Vos 1992). Indeed, the use of soil fumigants in producing starch potatoes is so high that they substantially raises the average intensity of pesticide use on arable and horticultural crops in the Netherlands. The estimated average use of pesticides for such crops is about 20 kgs of active ingredient per hectare (Oskam et al. 1992). Soil fumigants account for about 60% of this figure, and technical coefficients in models simulating the effects of policy on pesticide use are consistent with a mean use of nematicides

of about 130 kgs of active ingredient per hectare in the production of starch potatoes (Oskam et al., Table 3.4, p. 145).

Ware and seed potatoes are produced in different regions than starch potatoes. Nematode infestation is not as severe, and, typically, longer rotations of 3-5 break crops are practiced (Vos 1992).

Price is another important difference among the three generalized end use groups. Although the price ratios of starch and ware potatoes vary considerably year to year, starch potatoes usually fetch substantially lower prices than ware potatoes (Young 1977). Lower price is synonymous with a less discriminating market which, in turn, favors varietal change.

The combination of lower price, severe nematode infestation, and changing pathotypes greatly enhances the demand for nematode resistant potato varieties. The breeding objectives are also straight-forward: starch production and nematode resistance. Given this agronomic and economic setting, it is not surprising that varietal change has played a significantly more important role in contributing to and maintaining of starch potato productivity than to ware yields which also have more than doubled since 1950 (Vos 1992). Indicative of this dynamism, Prevalent and Prominent, the two dominant starch varieties in the mid-1970s, accounted for over one-half of the starch growing area in 1975. Five years later their share of starch growers' area had shrunk to about 20% (Young 1981). Indicative of rapid varietal turnover, throughout the 1980s average age of varieties destined for starch production was about ten years.

West Germany

Since the mid-1950s, the importance of potatoes in West Germany has declined dramatically. In 1954, West German farmers planted 1.2 million hectares to potatoes which accounted for 15% of the land under field crops (Young 1981). By the early 1990s, area was arriving asymptotically at about 200,000 hectares.

Although precise data are not available on utilization, the marked decline in the use of potatoes for animal feed is widely acknowledged. Potatoes destined for human consumption also experienced a sharp decline. In spite of a rising intake of processed potato products, per person consumption decreased from about 175 kgs in the early 1950s and appeared to have stabilized at about 75 kgs by the early 1990s (Reuter 1993). .

Turning to varietal change, the West German experience contrasts sharply with earlier histories of North America and Canada. Based on 1992 certified seed data (Bundessortenamt 1992), the average age of varieties (from date of release) was only about 15 years. (Actually, the average age is somewhat more than 15 years because the annual rate of seed replacement for the country as a whole was 36% in 1976 (Smith and Young 1979)). Young (1981) cites the results of an official survey, which shows that the four most popular varieties accounted for about one-half of harvested area in 1978/79. These same varieties, first approved for seed

production in the mid- 1950s and early 1960s, only comprised about one-twentieth of the area of certified seed production in 1992. They have been replaced by varieties released in the 1970s and 1980s.

What explains the quick pace of varietal change in West Germany? Potato breeding in West Germany is well-known for its productivity. Obviously, the supply of new varieties is not a constraint, but neither is supply a limitation in the Dutch potato industry where breeding is renowned for its efficiency and where the dominance of Bintje has thwarted varietal change.

To explain the high rate of varietal replacement in potatoes in West Germany one has to return to the (by now familiar) themes of specialization and intensification in production and preferences for quality in consumption. Although increasing, the degree of specialization in growing potatoes in West Germany is still a far cry from what one finds in North America and in the Netherlands. In the mid 1970s, there were still over 200,000 farms ranging from 2 to 20 hectares producing potatoes. They planted on average 0.5 hectares to potatoes. At the same time, potatoes were grown on another 175,000 farms larger than 20 hectares. Those farms produced on average 1.6 hectares. Comparable averages per farm in 1979 were 6.2 hectares for the Netherlands, 5.3 hectares for Great Britain (Young 1981), and 10.6 hectares in the United States in 1994 (Lucier et al. 1991). In the mid 1970s, it took about eight times more farms to produce about the same amount of potatoes in West Germany as in the United States.

Although a generalized trend throughout the country, by the late 1970s, the decline in potato growing area was more marked in the North than in the South. Potato production was increasingly concentrated in Lower Saxony and Bavaria particularly on smaller mixed crop and livestock farms where family or casual labor was still available and where soil conditions apparently restricted cropping alternatives (Smith and Young 1979).

The changing structure of potato production in West Germany was in sharp contrast to the rapidly evolving specialization and intensification of production in North America where declining area and number of farms growing the crop was accompanied by an increase in average potato area per holding. In West Germany between 1960 and 1971, the number of farms growing potatoes fell from about 1,000,000 to about 650,000 and the total area cultivated in potatoes fell sharply, but the average area per potato growing holding *declined* as well. To explain this surprising fact, analysts of the West German potato marketing system in 1979 surmised that:

> as the West German farm increases in size, so potatoes become less important to it - partly because a large farm is less likely to possess the type of labour (casual, seasonal, or family) which is required for potato production; but also because the growing of potatoes for use as animal feed is much less likely to take place on a larger unit (Smith and Young. p.10).

The same reviewers noted the marked regional variation within West Germany in consumer preferences for fresh potatoes. Floury potatoes are preferred in the South, firm-cooking ones in Northern Germany. Smith and Young (1979) speculate that this regional variation in demand is linked to the fact that traditionally certain areas have been able to produce only a limited range of potatoes (p. 14). Whatever the case, it is apparent that the structure of production and consumer preferences, prevailing in West Germany in the mid 1970s, may have been evolving in the same direction as those in the U.S. and Canada, but they were very far apart on this evolutionary path.

East Germany

Potato production and marketing in the former GDR was organized mainly on the basis of local self sufficiency in a planned economy. Potatoes were produced on large cooperative and state farms and a large share of production was destined for livestock, mainly pigs. Pig and cow slurry were also an important source of fertility as use of inputs internal to the state or cooperative farm were emphasized (B. Trognitz, personal communication). Use of external inputs, such as pesticides and inorganic fertilizer, was de-emphasized. Although enterprise size was large and some farms were specialized potato producers, the emphasis on local self-sufficiency meant that the production and market conditions were more congruent with a mixed farm semi-subsistence economy than with specialized, intensified production.

Reunification brought dramatic change to East German agriculture especially in potatoes. Trends toward intensification in production and quality in consumption which should have emerged in a market driven economy in the 1960s, 1970s, and 1980s suddenly became transparent in a very short time horizon. The potato area had fallen from around 500,000 ha in the mid-1980s to 113,000 ha in 1992, and this had been accompanied by a greater emphasis on quality in the processing and manufacturing sectors (Schulz 1992). Pig production declined sharply. By 1993, potato production in erstwhile East Germany was only 34% of the 1989 levels (Weidtmann, 1993).

During the last 30 years, varietal turnover in East Germany was probably as rapid as anywhere in the world. In 1992, the weighted average age of the varieties produced for certified seed was only 8.0 years (Bundessortenamt 1992).

In terms of varietal change, the findings for East Germany would also seem to apply to the other Eastern European Countries and to the former USSR. Data given in Swiezynski (1987) shows the share of each of the five most extensively grown varieties in potato growing area for Poland, East Germany, West Germany, France, the Netherlands, and Great Britain. For Poland, the five most popular varieties in 1985 accounted for about one-half of potato growing area, and their weighted average varietal age was 9.0 years. Similar calculations for East Germany gave estimates of about 70% of growing area and of 8.5 years for weighted average varietal age.

Swiezynski comments that in the former USSR the data on varietal release are consistent with "a comparatively quick rotation of cultivars (p. 54)." Of 129 cultivars, 59 were bred after 1974.

