Commercial Potato Production in North America

The Potato Association of America Handbook

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Commercial Potato Production in North America

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A Brief History of this Handbook and Use of the Information

The current publication, *Commercial Potato Production in North America* was originally published in July 1964 by the USDA Agricultural Research Service, Agriculture Handbook No. 267, with the title, *Commercial Potato Production*, authored by August E. Kehr, Robert V. Akeley and Geoffrey V. C. Houghland. It was for sale from the Superintendent of Documents, U.S. Government Printing Office for 60 cents.

The handbook was out of print in the late 1970's. The Extension Committee of The Potato Association of America (PAA) identified the need for the publication and for some revision. The USDA did not have plans to revise and reprint it and gave permission to The Potato Association of America to do so.

During the mid 1970's, Robert Thornton, Washington State University (retired), oversaw the editing and rewriting by North American potato specialists of the original publication for a revised handbook. In 1979, while on sabbatical leave at WSU, Joseph Sieczka, Cornell University (retired) assisted in the editing of the sections in the handbook so they had similar format. The first revision of *Commercial Potato Production* originally published by USDA was completed by The PAA and published in 1980 with Robert E. Thornton and Joseph B. Sieczka as co-editors. There were 16 authors including the two editors of the 1980 version of the publication that was titled, *Commercial Potato Production in North America.* The handbook was published as a supplement to the American Potato Journal (now American Journal of Potato Research) of The PAA.

The 1980 revision was quickly and widely accepted and was out of print by the end of that decade. By that time there were many changes in potato production and marketing so some sections of the publication needed significant changes and new sections needed to be added. Sieczka and Thornton agreed to again coordinate and edit the next version. In addition to the original authors of the previous two versions, eight more individuals contributed to the 1992 version (*Commercial Potato Production in North America,* Potato Association of America Handbook, Revision of American Potato Journal Supplement, Volume 57 and USDA Handbook 267 by the Extension Section of The Potato Association of America). Editors of the 1992 revision were listed as Joseph B. Sieczka, Cornell University, and Robert E. Thornton, Washington State University.

As with the previous versions of this handbook, changes in the potato industry lead to a need to revise the handbook for a third time beginning in the mid 2000's. In the current version of *Commercial Potato Production in North America*, some sections were extensively revised while some of the basic sections changed little. The current version has 26 authors who revised, rewrote or added sections. The task of editing and coordinating the handbook revision was initially undertaken by William H. Bohl, University of Idaho, Steven B. Johnson, University of Maine, and Alvin Mosley, Oregon State University. The current version is an on-line only publication with Internet links.

The editors of this and previous revisions acknowledge the efforts of individuals who contributed to the original USDA Handbook 267 and the following revisions.

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INTRODUCTION

(Joe Guenthner)

Commercial potato production is a complex, specialized commercial enterprise that requires a high degree of technical skill and practical experience on the part of the producer. With the trend towards increased processing use of potatoes, growers have oriented their production practices to the type of market in which they expect to sell. These processing operations that manufacture chips, frozen, and dehydrated products provide important, large outlets, which have reversed the declining per capita consumption of potatoes in the United States.

The continued application of farming technology has resulted in growers producing more potatoes on fewer acres. In the 1930s, 3 to 3.5 million acres (1.2 to 1.4 million ha) of potatoes were harvested in the United States. In 1985, production was nearly double the 1930 production on less than half the acres. By 2005, U.S. potato acreage declined to 1.08 million acres, less than one-third the acreage in 1930 (Table 1). More information on yield and production for other years or for individual states can be found at: http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1123

The average U.S. yield of potatoes has steadily increased, and with shifts westward to the high-yielding, irrigated fields of the Pacific Northwest, the national average yield reached 290 cwt per acre (32.5 t/ha) in 1990. Fifteen years later, average yield had increased by another one-third to 390 cwt per acre (43.7 t/ha). Increased yields have resulted not only from shifts in geographical areas of production but also due to increased grower specialization, changes in technology, and improved cultural techniques.

Table 1. U.S. Land Area, Yield and Production of Potatoes-Selected Years 1930-2005.

	Area		Yield		Production	
Year	(1,000 A)	(1,000 ha)	cwt/A	t/ha	1,000 cwt	1,000 t
1930	3,139	1,271	66	7.4	206,290	9,366
1935	3,469	1,404	66	7.4	227,337	10,321
1940	2,832	1,147	80	9.0	226,152	10,267
1945	2,664	1,079	94	10.5	251,639	11,424
1950	1,698	687	153	17.1	259,112	11,764
1955	1,405	569	162	18.1	227,692	10,337
1960	1,386	561	185	20.7	257,104	11,673
1965	1,383	560	210	23.5	291,109	13,216
1970	1,421	573	229	25.7	325,752	14,789
1975	1,260	510	256	28.7	321,978	14,618
1980	1,148	465	265	29.7	303,905	13,797
1985	1,361	551	299	33.5	407,109	18,483
1990	1,359	550	290	32.5	393,867	17,882
1995	1,372	555	323	36.2	443,606	20,140
2000	1,348	546	381	42.7	513,621	23,318
2005	1,087	440	390	43.7	423,926	19,246

Source: Agricultural Statistics Service, NASS, USDA

In Canada, much the same trend exists with about one-half million acres (0.2 million ha) of potatoes being planted in 1925 and only 302,000 acres (122,000 ha) in 1985 with about 50 percent more production in the 1980s than in 1925 (Table 2). Average yield has also increased in Canada by more than 3 times since 1925. Canadian yields are lower than the U.S. because Canada's major production is from non-irrigated areas with shorter growing seasons.

Table 2. Canadian land area, yield and production of potatoes-selected years.

	Area		Yield		Production	
Year	(1,000 A)	(1,000 ha)	cwt/A	t/ha	1,000 cwt	1,000 t
1925	522	211	77	8.6	40,217	1,826
1950	370	150	118	13.2	43,825	1,990
1965	295	119	155	17.4	45,786	2,079
1970	316	128	175	19.6	55,123	2,503
1975	263	106	184	20.6	48,469	2,201
1980	264	107	207	23.2	54,620	2,480
1985	302	122	221	24.8	66,792	3,032
1990	289	117	223	25.0	64,561	2,931
1995	355	144	237	26.6	84,340	3,829
2000	394	160	256	28.7	100,693	4,571
2005	386	156	253	28.4	97,754	4,438

Source: Statistics Canada
http://www.statcan.ca/bsolc/english/bsolc?catno=22-008-X&CHROPG=1

History

(Chuck Brown)

Most botanists agree that the potato originated in the New World, and there is general agreement that the greatest diversity exists in the Southern Peru-Bolivian Altiplano. The native home of the potato is in the Andean Cordillera stretching from Venezuela in the north to Argentina and Chile in the South of 4,000 to 12,000 feet elevation (1220 to 3660 m), where its wild relatives flourish even today. Historians record that the Spaniards found potatoes in Peru at the time of their conquest of the country beginning in 1524.

Historians disagree about the first introduction of the potato into Europe. Two hypotheses persist. One is that potatoes were taken from Southern Chile where they would already have long-day adaptation. Chilean cultivars probably have their origins from the central Andes and were transferred by man southward and selected for long-day adaptation. There is evidence, however, that the Spaniards introduced the potato from an Andean location in South America to Spain by 1580, or even as early as 1565. Hieronymous Cardan, a monk, is supposed to have been the first to introduce it from Peru to Spain. From Spain the plant was taken into Italy about 1585, into Belgium and Germany by 1587, into Austria by 1588, and into France soon after 1600. Philip de Sivry, Prefect of Mons, Belgium, sent two potato tubers to Carolus Clusius in Vienna, Austria, where they were received on January 26, 1588. Philip de Sivry had received a plant from an attaché' of the Papal Legation; he, in turn, had obtained plants from Italy. De Sivry's colored drawing, now in the Plantin-Moretus Museum at Antwerp, Belgium, was probably named soon after 1588 and is considered by some writers to be the first European illustration made of the potato.

However, the first published illustration and description was by Gerard, an English botanist. This 1597 sketch shows a plant with small leaflets, a large berry, and small numerous tubers, not unlike what one would have expected from a central Andean specimen that was reacting to long day conditions by inhibition of tuberization and prolific vegetative growth, flowering and berry formation. Gerard, unfortunately, gave it the misleading name of *Batata virginiana* (Virginia Potato), and thereby created confusion as to the origin, history, and proper identification of the potato. The origin of this confusion stems from the fact that in 1586, Sir Francis Drake introduced into England a plant that he incorrectly called potato. On this trip, Drake had stopped in Virginia and picked up survivors of Raleigh's Colony on Roanoke Island. Heriot, one of the colonists Drake brought back to England, later became farm manager of an estate in Ireland owned by Sir Walter Raleigh. However, the tubers or roots Heriot took back to England could not have been potatoes because none of his written descriptions of six root-or tuber-forming plants even approximates the potato.

There is an assumption that potato taken from the central Andes would have lacked long-day adaptation. Its adoption as a food crop under long day conditions required some selection, therefore, for adaptation to long days. Hypothetically this could have happened in the gardens where potato was first grown as more of a curiosity than an economically valuable plant. The accepted botanical name *Solanum tuberosum* was first used in 1596 by the Swiss botanist, Kaspar Bauhin, and this was the name adopted in 1753 by Linnaeus in his Species Plantarum.

Introduction of the potato into England probably was independent of its spread in Europe. The exact time of importation into England is clouded by the confusion that existed about the potato, the sweet potato, and other tuber-and root-forming plants.

Because trade was brisk between Spain and Ireland in the 17th century, it could very well be that the Spaniards first brought the potato to Ireland. Alternatively, it could have been sent there from another European location. Without question, the newly introduced plant first became an important agricultural crop in Ireland. Soon after its introduction there, the potato was readily accepted as a staple food, demonstrating for the first time the potential commercial value of a plant that previously was nothing more than a botanical curiosity.

Between 1650 and 1840 potatoes had become a vital part of the basic food supply in Ireland and certainly facilitated a quadrupling of the population. When late blight disease wiped out the crop in the 1840's, famine forced many Irish people to immigrate to America. Because of its early food use and importance in Ireland, the potato plant is often referred to as the Irish potato.

When or where the potato was introduced into the continental United States is not known. It is believed that potatoes did not exist in Virginia when Drake landed there in 1586; if he had potatoes aboard his flagship, it is thought that they came from Cartagena (Colombia). Potatoes were grown in Bermuda for sale to Virginia colonists as early as 1621. One of the early colonial records shows that potatoes were ordered to be taken from England to South Carolina by colonists settling on the Edisto River in 1674. There is no record, however, that potatoes were actually introduced at the time. Potatoes were introduced from Ireland into Londonderry, New Hampshire in 1719 by a group of Presbyterian Irish. This is the first introduction into New England and possibly into the United States. Acceptance of potatoes as food was very slow in North America. However, total production had reached 1,603,730 cwt (728,100 metric tons) in 1840 when potatoes were first mentioned in the U.S. Census.

The potato industry in Canada dates back to 1623, when a small patch was grown at Port Royal (now Annapolis Royal) in Nova Scotia. The captain of an English trading ship had presented a barrel of potatoes to the early Acadian settlers, who used some of the potatoes for planting. This early date emphasizes the rapid conversion of potato from a curiosity, with serious productivity deficits at the point of its introduction to Europe, to a source of sustenance. From this humble beginning the potato has become one of the most important Canadian crops and is grown on more farms and in more gardens than any other food plant.

Botany of the Potato

(David Spooner)

The name "potato" is believed to have originated from the Taínos Indian name, "batatas." The potato is one of about 2,300 species in the family Solanaceae. This family includes about 90 genera, the largest of which is the genus *Solanum*, including about 1,500 species. About 100 species of *Solanum* are tuber-bearing, and thus commonly referred to as "potato." The Solanaceae include such plants as tobacco, tomato, eggplant, chili pepper, horse nettle, bittersweet nightshade, ground cherry, and petunia. Botanically, advanced potato cultivars, today grown in North America, Europe, and other lands are classified as *Solanum tuberosum* L.

The taxonomy of wild and cultivated potatoes is complicated by interspecific hybridization at the diploid and polyploid levels, lack of breeding barriers among many of the species, the maintenance of sterile populations by aesexual reproduction by tubers, and morphological similarity among species. The number of species has varied depending on the author, but recent monographic treatments are greatly reducing the number of species from well over 200 species in 1990 to the current figure of about 100. All of these species are distributed entirely in the Americas from the southwestern United States south to Uruguay, Argentina, and Chile. Chromosome numbers vary from diploid ($2n = 2x = 24$), triploid ($2n = 2x = 36$), tetraploid ($2n = 4x = 48$), pentaploid ($2n = 5x = 60$) to hexaploid ($2n = 6x = 72$). The cultivated potato has all these ploidy levels except hexaploid, and originated along the high Andes of southern Peru. Landrace (native cultivar) populations today grow throughout the Andes from Venezuela to northern Argentina, and also near sea level in southern Chile. Despite having originated in southern Peru, modern cultivars grown worldwide come from the Chilean landraces.

The potato may be classified as an annual, although it can persist in the field vegetatively (as tubers) from one season to the next. In fact, volunteer plants growing from unharvested potato tubers, unintentionally left in the field, create many problems in pest management that affect the production of certified seed as well as that of commercial potatoes.

Being a dicotyledonous plant, the potato has the characteristics of all dicotyledons including stems with vascular bundles placed in a circular arrangement and containing definite layers of xylem and phloem. Some potato breeders have grafted cultivars of potatoes upon tomato stocks (or vice versa) to induce better flowering and seed setting, and for disease studies.

Morphology and Anatomy

(David Spooner)

The potato tuber is an enlarged portion of an underground stem (Figure 1), although these stems sometimes grow above ground as well when they are termed stolons. The term stolon is commonly used in the potato literature for both rhizomes and stolons.

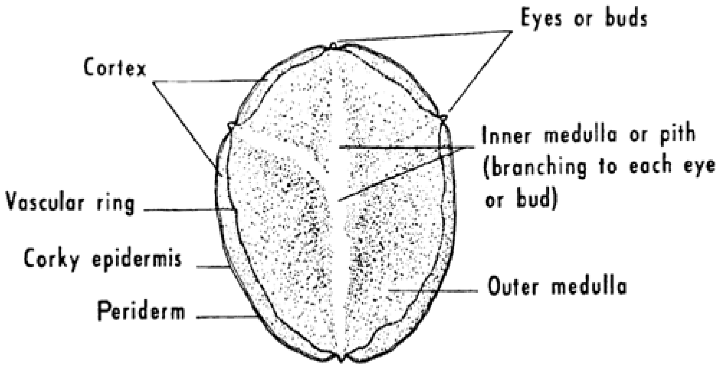

Figure 1. Cross section of a potato tuber.

The "stolons" (technically rhizomes) have leaf scales located alternately on their surface in the same manner as the above ground stems. The tubers originate from the tips of stolons, and occasionally tubers form along the stolon itself. The potato tubers contain all the characteristics of normal stems, including dormant true buds (eyes) formed at the base of a leaf (rudimentary in this case) with detectable leaf scars (the eyebrows). Lenticels or stem pores, through which air penetrates to the stem interior, are plainly found on most tubers.

The buds (eyes) are found in a spiral pattern on the tuber. The eyes tend to be concentrated at the seed or apical end of the tuber. They are fewer in number and farther apart toward the stem end where the tuber is attached to the stolon.

The buds (eyes) of the seed end possess apical dominance and will normally sprout first, a condition characteristic of buds at or near the apex of all conventional stems. When the apical buds are removed, or die, other buds are stimulated to sprout in the same manner as lateral buds on a stem are stimulated to sprout when the "leader" is removed. When whole tubers are planted, generally the buds near the apex will develop sprouts. The effect of apical dominance is reduced if a large tuber is cut into smaller seed pieces. There is a noticeable difference in the rate of emergence between stem-end and seed-end eyes.

The outer layer of single cells of the tuber, the epidermis, is usually colorless. Anthocyanin, the pigment that colors red and blue potatoes, is found in the periderm (several layers of corky cells immediately below the epidermis). The corky epidermis and periderm together comprises the "skin" of the mature tuber (Figure 1). The cultivars Norland, Chieftain, Red La Soda, LaRouge, Pontiac, and Viking are commercial cultivars with red pigment (anthocyanin) in the periderm. In a few cultivars the colored pigment is in the outer layers of the cortex, the region immediately inside the periderm that extends inwardly to the vascular ring. Cultivars known to have red pigment in the outer cortex are Spaulding Rose, Early Rose, and Early Ohio. Indigenous peoples in South America grow a great variety of landrace cultivars that differ by an amazing variety of colors and color distributions as well as shapes in the tubers.

The remainder of the tuber from the vascular ring inward, designated as the medullary area, is divided into outer and inner medulla and constitutes the fleshy part of the tuber. The outer medulla generally contains the denser portion of this area; the inner medulla includes the watery and more translucent part. Persons unfamiliar with the internal structure of the potato sometimes mistake the inner medulla for an

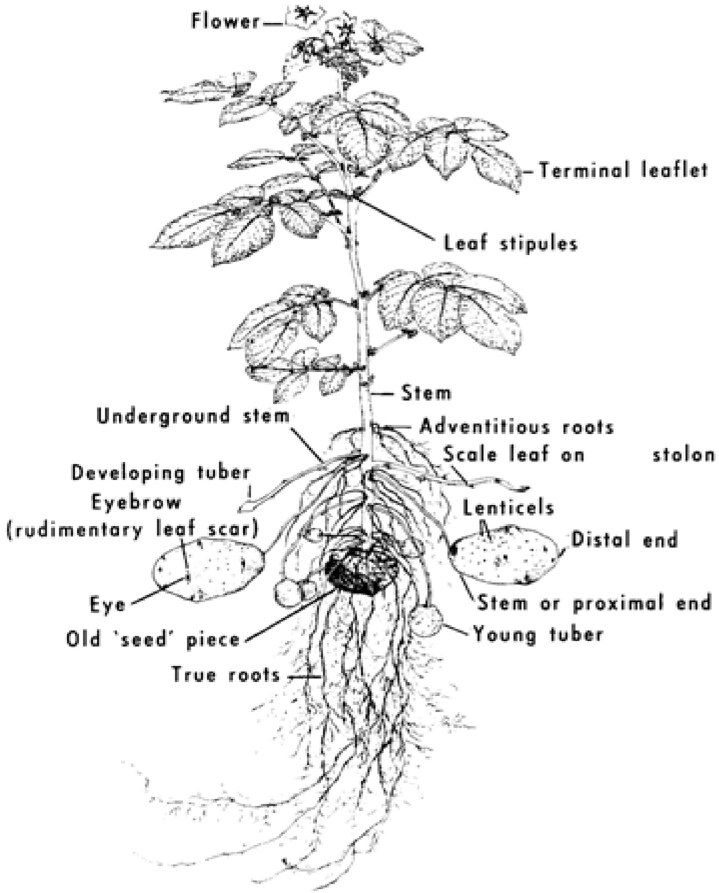

Figure 2. Diagrammatic drawing of a potato plant. Note that tubers are swollen underground stems, technically called rhizomes, but in potato commonly called stolons.

abnormality or defect. The inner medulla extends toward each eye, forming a continuous tissue that connects all the eyes of the tuber (Figure 1).

The initiation of young tubers at the tips of the stolons usually occurs when the plants are 6 to 8 inches (15 to 20 cm) high, or from 5 to 7 weeks after planting (Figure 2). Tuberization is affected by many environmental factors and depends largely on translocation and storage of carbohydrate reserves in excess of that needed by other parts of the plant in its growth and metabolism. Growth of the young tuber is the result of both cell division and elongation and storage of translocated carbohydrate reserves within the cells. Tuberization is not dependent upon flowering. Potato plants will form tubers without any flowers ever appearing on the tops.

Plant Introduction and Maintenance

(David Spooner)

For a long period after the potato was introduced into North America, little effort was made to improve it or to introduce new kinds. Thus, the period of 1719 to 1850 was characterized by no marked or lasting improvement in the crop. Improvement of potatoes near the end of this period became imperative because the available cultivars “ran out” to the extent that yields decreased to low levels and production was uneconomical. “Running out” was caused largely by high levels of tuber-transmitted virus diseases in existing stocks and lack of proper seed maintenance methods.

In 1851, C.E. Goodrich, a clergyman of Utica, NY, introduced a small amount of potatoes received from the American consulate in Panama. One of them, Rough Purple Chili, was one of the most valuable plant introductions in history and continues to have a tremendous impact on the North American potato industry. It contributed 100% of the pedigree of the main United States potato cultivar, Russet Burbank, and an average of about 25% of the pedigrees of the ten most important cultivars grown in North America.

Since 1925, plant exploration trips have been made into the United States, Mexico, Central America and South America in search of new wild species and landrace cultivars of potato for use in improving commercial types. In addition, many named cultivars of potato have been introduced into North America as parental material from most of the potato-producing areas of the world. The continual flow of new material coming into the United States is coordinated by the U. S. Department of Agriculture, and the U.S. germplasm system is also very significantly supported and directed by the state agricultural experiment stations. New material coming into Canada is governed by regulations of the Canadian Food Inspection Agency.

Potato introductions and their exploitation are especially important because: 1) The potato is the most economically important vegetable in the U. S. and the world, 2) there is a broad array of easily accessible related germplasm, 3) solutions to most of the present limitations of the potato have been demonstrated to exist in related germplasm, and 4) potato has a great potential to provide nutritious food in a diversity of environments for an increasingly hungry world.

A diverse genetic pool of tuber-bearing *Solanum* species is maintained at the United States Potato Genebank, Sturgeon Bay, Wisconsin (supported by USDA/ARS, all 50 states' Ag Experiment Stations, and significant additional inputs from University of Wisconsin). Because of the difficulty of maintaining vegetatively propagated stock disease-and insect-free, much of the genetic base is maintained as true seed populations. Clones that have some particular significance as an intact genotype are maintained via sterile in vitro. Small samples of this germplasm are distributed to public and private researchers and breeders worldwide, free of charge.

Potato Consumption

(Joe Guenthner)

Potato consumption has been a major part of the North American diet since early in the 17th century when potatoes were shipped from Europe to the colonies. As important as potatoes have been in the North American diet, consumers’ perceptions of potatoes have swung from lowly to fattening to healthy to high-carb.

The U.S. Potato Board was formed in the 1970s with a mission to educate consumers about the health benefits of eating potatoes. Their efforts gradually improved the image of the potato in the eyes of consumers. Potatoes, commonly believed to be fattening, became recognized for their nutritional value.

U.S. potato consumption in the 1960s reflects the negative attitude surrounding potatoes. Per capita consumption declined to 107 pounds (49 kg) per year in 1965. By 1985 per capita consumption had

increased to 122 pounds (55 kg), an improvement of about 15 pounds (7 kg) per person. For the next two decades total consumption per capita ranged from 129 to 138 pounds (59 to 63 kg), with year-to-year fluctuations caused by variations in crop size (Table 3). Information about per capita consumption in the U.S. for other years can be found at:
http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1235

Table 3. Potatoes: Production Per Capita Consumption in the United States.