Undoubtedly, the command nature of the economy played a significant role in the velocity of varietal replacement in Eastern Europe and in the former USSR. But, perhaps more importantly, a relatively non-discriminating market in product quality and an emphasis on internal inputs in production made important contributions to the high rate of varietal turnover. In particular, the demand for varietal disease resistance was substantially enhanced by the lack of market incentives for intensive plant protection and by institutional seed programs which were not as effective as their counterparts in Western Europe and in North America. Indicative of this demand, the German and Polish varietal material is prized as source of virus resistance and Russian genotypes are used to confer tolerance to abiotic stresses, such as drought. In summary, the high velocity in varietal turnover was consistent with rustic conditions of production; conditions which probably approached the production environments in the United States and Canada several decades earlier.

Australia

Historically, potatoes are not the staple in Australia that they are in Europe, but they are an important food. Figures on per capita consumption are roughly the same order of magnitude as those for the U.S. (BAE 1976).

With the exception of the Northern Territory, each of the six states in Australia have well-defined areas where potatoes are grown. Based largely on the timing of production, 32 reasonably homogeneous, small production regions have been identified (Hackett and Rattigan 1978). These are located mainly in coastal plains and valleys and in the Great Dividing Range.

Also, similar to the U.S. and Canada, potatoes are grown mainly on specialized farms. Since the 1940s, the industry has experienced significant structural change. The following quote by Bald in 1941 is illustrative of the structure of production before the emergence of specialization:

> One fact that is often lost sight of in discussion of the potato is that the production of potatoes is not confined to the specialized few who make it a principal crop and depend on it for a large part of their farm income; in suitable districts potatoes enter largely into mixed farming; and intermittent and speculative planting are common. In 1936/37 over 23,000 growers appeared in the statistical returns for the whole commonwealth (Bald 1941, p. 6).

By the early 1970s, the average area planted per holding was 7.5 hectares, and the number of farms growing potatoes had declined to about 5,000 (BAE 1976).

An increasing reliance on irrigation has been another manifestation of structural change in potato production. For example, in Tasmania, a large potato exporting state to mainland Australia before and during World War II, the incidence of irrigated area increased from less than 5 to over 80% in only 20 years between the mid 1950s and 1970s (Stephens 1979a). The shift to irrigation was accompanied by intensification in production. Planting density was doubled, and fertilizer use increased markedly.

In Western Australia, structural change in potato production largely resulted from the shift from furrow to sprinkler irrigation in one of the potato growing areas within the state (Hocking 1979). In that area, potato production had expanded by five times between 1947 and 1976; in contrast, in the main producing area in 1947, potato production in 1976 had declined to only one-fourth of its earlier level.

Parallels and similarities between the Australian and North American experiences in potato production also extend to varietal change. The rate of turnover of varieties in Australia has been as slow as in the U.S. and Canada. Australia has relied heavily on introduced varieties from North America and Europe. Because of similarities in growing conditions, some varieties from the U.S. are particularly well-adapted to Australia (Bald 1941).

One can divide varietal change during this century into three eras. At the turn of the century, several of the oldest named 19th century American varieties were popular. These included Early Rose, Bliss Triumph, and Beauty of Hebron. "These went out of cultivation, not because they were unsuited to Australian soil and climate, but principally because of degeneration due to virus infection (Bald, 1941, p. 41)." A late blight epidemic in Tasmania in 1908-12 also hastened the demise of disease-susceptible varieties.

By 1940, more than 90% of potato area in Australia was planted to six important varieties; most of them originating in the late 19th Century. Two of those varieties, Up-to-Date and Snowflake, were popular because of their ability to withstand the drier, more rustic conditions of growing potatoes in Australia. Brownell was prized for its storability and for its apparent resistance to late blight. The other three varieties, Carman (Rural New Yorker No. 1), Delaware, and Bismark, were known for their high yields in more protected production environments.

During the 1950s, 1960s and 1970s, these varieties, with one exception, were replaced by varieties released in the 1930s and 1940s by the federal USDA program in the U.S. By the early 1980s, Kennebec and Sebago were the dominant varieties in Victoria. Kennebec was the leading variety in South Australia. Kennebec was dominant in Tasmania, and Sebago was first in area planted in New South Wales and Queensland. Sequoia and Pontiac also laid claim to over 5% of cultivated area in several states. (Interestingly, Katahdin figured as a grandparent for Kennebec and was the male parent for Sebago, Sequoia, and Pontiac. Katahdin was reported by Bald in 1941 to be a new introduction of great promise and was praised for its

immunity to mild mosaic virus, the most common virus disease in Australia, and for its ability to yield a high proportion of marketable tubers even under drought conditions).

This varietal transition occurred in response to changing market and production conditions. Perhaps the best example is the replacement of Brownell, a red-skinned variety believed by Bald (1941) to be Adirondack (origin 1881), with Kennebec in Tasmania. Tasmania traditionally exported much of its production to mainland Australia, and Brownell was the main crop variety of choice. Following World War II, the export market declined rapidly and, by 1981, the area planted to potatoes shrank to about one-eight of its war-time peak (Department of Agriculture, Tasmania, 1981). The disappearance of the export market meant that potatoes had to suit the requirements of local markets within the state. Over time, processing became a more important end use, and investments in irrigation were required to maintain a competitive edge in producing for a declining market. Brownell is not a good variety for processing and is not suited to irrigation because of its tendency to develop hollow heart. Kennebec is an excellent processing variety, and it responds well to irrigation. Between 1961 and 1975, Kennebec's share in area expanded from about 5 to 80%; Brownell's share dropped from 68 to 6% (Stephens 1979b).

The exception to the rising popularity of the Katahdin-related varieties is notable. Since its introduction in 1909, one variety, locally named Delaware and probably derived from White Rose, an extra early cultivar with an origin in the 1890s in the U.S., has been cultivated to the exclusion of almost all others in Western Australia (Wilson and Jones 1989). With Delaware, farmers can obtain heavy yields in two consecutive cropping seasons within a year in peaty swampland where potatoes are grown in the State (Bald 1941). Much of the durability of Delaware is attributed to a unique seed production scheme which has not changed since it was introduced in 1922 (Wilson and Jones 1989). Seed is planted in wind-exposed, small, isolated coastal swamps every summer on the same land without a rotation. Natural flooding in winter and foraging by sheep greatly reduce the incidence of virus carryover on any tubers remaining in the ground. The longevity of Delaware as the dominant commercial variety in Western Australia underscores the earlier observation that an efficient seed program can lead to a low, negligible, or even a nil rate of varietal replacement. Without this unique seed scheme, it is likely that Western Australia would have followed a roughly similar pattern of varietal change as the other states.

Part of the popularity of North American varieties stems from the lack of supply of Australian bred cultivars. By the mid-1980s, only Victoria had an active breeding program. Some of the Australian bred varieties, such as Coliban, have gained a foothold in some states, but, overall, the impact had yet to be felt by the early 1980s.

That Australia has not overly invested in potato breeding is substantiated by the observation that, historically, the maximum number of seedlings grown for evaluation in any

year is about 50,000 (Bowen 1979). This number compares with more than one million seedlings in the Netherlands and West Germany where potato breeding is very active.

Given the likelihood of a slow rate of varietal replacement in potatoes and given the reasonably good adaptation of select North American and European cultivars to Australian conditions, one could argue that the past strategy of emphasizing the evaluation of introduced varieties combined with a limited investment of public sector resources in potato breeding was economically commendable or even optimal. In any case, the Australian experience in varietal change would appear to fit the pattern shown in Figure 8 for the U.S. and Canada: falling average age in the 1950s and 1960s with the diffusion of the USDA varieties followed by a steadily rising trend in the 1970s and 1980s. Based on data on statewise area planted in the mid-1970s and on varietal adoption in the early 1980s, the projected weighted average varietal age in Australia in 1990 would be about 50 years. This projection would be an overestimate if varieties bred in Australia or more recent introductions from abroad substantially replaced the USDA varieties released in the 1930s and 1940s. It would be an underestimate if the uptake of Russet Burbank increases in response to a rising demand from the fast food industry.