Year	Total Fresh Equivalent	Consumption, Pounds Per Capita				
		Fresh	Frozen	Chips	Dehydrated	Canned
1960	108	83.7	6.6	11.6	5.0	1.5
1965	107	68.2	14.3	15.8	7.0	1.7
1970	122	62.3	28.1	17.4	12.0	2.0
1975	122	52.6	37.2	15.5	14.7	2.0
1980	114	51.1	35.2	16.7	9.4	1.9
1985	122	46.7	45.1	17.7	11.0	1.9
1990	129	47.4	49.9	17.3	12.8	1.9
1995	137	49.2	56.2	16.4	13.2	1.9
2000	138	47.1	57.5	15.9	15.7	1.7
2005	126	42.4	53.6	16.0	12.6	0.9

While total consumption increased to year 2000, consumers adjusted consumption by product form. Fresh per capita consumption declined until 1985 then stabilized at 46 to 49 pounds (21 to 22 kg) for the next twenty years.

The decline in fresh consumption has been more than offset by a steady growth in consumption of processed products. During the 30-year period from 1960 to 1990 (Table 3), consumption of processed products, on a farm-weight basis, tripled. Most of that growth is attributable to frozen products. Per capita consumption of frozen products jumped from 6.6 pounds (3 kg) in 1960 to 49.9 pounds (23 kg) in 1990.

The 36-pound (16 kg) decline in fresh potato consumption between 1960 and 1990 was more than offset by a 43.3-pound (20 kg) increase in the consumption of frozen products. By 2000 frozen potato consumption jumped up to 57.5 pounds (26 kg).

Per capita consumption of chips also increased significantly from 11.6 pounds (5 kg) in 1960 to 17.3 pounds (8 kg) in 1990, an increase of about 50 percent. Since then, chip consumption has stayed in the range of about 16 to 17 pounds.

Use of dehydrated potatoes grew between 1960 and 1975, almost tripling from 5 pounds (2.3 kg) to 14.7 pounds (6.7 kg) during that period. Since that time, consumption declined to less than 10 pounds (4.5 kg), and then grew again to almost 16 pounds in 2000. Consumption of canned potatoes has remained a small part of the total potato market.

The shifts in yearly per capita potato consumption (Table 3) are the result of a number of factors. Some of these factors are the changing structure of the U.S. household, increased focus on health, and the increased availability of fresh fruits and vegetables throughout the year.

The structural shifts in U.S. households have had a major impact on potato consumption. Household size has been declining. Fresh potato consumption has long been heavily influenced by household size where the higher the number of household members the greater the consumption of fresh potatoes. While this pattern may still be true, the decline in the number of large households has a negative effect on total fresh potato consumption.

The increasing number of households with two or more members employed outside the household also has affected consumption patterns. Outside employment has reduced the amount of time available for food preparation. Traditional dishes that require significant amounts of time to prepare are seldom served. Processed products requiring minimal preparation time are filling this need. The advent of microwave ovens may have been a major factor in stemming the decline in fresh consumption.

The Potato as Food

(Al Bushway)

This section covers the basics of food value of potatoes. There is, however, much more research on potato nutrition and health, and information in this field is rapidly expanding. Readers are therefore encouraged to access additional sources for details not covered here.

The potato has spelled survival for millions during the last three centuries. For many people—from South America to Europe—daily servings of potatoes supplemented with other fruits and vegetables and small amounts of milk, meat and fish have been the cornerstone of a life-giving diet. But many are unaware of the important contribution relatively small amounts of potatoes still make to North American nutrition today.

The key to this contribution is what modern nutritionists call the high “nutrient density” of potato. This simply means that for each calorie of potato eaten there is an ample return of essential nutrients.

To see the potato as nutritionists view it, consider that the per capita potato consumption averages only a little more than 100 calories a day, about four to five percent of most adults’ total - caloric intake. Yet, for example, this small amount, roughly equal to a potato about 2.5 inches (6.4 cm) in diameter or 5.3 oz (150 g) in weight, provides a significant amount of the needed vitamin C (Table 4)

Table 4. Nutritional composition of a medium-sized potato (about 5.3 oz or 150 g)

NUTRIENT	Percentage U.S. Recommended Dietary Allowance (RDA)
Protein	6
Vitamin A	*
Vitamin C	45
Thiamin	8
Riboflavin	2
Niacin	8
Calcium	2
Iron	6
Vitamin B_6	10
Folacin (folic acid)	8
Phosphorous	6
Magnesium	6
Zinc	2
Copper	4
Pantothenic Acid	4
Iodine	15

*Values contain less than 2% of the US RDA of these nutrients.

Values for which U.S. RDA'S Have Not Been Established.	
Calories (number)	110
Carbohydrates	26 g
Fat	0
Dietary Fiber	2 g
Sodium	0 mg
Potassium	620 mg

Thus, the four to five percent of the calories that come from potatoes furnish 45 percent of U. S. recommendations for vitamin C. Moreover, these standards are high. A small daily potato can supply the whole body's need of vitamin C for most people. In fact, if we had no vitamin C except for that from potatoes, on a per capita basis, there would be no sign of scurvy (vitamin C deficiency disease) in the U.S.

The potato's nutrient density with regards to vitamin C is not equaled by its other nutrients, but at least 12 essential vitamins and minerals are furnished plus protein in amounts greater than or equal to its percentage contribution of calories consumed. Potatoes with skins on are a good source of dietary potassium supplying 18 percent of the Daily Value.

The nutritional values were established from data obtained through a multi-university study sponsored by the National Potato Council. They are based on the latest Recommended Dietary Allowances. These values were obtained through averaging, but skewed toward the low end to better assure that an average potato would yield at a minimum the amounts shown. The values also now serve as a national nutritional label for potatoes.

Why is the Nutrient Density of Potatoes Important?

A key problem of human nutrition in North America is that the need for calories is down at least a third from 1900 because of lower physical activity. Yet, there is a need for the same nutritional value from our lessened calorie needs. Unless nutrient-dense foods are eaten, too many calories are consumed in getting adequate nutrition, one of the major factors for the increase in obesity. The alternative is to control weight by reducing calories by consuming less nutrient-dense foods which can lead to inadequate levels of nutrients.

For example, iron is low in the diets of many children, younger women and the elderly. The potato is not rich in iron; few foods are, but consumption of a medium sized potato each day would provide 6 percent of the RDA. Similarly, folic acid is low in many diets, especially among pregnant women, and it is scarce in foods. Consumption of a single medium sized potato each day would supply 8 percent of the RDA for folic acid.

Many of us receive inadequate vitamin B_6, while a single medium-sized potato daily would supply 10 percent of the RDA. Potatoes offer even more of the needed thiamin, another marginal vitamin, and probably a still larger part of the recommended copper. Through such comparisons of calories to nutrients, one can see why nutrient-dense foods are being recommended to the public by nutritionists.

Potatoes and the New Balance of the Diet

Concern about diet and heart disease has alerted consumers to the high intake of saturated fats, cholesterol and trans fat. Unsuspected by many, this increase is often associated with efforts to eat more protein. But even among the lower income populations, U. S. protein consumption tends to be excessive. Furthermore, many people do not realize that saturated fat and cholesterol tends to be high in "high-protein" animal foods.

While the effect of diet on heart disease is still unclear, nutritionists have other reasons to suggest lowering fat intake (particularly saturated fats) and eating more complex carbohydrate foods. One reason is that fats have more than twice as many calories as do carbohydrates. So many carbohydrate foods have higher nutrient density than foods that are high in fat.

This higher nutrient density is not true of all carbohydrate foods. For example, sweeteners—such as table sugar, honey, corn syrup—are carbohydrates, but have few, if any, other nutrients. Thus, balancing the diet has come to mean cutting back on proteins, fats and sweeteners and increasing nutrient-dense complex carbohydrates.

Potatoes and the Nutrition Future

Nutritionists' interest in nutrient-dense foods, which have wide acceptance and low price, suggest a renewed appreciation of potatoes. The market has already reflected some of this change. Studies indicate that most North Americans have overcome old, unscientific prejudices that potatoes are especially caloric, hence, especially fattening. As new analyses explain how potatoes supported life in other, older cultures, as more consumers learn that they need no more protein, and that eating much fat tends to mean poor nutrition in societies that spend little body energy, the nutrient-dense potato, a nutritional staple of the past, becomes more and more a food of the future.

Potatoes and the Glycemic Index, the Glycemic Load and Satiety

One concern that has been expressed with diets high in potatoes and potato products is the fact that potatoes have been shown to have a high Glycemic Index. Foods with a high Glycemic Index have been associated with risk for type 2 diabetes. The Glycemic Index is a ranking of the effect that a carbohydrate food has on blood glucose in relation to consumption of a reference carbohydrate (white bread or glucose). Perhaps, a better measure of a foods affect on blood sugar level is the Glycemic Load which is an index of the Glycemic response that occurs after eating a food. Glycemic Load = Glycemic Index x amount of carbohydrate in a serving of the food/100. When examining the Glycemic Load values for potatoes, realizing that the values are affected by potato cultivar and method of preparation, many of the values fall between 10 and 20 which indicates that they are Intermediate Glycemic Index foods (Table 5). The website below provides information on the Glycemic Index and Glycemic Load of potatoes prepared by different methods. http://www.dietandfitnesstoday.com/glycemicIndexList.php?section=Potato Thus, depending on potato cultivar and method of preparation potatoes can be an important part of a healthy diet.

Table 5. Glycemic Load for potatoes prepared by different methods

Potato	Serving (g)	Glycemic Load[1]
Baked Russet	150	26
Boiled White	150	14
Instant Mashed	150	17
Microwaved, Pontiac	150	14
Microwaved, Not specified	150	27
French Fries	150	22

[1]Low Glycemic Load foods –less than 10; Intermediate Glycemic Load foods -10 to 20; High Glycemic Index foods more than 20

Satiety is often defined as the feeling of fullness that occurs after eating, and foods with a high Satiety Index (SI) are believed to delay a person's need to eat their next meal. A study by Holt et al. (1995) demonstrated that boiled potatoes had the highest SI of the 38 foods tested. Recent research by Leeman et al (2008) showed that processing can change the SI. Therefore, it may be that including potatoes in a healthy diet may be a tool for reducing totally daily caloric intake.

Potatoes in a Hungry World

Besides being an important nutrient-dense food, the potato is an efficient producer of food energy and nutrition per unit area and must figure prominently in combating any world food crises. Recent data indicate that potatoes have 75 percent more food energy per unit area than wheat and 58 percent more than rice. Also, potatoes have 54 percent more protein per unit area than wheat and 78 percent higher than rice. In fact, no other food can match the potato in its production of food energy and food value per unit area.

The potato, a nutritious, delicious, low-cost vegetable is truly a wonder food, which nutritionists recommend as part of a healthy, balanced diet. For a more comprehensive look at the nutritional value of the potato, you can visit the following websites. Information on allowable nutrient content and health claims for fresh potatoes are also provided on the website, http://www.uspotatoes.com

References

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MARKETING AND ECONOMICS

Production by Region and Season

(Joe Guenthner)

While potato consumption has been important in the North American diet, it has also been important to the agricultural community. Just as consumption patterns have changed so has potato production by region and season. The adjustment process in agriculture, however, is slower. Because of this, a broad historical perspective is needed to realize how dramatic those shifts have been.

Potatoes are grown commercially throughout North America. Harvested potato land area in North America expanded and peaked in the first quarter of the 20th century. The greatest amount of land in potatoes in the United States was in 1922 with 3.9 million acres (1.6 million ha) harvested. The record in Canada, appears to have been in 1921 when 702,000 acres (284,210 ha) were planted. Between 1900 and 1941 there were only four years when less than three million acres (1.2 million ha) of potatoes were harvested in the U.S. The changes that occurred between 1925 and 1950 were dramatic. During that period, the land in potatoes in the Midwest declined from 1.3 million acres to 496,000 acres (0.5 million to 200,810 ha), a drop of 60 percent (Table 6). In the Northeast, the reduction was over 40 percent. In total, harvested area during the period fell by 1.1 million acres (0.4 million ha).

The only increase in planted area from 1925 to 1950 occurred in the West and the Pacific Northwest. The gain in harvested area in the eleven western states comprising these two regions was only 141,000 acres (51,085 ha). In 1950, the combined harvested area in the two western regions was still less than the area in the Midwest [452,000 vs. 496,000 acres (183,000 vs. 200,810 ha)].

During the period of 1950-1975, only the Pacific Northwest increased in land planted to potatoes. The area in this region doubled from 245,000 to 490,000 acres (102,834 to 198,380 ha) during that period. The net change in the U.S. during this same period was a decline of about 400,000 acres (161,940 ha).

The statistics from the 1980s suggest that the long-term decline in land in potatoes appears to have ended. The 1980 harvested area at 1.14 million acres (0.5 million ha) was the low point. During the 1980s, U.S. harvested area was in the 1.2 to 1.3 million acres (0.46 to .53 million ha) range. In 2000, U.S. potato area harvested rose to 1.35 million acres, but in 2005 it had dropped again to 1.085 million acres.

Part of the reason for the dramatic decline in land planted to potatoes in the U.S. has been the steady increase in yields that have occurred in all parts of the country. During the 20th century, U.S. average yields improved more than seven-fold from 52 to 381 cwt per acre (8.6 to 43 t/ha). The South region improved the most (703 percent) while the Northeast improved the least (522 percent). During the last quarter of the 20th century, U.S. potato yields increased 50 percent.

As a result of the area and yield changes, production levels have also changed. The Pacific Northwest has gone from producing 3.4 percent of the U.S. crop in 1900 to producing 57 percent in 2000. The combined production of the West and Pacific Northwest states accounted for 68 percent of the 2000 U.S. production. At the beginning of the 20th century, 81 percent of the U.S. potato crop grown was in the Northeast and Midwest. The share of those regions at the end of the century was 30 percent. The Midwest, which alone had 51 percent of the production in 1900, had only 22 percent of the crop in 2000.

The shift in production to the Pacific Northwest is a result of the combination of a number of factors. Improvements in the U.S. transportation system made it possible for producing areas at a great distance from the major markets to be competitive with other producing areas near population centers. The decline in consumption of fresh potatoes coupled with the advantages associated with processing potatoes in the Pacific Northwest has been a major factor in the shift in production since 1950. Inherent in the more recent shift is the environmental advantage in the Pacific Northwest, including weather and ample opportunities for expanding acreage as the processing industry has grown. Low power, tax, and labor costs are other advantages in the Pacific Northwest.

Table 6. Potato Production, Yield and Acreage by Region in the U.S.					
	1900	1925	1950	1975	1990
			1,000 Acres		
N.E.	878	680	397	217	135
S.E.	236	375	229	85	83
M.W.	1,513	1,246	496	298	371
South	184	198	122	38	31
West	108	138	207	134	156
PNW	78	173	245	490	582
U.S. Total	**2,997**	**2,810**	**1,696**	**1,262**	**1,358**
	1900	1925	1950	1975	1990
			Yield in Cwt.		
N.E.	53	78	210	216	264
S.E.	46	51	90	143	205
M.W.	52	54	116	200	211
South	41	39	55	159	182
West	59	106	211	305	337
PNW	68	95	188	309	350
U.S. Total	**52**	**63**	**152**	**254**	**289**
	1900	1925	1950	1975	1990
			Production in 1,000,000 Cwt.		
N.E.	46.6	53.0	83.6	49.8	35.6
S.E.	10.9	19.2	20.5	12.1	17.1
M.W.	79.0	66.9	57.5	59.6	78.4
South	7.6	7.7	6.7	6.1	5.6
West	6.4	14.6	43.6	41.0	52.7
PNW	5.3	16.4	46.0	151.3	203.9
U.S. Total	**155.8**	**177.9**	**257.9**	**319.8**	**393.2**

N.E. Includes: ME, NH, VT, MA, RI, CT, NY, NJ, PA
M.W. Includes: OH, IN, IL, MI, WI, MN, IA, MO, ND, SD, NE
S.E. Includes: DE, MD, VA, WV, NC, SC, GA, FL, KY, TN
South Includes: KS, AL, MS, AR, LA, OK, TX
West Includes: CA, NV, UT, AZ, NM, CO, WY
PNW Includes: ID, OR, MT, WA
Data obtained from USDA, Bureau of Agricultural Economics, Statistical Bulletin 122 and USDA, Agricultural Statistical Board, Crop Production

The shift of potato production to the west has been significant; however, the increased diversity of consumption patterns will provide ample opportunities for market expansion in other production areas over time.

Changes have also occurred relative to seasonal production patterns (Table 7). The fall crop has registered consistent increases in production since 1950 while all other seasonal production declined to 1980. The ability of fall-producing areas to store potatoes longer while maintaining quality had eaten away at the fresh markets supplied by producers during the other seasons. The year round market presence of fall crop potatoes and the decline in fresh consumption were major factors in the loss of market share by the other seasonal areas.

Table 7. Production by Season in U.S.				
Year	Winter	Spring	Summer	Fall
		1,000 Cwt.		
1950	3,262	32,680	49,059	174,111
1960	3,264	29,484	49,285	175,071
1970	3,582	25,907	28,400	267,827
1980	2,363	17,067	17,240	267,236
1990	2,371	23,843	24,952	344,317
2000	4,960	21,921	19,236	513,621

Between 1980 and 2000 winter potato production more than doubled, but only made up a little more than one percent of total production. Spring- and summer-potato production surged upward in 1990 but fell back by 2000. Fall production represented a steady 87 to 90 percent of total production in 1980, 1990 and 2000.

Processing utilization has been the major growth factor for the fall crop. Processing use has exhibited steady upward growth since 1950 and this growth was particularly strong during the 1980’s (Table 3). The first year processing use of the fall crop exceeded fresh consumption was in 1989.

The 1980 to 1990 upturn in the size of the spring and summer crops reflects the effects of two markets. The fresh market decline had ceased and actually increased slightly. Potato chip consumption had also increased requiring an increasing volume of potatoes from all seasonal crops. The 1990 to 2000 decline in spring and summer crops corresponded to declines in demand for fresh potatoes and potato chips during that same period.

Potato production in Canada, like the U.S., was originally located near the major population centers. In 1925, the provinces of Quebec and Ontario grew 61 percent of the Canadian area. Over time, the land in potatoes declined until 1972 when 243,000 acres (98,380 ha) were planted. Since then, there has been a recovery with yearly figures in the 275,000 to 295,000 acres (111,000 to 119,000 ha) during the latter part of 1980s. In 1925, Prince Edward Island was a distant fourth to Ontario and Quebec in land planted to potatoes. It is now the leader in planted area, yields, and total production. During the 1990s and 2000s, potato production in western provinces increased due to the construction of new frozen potato processing factories.

The majority of the growth in yields has occurred since 1950. The significance of the improved yields is demonstrated in statistics for New Brunswick and Alberta. The planted area in those provinces was 15 to 20 percent higher in 1989 compared to 1925, but production in both provinces was nearly triple 1925 levels.

Utilization

(Joe Guenthner)

Not all the North American potato crop is sold for food. Nearly ten percent of the 2007 U.S. potato production went un-sold (Table 8). The largest non-sales category is ‘Shrinkage and Loss,’ which was more than eight percent of the 2007 crop. This category accounts for the normal water weight loss and loss due to respiration during storage. It also accounts for the potatoes that do not meet market quality standards due to decay, bruising, greening, sprouting, disease and other factors. For crops that are frost damaged or suffer from other quality problems the 'Shrinkage and Loss' category may be several percentage points higher.

In the 'Sales' category, the table stock and frozen potato market channels comprise nearly three-fourths of total sales-for-food consumption. The 'Other Sales' category consists of seed and livestock feed. Potato utilization for livestock feed is a function of quality and price. During low-quality, low price years the livestock-feed category utilizes a larger share of the crop, but not by grower choice. Potato sales prices for feed are usually the lowest of all categories.

There are two 'Seed' categories in Table 8. The seed sales total of 22.3 million cwt is more than seven times the size of the 2.98 million cwt in the "Seed Used on Farms Where Grown' category. The potatoes in both these categories are used to plant the next year's U.S. potato crop. Some of the potatoes in the Seed Sales group are exported to other countries.

Table 8. Utilization of the 2007 US potato crop.

	Quantity (1000 cwt)	Share (percent)
SALES		
Tablestock (fresh)	111,835	25.0%
Processing:		
Chips and Shoestrings	53,492	12.0%
Dehydration	49,491	11.1%
Frozen French Fries	140,878	31.5%
Other Frozen Products	26,992	6.0%
Canned Products	2,528	0.6%
Other Canned Potatoes (Hash, Stews, Soups)	808	0.2%
Starch, Flour and Other	4,082	0.9%
Total Processing	278,271	62.3%
Other Sales:		
Livestock Feed	1,230	0.3%
Seed	22,271	5.0%
Total Other Sales	23,501	5.3%
Total Sales	413,607	92.6%
NON-SALES		
Seed Used on Farms where Grown	2,985	0.7%
Household Use and Used for Feed on Farms where Grown	1,119	0.3%
Shrinkage and Loss	29,096	6.5%
Total Non-Sales	33,200	7.4%
Total Production	446,807	

Source: USDA National Agricultural Statistics Service

More information about potato production and utilization can be found at: http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1123

Processing Markets

(Joe Guenthner)

Much of the growth and development of the North American potato processing industry is recent. Potatoes have, however, been processed in the U.S. since 1831 when the first starch plant was established. Potato chips are also reported to have been first prepared during the mid-19th century, but remained on a small commercial scale until World War II when improved peeling and frying techniques were developed. The freezing industry was also launched in the 1940's.

The growth in potato processing has been phenomenal. Prior to 1960, reports on potato utilization did not differentiate between snack foods (chips and shoestrings) and fresh consumption. By 1970, U.S. processed utilization was nearly equal to that of fresh (Table 3). Major processing uses of potatoes now are chips, dehydration, and freezing. By the late 1980s, these three uses accounted for about 98 percent of all processing in the U.S.

The geographic dispersion of the processing industry varies according to product form. Typically, frozen and dehydration processing occurs in the vicinity of the sources of supplies. Accordingly, the freezing and dehydrating industries of the U.S. are concentrated in the Northeast, upper Midwest, and the Pacific Northwest. In Canada, the location is distributed from east to west near the U.S. border.

In contrast, the chipping industry is more evenly spread. Chipping plants can be found in every region. The fragility of potato chips and the high cost of shipping low-density products make long distance shipping undesirable. As a result, chipping plants tend to be located near heavily populated areas.

Similarly, production of chip stock is more dispersed. Prior to the drought in the late 1980s, North Dakota was the largest chip stock producer in the U.S. Florida ranked second. Other major producing areas included Arizona, central California, Maine, and Michigan. The market for processing potatoes exhibits some characteristics that are quite different from the fresh market. Since French fry processors are concerned about finished product quality, processing contracts place emphasis on those raw product characteristics that influence finished product quality. Specific gravity is of particular concern and processors pay premiums for high specific gravity and penalize for low specific gravity. Other characteristics, such as tuber size and grade, have also generated premiums. Contract provisions have changed over time in response to changes in processing technology, production practices and the appearance of new quality factors in individual growing areas.

Contracts are used by potato processors to guarantee some portion of their raw product needs. Typically, processors will contract for the majority of their expected requirements. The remainder of their needs is met by purchases on the open market.

Contracts offer some advantages to growers as they allow the producer to concentrate on production with emphasis on those practices that have the biggest impact on returns. Additionally, the contracts specify price and payment policies. Over time, contracts tend to stabilize grower prices and to a lesser extent returns. Returns are less stable than price because of the vagaries of weather each year.

The industry that makes frozen potato products obtains raw product from usable potatoes delivered to the plant. The dehydration industry operates a bit differently. Some dehydrators segregate potatoes according to suitability for the fresh market. That portion that can be profitably sold on the fresh market is shipped fresh and the remainder is processed. Other dehydration firms purchase off-grade material from fresh packers. While growers produce potatoes for specific markets such as freezing, fresh, and seed, the returns for potatoes that are dehydrated seldom are sufficient to attract growers to produce only for that market.

The processing industry is a major and expanding market for potatoes. While problems exist, as they do with every industry, the processing market has benefited both the producer and the consumer. Grower returns from sales to processors have added some stability to an otherwise highly volatile potato market. Processor demands for high quality raw product has encouraged production research that benefits the fresh consumer as well as consumers of processed products.

Fresh Potato Markets

(Joe Guenthner)

Fresh potatoes have been a staple in American diets, especially among those of northern European heritage for many years. A traditional evening meal consisted of “meat and potatoes” eaten at home. With the increasing popularity of fast-food restaurants, the traditional evening meal seems to have shifted toward “hamburgers and fries” eaten away from home. This shift in preferences partially resulted in a decline in fresh potato per capita consumption during the 1950s, 1960s and 1970s.

The decline in fresh potato consumption has bottomed out and appears to be flat or, at times, heading back up. One reason is microwave ovens have made it much more convenient to cook potatoes. Another reason is that fresh vegetables in general are seen as healthy foods. Successful promotion by the U.S. Potato Board has changed public opinion away from the image of potatoes as a fattening food. Still another factor is that many restaurants, especially quick service restaurants (QSR's), have added baked potato entrees and baked potato bars to their operations.

Most fresh market potatoes in North America can be classified as russets, reds, yellows or whites based on skin color. Regardless of their classification, most potatoes sold in North America have been white fleshed. Yellow-fleshed potatoes, however, have been popular in Europe for many years and are making headway in North America. Blue, purple, even black potatoes have been eaten in South America for centuries. Although markets for these “exotic” potato types have been small, that seems to be changing as consumers acquire more global food tastes.

The structure of the fresh-potato market varies only slightly between different parts of North America. In general, eastern potato growers are also packers. In the West, they have traditionally been separate businesses. Fresh potato packers in many parts of the West compete with processors in the market for potatoes at the grower level. In recent years more Western growers have also entered the packing business, often in partnerships or cooperatives with other growers.

Fresh potatoes are sold in a variety of containers and grade specifications. Russet potatoes are usually packed in three general size categories: consumer packs, count cartons, and institutional packs.

The most valuable potatoes are the 8- to 14-ounce (227 to 397 g) tubers that are packed in 50-pound (22.7 kg) cardboard boxes. These are called “count cartons” and each carton has a number printed on the box that indicates how many tubers are in the box (60, 70, 80, 90, 100, 110, or 120). Retail stores, as well as restaurants, buy count cartons. Count carton potatoes are typically used for baking.

Consumer packs consist mainly of 4- to 8-ounce (113 to 227 g) (non size A) tubers packed in plastic, paper, or mesh bags. Consumer bags are typically 5 or 10 pounds (2.3 or 4.5 kg).

Institutional buyers such as government military bases, schools, etc. like to buy 100-pound (45.4 kg) bags of large potatoes to minimize packaging, handling and peeling costs.

Although some potatoes with red, yellow or white skin are sold in the same three size categories as russets, it is more common to pack a wider range of sizes in one container. Only the very largest (jumbos) and smallest (B-size) of these kinds of potatoes are typically sold separately. The russet non-size A consumer packs are usually the closest competitors for the reds, yellows and whites.

Some fresh potato production areas have mandatory inspection for fresh shipments. The rules are usually administered through marketing orders that require all fresh shipments of potatoes leaving the state to meet grade standards via a required inspection. Strict quality control has been an important component in some state advertising and promotion campaigns.

Seed Potato Markets

(Joe Guenthner)

A small but extremely important component of the potato marketing picture is seed. As discussed in the seed/certification section of this handbook, use of high quality seed is one of the most important practices in potato production. Most of the seed produced in the U.S. and Canada is utilized in North America. There is, however, some exportation of seed to areas outside the western hemisphere. For more information on seed quality, please refer to the seed certification section of this handbook.

Costs of Production

(Paul Patterson)

Potatoes are an expensive crop to grow. In addition to a significant expenditure for variable inputs—seed, fertilizer, pesticides, labor, electricity and fuel—potato production requires a large investment in expensive, specialized machinery. The higher revenue potential for potatoes relative to most other crops also means higher land costs for potato growers because this higher revenue is capitalized into the price of land. For growers leasing land, it means paying higher cash rent for potato ground. Potato production costs under irrigation in the western U.S. range between $1,500 and $3,500 (U.S. dollars) per acre. Smaller-sized potato growers invest hundreds of thousands of dollars in potato production costs each year, while large growers spend millions. Cost of production will vary based on cultivar, location, yield, farm size, production practices and crop rotation, as well as the quality and intensity of management. The method used in calculating or in allocating costs to a potato enterprise will also influence cost of production. Care should always be used when comparing cost of production estimates for different locations to ensure methodological compatibility. Like many Land Grant Universities that publish cost of production estimates, the University of Idaho uses economic costs, not accounting costs. A market value opportunity cost is placed on all resources used in the production process, not just purchased inputs. This includes the owner's labor, management and equity. In contrast, some cost of production estimates are based only on cash costs, resulting in a much lower value. While there are several acceptable methods for calculating production cost, the method used should be clearly stated. Whether the methods used comply with recommendations set forth in the "Commodity Costs and Returns Estimation Handbook," developed by the American Agricultural Economics Association Task Force on Commodity Costs and Returns, should also be considered. http://www.economics.nrcs.usda.gov/care/aaea/index.html

Table 9 summarizes the typical costs for growing and storing potatoes in eastern Idaho under irrigated conditions for 2007. Costs are shown both per acre and per hectare. Production costs are divided into two general categories: operating (variable) and ownership (fixed). Operating costs include the direct costs of producing the crop—the inputs consumed in a single production cycle such as seed, fertilizer, pesticides, fuel, labor, etc. Seed has traditionally been the single biggest operating expense. But the substantially higher cost of fertilizer in recent years has pushed that category above seed. Together, fertilizer and seed account for 25 percent of the total production costs shown in Table 9. Operating costs account for roughly two-thirds of the cost of growing and storing potatoes. For a detailed list of inputs, quantities applied and input prices, refer Idaho's cost of production website referenced at the end of this section.

Ownership costs are tied to inputs lasting more than one production cycle, such as machinery, buildings and land, and account for roughly one-third of the costs of growing and storing potatoes shown in Table 9. Except for land, machinery and other capital items depreciate, or lose value over time. This loss in value needs to be included as a cost and allocated to the appropriate crop enterprise. An interest cost should also be included for money invested in machinery and buildings. This can be the actual interest paid when money is borrowed, or the interest that could be earned if the money was invested elsewhere. This is the opportunity cost of capital—what capital would earn if used in the next best alternative. Calculating interest on the average value of the equipment (purchase price + salvage value ÷ 2) is a simple yet accurate method to use.

Insurance can also be calculated on the average value of the equipment and buildings. Property taxes, insurance and repairs that are a function of time, and not of use, make up the remaining ownership cost "DIRTI Five": Depreciation, Interest, Repairs, Taxes and Insurance. Property tax on machinery is not included since Idaho no longer charges property tax on farm machinery.

Ownership costs for all field machinery and equipment used in potato production are summarized on one line in Table 9, and for the storage facility and storage equipment on another. Depreciation should be based on expected useful life, not tax life and depreciation should be straight-line, not accelerated tax depreciation. Ownership costs for machinery and equipment found in Table 9 includes equipment used only on potatoes as well as a prorated share of the ownership costs of equipment used on both potatoes and other crops. Ownership costs in Table 9 also include a management fee, estimated as 5 percent of expected gross returns, and the potato crop's share of general farm overhead expenses (office expenses, legal and accounting fees, etc.).

While cost per area of production (acre or hectare) is an important number, growers also need to know what price they need to cover these costs. Break-even prices can be calculated by dividing marketable yield into costs per unit of area (Table 10). Based on an expected yield of 345 cwt/acre (38.65 ton/ha) the break-even price for total costs from Table 9 is $6.33/cwt ($140/ton). To cover just operating costs requires $4.07/cwt ($90/ton) and to cover ownership cost requires an additional $2.26/cwt ($50/ton). A lower yield will result in higher breakeven prices and a higher yield will have lower breakeven prices. Since potatoes are sold per cwt (ton or kilo) and not per acre (hectare), knowing these breakeven prices is extremely important for a producer when developing a marketing plan, or evaluating the economic impact of alternative production management systems.

Costs of production will vary between production regions and will also vary from year to year and from field to field within an area. There can also be large cost differences among growers in the same area. While published cost of production values can serve as useful guidelines for a grower, each grower ultimately needs to calculate his/her own cost of production values.

Costs of Storage

(Paul Patterson)

Unless the potato crop is sold out of the field, costs do not stop accumulating at harvest. Table 9 includes the additional costs incurred after harvest to store potatoes for a five-month period. This includes $234/acre ($578/ha) in operating storage costs and $134/acre ($331/ha) in storage ownership costs. Storage operating costs per acre are based on storage operating costs of $.672/hundredweight ($14.81/ton), shown in Table 11, applied to the yield of 345 hundredweight ($38.67 ton/ha). The costs in Table 11 are based on a modern above ground storage facility with a 20 cfm per ton (cubic feet per minute) (0.62 cubic m per min per Mg) air system delivering humidified air with a storage capacity of 100,000 hundredweight (4,536 ton). An opportunity interest cost is charged on a $5.00 per hundredweight harvest value ($110/ton) using an annual nominal rate of 9.5 percent. The $5.00 per hundredweight value was also used in estimating the cost of shrink, based on a five-month accumulated shrink loss of 4.4 percent. Rather than using a market value for the potatoes, shrink and interest could be based on cost of production up through harvest. To the extent that money to raise potatoes is borrowed, then the interest charge is a cash expense, not an opportunity cost. Shrink and interest are the largest storage operating cost components, together accounting for 66 percent of storage operating costs. The other cost factors include labor, power, sprout inhibitor (one application), insurance and repairs. Potato storage operating costs accounts for 11 percent of the total costs, or 17 percent of the operating costs shown in Table 8.

Detailed information on the ownership costs for the storage facility, air system and storage equipment are not included in Table 11. Ownership costs for the entire storage system ($134 per acre or $331 per hectare), are shown in the ownership cost section of Table 9. They account for 6 percent of the total costs or 17 percent of the ownership costs. Storage system ownership costs contribute $0.39 per hundredweight ($8.60/ton) to the breakeven ownership price shown in Table 10. Five months of storage added $1.06 per hundredweight ($23.35/ton) to the breakeven prices shown in Table 10.

The decision to sell at harvest or store potatoes should be made as part of an overall marketing plan for the farm. If the grower owns the storage facility, the ownership costs are not relevant to his/her decision to store potatoes or sell at harvest because these costs are incurred in either situation (sunk costs). Only the storage operating costs should influence the decision of whether to store the potato crop. If the grower can't expect the price of potatoes to increase by at least the operating cost of storage, $0.67 per hundredweight ($14.75 per ton) during a five-month storage period, then he/she would be better off selling potatoes for $5.00 per hundredweight ($110/ton) at harvest. While $5.00 ($110) will not cover the cost of production, it will minimize the expected loss. Growers need to monitor costs closely and evaluate alternative management strategies using their cost of production and storage. In a competitive market-based system, only the low cost producer will survive.

Table 12 shows cost of potato production data for two states: Arizona and Washington. Costs will vary based on the approach used. Caution should always be used when comparing cost data from different states to ensure compatibility.

Cost of Production Websites

Note: The National Costs and Returns website has links to all 50 states, but not all states publish cost of production estimates and even fewer states have one for potatoes.

National Costs and Returns: http://www.economics.nrcs.usda.gov/care/index.html
Arizona: http://ag.arizona.edu/arec/ext/budgets/counties.html
California: http://coststudies.ucdavis.edu/
Idaho: http://www.ag.uidaho.edu/aers/r_crops.htm
Colorado: http://www.coopext.colostate.edu/ABM/abmndx.html
North Dakota: http://www.ext.nodak.edu/extpubs/ecguides.htm
Oregon: http://oregonstate.edu/Dept/EconInfo/ent_budget/
Washington: http://farm.mngt.wsu.edu/publication_lists.htm
Wisconsin: http://cdp.wisc.edu/Resources/crop/crop.htm

Table 9. Estimated potato production and storage costs, eastern Idaho, 2007.

	Per Acre	Per Hectare	Percent of Total
Operating Costs			
Seed, Cutting & Treatment	$235	$581	11%
Fertilizer	$307	$759	14%
Pesticides	$105	$259	5%
Custom Hire and Consultants	$ 53	$131	2.5%
Irrigation: Water, Pumping &Repair	$ 65	$161	3%
Promotion tax & Fees	$ 49	$121	2%
Crop insurance	$ 36	$89	1.5
Machinery: Fuel, Lube & Repairs	$144	$356	7%
Labor	$134	$331	6%
Storage Operating Costs	$234	$578	11%
Interest on Operating Capital	$ 44	$109	2%
Total Variable Cost	$1,406	$3,475	65%
Ownership Costs			
General Farm Overhead	$ 35	$86	1.5%
Management Fee	$ 95	$235	4%
Machinery & Equipment	$190	$469	8.5
Storage Facility and Storage Equip.	$134	$331	6%
Land and Irrigation Equipment	$325	$804	15%
Total Ownership Cost	$ 779	$1,925	35%
Total Cost	$2,185	$5,400	100%

Source: University of Idaho. Russet Burbank Commercial Potatoes with On-Farm Storage, EBB4-Po5-07.

Table 10. Eastern Idaho potato breakeven analysis: per hundredweight and per ton.

	$/ acre	$/cwt	$/ ha	$/ton[1/]
Operating Costs	$1,406	$4.07	$3,475	$90
Ownership Costs	$ 779	$2.26	$1,925	$50
Total Costs	$2,185	$6.33	$5,400	$140
Yield		345 cwt		38.67 ton

[1.] Metric ton: 2,204.6 pounds per ton, or 0.45359 tons per hundredweight.

Table 11. Eastern Idaho potato storage operating costs, 5 months storage: 100,000 cwt.

	Base Values and Rates	Cumulative Cost	Cost Per Cwt	Cost Per Ton
Units Stored:			100,000	4,536
Interest	9.5% Annual	$20,280	20.3¢	$4.48
Shrink	4.4% total	$22,000	22.0¢	$4.85
Labor	$9.30/hour	$8,040	8.0	$1.76
Power	$.055/kwh	$4,876	4.9¢	$1.08
Sprout Inhibitor	$.06/cwt	$6,000	6.0¢	$1.32
Insurance & Other	1.5% Insurance Rate	$2,335	2.3¢	$0.51
Repairs		$6,375	3.7	$0.82
Total		$69,906	67.2¢	$14.82

Base value of potatoes: $5/cwt ($110/ton). Total labor hours: 864. Other costs: $1,500.

Table 12. Cost of production estimates for other states.

Region and Year	Arizona 1/	Washington 2/
Yield: per acre	291 cwt	590 cwt
Operating Cost: per acre	$1,744	$2,312
Operating Cost: per cwt	$5.99	$3.92
Ownership Cost: per acre	$707	$726
Ownership Cost: per cwt	$2.43	$1.23
Total Cost: per acre	$2,451	$3,038
Total Cost: per cwt	$8.42	$5.15

1/ Arizona State University. Irrigated Early Red Potatoes, Maricopa County, Arizona: 2001. Economic costs.
2/ Washington State University. Farm Business Management Report EB 2015E. 2006 Cost of Producing Processing and Fresh Potatoes Under Center Pivot Irrigation, Columbia Basin, Washington. Economic costs.

POTATO CULTIVARS

(Asunta Thompson)

Potato cultivars (varieties) differ from one another in many respects and may visually be differentiated by as few as one trait, whether vague or obvious. Generally, identification of a cultivar is made by knowing basic characteristics and vague features unique to each. The art of cultivar identification is not learned quickly because some of the characteristics may be changed or modified by environment. Recent technology has provided means of verifying the identification of cultivars by their genetic “fingerprints”. Since many visual characteristics can be modified by environment, identification technologies are extremely important in specifically identifying cultivars.

As with all vegetatively propagated crops, potato cultivars are not static and slight mutations frequently occur in growing crops of all cultivars. Usually these mutations result in an inferior type of plant that may produce reduced yield, a poorer plant or tuber type, or often both. It is important for seed growers to be able to recognize growing plants of the common cultivars, but they should also know the differences between desirable and undesirable types within a growing crop. The most obvious and most easily recognizable variations in a cultivar are the “giant hill” and the “wilding.” The giant hill is taller, more vigorous, and is later maturing than normal plants. It has smaller leaflets and more flowers. The wilding is a bushy low-growing plant with many weak stems, no flowers, few primary and secondary leaflets, large heart-shaped terminal leaflets and numerous small unmarketable tubers. Tubers from both types of these variations reproduce similar plants.

Not all mutations, however, are to an inferior type. There are a number of mutant selections that have been more popular than the cultivar from which they were produced. Examples include the ‘Russet Burbank’, a selection from ‘Burbank’, red-skinned sports or deep red-skinned mutants such as ‘Red Pontiac’, ‘Red LaSoda’ and several selections of ‘Norland’ including Red Norland and Dark Red Norland. These are examples of mutations that have improved the salability and/or appearance of the original clone. Recently, line selections of ‘Russet Norkotah’ have been touted as possessing improved plant types to withstand environmental stresses. In most cases, the mutants differ from the non-mutated clone in one trait such as skin color, maturity, or vigor.

Cultivar Identification

Characteristics used to identify individual cultivars may, to varying degrees, be modified by environment. Even so, observations of foliage, flower, tuber, and sprout characteristics are helpful in proper identification. Familiarity with disease reactions may also help ascertain cultivars. Detailed characteristics are usually published in the American Journal of Potato Research when a new cultivar is released.

Foliage

Foliar traits that assist in cultivar identification are growth habit, leaf, and stem characteristics.

Growth Habit—The general appearance and vigor of the plants can be of great value for cultivar identification. Unfortunately, these traits are the ones most affected by cultural practices and environmental conditions. However, cultivar tendencies for plant height, shape, and vigor may be used in combination with specific information for foliar, floral, and stem traits to help confirm identification.

Leaves—A potato leaf is compound and made up of a petiole, a terminal leaflet, and two to four pairs of primary leaflets interspersed with secondary or interjected leaflets and occasionally tertiary or rudimentary leaflets along the midrib (Figure 3).

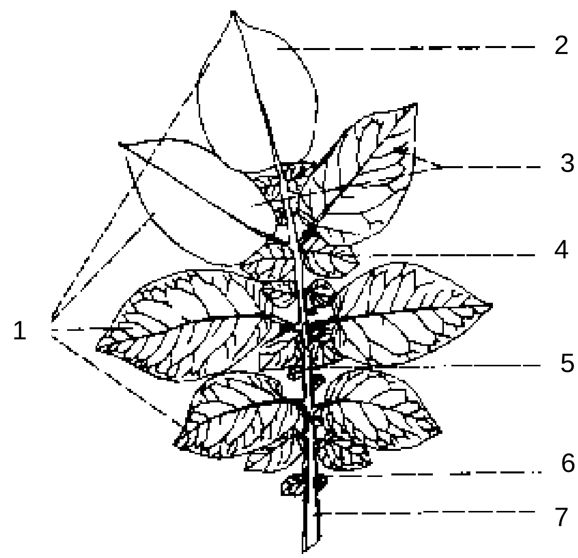

Figure 3. Parts of a compound potato leaf.
1. Primary leaflets
2. Terminal leaflet
3. First primary leaflets
4. Secondary leaflets
5. Midrib of the leaf
6. Rudimentary leaflet
7. Petiole

When pairs of primary leaflets are widely separated and there are a few secondary leaflets, the leaf is described as open (Figure 4). When primary leaflets are close together and the secondary ones are numerous, the leaf is described as closed. The relative denseness (open or closed) of potato leaves is a valuable feature in varietal identification. The length of the leaf, the angle between the leaf and stem, and the leaf rigidity are other leaf features used in identification.

The number of primary and secondary leaflets and leaflet characteristics vary by cultivar. Leaflet size, shape, color, hairiness, smoothness, glossiness, flatness, and rigidity are identifying traits, as is leaflet stalk length.

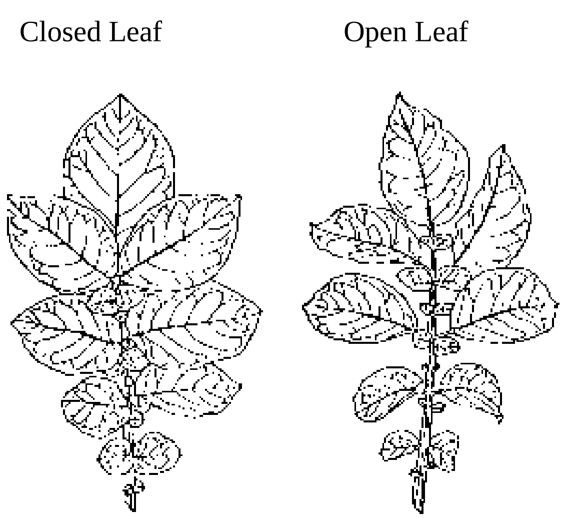

Figure 4. Examples of a closed and open leaf of potato.

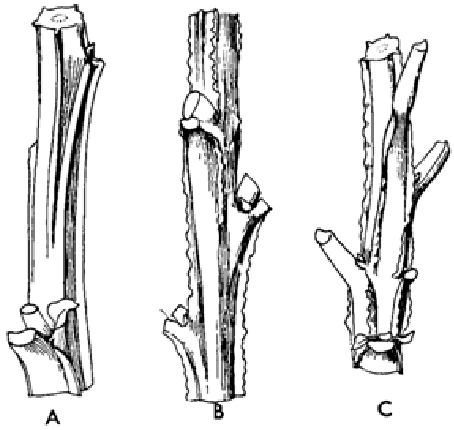

Figure 5. Potato stems showing types of wings: a) straight, double; b) waved, double; c) slightly waved, double. Wing characteristics are not generally changed by differences in environment.

Stems—The angles of the potato stem are extended to form structures called wings. The wings may be prominent or inconspicuous, straight or wavy, and may be so close together they appear as double wings (Figure 5).

Stems may be uniformly green, reddish, or purple in color, or may have varying degrees of mottling. Pigment may be localized at nodes or at certain internodes. Other distinguishing characteristics are thickness, brittleness, branching habit, internode length, and node size.