Synthesis, Implications, and Reflections

Average varietal age in the country case studies ranges from about 8 to 45 years. In this section, plausible explanations for the variation in the rate of varietal turnover are sought and implications for developed countries with "mature" potato industries and for developing countries with expanding potato production are drawn. The conceptual framework for the synthesis relies on relationships first articulated by M.K. Bennett in 1936 and later adapted by Gray et al. in 1954.

Synthesis

With the possible exception of Australia, strong breeding programs were common to the case study countries. What differed markedly across these countries was the variation in the demand for potatoes for different end uses and related changes in the structure of production. This variation can be analyzed by drawing on Bennett's pioneering work on the evolving importance of potatoes and cereals in the diet in western temperate countries. Bennett's principle was summed up by Gray et al. (1954, p. 15) as follows:

In its simplest form, (it) says that an impoverished nation relies heavily upon potatoes in its diet, that it shifts first to dark bread and then to light bread cereals as incomes rise and finally that with still further increases in income it shifts away from cereals and potatoes in the direction of other dietary elements.

As Gray et al. (1954) point out, Bennett essentially mapped out the transition from a potato economy, to a potato and wheat economy, to a wheat economy, and finally to an advanced economy emphasizing neither potatoes or wheat in the diet. Differences among countries in climate and preferences also explain intercountry variation in the importance of potatoes and cereals in human nutrition, but, with economic development, all countries which started at one time with a "potato economy" were destined to follow roughly the same transitional path culminating in an "advanced economy."

Using the same method of descriptive intertemporal analysis employed by Bennett, one can generate a plausible explanation to account for the intercountry variation in the rates of varietal change. The velocity of varietal change is hypothesized to depend on what potatoes are used for. Three of the key end uses which vary systematically over time are animal feed, fresh or tablestock consumption, and processed food. The evolution of these end uses with economic growth over time is graphed in Figure 17. With some important variations - feeding potatoes to livestock was never as important an end use in North America as in Europe, particularly Germany and eastern Europe - the same scenario applies to temperate countries where potatoes loomed large as a staple.

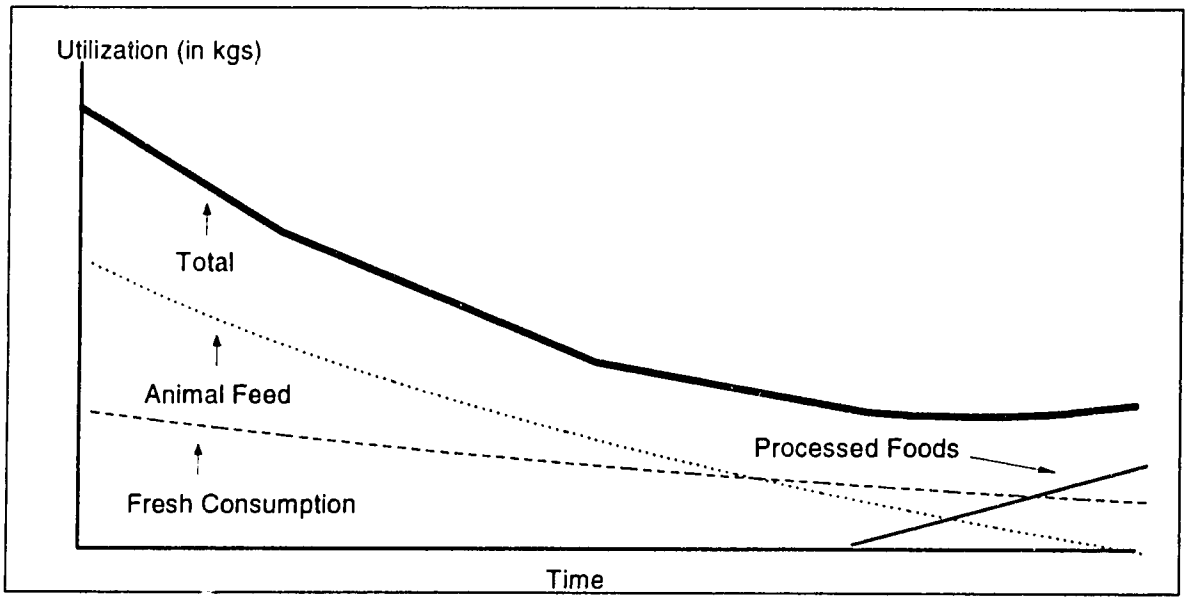


Figure 17. Evolution of end uses in the utilization of potatoes over time.

The story conveyed in Figure 17 is by now familiar. Negative rates of growth in utilization are synonymous with a sharply declining trend in potatoes fed to livestock and in fresh consumption. Over time the declining trend in fresh consumption is offset by a sharp rise in the consumption of processed products. Eventually, per capita consumption stabilizes and may even increase if the demand for "fast food" potatoes, such as french fries and baking potatoes, is strong.

To accommodate these emerging market trends, the locus of production shifts from semi-subsistence, mixed crop-livestock farms to intensified, specialized production. The number of farmers falls dramatically and the average area grown to potatoes rises. Positive rates of growth in utilization imply a "mature" potato-growing industry or a comparative advantage in potato production.

More fundamentally, the transition from a relatively low to a high value crop is traced in Figure 17. As the market orientation and value of the crop increases, it pays to invest more resources to fully protect production from the ravages of nature within and across production seasons. It becomes economical to employ higher cost or more institutionally complex substitutes for varietal disease resistance. Effective seed programs resulting in the annual renewal of seed mean that new varieties no longer have the advantage of competing against the degenerating seed of older varieties. Higher crop value also confers advantage to areas where the crop can be produced in more protected conditions. Increasing specialization in such localities of comparative advantage reduces the demand for more rustic varieties, such as Katahdin, which are stable yielders over time in regions of lower production potential. Therefore, the transition to higher market value is accompanied by a decline in the demand for varietal resistance to biotic and abiotic stress. Over time, yield potential and market value acquire increasing importance in determining varietal acceptance among producers and consumers.

The x axis in Figure 17 is not only positively correlated with product value but also with the opportunity cost of time. Raising pigs from a cereal base, particularly from purchased feed, requires only one-third to one-fifth as much labor as raising pigs from a potato base (Smith and Young 1979). Potatoes are normally steamed and sometimes made into silage before being fed to pigs. Both practices are relatively time-consuming and labor-intensive. As discussed earlier in this paper, rising women's labor market participation contributes substantially to the increasing opportunity cost of time which in turn shifts the demand upwards for processed food products, particularly fast foods.

The net result of the end use trends depicted in Figure 17 is that one should see sharply declining growth rates in total utilization in the initial stages of this transition. Eventually, positive growth is attained when the increase in the utilization of potatoes for processed food more than compensates for gradually declining or stagnant fresh market utilization and dwindling use for livestock feed. If the above reasoning is valid and if utilization is roughly equivalent to production, one should observe a negative relationship between the growth rate in total potato production and pace of varietal change.[9]

To test this relationship an index of varietal change is arrayed against the growth rate of production in the recent past. The index for varietal change is 100 minus the Weighted

---

[9] Time series data on utilization were not as readily available as time series data on production which were used in the analysis.

Average Age (WA_t) in each country for 1990. Thus an index of 85 for West Germany is consistent with a WA_{1990} of 15 years. The choice of 100 is arbitrary. Subtracting WA from a constant expresses varietal change in a positive sense i.e. the index is positively associated with varietal change. Estimates of varietal change are included in Figure 18 for Poland and France which were not treated in the country case studies.[10] Country estimates of potato production are based on FAO data from 1961-1990.