Flowers

Flower shape and color are distinctive features of cultivars, but by themselves cannot be used to identify cultivars. Colors range from white to purple and may be solid or a combination of colors. Anthers (male portion of the flower) are generally prominent and vary in color from orange, lemon-yellow, or greenish-yellow to nearly red or purple.

Other floral characteristics that may help confirm cultivar identity are size of flowers, the profusion of flower clusters and inflorescences (blooms) per cluster, hairiness and color of buds, and the size, frequency, and persistence of buds. Flower stalks range in color from green to various shades of purple and may be mottled. Leaf-like appendages, called stipules, at the base of the peduncles of the lowest inflorescence vary in size and may be spreading or may entirely clasp the peduncles or petioles.

Tubers

Characteristics of potato tubers that may be used to confirm identification include skin color and texture, shape, eye distribution and depth, and specific gravity. These characteristics may be modified by cultural practices and environment and, therefore, cannot be used alone for identification. Most cultivars can be classified as whites, reds or russets (brown-skinned cultivars). Less common skin colors include pink, purple, and combinations of white or buff and red or pink. The presence or absence of an under-skin may also be a distinguishing tuber trait.

Sprouts

When tubers are exposed to diffuse light and warm temperatures for about two or three weeks prior to planting, sprouts with color and shape characteristic of the cultivar are produced.

S*hape*—There are three distinct parts of a well-developed sprout: the base, the middle and the tip (Figure 6). Each part may vary in size and shape according to cultivar. The tip may be long or short and may tend to unfold its leaflets at an early or later stage. Typical shapes are ovoid, globose, or cylindrical.

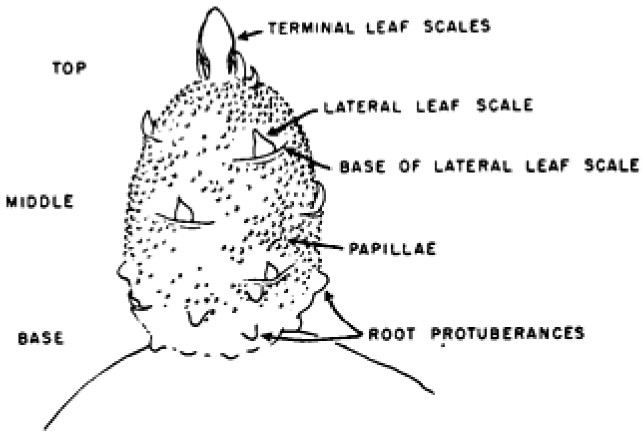

Figure 6. Distinguishing characteristics of a sprout developed in the dark.

Color—Sprout color may be uniform green or green with red or purple pigmentation. Color development may be localized to certain portions of the sprout. In some cultivars color is not present at the sprout base until after the color is well defined in other parts of the sprout.

Hairs—The amount and distribution of hairs on sprouts may help to further identify the sprout of a specific cultivar. Some are markedly hairy and others are essentially without hairs. The hairs may not be distributed over the whole sprout but according to cultivar may be concentrated on the tip, or the base, or the center.

Laboratory "Fingerprinting"

Relatively new laboratory procedures in molecular biology have expanded options in identifying potato cultivars. The techniques are similar to the ones used in humans to identify the unique genetic makeup of individuals. The standard procedure is referred to as restriction fragment length polymorphisms (RFLP), which are DNA-based markers. A variation to that approach is isozyme analysis. There are advantages and disadvantages to each analysis. However, the results of either are more conclusive than the standard morphological characteristics used to identify potato cultivars. As stated previously, morphological characteristics can be affected by environment where as the marker based procedures are not. However, these analyses should not be used to the exclusion of conventional characteristics. The real value of laboratory results is in combination with morphological characteristics. In practice, the standard morphological characteristics used in certification can be supplemented with these additional discrete characteristics.

Of the two tests referred to, the RFLP analysis is more precise. However, it is also more time consuming, costly and requires greater expertise.

Isozymes, which are multiple molecular forms of an enzyme derived from a tissue of a plant, have recently been used to characterize cultivars in a number of crops. They are usually separated when an electrical charge causes their migration through a starch gel (electrophoresis), and they are visualized as discreet bands when the gel is placed in a solution of a proper chemical substrate for the enzyme and the end product of the reaction is stained. Since these enzymes are coded by genes, starch electrophoresis has the advantage of revealing gene activity much more directly than do morphological traits.

Isozymes usually permit unequivocal identification of nearly all genetic classes of a gene. This is accomplished by examination of isozyme banding patterns, whether for alleles at one or many genetic loci. The electrophoretic method is rapid, economical, accurate, and the analysis can be made for nearly all loci in early growth stages of the plant or from the tuber.

Isozymes examined at Michigan State University did not separate sports or line selections of a cultivar. Duplicated finger-prints were observed for cultivars listed in Table 13. In general, duplicate fingerprints were found between line selections or sports of cultivars of the same name (i.e. ‘Burbank’ vs. ‘Russet Burbank’ or ‘Norland’ vs. ‘Dark Red Norland’).

Table 13. Cultivars with duplicate electrophoretic fingerprints

Clone	Duplicate
Russet Burbank	Burbank
Red Pontiac	Pontiac (white skin)
Red Warba	Warba (white skin)
Irish Cobbler ‘BC’	Irish Cobbler (Maine source)
Norgold Russet ‘BC’	Norgold Russet ‘MI’, Norgold Russet ‘19’, Norgold Russet ‘N2’
Norland	Dark Red Norland, Norland ‘BC’
Atlantic	Atlantic ‘WF-31-4’
White Rose	White Rose ‘Mettler W’
Superior	Superior ‘Neb’, Superior ‘Ont’
Centennial Russet	Centennial Russet ‘Colo 2’, Centennial Russet ‘Colo 1’
Keswick ‘NB 1’	Keswick ‘NB 2’
Green Mountain	Columbia Russet

Disease Resistance

Specific reactions to certain plant pathogens are the basis for another method of cultivar confirmation. Tests for what is termed a “hypersensitive reaction” to races of the late blight organism and viruses X, A, and Y (strain C) and perhaps an immune reaction of virus X, can be confirmatory features for some cultivars.

North American Cultivars from which to Choose

A relatively large number of potato cultivars are grown in the early, intermediate, and late-crop sections of the United States and the various provinces of Canada. Cultivars differ in time of maturity, yield, appearance, cooking and marketing qualities, and resistance to various diseases and insects. All other characteristics being equal, a cultivar resistant to even one disease or insect is better for planting than a susceptible one.

A cultivar that is good in one geographical area, however, may be of little value in another. Growers should be warned against buying large quantities of high-priced seed stock of a recently introduced cultivar or one reported superior in other localities until it is determined that the cultivar is adapted to local environmental conditions. The needed information on a cultivar can be obtained from agricultural advisors or small-scale grower trials.

Examples of potato cultivars released since 1990 are listed in Table 14. A more complete list of cultivars released in North American and a description of many of the major cultivars can be found at http://www.potatoassociation.org/Industry%20Outreach/varieties/inventory.html. The top ten cultivars produced for seed in the U.S. and Canada are listed in Table 14.

Table 14. Some Potato Cultivars Released Since 1990.

Cultivar Name	Year Released	Authors	Institutions	Published Data	Parentage[1]	PVP (+/-)
Alta Russet	2002	Lynch, et al.	Ag and Ag Food Canada	AJPR (2004) 81:195-201	Russet Nugget x Ranger Russet	+
Alturas	2002	Novy, et al.	USDA-ARS, ID, OR, WA	AJPR (2003) 80:295-301	A77182-1 x A75188-3	+
Beacon Chipper	2005	Douches, et al.	MI State Univ, Maine Seed Potato Board and Maine Potato Board	AJPR (2006) 83:241-247	?	+
Blazer Russet	2005	Stark, et al.	USDA-ARS, ID, OR, WA	AJPR (2007) 84:447-457	A7816-14 x Norking Russet	+
Canela Russet	2007	Holm, et al.	USDA-ARS, CO			+
Colorado Rose	2001	Holm, et al.	CO		NDTX9-1068-11R x DT6063-1R	+
Dakota Crisp	2005	Thompson, et al.	NDSU	AJPR (2007) 84:477-486	Yankee Chipper x Norchip	+
Dakota Diamond	2005	Thompson, et al.	ND Ag Exp Sta.	AJPR (2008) 85:171-182	ND4103-2 x Dakota Pearl	+
Dakota Jewel	2004	Thompson, et al.	NDSU Ag Exp Sta.	AJPR (2006) 83:373-379	ND2223-8R x ND649-4R	+
Dakota Pearl	1999	Thompson, et al.	NDSU Ag Exp Sta.	AJPR (2005) 82:481-488	ND1118-1 x ND944-6	+
Dakota Rose	2000	Thompson, et al.	NDSU Ag Exp Sta.	AJPR (2006) 83:317-323	ND1196 -2R x NorDonna	+
Gem Star Russet	2004	Love, et al.	USDA-ARS, ID, OR, WA	AJPR (2006) 83:171-180	Gem Russet x A8341-5	+
Ivory Crisp	2002	Love, et al.	USDA-ARS, ID, OR, WA, ND	AJPR (2003) 80:289-294	ND292-1 x A77268-4	+
Keystone Russet	2000	Holm, et al.	USDA-ARS, CO		CalWhite x A7875-5	+
Marcy	2002	DeJong, et al.	NY and PA Ag Exp Sta.	AJPR (2006) 83:189-193	Atlantic x Q155-3	+
Mega Chip	2002	Groza, et al.	UWI - Madison	AJPR (2007) 84:343-350	Wischip x FYF85	+
Millennium Russet	1998	Groza, et al.	UWI – Madison, WI Seed Certification	AJPR (2005) 82:211-219	Atlantic x FL1154Russ	+
Monticello	2003	Porter, et al.	UME, Cornell Univ.	AJPR (2004) 81:143-152	Steuben x Kanona	
Mountain Rose	2004	Holm, et al.	CO		All Red x ND2109-7	+
Northstar	2006	Bizimungu, et al.	Ag and Ag Food Canada	AJPR (2007) 84:437-445	Niska x ND860-2	
Pacific Russet	2002	Lynch, et al.	Ag and Ag Food Canada	AJPR (2004) 81:235-241	NDA8694-3 x Century Russet	+
Premier Russet	2006	Novy, et al.	USDA-ARS, ID, OR, WA	AJPR (2008) 85:198-209	A87149-4 x A88108-7	+

Purple Majesty	2004	Holm, et al.	CO		All Blue x ND2008-2	+
Red Pearl	1990	Groza, et al.	UWI – Madison, Rhinelander Ag Res. Sta.	AJPR (2004) 81:209-213	Red Norland x Redsen	+
Reeves Kingpin	2003	Ganga, et al.	Maine Seed Potato Board and McCain Produce	AJPR (2006) 83:141-147	CS7981-7 x CF7608-19	+
Rio Colorado	2007	Holm, et al.	CO, NDSU			+
Rio Grande Russet	2003	Holm, et al.	USDA-ARS, CO		Butte x A8469-5	+
Sierra Gold	2003	Miller, et al.	TX A&M Ag Exp Sta.	AJPR (2005) 82:369-377	Krantz x Delta Gold	+
Summit Russet	2003	Love, et al.	USDA-ARS, ID, OR, WA	AJPR (2005) 82:425-432	A77236-6 x TND329-1Russ	+
Wallowa Russet	2002	Hane, et al.	USDA, OR, ID, WA	AJPR (2003) 80:289-294	A82758-3 x Ranger Russet	+
Western Russet	2004	Love, et al.	USDA-ARS, ID, OR, WA	AJPR (2006) 83:161-169	A68113-4 x BelRus	+
White Pearl	2002	Groza, et al.	UWI – Madison	AJPR (2006) 83:259-267	Snowden x S440	+
Willamette	2003	Mosely, et al.	USDA-ARS, OR, ID, WA	AJPR (2008) 85:85-92	NDA2132-2 x A86463-3	+

[1] Every effort has been made to list the female parent first.
[2] PVP = Plant Variety Protection; a '+' means the cultivar is plant variety protected.

Table 15-a. Top ten potato cultivars grown for seed in the U.S. in 2008.

Cultivar	Year Released	% of all 2008 Seed Grown	Acres [1]	Hectares [1]
Russet Burbank	Late 1800's	22.3	24,324	9,848
Frito-Lay Cultivars	Various	8.1	8,855	3,585
Norland (+ sports)	1957	6.3	6,931	2,806
Ranger Russet	1991	6.0	6,595	2,670
Russet Norkotah	1987	4.7	5,092	2,061
Umatilla Russet	1998	3.8	4,097	1,659
Shepody	1980	3.2	3,464	1,402
Rio Grande Russet	2003	2.6	2,800	1,134
Atlantic	1976	2.4	2,604	1,054
Yukon Gold	1980	2.2	2,436	986
Totals		61.6	67,198	27,205

Table 15-b. Top ten potato cultivars grown for seed in Canada in 2008.

Russet Burbank	Late 1800's	24.2	13,405	5,425
Gold Rush	1992	7.3	4,215	1,706
Yukon Gold	1980	5.9	3,430	1,388
Shepody	1980	5.9	3,398	1,375
Superior	1961	5.2	2,995	1,212
Norland	1957	4.3	2,454	993
Russet Norkotah	1987	4.2	2,431	984
Atlantic	1976	4.0	2,283	924
Chieftan	1966	3.4	1,972	798
Kennebec	1948	3.1	1,786	723
Totals		67.5	38,369	15,528

Source: PAA Certification Section

[1] Acres and hectares have been rounded to the nearest whole number.

GROWTH REQUIREMENTS OF THE POTATO

(Carl Rosen)

Potential potato yield in any area is determined by the amount of radiant energy available, number of frost-free days, suitable temperature regimes during the growing season, and the amount and uniformity of the water supply. All other known requirements can be added. The many important factors that determine production can be divided into those in which a grower has some degree of control and those in which control is not possible or very limited. The maximum potential production is constrained by the uncontrollable factors. The ability of each grower to manage the controllable factors and the degree to which they are optimized determine the actual level of production.

Factors not controlled by growers include: frost-free period, air temperature, soil temperature, light intensity, day length, humidity, and soil type.

Grower controlled factors are: soil moisture, crop pests, days grown, fertility, seed quality, seed piece size, plants per acre, timely operation, and soil condition.

Soil Requirements

(Carl Rosen)

Potatoes grow well on a wide variety of soils. In some areas where potatoes are commercially grown the soils are acid, whereas, in others they are alkaline. Ideal soil for potato growing is deep, well-drained and friable. The soil is a water and nutrient reservoir through which air exchange between the soil and atmosphere must readily occur. Without oxygen the roots do not efficiently absorb either water or nutrients. In areas where potatoes receive moisture entirely from rainfall, the most desirable soils have a high water-holding capacity without a tendency to become saturated when wet or cloddy when dry. In the irrigated areas, especially where sprinkler irrigation is used, soil type is less critical because water can be applied as needed in quantities sufficient to meet the needs of the plants without undue runoff, leaching of nutrients, or saturation.

Soils high in clay content require special treatment such as proper crop rotation, cover crops, and timely tillage operations to keep them productive over long periods of time. High organic matter soils such as peat or muck, if adequately drained, can also produce high quality potatoes, particularly for the fresh market. Sandy soils, which contain little clay or little organic matter and have almost no soil structure, when properly irrigated and fertilized, will produce high yields of tubers with excellent culinary and processing quality. Wind erosion can be a problem on sandy soils; however, cultural practices in which a cover crop such as winter rye is planted following harvest or cover crop residues are left on or near the surface provide good control of wind-blown soil.

The cultural practices desirable in any production operation must be adapted to the soil in which potatoes are being grown. The potato plant requires an adequate supply of moisture, nutrients, and air throughout the growing period. The soil fertility status can be determined through routine soil testing procedures. The amount of water and nutrients that need to be added is determined by many factors including the fertility status of the soil, moisture content of the soil, and the rooting depth of the plants. Fertilizer and water inputs will be discussed in more detail in subsequent sections. Any interruptions in growth, regardless of the cause, can result in poor quality tubers. It appears to be especially easy to cause malformation of tubers during the early stages of growth due to stress.

Temperature and Moisture

(Carl Rosen)

All processes of living plants are governed by enzymes and all enzymes function faster at high temperatures, until eventually at some maximum temperature the enzymes are inactivated. The potato has long been classified as a short day, cool season crop, but does very well at high temperatures when water is supplied in uniform quantities sufficient to meet evapotranspiration demands. The highest yields are currently being produced in areas where the daytime temperature is often over 100°F (38°C) during the hottest part of the growing season and nights are cool (~ 65° F or 18° C), such as in Washington's Columbia Basin, eastern Oregon, California and Nevada. 'Russet Burbank', the predominant cultivar in these areas, is not unique in its adaptation to these environmental conditions, as evidenced by the fact that new cultivars, as well as many older cultivars, produce their top yields in these areas. The critical factor is a supply of water to maintain soil moisture at a level sufficient to keep the leaf stomata open during the heat of the day.

Yield potential or photosynthate produced is the result of rate per hour times the number of hours per day, times the number of days, times the number of functioning plants per production unit. Yield is the difference between the photosynthate produced as expressed in the formula above minus the amount used up by the living plant during respiration. Cool night temperatures are an asset because they reduce respiration. The vine temperatures change more rapidly and to a greater degree than tuber temperatures because of the latent heat capacity of the soil.

Contrary to expectations, in a hot environment high specific gravity (high dry matter) tubers and high yields can be produced at the same time. As a result, the tubers from high-yielding plants are excellent for most forms of processing.

Specific gravity of the tubers can be influenced by the relative rates of four physiological processes, respiration, transpiration, photosynthesis, and water absorption. Respiration pertains to the "rate of living" -- the higher the temperature, the faster the utilization of carbohydrates produced by photosynthesis. The amount of carbohydrates produced depends on the rate of photosynthesis and the length of time that it continues. Consequently, there is a direct relationship between length of the growing season and production of high yields of high dry matter content (high specific gravity) potatoes. Specific gravity tends to be lower when the crop is killed early due to higher tuber moisture content and lower dry matter accumulation. There is also a direct relationship between high yield and amount of nutrients in a crop. Fertilization may have little direct effect but a large indirect effect on the specific gravity because of the effect of size of the plant on the relative rates of water lost by transpiration and water absorption by the roots.

The specific gravity of potatoes attached to living plants in the field can change rapidly because of water movement into and out of the tubers. When transpiration (water loss through the leaves) exceeds the rate of water absorption by the roots, the vines draw water from the tuber, causing the tuber to decrease in weight, shrink in size, and at that point in time have an increased specific gravity. This process will continue until the leaf cells lose their turgor pressure, the leaves wilt, the stomata close, and photosynthesis ceases.

If the rate of water absorption by the roots exceeds water loss by transpiration, the excess water is pumped into the tubers and they expand, increase in weight, become more brittle, and the specific gravity decreases. The increase in weight of potatoes and decrease in specific gravity, because of absorbed water, are at times sizeable.

Rotations

(Bryan Hopkins)

Length of time between potato crops and the number and types of species grown in rotation with potatoes can impact potato production and sustainability of the soil. In general, longer rotations result in increased yields and reduced fertilizer and pesticide requirements.

The number of years since the last potato crop is an important consideration when selecting a field for potato production. Many potato pests (weeds, wireworms, nematodes, insects such as Colorado potato beetle, and diseases such as white mold, pink rot, pythium leak, Verticillium wilt, and powdery scab) build populations in proportion to the frequency of potato cropping. Potato production is not very conducive to maintaining healthy soil conditions due to intensive tillage, minimal crop residues, heavy field traffic, and long periods of bare soil exposure.

As a result of these soil and pest issues, potato roots are often damaged or poorly developed under short rotation frequencies. Therefore, nutrient and water uptake are often impeded. For these reasons and others, fertilizer, water, and pesticide inputs are often higher and yields are often lower for short rotations.

Additionally, the fact that certain rotational crops also serve as a host for potato pests should be considered before selecting fields. For example, dry beans and canola are susceptible to white mold. Growing these crops in rotation with potatoes can increase the severity of white mold in the potato crop. Verticillium wilt has many alternative plant hosts, such as mint, alfalfa and many weed species. Nematodes and insects can also have alternative hosts and build significant populations in the years potatoes are not grown. Pasture grasses serve as a good host for wireworms and should be avoided altogether as a rotational crop if the field has a history of wireworm damage. Clover is also a host for wireworms. There are many more examples of alternative pest hosts that cannot be fully enumerated in this discussion but should be identified and discussed with a local pest control specialist.

Biofumigation has recently become an important rotational crop consideration. Biofumigants are released from certain green manure crops (crops grown and tilled into the soil green) for the purpose of controlling particular nematode, weed, insect, and disease pests. As with other rotation crops, biofumigants typically improve soil organic matter and nutrient and moisture retention. Biofumigants release natural chemicals from the decaying crop if substantial quantities are plowed into the soil while still green. Green manure crops can be planted during the summer, fall or spring.

It is important to add as much biomass as possible to the soil from rotational crops and green manures. Green manure crops are planted for the purposes of providing ground cover to minimize soil erosion, adding carbon to the soil, and scavenging nutrients that might be lost to leaching or volatilization. Adding large quantities of corn stalks, grain straw or similar materials that are very high in fibrous carbon residues can present problems with planting and plant growth. In these cases, it is important to spread the residue uniformly and work it into the soil as early as possible the fall before potato cropping. Microbes will begin decomposing the residue if the soil has adequate moisture and a small amount of nitrogen (about 15 pounds of N per ton of residue, up to 60 pounds) remains from the previous crop and/or is applied as fertilizer. Leaving a portion of residue on the surface will minimize soil erosion, but burying the crop residue completely helps reduce disease inoculum.

The effects of Verticillium wilt can be significantly reduced with long rotations and incorporation of green-manure residue of oilseed radish, yellow mustard, rapeseed, sudangrass, barley, wheat, corn, and various other crops. The effects of Rhizoctonia stem canker and black dot may also be suppressed with green manures. In addition to reduced soil concentrations of certain pathogens, other benefits of using green manure trap crops include increased potato yields, improved soil tilth and water-holding capacity, reduced nitrogen leaching into groundwater, improved weed suppression, reduced soil erosion, and potential suppression of nematodes.

Reduced nematode populations can be partially achieved through good rotational management. Avoidance is aided by lengthening the time between potato crops to four or more years. Avoiding rotational crops, potato volunteers, and weeds that host nematodes known to be problematic in the field in question is also important. Alternatively, biofumigants released from oilseed radish, mustard, rapeseed, and sudangrass green manures all show effectiveness in nematode control for about the same cost as fumigation, but with the added benefits associated with a green manure. Oilseed mustard and white radish have shown excellent results for nematode control when used as a green manure trap crop. Other green manures have also been shown to be effective.

The length of time between potato crops is important when attempting to minimize soil-dwelling insects. Soil insect populations can also be favored if the previous crops/weeds were hosts for the insect in question, such as with certain grass species and wireworms. Clover, cereal grains, and corn are also hosts for wireworms and should be avoided in recent rotation in fields where wireworms are a problem.

The Colorado potato beetle is another serious insect pest. Prevention is aided by avoiding planting in or close to fields where potatoes were grown or where volunteers were not controlled the previous year. Closely related plants, such as nightshade weeds, can also serve as a host for the Colorado potato beetle and should be controlled. Green peach aphid is another major pest of potatoes. As with Colorado potato beetle, nightshade is a favored host of green peach aphids. Effective control of nightshade and other plant hosts for aphids can help reduce problems. Preventing weeds is as important as controlling the weeds. Weeds, especially potato volunteers and closely related species, should be controlled in rotational crops and in field borders.

In summary, length of time between potato crops and the number and types of species grown in rotation with potatoes can impact potato production and the sustainability of the soil. In general, longer rotations result in increased yields and reduced fertilizer and pesticide requirements.

Soil Preparation

(Peter Sexton)

Tillage serves several purposes for preparing the land to support crop growth. Timely tillage improves the physical condition of the soil which helps roots to develop and explore the soil profile in depth in order to acquire nutrients for growth. Tillage helps to control weeds, and it may be used to incorporate fertilizer, lime, organic matter, or other agricultural compounds. Tillage is necessary to develop a well-prepared seedbed, which allows for uniform planting and stand establishment. On the other hand, excessive or poorly timed tillage destroys soil structure and compacts the ground besides wasting fuel. Working the ground when it is wet can also destroy soil structure and compact the land.

Potato growers commonly use a moldboard plow or chisel plow for their primary tillage method (Figure 7). Fall plowing offers advantages by decreasing the amount of work that has to be done the

Figure 7. Moldboard plow.
(S. Johnson)

following spring. Fall tillage generally results in warmer soil temperatures in the spring which allows for earlier planting; it allows for greater breakdown of crop residues; and the freezing and thawing action of winter helps to break up clods and improve tilth. However, the disadvantage of fall plowing is that the more the soil is exposed by tillage, the more susceptible it is to erosion. And fall tillage, especially moldboard plowing, can leave the soil exposed for a long period. It is preferable to plow sloping lands in the spring to help prevent erosion. Strip and/or contour plowing of sloping lands will also help control erosion. Prevention of soil erosion, either by wind or water, cannot be over-emphasized. Any waste of topsoil ultimately means a serious loss of capital to the potato grower. Use of a fall cover crop, or promoting development of a stand of volunteer cereals, are practices some growers use to help control erosion.

In recent years, fall bedding has become more widely practiced in the Pacific Northwest. Fall bedding allows for soil preparation work to be done when the growers typically have more time and labor available to them. In this system, growers usually irrigate, broadcast fertilizer as needed, plow, and then form beds which they plant into the following spring.

In the spring, unless beds have already been formed, fields that have been plowed are disked or harrowed ahead of planting as soon as conditions permit. If fertilizer is going to be broadcast applied, it is usually put on ahead of spring tillage. A relatively small number of growers will broadcast a portion of their fertilizer after planting operations are finished and just ahead of cultivating.

In some irrigated areas, as a final pass, dammer-diking equipment is run through the field at final cultivation after planting. This equipment forms small catchment basins between the rows. These indentations through the field help prevent water run-off between the rows, and promote uniform infiltration by holding the water in place.

Building Up Soil Organic Matter Content

(Carl Rosen)

The advantages of organic matter in the soil are many. An ample supply of decaying organic matter helps keep the soil loose and mellow and thus reduces soil compaction. Potato tubers develop and maintain normal shape better in loose, well-aerated soils. Organic matter facilitates plowing and cultivating, enables roots of potato plants to penetrate the soil more readily, improves water retention, provides food energy for the growth of desirable soil micro-organisms, and supplies plant nutrients. Maintaining a desirable level of organic matter in the soil is a problem in practically all potato regions except those with muck and peat soils. In warm regions with long growing seasons, the decomposition of organic matter in the soil is rapid and almost continuous. In colder regions, decomposition takes place in the summer and does not occur appreciably during the winter.

Potatoes, as a crop, provide little organic matter to be returned to the soil. General methods of getting organic matter into the soil include a crop rotation in which legumes or other crops are grown and plowed under as a green-manure crop. Such crops include crimson or red clover, vetch or a combination of peas and vetch, soybeans, cowpeas, rye, oats, barley, wheat, millet, sudangrasss, field corn, or other suitable crop plants. The application of barnyard manure and the plowing under of the organic residues of all crops produced will contribute to the organic matter content of the soil.

Barnyard manures help improve the physical condition of the soil, provide plant nutrients, and increase bacterial activity. Fresh manure should not be applied just before the potato crop is planted. Manures may produce a favorable environment for common scab development, particularly if the soil is near pH 7.0. If large quantities of manure are used, there may be enough salt present to injure young plants. If fresh manure is used, it should be applied 3 to 4 months before planting. Aged or composted manure can be applied 1 to 3 weeks before planting.

Liming

(Peter Sexton)

The availability of nutrients and other elements in the soil is strongly influenced by pH. As soil pH drops below 6.0, the availability of P (phosphorus), Ca (calcium), and K (potassium) decline in the soil. At the same time, the availability of Al (aluminum), Fe (iron), Zn (zinc), Mn (manganese), and Cu (copper) increase. Aluminum is detrimental to plant growth, and as the pH drops, Al toxicity can become a problem. Crop plants and soil microorganisms differ in their ability to tolerate low pH. At a given pH, soil organic matter and texture also influence nutrient availability. Therefore, optimum pH for growth varies somewhat among soils. Potatoes are more tolerant to low pH than most other crops. Incidence of common scab tends to be less of a problem where soil pH is less than 5.4. Often times for cultivars that are susceptible to common scab, the disease is managed by maintaining soil pH in the range of 5.0 to 5.4. Although potatoes tolerate acid soil, there are benefits from raising the pH of acid soils up to 6.0 to 6.5. This increases the availability of P and K, increases microbial activity and decomposition of organic matter to release N, and increases soil cation exchange capacity. Thus in areas with acid soils, there tends to be two levels of pH management, one for cultivars that are susceptible to common scab (target pH of 5.1 to 5.3), and one for cultivars that are resistant to common scab (target pH of 6.0 or more). The practice of liming is used to maintain pH in the desired range for a given management system.

Lime is primarily calcium carbonate ($CaCO_3$). When it is incorporated in the soil, the CO_3^- (carbonate) reacts with free H^+ to form water (H_2O) and carbon dioxide (CO_2). Ideally, the Ca in the lime displaces exchangeable Al. These two actions work to neutralize soil acidity. Exchangeable Al in the soil and exchangeable H^+ in organic matter act as buffers on pH. The more Al and exchangeable H^+ there are, the more lime will be needed to neutralize acidity and increase the pH of the soil. Removal of exchangeable Al and H^+ not only increases pH, it also increases the cation exchange capacity of the soil, which is another benefit of liming.

In general, fine-textured soils require more lime to increase their pH than do coarse-textured soils. This is because fine-texture soils tend to have greater amounts of exchangeable Al that must be neutralized. Organic matter, on the other hand, tends to decrease the amount of exchangeable Al present in the soil. Therefore, soils with high levels of organic matter tend to behave as if their pH were greater than it actually is.

Several factors influence the effectiveness of lime application. The composition or purity of the liming material used, how finely it is ground, how well it is mixed with the soil along with soil moisture and temperature all influence how quickly it will act to increase pH. In terms of composition, the effectiveness of a given material is measured by its “calcium carbonate equivalence” expressed on a percent basis with 100 % being equal to pure calcium carbonate. The smaller the particle size and the more thoroughly the lime is mixed with the soil, the faster it will act to neutralize acidity and increase pH.

There are a number of materials such as wood ash, paper mill waste, refuse from sugar beet plants, and slag from steel mills that are sometimes used as alternatives to ground limestone for increasing soil pH. These materials can be effective for neutralizing acidity and raising pH, but the user should be careful about what other elements or impurities they may be adding to their soil. Caution is needed with materials that may contain heavy metals such as cadmium. Also, materials such as wood ash will add potassium to the soil, which means the fertilizer program may need to be adjusted accordingly to avoid excessive application of potassium.

To make prudent decisions on use of liming materials, a grower will need a soil test to determine how much lime is needed and an analysis of the liming material to know how effective it will be and to understand what other elements the material may be adding to the soil.

SELECTING, STORING, PREPARING AND PLANTING SEED

Seed Potato Certification

(Rob Davidson)

Potatoes are one of a number of vegetatively propagated crops. Simply put, a tuber rather than a true seed typically used for other vegetable crops is used as the propagative unit. Potato tubers are either planted whole (single-drop seed) or cut into seed pieces containing two to three eyes (clusters of buds). The process of vegetative propagation, however, can result in unique problems regarding maintenance of varietal purity and in the management of "seed-borne" diseases. Disease pathogens present in the propagative material are most often transmitted to the progeny, thus they are "seed borne". Additionally, the cut surfaces of seed potato tubers are, until properly suberized and healed, open wounds that provide pathogenic organisms from other tubers or external sources a route for infecting the seed piece.

In an effort to provide the commercial potato industry of North America potato "seed" stocks that have varietal purity and are relatively free of disease-causing organisms, an elaborate seed potato certification system evolved. The process of certifying seed potatoes has changed a great deal in response to technological advances in rapid multiplication of potatoes under laboratory and greenhouse conditions as well as more sophisticated and sensitive pathogen testing techniques. These advancements have revolutionized the seed potato industry, providing higher quality certified seed stocks than ever before and making the industry more competitive.

Concepts of Seed Potato Certification

Seed potato certification in North America was first discussed during the first annual meeting of the Potato Association of America in 1914. By 1920, 12 states and all Canadian provinces were engaged in seed potato certification. In Canada, seed certification is under the general control of the federal government through the Canadian Food Inspection Agency with each province maintaining provincial authority over many aspects of certification. In the United States, however, seed potato certification is the responsibility of each state with legal authority to carry out certification given to the land-grant university within the state, the state department of agriculture or through grower (crop improvement) associations. On the surface it may appear there is a great deal of diversity among programs in the rules and regulations that govern the certification process. In reality, certification officials meet on a regular basis, discuss the best methods for conducting certification and pathogen testing, and work continually on developing more uniform rules and regulations. The past few years has seen excellent cooperation among programs resulting in relatively uniform standards and approaches to certification.

The certification agency is responsible for conducting all required field, storage and shipping-point inspections. Since participation in any seed certification program is voluntary, the responsibility to carry out all recommendations and to follow seed certification regulations rests solely with the grower. Interaction and communication among seed certification agency personnel, the seed potato grower and the commercial potato industry is critical.

The primary purpose of seed potato certification is to provide reasonable assurances of varietal purity while reducing the incidence of seed-borne pathogens and/or other problems (i.e., chemical carryover or germination issues). Early efforts in certification were focused on control of viruses, which were responsible for the phenomenon known at the time as the "running out" of cultivars. Today, in addition to assuring varietal purity, programs deal with a myriad of other disease issues through both visual inspection and laboratory testing. To minimize these problems, programs have established tolerances for cultivar mix and levels of specific diseases allowed within the seed fields. These tolerances are tied to seed classes and field generation levels. Generally, the more years the seed has been propagated in the field, the higher the tolerance levels allowed.

In the past, tubers from individual plants or hills that appeared to be visually free of disease problems were saved for replanting. These hill selections were frequently planted together as a "tuber-unit." In a tuber-unit, a tuber from a hill is cut into seed pieces and planted sequentially in a unit. This unit is followed by the remainder of the tubers from the hill, also planted as units. If a disease problem appeared in any plant of a tuber-unit, the entire unit would be destroyed **(**Figures 8a and 8b**)**. This procedure was used for several decades as a means of producing and multiplying seed stocks that were relatively free of major disease problems. This technique may still be used today to help clean lots with virus problems.

Figure 8a. Tuber unit consisting of four seed pieces. The four seed pieces are planted as a unit in the field. A sizeable space separates units within the field (right).

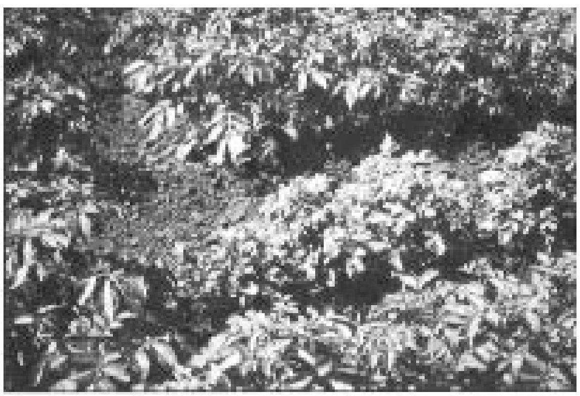

Figure 8b. Tuber unit plants in the field showing healthy and diseased units. The diseased units can be identified and eliminated easily (left).

A number of disease-causing pathogens, however, can remain latent or symptomless within a seed tuber and will remain visually undetected during the inspection process. There have been instances when the disease problem was not detected until the seed lot was purchased by a commercial grower, resulting in severe economic losses. This resulted in the development and adoption of new laboratory testing and seed stock multiplication techniques that had a dramatic influence on the quality of certified seed potatoes. Today, nearly all certified potato seed stocks originate from tissue-culture plantlets derived from meristems or clean material and produced under aseptic laboratory conditions.

Meristem, Tissue-Culture Seed Stock Development

The advent of tissue culture, in which plants are grown in artificial media under sterile conditions in the laboratory, revolutionized nuclear seed stock development. Most certification agencies currently operate tissue culture laboratories that produce the initial stocks of pathogen-free planting material. A number of private companies and individual certified grower operations throughout the United States and Canada also produce meristem-derived, pathogen-free seed stocks. These stocks are either marketed locally, on a national scale, or are used within the seed grower's own operation.

The tissue culture procedure involves the removal of the small growing point or meristem, approximately the size of a flake of black pepper, from a tuber sprout or stem of a potato plant. The few cells removed from this region of the plant are typically free from virus and other pathogens causing disease in plants. Through the judicious use of certain viracidal agents and heat therapy, a high percentage of the cells in the sprout or stem's meristematic region can be freed of any pathogens. The meristem is placed in a test tube or other vessel with media containing all of the necessary macro- and micronutrients, carbohydrates, growth regulators and salts required for growth and development into a plantlet. Once the plantlet is growing, it is ready for nodal cutting and pathogen testing (Figure 9).

Figure 9. Tissue culture plantlets in test tubes. The plantlets have to grow in an environment designed to produce disease-free planting stock.

A nodal cutting from a tissue culture plantlet is a stem segment containing a growing point (axillary meristem) and a leaf. Since a tissue culture plantlet has its own leaves, it is capable of producing its own food. Therefore, the nodal cutting is placed on an artificial medium that promotes root and shoot development. The nodal cutting process will be repeated many times in order to increase and obtain the number of tissue culture plantlets needed for minituber production.

During the initial nodal cutting process, pieces of the plantlet are retained for laboratory testing for the presence of disease-causing pathogens. Each plantlet of each cultivar is exhaustively tested for the pathogens causing soft rot, blackleg, ring rot and spindle tuber. In addition, each plantlet is tested for several potato viruses including, but not limited to, leaf roll, potato viruses Y, X, S, A, and M. At this stage, 100 percent of all tissue culture seed stock is tested for disease-causing pathogens. During latter stages of seed stock production in the greenhouse or field, seed certification agencies test 0.5 to 25 percent of the plants, and then, only for certain pathogens known to easily move between plants.

Once the laboratory has produced the desired number of plantlets for each cultivar, they are ready for tuber production. These plantlets can be planted outdoors directly into the field or into a greenhouse or screenhouse for minituber production. Under the controlled conditions of a greenhouse or screenhouse, the plantlets can be carefully cultivated and monitored. Within three to four months after planting,

Figure 10. Minitubers derived from greenhouse production. Minitubers range in size from 0.5 to 2.0 in (1.3 to 5.1 cm).
(Joe Pavek)

minitubers can be harvested. These stocks are sorted, sized and stored until the following growing season. Minitubers range in size from 0.5 - 2.0 in (1.3 - 5.1 cm) and are priced accordingly (Figure 10). Microtubers, tubers produced in tissue culture medium, are also being marketed for use in the production of disease-free seed stocks. At the current time, microtubers appear better suited for planting in greenhouses and screenhouses rather than in the field due to their extremely small size and difficulty in breaking dormancy.

Minitubers or tissue culture plantlets planted into the field are the initial source of certified seed potato lots. These lots will be multiplied and increased until a sufficient quantity of seed potatoes are available for commercial use. During the increase process, the seed lots are subjected to visual field inspections and further pathogen testing. The number and intensity is greatly dependent upon the certifying agency's rules and regulations where the seed is being produced. However, all states and provinces have either a voluntary or mandatory limited generation system, depending on the seed production area.

Limited Generation Program

During potato production, seed or commercial, the plant is constantly exposed to sources of contamination by disease-causing pathogens. The probability of a seed tuber or seed lot becoming contaminated with pathogenic organisms increases every year the seed lot is in production. To minimize this, seed certification agencies have enacted regulations that basically restrict or limit the number of years the seed lot can be eligible for the seed certification process. This is referred to as a limited generation or "flush through" system. Limited generation systems are handled differently in each seed production area. Additionally, the seed class identity or number of seed lot field generations varies considerably among seed certification agencies. In principle, limited generation begins when the seed lot is planted in the field and after the tissue-culture derived material has left the laboratory or greenhouse. This varies from five to nine years, depending upon the seed production area (Table 16). Seed certification agencies also differ in what term is used to describe the generation of the seed lot. Much of this variation is influenced by whether or not the tissue culture plantlets or mini-tubers were produced on a state or provincial farm or on individual seed grower farms. Maine, New York, Wisconsin and Canada all operate government seed farms. In general, seed produced from these farms does not receive a generation number until it leaves the farm and is grown by individual seed potato growers.

Table 16. Limited generation certified seed potatoes: Field planting equivalency table[1].

AGENCY	YEAR IN THE FIELD							
	1[2]	2	3	4	5	6	7	8	9
Alaska	G1[3]	----	G3	G4	G5	G6	G7	G8	……
California	N	G1	G2	G3	G4	G5	……	……	……
Colorado	G1	G2	G3	G4	G5	G6	……	……	……
Idaho	N	G1	G2	G3	G4	G5	G6	……	……
Maine	N1	N2	N3	N4	G1	G2	G3	G4	
Michigan	FY1[6]	FY2	FY3	FY4	FY5	FY6	……	……	……
Minnesota	N	G1	G2	G3	G4	G5	C	……	……
Montana	N	G1	G2	G3	G4	……	……	……	……
Nebraska/ Wyoming	N	G1	G2	G3	G4	G5	……	……	……
Nevada	N	G1	G2	G3	G4	G5	……	……	……
New York[4]	N1	N2	N3	G1	G2	G3	G4	G5	G6
North Dakota	N	G1	G2	G3	G4	G5	C	……	……
Oregon	1	2	3	4	5	6	……	……	……
Utah	N(G1)	G2	G3	G4	G4	G6	……	……	……
Washington	N	G1	G2	G3	G4	G5	……	……	……
Wisconsin[5]	FY1	FY2	FY3	FY4	FY5	FY6	C	……	……
Canada	PE	E1	E2	E3	E4	F	C	……	……
	(G1)	(G2)	(G3)	(G4)	(G5)	(G6)	(G7)		

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Prepared by the Certification Section of the Potato Association of America

[1]The purpose of this table is to express equivalency of terms used by various certification agencies for seed potatoes harvested from a series of successive field plantings. For specific criteria relating to disease tolerances and other requirements, the reader is referred to the certification regulations of the agency in question.

[2]The first field planting utilizes laboratory-tested stocks which may be tissue-cultured plantlets, greenhouse-produced minitubers, stem cuttings, or line selections. Contact agencies for details as to types of stocks planted in their programs.

[3]Term used by agency for seed potatoes for a particular year in the field: C=certified, E=elite, F=foundation, G=generation, N=nuclear, PE=pre-elite.

[4]If lots originate at Cornell-Uihlein Farm, the first three generations (G1-G3) are also designated by a U to denote source. All generation codes are preceded with C or F (Certified or Foundation).

[5]Lots NOT originating at the UW Lelah Starks Elite Foundation Seed Potato Farm are designated G*n* where *n* = years in the field.

[6]FY = Field Year

Seed Certification Process

The process of seed potato certification is relatively straightforward. At the start of each growing season growers wishing to enter the certification program must provide an application to certification authorities. These applications list the grower's information (name, address, etc.) and the seed stocks to be certified. The application includes the cultivar name, source of the seed, planting date, generation and class to be certified and any other pertinent information to help officials make eligibility decisions. This history is verified by the certification agency and growers are informed about their eligibility for certification for that year. Most states and provinces require all seed lots on a farm be eligible for certification even if the lot is not intended to be sold as seed. Additionally, growers will pay their primary fees for certification when the application is submitted. Certification programs, for the most part, are funded by the growers through acreage fees and other additional fees assessed for testing, tissue-culture stocks, etc.

Once eligibility, class designation, and generation level have been established, the seed moves through a series of inspections. Visual field inspections are the first step conducted by highly trained inspectors that work for the certification agency or state/province. Up to three or more inspections are conducted at various times during the growing season to maximize the opportunity to detect seed-borne disease and pest problems, which can affect the crop the following year. At this point, tolerances are in effect. Each inspection has specific tolerances for cultivar mixes and disease levels. Tolerances tend to be higher for the first inspection and lower for the second and final inspections. By setting up the program in this manner, growers are given the opportunity to “rogue” or remove diseased plants from the lot. This can be a very effective mechanism for reducing certain disease problems (such as those caused by viruses) or cultivar mixture. Precise plant counts are made by inspectors with the number of plants affected by diseases or pests recorded so that a percentage reading on any given problem can be determined. In this way, a seed lot can be found to be within acceptable tolerances. If a lot is deemed over tolerance, the program may downgrade the lot in class or outright reject the lot from certification when levels are too high. Lots rejected from certification will not be sold as seed, but instead are moved into the commercial table stock (fresh market) or processing channels for disposal.

After each lot is found to meet field inspection tolerances and other applicable rules and regulations, the grower is permitted to harvest and store the crop. Certification officials will conduct a storage inspection to verify that lot identity has been maintained, that the lot is stored properly and within the regulations established by each program, and that there are no obvious disease issues. At harvest, growers will remove a set number of tubers from each lot to be submitted for a post-harvest evaluation. These tubers are normally grown in the field during the off-season in more temperate regions such as Florida and Hawaii, or in greenhouses. Again, trained inspectors visually inspect and laboratory test, when needed, these stocks. This is the primary method for determining if a lot has had late-season, non-detectable infections of virus, cultivar mixing at harvest, or carryover chemical damage. All programs use the post-harvest evaluations to determine re-certification eligibility for the following year’s seed crop. Many programs additionally use this evaluation to determine whether or not a lot should be eligible for sale and tagging as certified seed.

Most programs print a seed directory listing all eligible seed lots for sale each year, often with information about disease levels found in the lot. This directory is used by seed producers to advertise their available seed lots and by the commercial industry to help in purchasing the certified seed needed for their following year’s crop.