The hypothesized inverse relationship between varietal change and the growth rate of production is confirmed in Figure 18. Rapid varietal change has taken place in countries where total production in the recent past was decreasing; varietal turnover was slow in countries

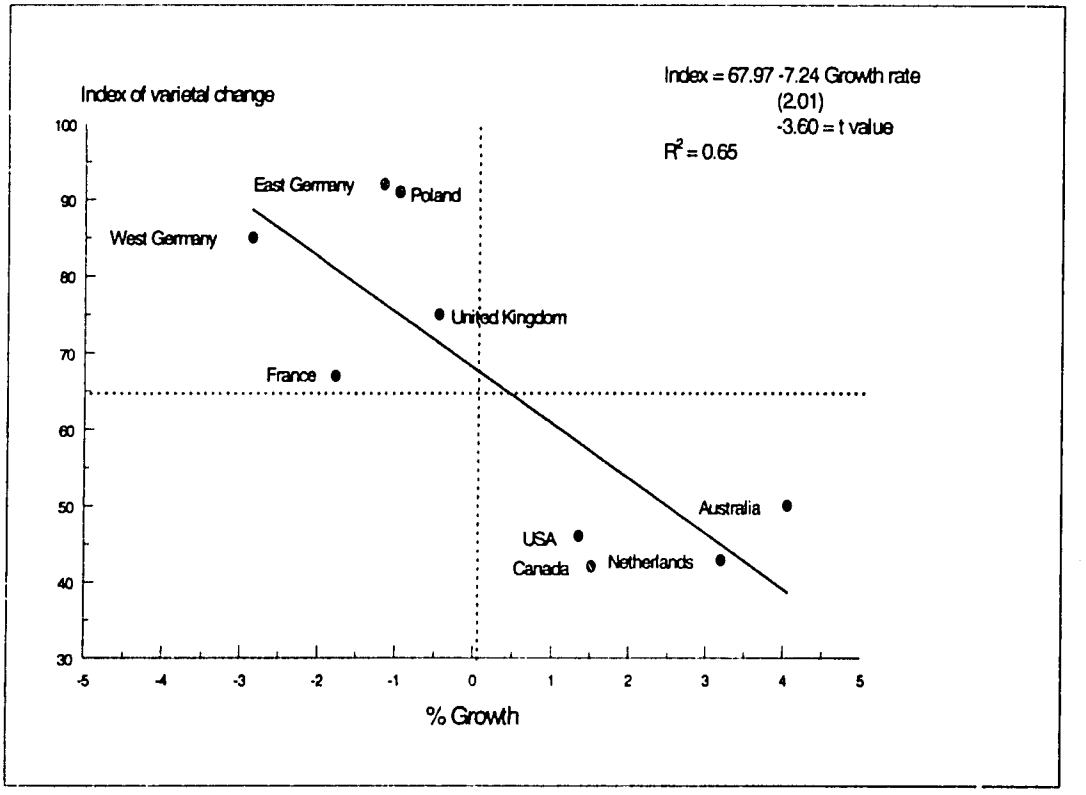


Figure 18. Growth in potato production and varietal change.

10 Those estimates refer to 1985 for Poland and 1984 for France and are based on data reported in Swiezynski (1987) on the area coverage of the five most extensively grown varieties in each country. For Poland, the share of these five was about 50% of potato growing area, and I assumed that the age of the remaining 50% was the same as for these five. For France, the five most extensively grown varieties accounted for about 60% of potato growing area; Bintje was by far the oldest and the most popular variety. I assumed that the age of the remaining 40% was the same as the weighted average age of the varieties ranked second, third, fourth, and fifth.

where total production was increasing. In other words, varietal change is negatively associated with the rate of growth in production, which reflects the quality or the maturity of the marketplace and the production environment. Superficially, this inverse relationship is shaped by the absence of observations in the northeast and southwest quadrants of Figure 18; no countries of positive growth in total production and rapid varietal change or with negative growth rates and slow rates of varietal change.

More fundamentally, the results in Figure 18 suggest that the earlier reasoning on how the transition from a low to a high value crop reduces the demand for varietal change is valid. But there is still one loose end to tie up. A priori, one could hypothesize that the rising importance of processed products would create more market niches which should facilitate varietal change. The evidence, admittedly largely anecdotal, does not appear to bear out this thinking. Varieties, such as Bintje and Russet Burbank, which satisfy minimum specifications in several end uses, are characterized by unparalleled longevity in the market.

Perhaps more importantly, processors, including retailers of fast food, appear to be slow in accepting new varieties (N. Simmonds, personal communication 1993; J. Bryan, personal communication, 1994). New varieties potentially imply changes in specifications for processed products. For example, it is often stated that changing the variety for the elaboration of frozen french fries sold by a fast food chain would require a change in the recipe for food preparation which could translate into an investment of millions of dollars (Nelson Estrada, personal communication, 1993). The fresh or tablestock market appears to have fewer technological rigidities in responding to varietal change than the market for processed products. Cursory inspection of the adoption profiles similar to those in Figure 14 lends credence to the argument that it takes time for processors to adjust to new varieties in North America. Successful processing varieties, such as Kennebec, Atlantic, Superior, and Norchip, were relatively tardy in reaching peak adoption, which is/was extended over several or even many years. In contrast, the adoption pattern of tablestock varieties, such as Katahdin and Red Pontiac, is characterized by a steeper ascent and a sharper descent. Within processed products, varietal turnover seems to be faster in chipping varieties than in french frying varieties (J. Bryan, personal communication, 1993). Whatever the case, the extent to which rigidities in the processing sector dampen varietal change is largely speculative and is an area of high priority for further research.

Three other aspects of Figure 18 are worth noting. First, the inverse relationship should not be narrowly construed to mean that varietal change is undesirable; without new varieties, potato production would have fallen even faster in countries experiencing negative rates of growth in the recent past. Netting out the effects of the impact of varietal change on production would in all likelihood have resulted in an even steeper negative tendency. Secondly, the estimated relationship in Figure 18 depicts a fundamental tendency in the evolution of production and consumption for countries where potatoes loomed large as a staple

and where the supply of new varieties was not constrained. Only for Australia could one make the case that the slow rate of varietal change is partially attributed to the lack of investment in plant breeding. Lastly, one can provide explanations for several of the outliers in Figure 18. The dramatic fall in growing area in East Germany following reunification suggests that a command economy had considerably delayed the onset of the long term market trends of declining production in both Poland and East Germany. Including more recent observations since 1990 will (most likely) position those two countries to the left of West Germany in the growth rate of production in Figure 18.

Implications for Developed Countries

The most transparent implication of the above synthesis is that the pace of varietal change will diminish for countries which are still in the "early stages" of these evolving market and production trends. Consistent with this implication, one would predict a rising varietal age for the East European countries and independent states of the former USSR. The penetration of older, commercially established Western European varieties, particularly Dutch cultivars, into these countries could accelerate the expected upward trend in varietal age.

Figure 18 also raises several questions. What will it take to break or even reverse the inverse relationship between varietal change and product value? More specifically, is the rate of varietal change destined to be as slow as it has been in the recent past in countries with a "mature" potato industry? Increasing environmental concern and biotechnological innovations are the two forces which could accelerate the pace of varietal change.

Environmental Concern

The effects of increasing environmental concern on the production technology of horticultural crops, which are often heavy users of pesticide, is receiving increasing research attention. Studies on consumer willingness to pay suggest that the size of the "environmental" market is, at this time, likely to be small. For example, the demand for chemical pesticide residue-tested tomatoes in the United States would appear to be weak if their costs exceed by more than 20% of the unit costs of commercial tomatoes produced with pesticides (Weaver et al. 1992). Based on results in Maine, residue-tested potatoes would appear to "have the potential for successfully acquiring a small, but seemingly dependable share in the tablestock market (Peavey et al. 1990, p. 33)." Both studies highlight the importance of product appearance in purchasing decisions.

Research has also been carried out on the willingness of fruit and vegetable growers to adopt more environmentally friendly technologies. Recent findings from a nation-wide survey of small strawberry and raspberry growers in the U.S. are perhaps indicative for other input-intensive crops (Weaver and Goulart 1993). Producers viewed chemical control as effective,

reporting losses of less than 10% with chemical control. Nor was the application chemical-based technologies viewed as a substantial health risk. Nevertheless, producers were willing to adopt more environmentally friendly practices even when profits would be reduced as much as $ 200 per acre. Most importantly, growers indicated that practices resulting in a decrease in chemical expenditure should not be accompanied by a substantial increase in labor and management time. They were willing to trade less than a 5% increase in labor and management time for a 10% decrease in the cost of chemicals. Presumably, the adoption of resistant varieties should not be as time-intensive as the acceptance of some other environmentally friendly practices.

For potatoes, increasing demand for disease resistance could not only be derived from a growing concern about the health and contamination effects of pesticide use but also from the threat of more virulent types of disease. Recently, concern is mounting about increasing virulence of late blight. Increasing virulence is associated with the spread of the sexual form of the disease from Mexico to Europe.

That mounting environmental concern will translate into changes in production technology in countries with a mature potato industry is a virtual certainty, but the extent that such changes in the medium term will fundamentally alter the relationship in Figure 18 is still largely an empirical issue. Indeed, one could argue that increasing environmental sensitivity may not have important consequences for the pace of varietal change. This contention is based on the fact that within some countries the regions, where pesticides are most heavily used in potato production, are also the areas where varietal change is relatively rapid. For example, environmentally induced technical change is imminent in the nematicide-intensive system of producing starch potatoes in the Netherlands, but varietal turnover in this sub-sector, historically, has been much faster than in the market for tablestock consumption. In the U.S., late blight is almost unknown in the arid Northwest east of the Cascades, the heartland of Russet Burbank production (J. Bryan, personal communication 1994). An increase in the virulence of late blight will most likely be expressed in the relatively lower yielding states which are characterized by relatively younger varieties in Figure 12. Greater severity of late blight could accelerate the loss in market share from the Northeast and Midwest to the Northwest, which, in turn, would lead to further increases in average varietal age. If market forces warranted, more land with a high yield potential could be brought under potato cultivation in the Columbia River Basin of Washington (Jones 1987).

The strategy in resistance breeding to late blight also has implications for the longevity of varieties. The consensus strategy emerging during the past 30 years increasingly focuses on the desirability of horizontal, unspecific, or "durable" sources of resistance to combat late blight. As its name implies, durable means that a variety's resistance should not lead to changes in the pathogen and subsequently break down. Therefore, the present cost of sacrificing some production to late blight generates the future benefit of diminishing the prospect of being

wiped out by the disease. Combining a few timely fungicide applications with appropriate cultural practices with a durably resistant variety should protect against heavy economic losses from the disease. Although "a remarkable increase in resistant varieties cannot be expected because the genetic background of the unspecific resistance is largely unknown and the evaluation of its characteristics is difficult (Schober et al., 1987)," it is clear that success in attaining the goal of durable resistance should allow farmers to plant the same variety for many years without having to worry about technology-induced infestation. Therefore, success in combating this increasingly virulent disease may not be characterized by an acceleration in the pace of varietal turnover. At least, one would not expect the consequences for varietal change for late blight in potatoes to be as marked as for rusts in wheat where varietal replacement is high in response to races of the pathogen overcoming vertical sources of resistance.

Biotechnology

The above reasoning leads to the conclusion that the demand for environmentally sensitive technologies may not be a strong enough force to spark a substantial increase in the rate of varietal turnover in a mature potato industry. Does the same conclusion hold for supply side considerations, particularly for biotechnology? A priori, modifying one or a few genes of a commercially established variety via biotechnological techniques, which result in improved transgenic plants of varieties already commercially established in the market, would appear to be the perfect solution to the varietal demands of a mature potato industry. One could envisage an improved Russet Burbank resistant to verticillium wilt or net necrosis or even an improved, more stable yielding Russet Burbank characterized by greater water use efficiency.

Unfortunately, nature is not so benevolent to make the vision of successive and cumulative transgenic alterations leading to a "perfect" cultivar a reality in the near or even in the medium term future. The majority of problems and opportunities require poligenic solutions. The quest for a "cold chipper," a variety which does not sweeten in cold storage, is an apt example of a poligenic opportunity which is controlled by the combined effect of a number of genes (Sowokinos 1994).

A selective impact on varietal change is anticipated from genetically transformed plants particularly in those areas where conventional breeding has made limited or negligible progress. For some time, perhaps the best hope for a genetically transformed variety to contribute to varietal change in a mature potato economy has been exemplified in the potential expression of resistance to Colorado Potato Beetle, a major pest in North America, from Bacillus thuringiensis (Slack 1987). Nonetheless, the set of problems and opportunities which can be effectively addressed by transgenic plants is still quite restricted.

Biological techniques, such as marker-assisted selection, should improve the efficiency of conventional breeding. Indeed, this effect may be the principal impact on varietal change in the

medium term. Incorporation of biological techniques in a conventional breeding program should shorten the gestation period in varietal development from crossing to release. Ample scope exists to shorten the gestation period of varietal development. For varieties recently reported in the American Potato Journal for release between 1990-93, the median duration for varietal development from the time the cross was made or the seedling was first selected was still about 15 years.

Summing up, growing environmental concern and expanding biotechnological applications are expected to make a small, but potentially important, contribution to accelerating varietal change in countries with a mature potato industry in the next 25 years. I would be surprised if such a contribution were of a large enough magnitude to fundamentally alter the relationship in Figure 18 or to substantially improve the varietal acceptance record of potatoes relative to other field crops.

Implications for Potato Crop Improvement in Developing Countries

The implications of the above analysis on varietal change in potatoes in developed country agriculture for potato improvement in developing countries are twofold. The first implication is largely a contrast; the second a similarity.

Varietal change, the quality of the production environment, and the strength of market preferences

Several factors make varietal change more likely in developing countries than in developed countries with a mature potato industry. Firstly, institutional seed programs, if they exist, do not function that well (Crissman 1989). The inability of seed programs in the organized sector to deliver clean seed is a transparent constraint as well as a disguised advantage. Without clean seed from government-supported programs, it is hard to transfer new varieties, but the scarcity of such seed means that any new varieties, which are produced through ad hoc special projects in the public sector or in the informal sector, compete with farmers' degenerating seed. The demand for virus resistance is strong.

Secondly, chemical control is widespread in developing country agriculture, but farmers are less resource well-endowed and infrastructure is less well-developed. Disease pressure, particularly the severity of late blight, is often more intense.

Thirdly, with the exception of the Andean Region, preferences are not that marked. Although potatoes are too precious to be fed to livestock and although the demand for processed potatoes is increasing, the market for potatoes in many tropical countries is not yet that differentiated.

In contrast to developed country potato agriculture, one can cite several examples where the nexus between adoption performance and disease resistance is positive and significant.

Perhaps the best documented case refers to the popularity of the late blight tolerant varieties, originating or screened in the Mexican national program and pathogen-tested and distributed by CIP, in the East African Highlands. Recent surveys show that these varieties now account for the lion's share of potato growing area in Rwanda, Burundi, Zaire, and Uganda (International Potato Center 1992). They displaced degenerated varieties which farmers abandoned because of their susceptibility to late blight and bacteria wilt. Presently, the most popular variety in East Africa is Cruza-148, which has horizontal resistance to late blight and has some tolerance to bacterial wilt. The flesh of Cruza-148 is discolored with a purple vascular ring and it fetches a lower market price than most other more susceptible varieties. At this time, this clone's yield advantage in conditions of high disease infestation more than compensates for its inferior market quality.