Three additional steps are needed to complete the certification process. After a certified seed lot is bought, shipment will take place. At the time of shipment, a shipping-point inspection is conducted by Federal/State officials to verify the seed meets the official requirements for grade and size. In the U.S., for instance, this means meeting the U.S. No. 1 seed grade or a variation thereof, depending upon each state’s regulations. After shipping-point inspection, the lot will be tagged as officially certified. Each tag or bulk certification (for loads moved in larger quantities and not placed in individual 100-pound sacks) must indicate the state/province of origin, the cultivar, the class and generation level, and the grower producing the seed. The final step for most seed moved is the request and preparation of the North American Health Certificate (NAHC) listing all of the crucial information about the seed lot including origin, lot identity, all inspection readings, disease testing performed and pertinent grower information. Since seed certification agencies also have specific criteria relating to disease tolerances and other regulations for each successive field planting, this can be very confusing. Thus, the NAHC is used by the buyer to obtain full disclosure about each seed lot.

Certified seed production programs in the U.S. and Canada have been very successful in limiting cultivar mixing and disease problems. The high quality of the certified seed has allowed the potato industry to increase overall yields and quality while allowing for rapid mainstreaming of new and improved cultivars from the breeding programs. This success has been instrumental in keeping the U.S. and Canada potato industries competitive and profitable.

Maximizing Potato Seed Performance

(Alvin Bussan and Nora Olsen)

Factors Affecting Seed Performance

Seed productivity is dependent on quality, handling, and preparation of seed for planting. A primary factor of seed quality is maintaining disease levels in tubers at levels equal to or lower than those established by seed certification agencies, which is covered in the Seed Potato Certification section of this handbook. Other quality factors to be discussed in this chapter include seed tuber age and size, storage, handling, pre-plant warming, preparation and cutting, dormancy, disease prevention and seed planting and placement. All these factors contribute to seed quality and failing to manage any one area appropriately can lead to poor seed performance. Seed performance is generally characterized by time to emergence, plant vigor, stem and tuber set per plant, and stand establishment. Poor stand and crop vigor can lead to delayed canopy closure and uneven tuber set which contributes to reduced yields and quality.

Seed Age

Potato seed age is typically documented physiologically or chronologically. Physiological age accounts for environmental and management effects on seed performance, but has been difficult to quantify. Chronological age (defined below) is correlated to physiological age, but does not account for the influence of crop or storage management. Physiologically old seed emerges sooner and produces more stems and tubers per hill than younger seed tubers. Physiologically older seed is more desirable for potato crops that have smaller tuber size requirements (i.e. seed, red-skinned potatoes, chips) as larger tuber set increases yield of smaller to mid-size tubers. Physiologically young seed has more vigor, produces higher yields of larger tubers than old seed and is ideal under long production seasons typical of processing and fresh market russet potato production. Very old seed is undesirable in any area as seed pieces often produce tubers without above ground plants or produce tubers shortly after plant emergence.

Young potato seed is generally characterized by buds that lack any evidence of sprout development, uniform tuber shape and size, no evidence of physical damage on the tuber surface, and lack of internal defects such as bruising. Tubers that do not fit the above description are considered old. Visual inspection of seed, although important, has limitations in predicting seed age and subsequent performance. Seed lots with similar appearances have performed drastically different in terms of stems and tubers per plant, time to emergence, and vigor indicating differences in seed age. Stem and tuber set has become more important than previous as the demand for certain size tubers has increased. Prediction of seed age allows for estimation of stem and tuber set per plant prior to planting. Manipulating stem density per unit planted area allows for management of tuber set, which controls tuber size.

Chronological age is the duration between some beginning point in the development of the seed tubers and the subsequent time of planting..

The chronological age of seed is an imperfect indicator of seed performance as growing and storage conditions, seed handling, and other factors can also influence seed performance. Chronological age fails to account for production or storage conditions that influence seed performance. Physiological age has become the primary indicator for describing the quality of potato seed. Physiological age provides a summation of chronological age as well as environmental and management factors influencing seed tubers and their buds. Quantification of physiological age and subsequent prediction of seed performance, especially stem and tuber set, has become the focus of recent research. Several advances have been accomplished in predicting physiological age, but several challenges remain.

Factors that contribute to aging of potato seed include temperature, stress, physical damage to tubers, and other factors influencing seed during growth and storage. Recent research has focused on the effects of storage temperatures on physiological age of seed tubers. Storage temperatures between 38 and 40°F (3.3-4.4°C) minimized aging of seed. Temperatures exceeding 38°F from the time of vine kill to harvest, during storage, and during warming of seed were shown to contribute to aging of seed and could be related to stem density. Thermal time calculated on base temperature of 38°F provides methodology for predicting physiological aging from the time of tuber harvest until planting the subsequent spring.

Research is still attempting to address the influence of growing conditions on the physiological age of seed. We know that potato seed produced under normal field and storage management practices commonly differ in physiological age. Differences in physiological age have been partially explained by potato seed planting date or tuber initiation date. However, growing conditions such as light intensity and duration, soil and air temperatures, irrigation management, pest pressures, and other factors conceivably contribute to physiological age of seed. Tools for assessing the physiological age of seed tubers have also begun to emerge. The relation of physiological age indices with seed performance has been reported.

The development of precise seed management recommendations for targeted physiological age is beginning to emerge as advances in the prediction and management of physiological age continues. This will maximize the value of seed due to the ever increasing demand for production of tubers within precise size categories to maximize potato crop value. The remainder of this chapter will discuss how manipulation of various management factors influences the physiological age and performance of seed potatoes.

Storage

Desired storage temperature for seed potatoes after initial curing is 38 to 40°F (3.3 to 4.4°C). Potato respiration is minimized at 37°F (2.8°C). Storage temperatures above 40°F (4.4°C) results in physiological aging of tubers and promotes premature sprouting of seed potatoes, particularly of cultivars with short dormancy. Seed tubers stored below 37°F (2.8°C) have increased respiration and will increase in physiological age compared to tubers stored at 38 to 40°F (3.3 to 4.4°C). Seed tubers of cultivars susceptible to cold temperature stresses that are stored at 32°F (0°C) for long periods (20 weeks or longer) can develop mahogany browning. Mahogany browning results in an internal reddish-brown discoloration often found in irregular patches randomly occurring in the tuber with irregular and indefinite boundaries. Mahogany browning differs from freezing injury because tubers are never actually subjected to freezing temperatures. Tuber tissues with freezing injury become soft and watery when placed in a warm environment.

Recent research has demonstrated the influence of storage air quality on the physiological condition of potato tubers. Ethylene and CO_2 influence tuber respiration and prolonged exposure to elevated concentrations of both could conceivably increase physiological age of potato seed. Limited O_2 concentrations in severe cases have caused black heart in tubers in the field and storage. Although limited research has documented the influence of these conditions on potato seed quality, the influence on physiological age is conceivable. Seed potato storages must allow for ventilation and fan run times allowing for daily purge with outside air. Heat and refrigeration to manage storage temperature may be necessary to allow for daily purge depending on location.

Potato seed intended for planting shortly after harvest, such as fall or winter plantings in the Southern U.S., must be aged to allow for breaking of dormancy (wake up the seed). Cultivars differ in the thermal time required to allow for seed aging with time required to break dormancy, ranging from 6 to 16 weeks. Seed potatoes can be aged by storing at 55°F (12°C) to allow for increased respiration and more rapid loss of dormancy. Seed not needed until later in the winter can be stored between 40 and 55°F. At these temperatures, other aspects of the storage management must be carefully monitored to prevent the development of pathogens in storage. In addition, seed that is not fall or winter planted, but has been managed to break dormancy will have advanced physiological age in the spring and may have sprouted.

Handling

Physical damage to potatoes causes stress and leads to physiological aging of the tubers. Potato tuber damage of greatest concern is skinning and bruising. Skinning typically occurs during physical handling of the crop such as harvesting, but the influence of skinning on physiological age of potato seed has not been thoroughly evaluated. Seed potatoes are managed to set skin prior to harvest to minimize potential for skinning during harvest and placement of the crop into storage. Vine-killing of seed potatoes is done to decrease potential for disease and virus occurrence and promote skin set. However, vine-killing results in soils exposed to direct sunlight, which can lead to increased soil temperatures. Some years and for some cultivars, vine-killing is done early to prevent transmission of potato viruses, but this will result in even warmer soils. Accumulation of heat units after vine-killing can increase physiological age of potatoes. Soil temperatures exceeding 38 to 40°F (3.3 to 4.4°C) contributes to physiological aging of seed. Seed potatoes should be dug as soon as possible after vine-killing to minimize physiological aging if young seed is desired. In contrast, delaying harvest after vine-killing can increase physiological age resulting in shorter dormancy in storage and more stems and tubers per plant. Optimal vine-kill and harvest timing for managing disease, skin-set and physiological age has not been thoroughly studied and likely varies by cultivar.

Recent research shows that damage (bruising) to seed potato tubers during harvest, in storage, and following storage causes stress and increases physiological age of tubers resulting in reduced yield potential by as much as one-third. Handling seed tubers with low damage levels can be accomplished by implementing the same concepts that reduce tuber damage during harvest. These concepts are covered in detail in the section on Harvesting the Potato Crop.

Warming Seed Prior to Planting

Tubers of seed potatoes should be warmed to 50 to 60°F (10 to 15.6°C) before handling and cutting to minimize potential for bruising. Seed should be warmed and removed from cold storage 7 to 14 days before planting. Tubers should never be taken from 40°F (4.4°C) storage and planted directly. Condensation occurs on the surface of tubers with a pulp temperature of 40°F (4.4°C) when planted in soil temperatures warmer than 40°F (4.4°C). Free moisture on the surface of tubers contributes to seed piece decay, particularly with cut seed.

Type and Size of Seed

Some growers prefer to plant uncut, small, seed tubers (single-drop seed). The use of uncut or whole seed tubers reduces the hazard of spreading disease in the cutting operation and helps ensure a better stand of plants, particularly under adverse field conditions. The desired size range for planting whole tubers without any cutting ranges from 1 1/2 to 3 oz (43 to 85 g) (Figure 11). Cutting seed tubers less than

Figure 11. Small whole size seed exhibiting apical dominance and a large seed tuber suitable for cutting into four seed pieces. Seed size ranges from 1.5 to 3.0 oz. (43 to 85 g).

3 oz (85 g) in size results in seed pieces weighing less than 1 ½ oz (43 g) and results in excessive waste.

Seed pieces, either freshly cut and planted or properly healed before planting, can be just as productive and healthy as uncut seed tubers. Seed tuber size affects the productivity of cut seed pieces as well. Seed tubers greater than 9 or 10 oz (255 to 284) give a higher percentage of seed pieces without eyes (blind seed pieces) when cut than smaller tubers. This can be a substantial problem in cultivars with uneven eye distribution across the tuber surface. Seed pieces less than 1.5 oz (43 g) produce fewer stems than do large ones. Excessively large seed pieces can produce too many stems per hill increasing tuber set and reducing tuber size as well as increasing cost of seed. Seed pieces that are too small or large can inhibit proper planter operation. The seed piece size for optimal productivity, planter performance, and seed cost/unit area ranges from 1.5 to 3.0 oz (43 to 85 g).

Seed Potato Preparation and Cutting

Several types of mechanical seed cutters are available to cut tubers into seed pieces, all of which do an effective job if properly managed. Machines are designed specifically for cutting round- or long-tuber cultivars. Some machines can be effective for cutting both tuber types when properly adjusted. Best results are obtained when seed tubers are graded to a uniform size before cutting. Seed cutters should be kept in good repair, properly adjusted, and knives kept sharp to allow for clean cut. Sanitation during the seed cutting and handling operation is essential to reduce disease pathogen spread. Every machine should be thoroughly cleaned and disinfested often and at least between each seed lot. Thorough cleaning and sanitization of cutting equipment should be done every day at a minimum when seed lot changes do not occur. More frequent cleaning and sanitation may be necessary depending on the quality of seed. Mechanical cutters rarely eliminate the need for some human labor to remove the undersize pieces and hand-cut the excessively large seed pieces.

Blocky seed pieces are desired. Cutting of long-tuber cultivars with a machine designed or adjusted for round cultivars will result in long slender seed pieces with too much cut surface area. A large cut surface provides a greater hazard for seed piece decay if environmental conditions are favorable for decay organisms after cutting. Growers should periodically take samples and determine the average seed piece size. When evaluating the sample for size, the number of chips or slivers, blind seed pieces (no eyes), and other non-usable seed pieces should be noted. The cutter should be adjusted to deliver optimal seed piece size and shape.

The distribution of seed piece sizes should also be evaluated. A distribution which has most of the seed pieces within the 1.5 to 3.0 oz (43 to 84g) size range will result in the best planter operation and will give the best economic return. Seed pieces less than 1.0 oz (28 g) should be discarded with a “sliver eliminator” and the cutter should be adjusted to minimize the number of seed pieces over 3.5 oz (99 g).

Suberization of seed prior to planting has repeatedly been shown to be as effective at minimizing seed piece decay as various seed treatments. Sharp knives are important to ensure a clean cut that will promote rapid development of the closing layer on cut surfaces of the seed piece. Suberization is promoted by: 1) holding the cut seed pieces 3 to 5 days at 55°F (12.8°C), 2) maintaining relative humidity at least 85 percent but no free water, 3) ventilation of 1 cfm/cwt to promote rapid drying of cut tuber surfaces, and 4) an oxygen rich environment. Failure to provide any of these conditions can lead to seed piece decay. Seed pieces which are blocky and well healed are as sound as whole seed tubers. Cultivars susceptible to seed piece decay should be suberized prior to planting.

Potato seed should not be exposed to hot sun or wind for even a short time or they will severely shrivel and may decay, especially cut seed that has not been suberized. Covering loads of seed pieces with a canvas during transport is recommended. If planting is delayed, hold seed pieces in a potato storage facility with good air circulation, high humidity, and temperature control to maintain good quality.

Seed potatoes should never be put into used fertilizer bags, bulk boxes, or other containers where fertilizer or pesticide residues are present, as damage to the seed may result. All vessels used for storage, transport, handling, etc. should not be treated with sprout inhibitors. In addition, all vessels should be thoroughly cleaned and sanitized before being filled with seed. If vessels are used to hold or transport seed more than once, they should be cleaned and sanitized between each use.

Dormancy and Sprout Status

Dormancy is explained many ways, but can be loosely defined by the regulation of bud development on potato tubers. Dormancy must be broken for buds on seed pieces to begin sprouting. Tubers differ in their dormancy and this can influence the rate of stand establishment and crop emergence. Seed of more dormant cultivars may need to be warmed for a longer period prior to planting to ensure good stand establishment. Correspondingly, less dormant cultivars may need specialized management to prevent excessive sprouting prior to planting.

Typically, U.S. potato growers try to minimize sprouting prior to planting seed. The first sprouts to develop by a seed tuber are the most productive. Sprouts that form on seed prior to cutting or planting are typically damaged by handling. In extreme cases, large sprouts must be removed to minimize interference in the operation of planting equipment. If sprout removal is necessary, it should be done only once as repeated sprout removal will increase the physiological age of the seed, thereby, adversely affecting seed performance. Some growers physiologically age seed and de-sprout or purposely cause physical damage to increase stem number and tuber set per plant. Caution must be used to not excessively damage the seed due to the potential to reduce vigor.

Seed Treatment for Disease Control

The need for seed piece treatment varies from region to region. Numerous studies have been performed to evaluate seed piece treatment. Seed treatments primarily affect disease pathogens present on the surface of tubers, but only minimal prevention of transmission of virus or growth of bacteria. Seed treatments are applied as a powder, dust or as a liquid. There may be some benefit from the drying action of a powder or dust on a fresh-cut seed piece surface. Seed treatments also provide some protection from invasion of the seed pieces by soil inhabiting organisms, and thus, may result in a reduction of seed piece decay following planting. Seed treatment is not to be considered a cure for poor seed handling or for a poor seed environment, either before or after planting.

Planting the Crop

(Mark Pavek)

Time of Planting

Planting time varies considerably from region to region depending on local climatic conditions, potato cultivar, and intended market use. The major portion of potatoes grown in the northern tier of U.S. states and bordering provinces in Canada are planted from April to early June. Southern states typically plant from November to February while middle-zone states typically plant during March and April. In general, potatoes should be planted when the soil temperature is higher than 45°F (7°C) and lower than 70°F (21°C). At the time of planting, soils should be moist but not excessively wet. In irrigated desert areas, it is common to irrigate prior to planting to add moisture to dry soils. Planting into soils that are excessively cold, hot, wet, or dry may increase the potential for seed piece decay. Within reasonable limits, the early establishment of a crop may increase yield and dry matter potential. In regions where the growing season length doesn't limit the plant's ability to fully mature, planting dates are often selected in an effort to provide the crop with a growing environment that will produce the highest economic yield for the desired market.

Seed Piece Spacing

Potato seed piece and plant spacing often influence how large the average tuber size will be upon maturity. Along with marketplace knowledge, the right combination of environment, growing conditions, cultivar, and seed piece spacing is essential for maximizing economic yield. The primary factors that dictate potato seed piece spacing are consumer demand, market needs, and the associated economic return to growers and marketers. Other important and often growth-limiting factors include, season length, cultivar, irrigation and nutrient availability, and soil type. Row widths generally range from 30 to 36 inches (76 to 91 cm), although both wider and narrower rows are used. In-row seed piece spacing is routinely adjusted by growers in an effort to produce the most valuable tuber size profile for the intended market. Because growing conditions and market needs vary from region to region, seed piece spacing requirements for particular cultivars are not consistent across regions. In-row spacing generally ranges from 6 to 14 inches (15 to 35 cm). In-row spacing between 9 to 11 inches (18 to 23 cm) is probably most common. Cultivar characteristics like tuber number per plant (tuber set), average tuber size profile, and days to reach maturity need to be defined prior to selecting the seed piece spacing. To reduce oversized tubers, cultivars with a low tuber set that tend to produce oversized tubers should be spaced closer together than those with a high tuber set, and vice versa. Wider in-row spacing may be used to increase average tuber size when growing late-maturing cultivars in season-limiting regions. Closer in-row spacing may be more desirable when season length, moisture, and nutrients are not expected to be limiting. Excessively large tubers may develop defects such as hollow heart, knobs, and growth cracks. Reducing the in-row spacing to minimize oversized tuber production may lead to higher quality tubers.

Depth of Planting

The proper planting depth positions seed pieces, stems, roots, and tubers in the most favorable season-long growth environment while allowing tubers room to expand and mature under a protective layer of soil. Because there are moisture and temperature differences throughout a soil profile, planting depth can strongly influence emergence rate. This is because the shallower soil generally accumulates more heat-units between planting and emergence. In addition, there is less soil for sprouts to travel through prior to breaking through the soil surface. However, if the soil is too dry or the temperatures are extremely high, a deeper planting depth with greater soil moisture and less heat may prove to be superior. Rapid sprout emergence can promote early-season disease resistance in potato shoots and stems. Moreover, rapid emergence allows plants to capture solar radiation earlier in the season, which is important for optimizing final tuber yield and dry-matter content.

Often a balance must be struck between rapid sprout emergence and the late-season space requirements of expanding tubers. If high yields and large tubers are expected, a deeper planting depth and a wide hill may provide a more favorable environment for mature tubers than a shallow planting depth. A favorable environment for mature tubers provides a protective layer of soil that limits tuber greening caused by exposure to the sun, and protects the tubers and roots against temperature and moisture extremes throughout the season.

Concerns regarding shallow planting depths may include reduced early-season moisture to plants and lower marketable yields due to an increase in undersized, green, and surface exposed tubers. Deeper planting depths may provide better soil moisture, less green and surface-exposed tubers, and occasionally, larger tuber size and higher market yields. Drawbacks of deeper planting depths may include delayed plant emergence and development, yield reductions, and a likely increase in soil volume that harvesters would have to lift.

In certain locations, growers "drag off" the planting ridge by removing the tops of the ridges before potato plant emergence as a weed control measure as well as to enhance emergence. When planting ridges are shaped to the grower’s desire during planting and effective pre-emergence herbicides are used, this practice is not needed. Ridging or hilling as the plant develops is usually practiced to enhance stolon development, prevent tuber greening, and facilitate harvest. Ridges or hills are sometimes built up gradually in two or more tillage operations or it may be done in one. In some low and flat areas in humid regions, it may be desirable to place the seed at a level above that between the rows. This is done to protect the seed pieces from excess water which may stand on the surface because of poor or slow drainage.

Planters

Two general types of potato planters (Figure 12a) are most frequently used in commercial potato production: automatic cup (Figure 12b) and pick type planters (Figure 12c). Pick planters operate on the principle of forcing nail-like picks into the seed piece to carry it out of the filling reservoir and then dropping it into an open seed furrow. The punctures made in the seed piece can result in the spread of disease and can provide an entry for decay organisms. The picks must be straight, sharp, and properly spaced to obtain desired seed piece spacing. Pick length and arrangement should be adjusted to the seed size to prevent skips or multiple plantings.

Figure 12a. Semi-mounted potato planters are used widely. Potato planters come in two-, four-, six-, or eight-row units. Picker-arm and cup-type planters are the most popular (left). (M. Pavek)

Figure 12b. Cup-type planter. (S. Johnson)

Figure 12c. Pick-type planter. (S. Johnson)

Cup-type planters use a cup device to convey the seed to the soil. Some cup-type planters incorporate a vacuum system which assists in picking up and dropping the seed pieces at the proper time. Seed pieces are not punctured with this type of planter. The size of seed pieces must be nearly uniform to obtain optimum spacing. These planters are well adapted for use with whole small seed tubers.

Seed spacing and uniformity of spacing is a function of properly designed, maintained, and operated planters, seed piece size and shape, seed depth in the planter seed reservoir, and planting speed. Planters need to be in excellent operating condition before the planting season begins. Planter mechanisms should be regularly inspected throughout the planting season and the equipment should be properly cleaned and stored after planting is through.

Seed piece size and shape greatly influences planter performance regardless of the type or make of planter used. Use of blocky cut seed pieces and/or uniformly sized whole seed enable the planter to more nearly achieve uniform, accurate seed piece spacing. Pick length and arrangement or cup diameter and chain or belt vibration should be adjusted for the type and size of seed being planted.

The depth of seed in the picker or cup reservoir should be at a level so all picks or cups leaving the reservoir should have a seed piece on them. Generally, the reservoirs should be approximately three-quarters full. Having the reservoir too full or not full enough results in poor and erratic seed piece spacing.

Planter speed also affects seed piece distribution. Planting too fast or too slow will give undesirable results. The optimal planting speed is a function of planter operation and seed piece size and shape.

There is considerable variation between planters, seed lots and field conditions. Regular checks of seed distribution within the planted row are required to achieve the desired spacing. Seed piece placement by each planter unit should be inspected routinely. Precise placement of seed at the desired spacing is essential to optimize tuber size distribution and yield and requires considerable management input. Every effort should be made to have the distribution as uniform as possible by altering planter speed and making appropriate mechanical adjustments.

Amount of Seed to Plant

The amount of seed needed to plant an acre (hectare) varies according to seed piece size, distance between rows, and seed piece spacing within the row. Table 17 shows the seed amount required for several spacings and seed piece sizes. Growers should strive for plant populations that are optimum for their area, growing conditions, cultivar and market.

Table 17. Seed potatoes required to plant an acre at different spacing with seed pieces of various weights.

	Seed required per acre when seed pieces weigh an average of:			
Spacing of rows and of seed pieces within rows	**1 1/2 oz (43 g)>**	**1 3/4 oz (50 g)**	**2 oz (57 g)**	**2.25 oz (64 g)**
	----------cwt/a (kg/ha)[1]----------			
Rows 30 in (0.76m) apart				
6 in (15.2 cm)	32.7 (3659)	38.1 (4269)	43.6 (4879)	49.0 (5488)
8 in (20.3 cm)	24.5 (2744)	28.6 (3202)	32.7 (3659)	36.8 (4115)
10 in (25.4 cm)	19.6 (2195)	22.9 (2561)	26.1 (2927)	29.4 (3293)
12 in (30.5 cm)	16.3 (1830)	19.1 (2134)	21.8 (2439)	24.5 (2744)
14 in (35.6 cm)	14.0 (1568)	16.3 (1830)	18.7 (2091)	21.0 (2352)
Rows 32 in (0.81 m) apart				
6 in (15.2 cm)	30.6 (3430)	35.7 (4002)	40.8 (4574)	45.9 (5146)
8 in (20.3 cm)	23.0 (2573)	26.8 (3001)	30.6 (3430)	34.5 (3859)
10 in (25.4 cm)	18.4 (2058)	21.4 (2401)	24.5 (2744)	27.6 (3087)
12 in (30.5 cm)	15.3 (1517)	17.9 (2001)	20.4 (2287)	23.0 (2573)
14 in (35.6 cm)	13.1 (1470)	15.3 (1715)	17.5 (1960)	19.7 (2205)
Rows 34 in (0.86 m) apart				
6 in (15.2 cm)	28.8 (3229)	33.6 (3767)	38.4 (4305)	43.2 (4843)
8 in (20.3 cm)	21.6 (2421)	25.2 (2825)	28.8 (3229)	32.4 (3632)
10 in (25.4 cm)	17.3 (1937)	20.2 (2260)	23.1 (2582)	25.9 (2906)
12 in (30.5 cm)	14.4 (1614)	16.8 (1883)	19.2 (2152)	21.6 (2421)
14 in (35.6 cm)	12.4 (1384)	14.4 (1614)	16.5 (1845)	18.5 (2076)
Rows 36 in (0.91 m) apart				
6 in (15.2 cm)	27.2 (3049)	31.8 (3557)	36.3 (4066)	40.8 (4574)
8 in (20.3 cm)	20.4 (2287)	23.8 (2668)	27.2 (3049)	30.6 (3430)
10 in (25.4 cm)	16.3 (1830)	19.1 (2134)	21.8 (2439)	24.5 (2744)
12 in (30.5 cm)	13.6 (1525)	15.9 (1779)	18.1 (2033)	20.4 (2287)
14 in (35.6 cm)	11.7 (1307)	13.6 (1525)	15.6 (1742)	17.5 (1960)

[1]Converting between cwt/a (cwt = 100 lb) and kg/ha may not be exact because of rounding of numbers.

GROWING THE CROP

Crop growth is affected from the time of planting until harvest. Fertilization, cultivation, rainfall and/or irrigation, and weed, insect, and disease control all have an influence on the crop growth.

Cultivation

(Joseph Sieczka)

The purpose of cultivation includes maintaining proper soil aeration, shaping beds to allow space for maximum tuber growth and minimize tuber greening, establish irrigation furrows, and control weeds. If a cultivation operation does not accomplish one of these purposes, the operation is a waste of effort. The kind and amount of cultivation will depend on the planting method, kind and severity of weed infestation, irrigation method used, and to a lesser extent, the potato cultivar grown.

If potatoes are planted in such a manner as to leave the field quite flat, one or more post-planting bed shaping or hilling may be necessary. If potatoes are planted into pre-made beds or if beds are formed at planting, bed (hill) shaping may be the only cultivation necessary. The implements used for shaping hills vary considerably, but when used properly, all can form acceptable beds (Figure 13). No matter what type of cultivating or hilling implement is used, tillage should not take place in wet soils. Working wet soils results in compaction and clods that will present problems at time of harvest.

Figure 13. Beds being made with one pass of a cultivator. Weeds are also being controlled with this operation.
(S. Johnson)

Working the ground to aerate the soil should be practiced only if the grower is certain the benefits from aeration will more than offset the compaction in the furrows that results from the operation.

Some cultivars tend to set tubers higher in the beds than others. To prevent tuber greening from exposure to sunlight, additional soil may be required to cover the tubers. However, late cultivation can also be harmful due to root and stolon pruning.

Cultivation can be a very effective method of weed control. The principal benefits come from post-plant, pre-emergence cultivation to kill early emerging weeds and cultivation during the first 30 to 40 days after emergence to control weeds in the furrows and on the sides of the beds. Thereafter, shading and herbicides must be depended upon for weed control.

Water Requirements and Irrigation

(Clinton Shock)

Water management and/or rainfall are among the most important factors determining yield and quality of potatoes. Knobby tubers, growth cracks, internal necrosis, black spot, hollow heart, heat sprouting, and other disorders are directly related to amount and distribution of water during the growing season. Diseases such as seed piece decay, Rhizoctonia stem canker, tuber late blight and other problems can be related to excessive amounts and poor distribution of water. Factors to consider are the water application method (rainfall, sprinkler irrigation, furrow irrigation, drip irrigation, or sub-irrigation), irrigation scheduling, and irrigation amount.

Specific guidelines for irrigation cannot be given here because of the wide diversity of rainfall, temperature, and soil conditions under which potatoes are grown. State and local agencies provide region-specific guidelines. However, many general guidelines are pertinent to all potato-producing areas.

In the eastern one-half to two-thirds of North America most of the potato producing areas usually receive substantial amounts of rainfall during the growing season. Most of the areas in the western one-third to one-half of North America, except the northernmost coastal areas, rely on some type of irrigation to assure the tuber yield and quality are acceptable.

While the amount of water required for optimum growth of potatoes varies somewhat with cultivar, relative humidity, solar radiation, day length, length of growing season, and other environmental factors, the seasonal requirement for cultivars in all areas will be at least 18 inches (460 mm) of water. As much as 30 to 36 inches (760 to 910 mm) of water are required in some specific production areas depending on soil type, climatic conditions, and potato cultivar. Water should be applied to the soil frequently in light amounts to maintain the crop with an adequate water supply throughout all growth stages of the crop, particularly during tuber initiation and tuber enlargement.

For irrigation scheduling decisions, the following considerations should be kept in mind: 1) the effective rooting depth of potatoes is 2 ft (0.6 m), 2) the soil should not be allowed to dry below 65 percent of field capacity, 3) moisture levels above field capacity will seriously affect yield and quality, and 4) soil types can vary threefold in their respective water holding capacities. Precise criteria for irrigation scheduling have been specified in units of soil water potential (cbar = kPa) for many climates and soils.

Studies in several different growing areas have shown that daily water needs increase rapidly from emergence until about two weeks after row closure. From this time the potato plants' daily water requirements remain nearly constant until the vines begin to mature, at which time water requirements decline rapidly.

The amount and rate of water that should be applied during irrigation is dependent on the infiltration rate and water holding capacity of the soil, as well as on the amount of water already present in the soil profile, and plant growth stage, including depth of rooting. The amount of runoff can be minimized, if not eliminated, by accurate determination of infiltration rates into the soil profile and adoption of irrigation practices that apply water at a rate compatible to the rate the soil can absorb it at a given site.

The amount of water transpired by plants plus the water evaporated by the soil plus the fraction of water held by the vegetative tissues is referred to as consumptive use or a crop's water requirement. The amount of water retained by the plant's metabolic activity is 1 percent of the overall water taken up by plants. Thus, in practical terms crop water consumption corresponds to crop evapotranspiration (ET_c). Potato ET_c can be estimated using weather data and is the amount of water to be replenished during the growing season to assure that tuber yield potential is realized. Potato ET_c is a well-developed strategy to improve the effectiveness of irrigation. It is important to consider potato ET_c in irrigation scheduling.

Where rainfall is the major source of moisture, water use efficiency can be improved by not planting on steep slopes, by properly preparing the soil so infiltration is enhanced, and by forming small ridges periodically in the furrows ("dammer-diker", Figure 14) to reduce the speed of the water running down the furrows.

Figure 14. A dammer-diker used to make small basins between potato rows to prevent water from running off the field.
(W. Bohl)

Where irrigation is used, several methods are usually available. The most common systems are center pivot sprinkler irrigation, solid set sprinklers, wheel line sprinklers, hand-move sprinkler systems, furrow irrigation and sub-irrigation.

Sub-irrigation is a method used in peat-like soils or other soils where the water table can be easily raised. For this to be a suitable method, fields must be relatively level and soils uniformly porous. Otherwise, excessively wet and excessively dry areas will occur in the same field, impairing the development of the crop resulting in negative impacts on potato yield and grade.

Furrow irrigation can be efficiently and effectively used in fields with little slope (0.3-1.5%) and where the length of rows is not too long [600-1320 feet (182-402 m)]. Care must be taken to ensure that water is not applied at rates that will cause excessive run-off or nitrate leaching. Uniform application rates from one end of the row to the other are more difficult to achieve with this method than with sprinkler irrigation.

Sprinkler irrigation systems often provide the most flexibility and the best opportunity of efficient water application (Figure 15).

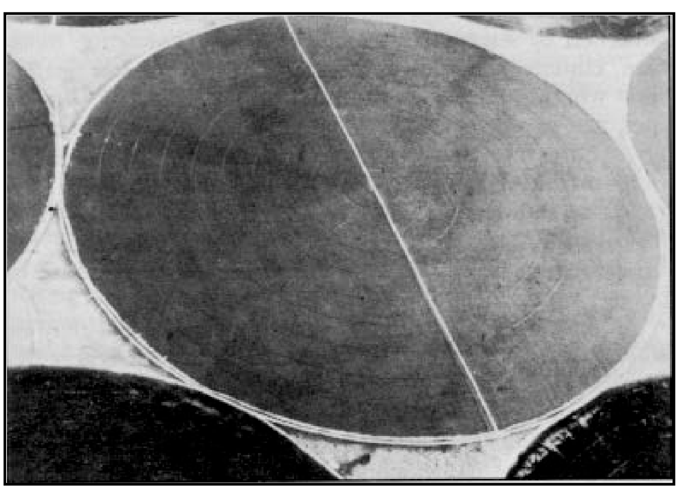

Figure 15. Aerial view of a center pivot or "circle" sprinkler irrigation used widely for potato irrigation. Acreage covered by each unit varies from as small as 20 acres to over 200 acres.

Fields need not be flat and application rates can be adjusted through variable nozzle size, pump pressure, and nozzles spacing. Sprinkler irrigation can also be used to apply (Figure 16) some fertilizers and pesticides as long as the equipment has appropriate safety back-flow devices and operators are licensed to apply products through a sprinkler system. Several studies have shown economic advantages of sprinkler irrigation over furrow irrigation. Today, most of the irrigated acreage of potatoes in North America are by one of the sprinkler systems.

Figure 16. A center-pivot sprinkler irrigation system applying water.
(W. Bohl)

Potato Nutrition

(Bryan Hopkins and Jeffrey Stark)

Importance

Proper nutrition is crucial in determining potato yield and quality, as well as the potato plant's ability to withstand pest, environmental, and other stresses. There are 17 nutrients essential for plant growth. Three of these are non-mineral elements (carbon, oxygen, and hydrogen) and are supplied primarily through air and water. The remaining mineral nutrients are derived primarily from the soil and added fertilizers (Table 18).

Table 18. Mineral plant nutrients and their uptake/removal amounts.[1]

Nutrient	Uptake (whole plant)	Removal (tubers)
	---pounds of nutrient for a 500 cwt/acre crop---	
Primary Macronutrients		
nitrogen (N)	200-300	150-250
phosphorus (P[2])	30-40 (69-92 P_2O_5)	25-35 (58-81 P_2O_5)
potassium (K[3])	220-320 (264-384 K_2O)	220-320 (264-384 K_2O)
Secondary Macronutrients		
sulfur (S)	18-30	15-25
calcium (Ca)	50-75	2-15
magnesium (Mg)	40-50	5-15
Micronutrients		
zinc (Zn)	0.3-0.4	0.1-0.2
manganese (Mn)	1-2	0.1-0.3
iron (Fe)	5-10	1-2
copper (Cu)	0.02-0.09	0.01-0.02
boron (B)	0.12-0.18	0.01-0.03
chloride (Cl)	30-120	5-30
molybdenum (Mo)	<0.01	<0.01
nickel (Ni)	<0.01	<0.01

[1]Based on various data with *Russet Burbank, Ranger Russet,* and *Shepody* cultivars in semi-arid zone soils. Other cultivars and soils would have varying nutrient uptake and removal, but these levels provide an approximation.
[2]The chemical symbol for phosphorus is P, but it is expressed as P_2O_5 in the fertilizer industry. Convert from P to P_2O_5 by multiplying by 2.3.
[3]The chemical symbol for potassium is K, but it is expressed as K_2O in the fertilizer industry. Convert from K to K_2O by multiplying by 1.2.

Although the indigenous minerals in soils have varying quantities of these essential nutrients, crop removal can deplete them over time. In addition, the soil physical, chemical, and biological properties result in conditions that affect nutrient availability to plants. Therefore, addition of readily plant available nutrients is necessary for optimal potato production. These nutrients can be added as commercial fertilizer and/or other soil amendments (such as manure or compost). Nitrogen can also be supplied from legumes as a previous crop.

Many cultivated soils have high fertility levels and, as a result, a single year without fertilization may result in no or only minor yield and tuber quality reductions. However, yield reductions will dramatically occur over time if soil fertility levels are continually depleted.

Tuber quality is also significantly affected by plant nutrition. Phosphorus deficiency and nitrogen or potassium excesses can decrease specific gravity. Excess nitrogen can delay tuberization and slow skin development at maturity. Vines with excessive nitrogen can create an environment more conducive to infection by certain pathogens. Growth disruptions, due to fluctuations in nitrogen supply, can cause misshapen tubers, brown center, and hollow heart. Potassium deficiencies can result in increased black spot bruise at harvest, darkened fry color, and storage problems. Calcium deficiency has been associated with internal brown spot. These are only a few of the major and well documented tuber quality problems caused by nutrient deficiencies and excesses. However, there are many more nutrient management factors that affect potato yield and quality.

The primary macronutrients found in Table 17 are needed in large quantities and are deficient in most soils. The secondary macronutrients are also needed in large quantities, but are more commonly found at adequate concentrations in the soil. In contrast, the micronutrients are needed in very small quantities. Some micronutrients are commonly deficient in soils, despite the low quantity needed, and need to be added as fertilizer.

Alternatively, excessive macro- or micro-nutrient concentrations, as well as those of other elements or compounds, can be detrimental to plants due to direct toxicities or induced imbalances with other nutrients. Unnecessary fertilization also squanders time, money, and natural resources and can be potentially damaging to the environment.

Determining Base Fertilizer Recommendations

The amount of each nutrient that should be applied to a potato crop depends upon a combination of factors, including: yield potential, residual amount of each nutrient in the soil, nutrient concentrations in the irrigation water, amount and type of previous crop residues, amount and type of manure, composts or other slowly decomposing nutrient sources, soil texture, pest pressure, and, in the case of nitrogen, the presence of legumes in the rotation during the previous year.

Representative soil samples should be taken from each unique soil type and/or crop management zone in each field. Farmer experience, soil survey maps, soil color, cropping and fertilization history, aerial imagery of previous crops, yield map histories, and/or soil maps based on various soil sensing devices (salts, pH, etc.) can all be used as layers of information to help identify zones that may have unique soil properties.

The amount of recommended fertilizer should be based on a soil test and realistic yield expectations, with the amount of nutrient being recommended increasing with increasing yield. A yield goal is best derived from the average of the last three to five crops grown in the same field, adding approximately 5-10% to account for improving management (and possibly genetic potential) over time. Alternatively, the local average can be used in the absence of field history.

Fine Tuning the Fertilizer Recommendation

After a base rate of fertilizer is determined, it should be modified based on site-specific conditions. Credits should be given for nutrients added with irrigation water, slowly decomposing nutrient sources, and legumes. Adjustments may also need to be made for pathogens and pests, soil pH, compaction, soil texture, organic matter and climate.

Crops grown after legumes generally need less nitrogen than when following non-legume rotational crops.

Other, non-legume crop residues will also impact nitrogen nutrition and, to a lesser degree, the availability of other nutrients. In general, soil incorporation of crop residues that have high carbon concentrations, such as wheat straw or corn stalks, increase the nitrogen requirement in order to supply the microbes that feed on the carbon. Alternatively, crop residues with high nitrogen and low carbon content (such as sugar beet tops) generally release nitrogen into the soil much more rapidly and without requiring additional N application. As with soil organic matter, fertilizer recommendation tables generally account for an average nutrient release from the previous crop. Adjustments usually only have to be made for nitrogen and only in the case of large quantities of high carbon crop residue decomposing in the soil during the time that potatoes also need nitrogen.

Soil physical conditions can also have an impact on crop nutrition. In general, soils that promote deep and prolific rooting result in improved nutrient uptake. Soil compaction tends to reduce rooting depth, thereby limiting access to soil water and nutrients.

Soil pH also plays a major role in potato nutrition. Acidic soils (pH of about 6 or less) impact the solubility of some nutrients and result in reduced activity of many microbes that decompose organic matter and fix atmospheric nitrogen. Soils develop acidity as the hydrogen in water replaces leached potassium, calcium, and magnesium in the rooting zone over long periods of time. As a result, acidic soils are generally more deficient in these nutrients than alkaline soils.

Pathogen and pest pressures are additional factors affecting plant nutrition. Pathogens (such as *Rhizoctonia* spp., *Erwinia* spp., and *Verticillium* spp.) damage roots and slow nutrient uptake. Insects and nematodes that feed on roots can have similar effects. Fields with high soil borne potato pest/pathogen pressures, which are often those with a history of short rotation between potato crops, tend to result in plants with poor nutrient uptake ability.

In summary, fertilizer guides are a starting point for generating recommendations. It is up to the grower and his advisors to adjust the fertilizer recommendations to maximize profits for each field. The recommendations must account for all nutrient sources, such as previous crop residues, irrigation water, soil amendments and residual nutrients. There are also factors that will affect the plants ability to absorb nutrients, which must be accounted for, including: pathogens and pests, soil pH and salinity, and restrictive layers in the soil. Finally, there are factors over which the grower has little or no control, but must be accounted for in the management plan, such as soil texture, organic matter and climate.

Nutrient Chemistry and Sources

Nutrients taken up by plants are identical regardless of whether they originated from soil minerals, irrigation water, crop or animal residues, or commercial fertilizer. However, nutrient sources can differ in their efficiency with regard to loss potential and rate of conversion to plant available forms.

Nutrients contained in fertilizer granules must first dissolve in the soil solution before they can be absorbed by plant roots. Therefore, one of the most important characteristics of fertilizers is water solubility[1]. However, some fertilizer materials are slowly soluble or have to transform in some other way over time before they can become plant available. Similarly, nutrients contained in organic materials must be released through decomposition and enter the soil solution before plants can utilize them. There can be an advantage to application of organically bound nutrients or slow release fertilizers, if they provide adequate nutrient availability in a timely fashion. However, some fertilizer materials, such as many of the metal oxides, are so insoluble that they are extremely ineffective at supplying nutrients to plants. As long as the fertilizer is in a form conducive to plant uptake, cost and ease of application are the next most important considerations. Some nutrients are also subject to leaching or volatilization losses and the form applied may influence the loss potential.

Certain forms of nitrogen are particularly susceptible to losses. Therefore, it is important to have a rudimentary understanding of the nitrogen cycle when choosing and managing nitrogen sources. Organically bound nitrogen, such as that which is found in plant and animal proteins, has to decompose

[1] Fertilizer granules are often made with clay or other materials as carriers, which can remain intact long after the nutrients have entered the soil solution. This phenomenon often results in a false conclusion that the fertilizer was not sufficiently water soluble.

before it becomes available for plant uptake. The urea $[CO(NH_2)_2]$ form of nitrogen is one breakdown product of organically bound nitrogen. Urea converts to ammonia (NH_3) in the presence of water and the urease enzyme found in soil. Application of urea when temperatures and moisture are low slows the reaction. Conversely, warm, moist soil conditions facilitate the reaction. Ammonia gas formed from urea or applied as anhydrous ammonia fertilizer is readily lost to the atmosphere if it is on the soil surface or can escape through soil cracks. If sealed in the soil, ammonia is rapidly converted to ammonium (NH_4^+), which is not subject to loss. Under normal conditions, the ammonium is converted to nitrate (NO_3^-) within a few days. The positively charged ammonium ion is attracted to the negatively charged soil particles, but nitrate is negatively charged and, as such, is readily leached with water moving through the soil profile and potentially below the rooting zone.

In contrast to the volatilization and leaching issues with nitrogen, solubility is the primary concern with phosphorus fertilization. Most commercial phosphate sources are highly water soluble, with the phosphate readily dissolving into soil solution. Even polymerized phosphate, such as ammonium polyphosphate (10-34-0), will readily hydrolyze and convert to orthophosphate ions (PO_4^{3-}), which is the form absorbed by plant roots. Once the fertilizer enters the soil solution as orthophosphate, it is indistinguishable regardless of source. As a result, the choice of phosphate material should generally be based on price and whether a liquid or dry material is needed.

The amount of phosphate that will remain in the soil solution for plant uptake is controlled by equilibrium reactions. The high soil solution phosphorus concentrations immediately after fertilization are in excess of the equilibrium levels and, as such are not stable. As a result, calcium and magnesium phosphate precipitates form in high pH soils, while iron and manganese phosphates form in low pH soils. These precipitates result in the soil solution phosphorus concentration dropping back down to the equilibrium level. This mechanism works in reverse as plants take up orthophosphate (PO_4^{3-}) from the soil solution. The previously precipitated phosphate minerals slowly re-solubilize to bring the soil solution back up to equilibrium levels. The soil solution level will not be high enough to meet plant needs if there are not enough of these phosphate compounds in the soil. The equilibrium concentration is determined by many factors including: soil pH, mineral composition, and concentration and type of phosphate minerals in the soil. As a result of these reactions and the fact that roots do not fully explore the soil, only a small percentage of the fertilizer phosphorus is taken up by plants during the first year after application. The remainder stays in the soil, as a part of the soil's fertility reserve, for uptake in future years.

The main forms of potassium fertilizer are potassium nitrate, sulfate, or, most commonly, chloride. The potassium found in these various forms of fertilizer is identical in form and the choice of which to use should be based on price, salt effect, and the need for the accompanying nutrients. Generally, the sulfate or chloride that accompanies potassium greatly exceeds the amount needed by plants if applied as a single product. Applying a combination of products may provide the best balance of cost and nutrient supply, but the entire nutrient management plan should be considered before such a decision is made.

The sulfur from fertilizers applied in the sulfate (SO_4^{2-}) form tends to remain in the soil solution, although precipitates can form, especially at low pH. Elemental sulfur can also be used to supply this nutrient, especially in alkaline soil. Elemental sulfur has to be oxidized to sulfate before plants can take it up. This reaction is slow, taking several months or years before all of the sulfur is converted to sulfate. The benefit of elemental sulfur is that it serves as a slow release S fertilizer, as well as providing an acidifying effect in the zone around the fertilizer granule, which can improve nutrient availability in alkaline soils.