Other examples, where disease resistance has been the driving force behind good adoption performance, range from the Andes to Southeast Asia in developing country agriculture. In Peru, the commercial acceptance of Perricholi and INIAA-Canchan, a more recent release, is mainly derived from their tolerance to late blight. In the Philippines, Granola, a German clone, owes much of its widespread acceptance to moderate levels of virus resistance.

The demand for stable-yielding rustic clones is also high, particularly in rain-fed environments. Part of the popularity enjoyed by Achirana INTA in North China is attributed to its ability to set large-sized, marketable tubers in years when rainfall is sparse.

The comparison of varietal change between developed and developing potato-producing countries has thus far emphasized the contrasts, but the driving forces behind the relationship in Figure 18 are the same: as quality becomes more prized in the market and as production becomes more specialized and commercially-oriented, the prospects for varietal change diminish.

This stylized relationship is depicted in Figure 19. At the right end of the figure, one finds the environments of very high production potential together with markets of marked consumer preferences. Presently, perhaps no low or even middle-income developing countries would qualify as falling to the right of 0C, but several countries would lie in segment BC characterized by high production potential in a relatively discriminating market. These conditions describe well potato production in the countries of the Southern Cone where the prevailing varieties in the intensive, commercial farming sector come mainly from the Netherlands. In such a context, prospects for making practical impact from the excellent national breeding programs, existing in this region, are often brighter with smaller, less commercially-oriented producers (Marcelo Huarte, personal communication, 1993).

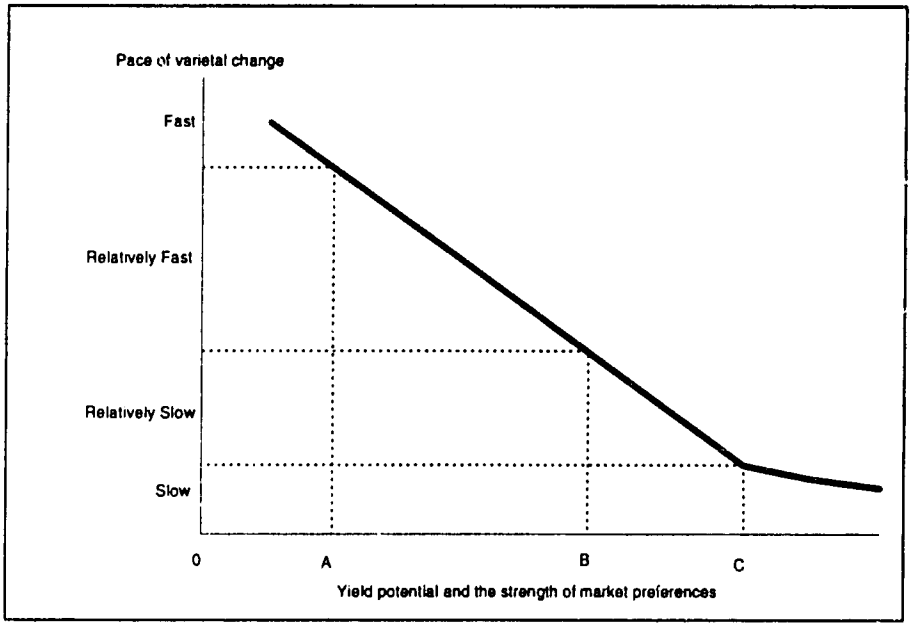


Figure 19. The hypothesized relationship between varietal change and the quality of the production and consumption environments.

A few countries in North Africa could also fit the production and market conditions described in interval BC. Because varietal production potential is still not a constraint on yield and because yield potential is high, returns to research on crop and water management should be attractive in such well-endowed environments for potato production. Growth in yields in the Russet Burbank-producing states from 3 to 8 percent per year during the past 50 years in the United States suggests that returns to crop and water management research were potentially high. The relative homogeneity within such environments should lead to reduced location specificity in applying the results of crop and water management research. In addition, the commercial orientation and size of producers should enhance the prospects for adoption of practices requiring group action such as recommendations from integrated pest management research.

Lastly, the production and market conditions in these countries should be conducive to the emergence of strong seed programs. Investments in seed program development should generate attractive rates of return.

At the other extreme, one encounters environments of lower yield potential accompanied with markets which do not significantly reward quality. Potato cultivation in countries falling into segment 0A is largely rain-fed and both biotic and abiotic stresses exact a high toll on production. Prime examples of countries belonging to this group would be almost all the nations (with the exception of South Africa) in Sub-Saharan Africa where potatoes can be grown. Although market conditions appear to be rapidly changing, the demand for disease-resistant varieties which yield well in rustic production conditions is also very strong in North and Southwest China. The main constraint in satisfying the demand for new varieties in the production and market circumstances of OA is the provision, especially the field multiplication, of clean seed.

The majority of developing country potato producers would fall somewhere in AB. If the supply of new varieties was forthcoming and field multiplication was effective, one would expect a fairly rapid rate of varietal replacement in these environments which are comprised of high or moderate production potential with a moderately discriminating market (the northern Andes), or relatively low production potential with a discerning market (the southern Andes), or relatively high production potential with a less discriminating market (irrigated dry-season production in South Asia).

One caveat about the region 0A in Figure 19 is worth discussing. This discussion applies more to the Andes than to other regions of the potato-growing world where production is expanding. Although the counsel provided by Figure 19 is consistent with giving more emphasis in a breeding or screening program to the lower yielding, production regions within a country, one should be aware of the dynamics of comparative advantage.

One could argue that breeding success could enhance the comparative advantage of low production, often drought-afflicted regions, but it is questionable that the results of potato breeding could radically alter the fundamentals of emerging comparative advantage. Indeed, the U.S. experience suggests otherwise. For many years, one of the most impressive potato breeding programs in the U.S. was Julian Miller's in Louisiana State University where Robert Johansen received his Ph.D. Several important commercial varieties were released from the Louisiana State program. But that success did not arrest the declining trend in potato production in Louisiana from about 15,000 acres in the late 1940s to less than 400 acres today.

Breeding and screening for frost tolerance could be an exception to the general implication that the returns to breeding would be unattractive in environments of very low production potential. Small farm households in the high Andes where frost risk is high have few cropping alternatives to potatoes.

Wide Adaptation

The second implication refers to the scope for and desirability of wide adaptation. One can also muster some empirical support for wide adaptation in potato production in developing country agriculture. As discussed earlier, Cruza-148 is now the dominant variety in the East African Highlands. Achirana-INTA, a hardy clone selected in Argentina in the early 1970s, is cultivated in several countries ranging from Bhutan to Madagascar and is reported to account for over 250,000 hectares in North China (Song Bo Fu, et al. 1994). ICA-Huila, of Colombian origin, is becoming popular in Ecuador. Revolution, bred in Peru, appears to have good prospects in parts of Bolivia.

Ample scope for wide adaptation enhances the value of multi-locational testing. In particular, regional networks for multi-locational testing would appear to be highly beneficial

in identifying material with wide adaptation. Other implications of wide adaptation are more subtle and relate to spill-over benefits.

Wide adaptation does not negate the importance of investing in national breeding programs or in networks which further national comparative advantage at a regional level, but wide adaptation does imply spill-over benefits in the form of varietal diffusion across borders within a particular region or agroecology. Strong breeding programs oriented towards practical impact are going to dominate others in the same region. It is difficult to compete with the Robert Johansens of this world. Based on the North American experience in potato breeding, the notion that every national breeding program can generate practical impact by selecting material uniquely suited to its conditions would appear to fly in the face of reality. The challenge facing CIP and other international organizations is to maximize the potential that strong or key programs within larger regions or agroecologies have for generating regional and global spill-over benefits.

Reflections

The above findings and implications need to be placed in a commodity perspective. Earlier, varietal change in wheat was briefly examined to provide a contrast. Is varietal change in potatoes really that different from what one finds in other crops? An inverse relationship between market quality and the scope for varietal change does not appear to be unique to potatoes. For example, high quality, aromatic basmati rice has proven particularly resistant to varietal change (D. Byerlee, personal communication, 1993; Barker and Herdt, 1985). Moreover, the prediction that the prospects for varietal change are brighter in poorer quality production and market environments may seem counterintuitive to students of cereal agriculture, but it is not unprecedented in forecasting differential success rates for new varieties of vegetatively propagated crops. Among producers, small banana and plaintain farmers may benefit disproportionately from new varieties resistant to the potentially devastating Black Sigatoka disease (Hibler and Hardy 1994). The uptake of these varieties is not expected to be as fast among plantations producing for export because chemicals, although increasingly expensive, can still be used to control the disease and because a change in variety necessitates changes in packaging and shipping which imply a substantial investment for major exporters.

Still, not much is known about the extent to which these findings on varietal change apply exclusively to potatoes. Examining rates of varietal change over space and time across several crops with widely varying technical and market attributes may provide the basis for better understanding the incidence of and conditions for slow rates of varietal turnover characteristic of potatoes in a "mature" production and market setting. For potatoes, the most interesting and relevant contrasts and similarities would be derived from work on other horticultural crops especially those which are vegetatively propagated.

Some of the conceptual building blocks to support such an empirical enquiry on the determinants of varietal change across commodities with widely varying attributes already exist. Buddenhagen (1983) shows that the perceived value of varietal disease resistance declines as the value of the crop, relative to other crops, increases. Buddenhagen (personal communication, 1994) believes that the identical nature of clonally propagated crops can give rise a market uniqueness in terms of taste or quality which can lead to a technological uniqueness in the production and processing of the clone. Both of these mutually reinforcing sources of uniqueness lead to commerical longevity. In the jargon of economists, market preferences and technical change are partially endogenous to or depend on commercially established, individual varieties in a vegetatively propagated crop.

In closing, I return to the question posed at the outset of this paper: Russet Burbank : Is it here to stay? The subsequent analysis did not shed much light on that specific question, but the findings are consistent with the prediction that whatever eventually does replace Russet Burbank is likely to remain in the market and in growers' fields for a long time.

References

Ackerson, C. 1992. Dr. Bob Johansen to retire after 42 years of plant breeding. Valley Potato Grower 58(105):6-7.

Akeley, R.V., Stevenson, F.J., and E.S. Schultz. 1948. Kennebec: A new resistant to late blight, mild mosaic, and net necrosis. American Potato Journal 25(10):351-361.

Akeley, R.V., Stevenson, F.J., Blood, P.T., Schultz, E.S., Bonde, R., and K.F. Nielsen. 1955. Merrimack: A new variety of potato resistant to late blight and ring rot and adapted to New Hampshire. American Potato Journal 32:93-99.

Bald, J.G. 1941. A report on agricultural features of the Australian potato industry. Pamphlet No. 106, Council for Scientific and Industrial Research. Melbourne: H.E. Gaw, Government Printer.

Barker, R. and R.W. Herdt. 1985. The rice economy of Asia. Washington, D.C.: Resources for the future.

Beekman, A.G.B. 1987. Breeding for Resistance. In Viruses of Potato and Seed Potato Production, ed. J.A. de Bokx and J.P.H. van der Want, 162-170. Wageningen, The Netherlands: Padoc Wageningen.

Bofu, S., T. Weiming, W. Jimin, W. Chunlin, Y. Zhengui, and W. Shengwu. 1994. An impact assessment of CIP-24 in China. (processed) Lima, Perú: International Potato Center.

Bowen, R.W. 1979. Potato breeding: a review. Pages 2-1 to 2-7 in Australian Potato Research Conference 1979, Cowes, Victoria.

Brennan, J.P. 1989. Wheat varietal turnover and diversification in NSW. Agricultural Science (March 1989):27-31.

Brennan, J.P. and D. Byerlee. 1991. The rate of crop varietal replacement on farms: measures and empirical results for wheat. Plant Varieties and Seeds (4):99-106.

Buddenhagen, I.W. 1983. Plant breeding or pesticides to narrow the yield gap? 10th International Congress of Plant Protection 2:803-809.

Bundessortenamt. 1992. Beschre bende sortenliste Frankfurt Germany: Verlag Alfred Strothe.

Bureau of Agricultural Economics (BAE). 1976. Australian potato production, consumption, and trade: a descriptive analysis of recent trends and developments. Occasional Paper No. 36. Canberra: Australian Government Publishing Service.

Chase, R.W. 1992. North American Potato Variety Inventory. Certification section. Potato Association of America. 12p.

Clark, C.F. and F.J. Stevenson. 1935. The Katahdin, Chippewa, and Golden Potatoes. Circular No. 374 Washington, D.C.: United State Department of Agriculture.

Clark, C.F., Stuart, W., and F.J. Stevenson. 1931. The Katahdin Potato; a new variety. American Potato Journal 8(5):121-125.

Crissman, C.C. 1989. Seed Potato Systems in the Philippines: A case Study. (Lima: CIP-PCARRD) 89p.

Dean, D. 1933. Our Changing Potato Industry. American Potato Journal 10:108-114.

Department of Agriculture, Tasmania. 1981. Potato growing in Tasmania. Bulletin 57. Tasmania: T.J. Hughes, Government Printer.

Douglas, E. 1927. Potato Situation in Monmouth Country New Jersey. American Potato Journal 4:121-123.

Dreyer, P. 1985. A gardener touched with genius: the life of Luther Burbank. Berkeley, CA, USA: University of California Press.

Fernow, K. 1928. Spraying and Dusting Potatoes. American Potato Journal 5:157-159.

Fitch, C.L. 1914. Identification of potato varieties. Agricultural Extension Department, Extension Bulletin No. 20. Ames, Iowa: Iowa State College of Agriculture and Mechanic Arts.

Gray, R.W., Sorenson, V.L., and W.W. Cochrane. 1954. An economic analysis of the impact of government program on the potato industry of the United States. North Central Regional Publication No. 42. Minnesota: University of Minnesota.

Guenthner, J.F., Lin, B.H., and A.E. Levi. 1991. The Influence of Microwave Ovens on the Demand for Fresh and Frozen Potatoes. Journal of Food Distribution Research 22(3)45-52.

Hackett, C. and Rattigan, K. 1978. The location and timing of potato production in Australia. Division of Land Use Research Technical Paper No. 38. Melbourne: Commonwealth Scientific and Industrial Research Organization (CSIRO).

Hawkins, A. 1957. Highlights of a half-century in Potato Production. American Potato Journal 34(1):25-29.

Heisey, P.W. and J.P. Brennan. 1991. An analytical model of farmers' demand for replacement seed. American journal of Agricultural Economics 73(4):1044-1052.

Hermsen, J.G. Th. and K.M. Swiezynski. 1987. Introduction. Pages kviii-x in The Production of New Potato Varieties: Technological Advances. Ed. G.J. Jellis and D.E. Bicardson. Cambridge, Great Britain: Cambridge University Press.

Hibler, M. and D. Hardy. 1994. Breeding a better banana. IDRC Reports 22(1) 16-19.

Horton, D. 1988. Underground Crops: Long-Term Trends in Production of Roots and Tubers. Morrilton, Arkansas: Winrock International. 132p.

Hosking, D.C. 1979. Geography, Economics, and Marketing: Western Australia. Pages 8-43 to 8-45 in Australia Potato Research Conference 1979, Cowes, Victoria.

International Potato Center. 1992. The PRAPACE Network: CIP-NARS Collaboration for Sustainable Agricultural Production in Africa. Paper presented at a Symposium The Impact of Technology on Agricultural Transformation in Africa, Washington D.C., October 14-16. 31p.

IVP. 1993. Beschrijvende rassen lijst voor landbouwgewassen (68). Wageningen: IVP.

Johansen, R.H., Farnsworth, B., Nelson, D.C., Secor, G.A., Gumestad, N., and P.H. Orr. 1988. Russet Norkotah: A New Russet-skinned Potato cultivar with Wide Adaptation. American Potato Journal 65(10)597-604.

Jones, E.D. 1987. Trends in commercial and seed potato production in North America and expected future developments. Pages 95-104 in Recent and Future Development of the Ptoato in the World, eds. J.C. Hesen, C.D. van Loon, J.G. Hermsen, and L.J. Turkensteen. Acta Horticulturae 213, Wageningen, The Netherlands: Drukkerij Jansen.

Livermore, J.R. 1951. The Canoga Potato. American Potato Journal 28:672-674.

Lucier, G., Budge, A., Plummer, C. and C. Spurgeon. 1991. U.S. Potato Statistics, 1949-89. Statistical Bulletin Number 829. Economic Research Service, United States Department of Agriculture. Washington, D.C. 20005-4788.

Makus, L.D., Guenthner, J.F., and B.H. Lin. 1992. Factors influencing producer support for a state mandatory seed law: an empirical analysis. Journal of Agricultural and Resource Economics 17(2)286-293.

National Seed Development Organisation Limited (NSDO). 1976. Potatoes: a Choice of Varieties from the State Plant Breeding Stations. Cambridge: NSDO.

Nelson, D.C. 1982. Robert H. Johansen. American Potato Journal 59(9):440:441.

Oskam, A.J., Van Zeijts, H., Thijssen, G.J., Wossink, G.A.A., and R. Vijftigschild. 1992. Pesticide use and pesticide policy in the Netherlands. Wageningen Economic Studies 26. Wageningen Agricultural University: Wageningen, The Netherlands.

Page, O.T. 1985. Reflexions on CIP Research for the Future. CIP Seminar. Lima-Peru. 28p.

Pavek, J.J., Corsini, D.L., Douglas, D.R., Ohms, R.E., Gasner, J.G., McKay, H.C., Stranger, C., Vogt, G.E., Sparks, W.C., Kunkel, R., Davis, J.R., Walz, A.J., Dallimore, G.E., and J. Augustin. 1978. Butte: A long russet potato variety with excellent dehydrating quality. American Potato Journal 55(12):685-690.

Peavey, S., Smith, D., and A. Kezis. 1990. Value Determination of Pesticide Residue-Tested Potatoes. Journal of Food Distribution Research. 21:21-34.

Potato Marketing Board. 1990. Potato Statistics in Great Britain 1985-1989. Oxford: Potato Marketing Board.

Reuter, L.B. 1993. Trends in the potato market for Germany as a whole. Kurtoffelbau 44(2):60-63.

Ross, H. 1986. Potato Breeding-Problems and perspectives. Berlin: Verlag Paul Parey.

Ross, H. 1966. The use of wild solanum species in German Potato Breeding of the past and today. American Potato Journal 43(2):63-80.

Rowe, R.C. (ed.) 1993. Potato Health Management. Minnesota: APS Press.

Schober, B. and Schiessendoppler, E. 1987. Some interesting aspect of recent and expected developments of diseases and pests and their control in Europe. Pages 169-176 in

Recent and Future Development of the Potato in the World, eds. J.C. Hesen, C.D. van Loon, J.G. Hermsen, and L.J. Turkensteen. Acta Horticulturae 213, Wageningen, The Netherlands: Drukkerij Jansen.

Schulz, O. 1992. Die Kartoffelwirtschaft in Ostdeutschland. Landbauforschung Volkenrode 42(4):255-259.

Seed Certification Committee. 1936. Report of the Seed Certification Committee. American Potato Journal 13:16-22.

Slack , S.A. 1987. Some interesting aspects of recent and expected developments in control of diseases and pests in Nort America. Pages 161-168 in Recent and Future Development of the Ptoato in the World, eds. J.C. Hesen, C.D. van Loon, J.G. Hermsen, and L.J. Turkensteen. Acta Horticulturae 213, Wageningen, The Netherlands: Drukkerij Jansen.

Smith, O. 1951. Potato quality. American Potato Journal 28:732-737.

Smith, P.E. and N.A. Young. 1979. The West German Potato Marketing System. Ashford, Kent, Great Britain: CEAS, Wye College, University of London.

Sowokinos, J. 1994. To chip or not to chip: Red River valley advanced breeding selections with resistance to sweetening in cold storage. Valley Potato Grower 59(108):36-37.

Stephens, J.G. 1979a. Geography, Economy, and Marketing: Tasmania. Pages 8-36 to 8-42 in Australian Potato Research Conference 1979, Cowes, Victoria.

Stephens, J.G. 1979b. Varietal Impovement: Tasmania. Pages 2-16 to 2-19 in Australian Potato Research Conference 1979, Cowes, Victoria.

Stevenson, F. J. 1966. Bintje. American Potato Journal 43:458-459.

Stuart, W. 1918. Group classification and varietal descriptions of some American potatoes. USDA Bulletin No. 176. Government Printing Office: Washington, D.C.

Stuart, W. 1926. The value of good seed potatoes. American Potato Journal 3(3):83-85.

Swiezynski, K.M. 1987. Some interesting aspects of potato breeding in Europe. Pages 51-60 in Recent and Future Developments of the Potato in the World, eds. J.C. Hesen, C.D. van Loon, J.G. Hermsen, and L.J. Turkensteen. Acta Horticulturrae 213, Wageningen, The Netherlands: Drukkerij Jansen.

Thomson, A.J. 1987. A practical breeder's view of the current state of potato breeding and evaluation. Pages 336-346 in The production of new potato varieties: technological advances. Eds. G.J. Jellis and D.E. Richardson. Cambridge, Great Britain. Cambridge University Press.

Tucker, J. 1937. The Value of Seed Potato Certification to the Potato Industry. American Potato Journal 14:41-45.

Twomey, J.A., Hoyman, W.G., and J.J. Shanghnessy. 1977. Centennial Russet: An oblong russetted variety adapted to certain irrigated potato growing areas of the West. American Potato Journal 54(12):603-605.

United States Department of Agriculture (USDA). 1953. Potatoes. Statistical Bulletin No. 122. Bureau of Agricultural Economics.

United States Department of Agriculture (USDA). 1993. Potato Facts, Fall/Winter 1992/93. Economic Reserch Service. Washington, D.C.

Valley Potato Grower. 1992. Goldrush - a new russet potato variety. Valley Potato Grower 57(112):25.

Vos, J. 1992. A case history: Hundred years of potato production in Europe with special reference to The Netherlands. American Potato Journal 60(11)731-751.

Weaver, R.D. and Goulart, B. 1993. Grower interest in adopting alternative technologies: results from a nationwide survey. Pennsylvania Fruit News 73(12):12-32.

Weaver, R.D., Evans, D.J., and A.E. Luloff. 1992. Pesticide Use in Tomato Production: Consumer Concerns and Willingness-to-Pay. Agribusiness 8(2):131-142.

Weidtmann, J. 1993. In Deutschland weniger in der EG mehr Schweine, Ergebnisse aus der August-Viehzahlung. Scheweinezucht und Schweinemast 41(5):6-7.

Wilson, C.R. and R.A.E. Jones. 1990. Virus content of seed potato stocks produced in a unique seed potato prodcution scheme. Annuals of Applied Biology 116(1):103-109.

Young, N. A. 1977. The Dutch Ware Potato Marketing System, Report no. 9, Wye College, Ashford, Kent, England: Center for European Agricultural Studies (CEAS), 152 pages.

Young, N. A. 1990. Seed Potato Systems in Development Countries: Canada, The Netherlands and Great Britain. Lima:CIP. 128p.

Young, N.A. 1981. The European Potato Industry. Ashford, Kent, Great Britain: CEAS Wye College, University of London.

Zalewski, J. 1992. Russet Burbank: Is it here to stay? Valley Potato Grower 57(112):20-24.