Timing and Method of Application

It is important to understand nutrient uptake patterns when trying to optimize nutrient management. Most of the early season nutrient supply comes from the seed piece. Approximately 4 to 5% of the amounts listed in nutrient removal column of Table 17 are added to the field through the seed (at a 20 to 25 cwt per acre seeding rate). Nutrient uptake from the soil is slow at first due to low demand and a limited rooting system. The rate of uptake increases dramatically as the canopy and roots develop; and then levels off as tubers approach maturity (Figure 17). Nearly half of the nitrogen and potassium and about one third of the phosphorus and sulfur are taken up by the time the leaves touch across rows. The other nutrients have similar uptake patterns.

Timing of application is most important with nitrogen. If nitrogen is applied too early, it is more subject to volatilization and leaching losses. Also, excessive nitrogen early in the season can delay tuber initiation and bulking for indeterminate varieties. For these varieties, it is generally recommended to apply 25 to 50 percent of the crop's anticipated nitrogen needs pre-emergence, with soils more prone to losses (such as sands) receiving the smaller proportion. It is best if the remaining nitrogen is applied after tuber initiation through the irrigation water, as side-dress application, or as a controlled release fertilizer. In general, approximately two thirds of the crop's nitrogen needs should be applied by 75 days after planting. Late season cultivars will take up 25 to 30 lb of nitrogen per week during bulking. Early maturing cultivars have higher early season nitrogen needs and can receive the bulk of their seasonal nitrogen requirement prior to planting and as side-dress applications.

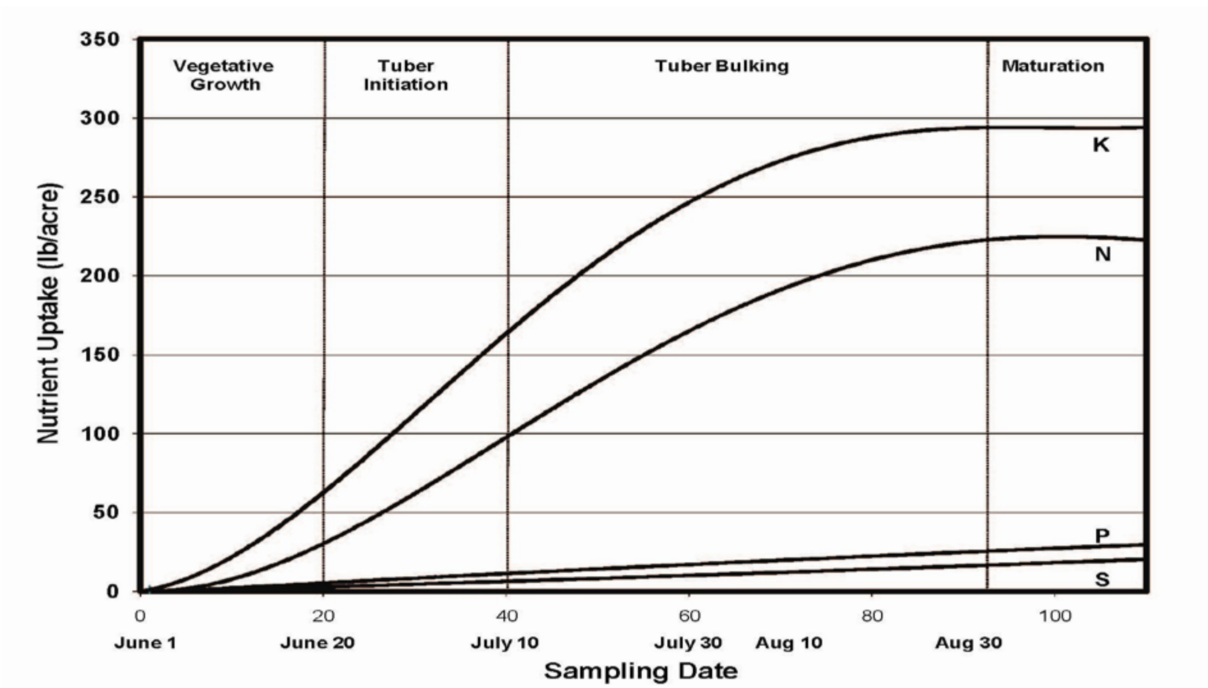

Figure 17. Uptake rates of nitrogen (N), phosphorus (P), and potassium (K) for studies performed in Aberdeen, Idaho from 1991-1993 (adapted from Stark and Westermann, 2003).

In intensively managed irrigated cropping systems, it is preferable to apply in-season nitrogen to indeterminate varieties every 7 to 10 days. Although petiole nitrogen concentrations vary by cultivar and locale, in general, the concentration should be between 18,000 and 25,000 ppm at tuber initiation, dropping by nearly one third during early bulking, and then dropping by about half or more at maturity (~10,000 ppm). Soil analysis, particularly late in the season can also be useful to determine if adequate nitrogen is available in the soil. In some cases, there is adequate nitrogen in the soil, but plants are not taking it up due to adverse environmental conditions or poor root/stem health.

Because nitrogen is mobile in the soil, method of application is not a critical issue, as long as the forms of nitrogen subject to gaseous loss are moved below the soil surface with water infiltration or mechanical incorporation. The method of application is also less important for sulfur, boron, and chloride because they are also mobile and readily move to the roots as they draw in water.

The other nutrients are less mobile in the soil and, therefore, placement is relatively important, especially for extremely immobile nutrients, such as phosphorus, zinc, and manganese. It is best if these nutrients are incorporated into the soil prior to bed formation or, less desirable, prior to final hilling. This allows for a uniform distribution of the nutrients throughout the surface soil where the majority of the roots are located. In addition to broadcasting and incorporating less mobile nutrients into the soil, applying them in a concentrated band to the side of the seed piece can improve yield and tuber quality

With regard to the timing of application of these immobile nutrients, in principle, it is best to apply them as close to the time of plant need as possible. The reason for this is that the precipitates that form become increasingly less soluble with time, even though the reduced solubility is often not very measurable in terms of nutrient availability over a few months. Although it is best to soil incorporate the immobile nutrients, they can be foliar-sprayed or injected in the irrigation water if petiole samples indicate deficiency. Application of phosphorus, potassium and most of the secondary nutrients and micronutrients is not as efficient as soil incorporation, but it has been shown that these nutrients can be taken up by surface feeding roots once they proliferate near the soil surface after canopy closure.

Although potassium, calcium, magnesium are more mobile than phosphorus, they will generally not move more than a few inches annually in most soils. Therefore, placement in most soils is also important, with application prior to final ground preparation being preferable. However, these nutrients will move more readily in sandy soils and, in this case, in-season application may be more effective.

Weed Control

(Pamela J. S. Hutchinson)

Weeds compete with potatoes for light, water, and nutrients, and can cause harvest interference. In addition, weeds may host other pests such as insects, nematodes, and common potato pathogens. An effective weed control program takes into account the primary weed problem, cultivation effectiveness and impacts, available herbicides, the competitive ability of potato cultivars, crop rotation, and herbicide mode-of-action rotations. A coordinated control plan including all crops in the rotation, not just potatoes, will help maximize weed control, minimize herbicide carryover potential, and reduce selection for resistant weeds.

An integrated weed management plan makes use of all tools available for weed control. Planting competitive crops in rotation such as winter wheat, winter canola, barley, or alfalfa, and using certified seed to maintain vigorous, competitive crop growth are examples of tools in an integrated approach. Irrigating after harvest of short season crops like small grains or canola, promotes weed seed and volunteer grain germination and emergence and the seedlings and volunteers can then be controlled with tillage or herbicides in the fall.

Although weed problems can be quite specific to given production areas, they may be categorized into three main classes: annual broadleaf weeds, annual grasses, and perennials. Broadleaf annuals, with the exception of nightshade (*Solanum* spp.), are usually the easiest to control. The most widely distributed broadleaf weeds of concern in potato fields are: hairy nightshade (*Solanum sarrachoides* Sendtner or *Solanum physalifolium* Rusby), common lambsquarters (*Chenopodium album* L.), redroot pigweed (*Amaranthus retroflexus* L.), kochia (*Kochia scoparia* (L.) Schrad.), ragweed (*Ambrosia artemisiifolia* L.), and Pennsylvania smartweed (*Polygonum pensylvanicum* L.). Annual grasses such as barnyardgrass (*Echinochloa crus-galli* [L.] Beauv.), foxtail (*Setaria* spp.), wild oat (*Avena fatua* L.), and fall panicum (*Panicum dichotomiflorum* Michx.) may germinate later than most broadleaf annuals. Because of the later germination, a pre-emergence herbicide with residual activity or an effective herbicide that can be applied after potato emergence is needed for control of these weeds.

The most difficult weeds to control are the perennial weed species. The major perennial problem weeds include nutsedges (*Cyperus* spp.), quackgrass (*Elytrigia repens* (L.) Nevski), and Canada thistle (*Cirsium arvense* (L.) Scop.). In addition to causing yield reduction and decreasing harvest efficiency, rooting structures of perennial grasses and nutsedges can penetrate potato tubers causing severe reduction in quality. When perennial weeds are the primary problem, more than the standard number of tillage operations may be needed for effective weed control even though herbicides are used. Perennial weed control may be more effective and economical in crops rotated with potatoes, such as winter wheat. Tillage and herbicides applications can be made post-wheat harvest in the late summer or early fall. Control measures may be more effective at this time since movement into the root system is occurring in these perennial weeds in preparation for winter. Sanitary precautions should be used so that weed rhizomes/rooting structures and seed are not spread from infested to non-infested fields with harvest and tillage machinery.

Potato cultivars that develop and maintain a dense canopy with early row closure can be competitive with many weeds. Weed control practices in potatoes include cultivation and herbicides, and a combination of the two is often more effective than either alone. Heavy weed infestations can require multiple cultivations. However, strict tuber quality requirements may limit the use of mechanical cultivation for weed control. Multiple cultivations can cause soil compaction which reduces aeration and potato growth, and can produce clods that bruise potatoes at harvest. Cultivation also may directly damage potato foliage and roots, reducing yield and tuber quality. In seed growing areas, cultivation after potato emergence may spread diseases. Wet soil interferes with cultivation timeliness, and in-row weed control is usually not effective.

Herbicide may be more effective than cultivation, may take less time to apply than to cultivate, and can often be applied in a single application versus multiple cultivations necessary for moderate to heavy infestations. There are environmental and safety concerns associated with herbicides, potential for crop injury, carryover, and plant-back restrictions. If herbicides are used, potato producers must select one or ones that are tailored to the kinds of weeds present, when these weeds germinate, and consider potato cultivar tolerance.

Herbicide application methods and rates should be in accordance with the manufacturer's label and local recommendations (Figures 18 a and 18b). Methods of herbicide application vary from pre-plant soil incorporation (PPI), post-plant but pre-emergence to the potato crop (PRE), to post-emergence (POST) applications. Various herbicides can be applied by ground, airplane, or through sprinkler irrigation systems. Specific herbicides, rates, and methods of applications vary throughout the United States and Canada. Soil characteristics such as texture, percent organic matter (O.M.), pH, and cation exchange capacity (CEC), often play an important role in determining appropriate herbicide rates. Most agricultural universities regularly publish specific recommendations for each area. Consult your local crop protection advisor and/or government office for specific recommendations.

Figure 18a. Potatoes growing with nearly no weed competition.
(W. Bohl)

Figure 18b (below). The use of appropriate herbicides at the proper timing and rates can help control weeds. Compare no herbicide application (left) vs. an appropriately timed herbicide application (right). (P. Hutchinson)

A combination of a timely pre-emergence herbicide application and cultivation as the weeds are germinating and emerging provides effective early season control. Many pre-emergence herbicides do not control emerged weeds. These herbicides work most effectively when applied shortly after a hilling operation that is performed just before potato emergence. Weeds emerged after planting are killed by the hilling operation and herbicides are applied to a "clean bed." Pre-emergence herbicides usually need to be incorporated into the soil 1 to 2 inches where the weed seeds are germinating. This can be done by irrigation and sometimes by tillage if adequate rainfall has not occurred after application. A few non-selective herbicides also are labeled for use before potato emergence. These herbicides control emerged weeds and have no residual activity for later-emerging weeds. Some herbicides may be applied post-emergence to the potato crop. If a given herbicide applied POST does not control emerged weeds, an herbicide effective on emerged weeds must be used in a tank mixture, or some other means of controlling the emerged weeds must be used. Care should be taken to follow POST-applied herbicides label restrictions for potato crop stage at application and post-harvest interval (PHI) after application.

Other crops in a potato cropping system may not be tolerant to herbicides used in potatoes, so crop rotation should be considered when making herbicide choices. Repeated use of an herbicide(s) with the same mode of action for killing a weed can cause selection pressure for weed biotypes naturally resistant to that mode of action. These biotypes are usually present in a given weed population in very small numbers. If susceptible weed biotypes are killed and the resistant biotypes survive, then the weed population can become dominated by the resistant biotypes. Herbicides with the same mode of action that has been used repeatedly may no longer be effective. Rotating herbicides with different modes of action from year-to-year and/or tank-mixing herbicides with different modes of action and overlapping weed control spectrums can help prevent or delay the development of herbicide-resistant weed populations.

Insect Control

(Edward B. Radcliffe)

In North America, potato is attacked by more than 150 species of insect pests. Most are of local, minor, or only occasional importance, but in each production region there are a few species that, were they not routinely controlled usually by insecticides, would consistently cause unacceptable losses of yield or tuber quality. These losses can result directly from damage inflicted by the insects or indirectly as the result of transmission of pathogens such as viruses.

Many insect pests are potential vectors of potato pathogens. This association can be casual with the insect serving as a mechanical vector or providing an entry for invasion by pathogens present in the environment. Of greatest importance are those species where the insect is the principal or sole means of pathogen transmission. It has been observed that aphid-transmitted viruses cause greater economic losses to the potato industry than all other insect related damage put together. At least 9 potato viruses are aphid-transmitted, but the most important of these are potato leaf roll virus (PLRV) and potato virus *Y* (PVY).

Green peach aphid, (*Myzus persicae* Sulzer), is the most efficient and in North America the only consequential vector of PLRV, but several other species can transmit this virus including potato aphid, (*Macrosiphum euphorbiae* Thomas), buckthorn aphid, *(Aphis nasturtii* Kaltenbach), and melon (cotton) aphid, (*Aphis gossypii* Glover). PLRV is only transmitted by aphids that colonize potato and not by all colonizing species. PLRV is found almost exclusively in phloem tissues and most abundantly in companion cells, hence, potential vectors must feed in the phloem to acquire the virus. PLRV is transmitted in a circulative and persistent manner. Because there is a substantial lag (approximately 24 to 36 hr.) between PLRV acquisition and onset of transmission capability, insecticide use can limit within field spread of PLRV.

All other aphid-transmitted potato viruses are transmitted in a non-persistent manner. These viruses are stylet-borne and thus can be acquired and transmitted in “host-tasting” probes of a few seconds duration. Insecticides are essentially useless in interrupting the transmission of such non-persistently transmitted viruses. Many aphid species are capable of transmitting PVY. Green peach aphid is the most efficient vector of PVY, but the greater abundance of some less efficient vector species, or their propensity to develop winged adults, can make them more important in PVY epidemiology. Most potential PVY vectors have only transient association with potato, alighting and probing, but not colonizing. Aphid species implicated as important PVY vectors include potato aphid, pea aphid, (*Acyrthosiphon pisum* Harris), melon aphid, buckthorn-potato aphid, soybean aphid, (*Aphis glycines* Matsumura), and several species of cereal aphids with bird cherry-oat aphid, (*Rhopalosiphum padi* L.) being one of the most important.

Potato is attacked by numerous leaf-feeding insects, the best known and most destructive being Colorado potato beetle. Plant damage inflicted before tuber-bulking delays haulm and tuber growth rates but the plants generally recover, whereas damage during tuber-bulking permanently reduces growth rates indicating decreased assimilation efficiency.

Colorado potato beetle overwinters as an adult in the soil and typically completes 1 to 2 generations a year. Even where two generations are the rule, a significant portion of newly emerged summer generation adults burrow directly into the soil and enter diapauses (rest). Photoperiod at time of emergence from pupation is critical in determining onset of diapause in summer adults. Emergence in spring usually occurs before potatoes have emerged. Eggs are laid in masses of 20 or more. At constant temperatures, development is optimal at 28ºC, with the beetle going from egg to adults in as little as 21 days. At optimal temperatures, larval development can be completed in as few as 7 days. There are four larval instars, with 75 percent of total foliage consumption by larvae occurring in the final instar (Figure 19). Colorado potato beetles are voracious feeders and complete defoliation and even haulm destruction can result. Fourth instar larvae consume more than 500 mm^2 of foliage per day and adults from 130 to 1200 mm^2. Colorado potato beetle is notorious for its capacity to develop resistance to insecticides. Resistance has been reported in this species to at least 41 different insecticides, representing all major classes of synthetic insecticidal classes including the neonicotinoids, the current insecticide class of choice for Colorado potato beetle control. Crop rotation has been shown to be effective in delaying establishment of Colorado potato beetle in new plantings.

Figure 19. Colorado Potato Beetle - Larvae are the most destructive, however, high populations of overwintering adults can cause damage to emerging potato plants.
(S. Johnson)

Insects with piercing-sucking mouthparts damage potatoes by direct physical injury, extracting phloem, injecting toxic saliva and transmitting pathogens or facilitating their establishment on the host. While potato has considerable ability to compensate for early season loss of foliage by defoliators, there is little compensation for adverse effects on plant health, e.g., disruption of nutrient transport, reduced photosynthetic efficiency, or infection with plant pathogens. Direct physical injury by sap-feeding insects often results in premature leaf senescence.

Potato leafhopper is a consistently important potato pest in central and eastern North America, but its destructive potential was not fully appreciated until introduction of modern synthetic insecticides. Potato leafhopper overwinters in a permanent breeding area along the Gulf Coast. In spring, flying adults are caught in updrafts and transported north on upper level airstreams. Influxes of leafhoppers into the North Central States are associated with southerly winds of 36 hours or more duration and precipitation in the fallout area. Yield loss in potato can occur before visual symptoms of potato leafhopper damage are obvious. Damaged plants show large increases in respiration that deplete photosynthates required for haulm and tuber development. These initial effects are reversible if leafhoppers are controlled before leaf tissue is destroyed ("hopperburn"), but any impairment of photosynthetic efficiency is irreversible. Hopperburn affects plant biomass accumulation by reducing green leaf area and efficiency of solar radiation capture. Potato is most susceptible to damage by leafhopper in early tuber-bulking.

Other leafhopper species are important potato pests not because of any direct feeding injury, but because they transmit disease causing phytoplasma (Class Mollicutes), formerly known as mycoplasma or mycoplasma-like organisms. Various phytoplasma occur on potato and these are difficult to separate or group. In North America, aster leafhopper (*Macrosteles quadrilineatus* = *fascifrons* Forbes) transmits a phytoplasma belonging to the aster yellows complex that causes potato purple-top wilt, "purple top."

Potato psyllid, [*Bactericerca* (= *Paratrioza) cockerelli* (Sulc) (Psyllidae)], occurs throughout the western U.S. and is of greatest economic importance in the Mountain states. In potato, the primary diagnostic symptoms of this disorder include stunting, increasing chlorosis, basal cupping and erectness of leaflets, reddish coloration of new foliage and aerial tubers. Progress of psyllid yellows can be interrupted and even reversed if psyllid infestations are controlled early. Only the nymphs cause psyllid yellows.

Insect damage to potato roots and tubers is caused by the feeding of larval stages with adults causing little to no subterranean damage. Soil insects tend to have minor effects on yield, but can affect tuber quality. Presence of damaged tuber may necessitate post-harvest sorting, reduce saleability or market price and can create storage problems.

Wireworms, the larval stage of click beetles (*Elateridae*) are among the most destructive tuber pests. Wireworms are long lived with typical life of 1 to 3 years, so it is important to know the cropping history of a particular field. There is great local variation in which wireworm species are important. Usually no single wireworm species can be regarded as a key pest, but collectively wireworms can represent a serious problem. In many potato producing regions, relative importance of the various wireworm species has not been documented. Important genera in North America include *Limonius*, *Melanotus*, *Ctenicera*, *Agriotes*, *Hypolithus* and *Conoderus*.

In terms of its worldwide importance, no tuber pest equals the economic importance of potato tuber moth, (*Phthorimaea operculella* Zeller). Potato tuber moth damages both foliage and tubers but potential for loss is greatest in storage. Larvae entering storage in infested tubers can continue their development filling the tubers with frass and enabling entry of decay organisms. When tubers are exposed in the field, moths may oviposit directly on them. Also, partially grown larvae sometimes descend from the plant and invade tubers, particularly when the soil is dry and deeply cracked. When tuber infestations are high, the crop may not be worth harvesting as it is prohibitively time consuming to sort out infested tubers.

This chapter has mentioned only a few of the more important potato insect pests. Space did not permit comprehensive discussion of life cycles, crop damage or control. Detailed information on these topics and related aspects are available from many sources, printed and electronic. When making pest management decisions care should be exercised to ensure that the sources consulted are reliable, current and specific to the location. Managers will often find that recommended action thresholds are subjective or are situation specific. Individual judgement will be necessary. Pesticide resistance management considerations are another topic beyond the scope of this chapter, but extending the useful life of these vital production tools is something all farm managers should try to factor in their crop pest management decisions.

Disease Control

(Steven B. Johnson, Walt Stevenson, and Jeff Miller)

A potato disease is an interaction between the potato, the environment, and a pathogen that impairs productivity or usefulness of the crop. Before a potato can become diseased, several conditions must exist: a susceptible host, a virulent pathogen, and a suitable environment for survival, infection, and colonization of the susceptible host by the virulent pathogen. Diseases can be caused by fungi, bacteria, viruses, viroids, algae, mycoplasma-like organisms and perhaps more agents. Fungi, bacteria and viruses dominate the causes of potato diseases.

Fungi are complex microorganisms which are generally characterized by having thread-like vegetative growth called mycelia and reproduce by means of structures called spores. These spores can be asexually or sexually derived, and can be chlamydospores, conidiospores, sporangiospores, zoospores, ascospores, basidospores, or oospores. Fungi that attack the potato can overwinter in the soil, in or on the potato tubers, in or on potato plant debris, or in or on another host plant. Fungi that cause plant disease in potatoes can enter the plant or tuber through wounds or through natural openings such as lenticels or stomata, or by direct penetration of the epidermis. Once the fungus is inside the tuber or leaf, mycelial strands grow between the cells or directly inside the cell. Fungi are disseminated by soil movement, rain, wind, drainage water, insects, infested equipment, movement of the actual diseased portion of the plant, and nematodes.

Bacteria are single-celled organisms that do not form reproductive spores and reproduce by fission or splitting. As a generalization, bacteria survive under warm, moist conditions. Bacteria that cause disease in potatoes gain entry through wounds or through natural openings such as lenticels or stomata. Bacteria are disseminated by soil movement, rain, drainage water, insects, infested equipment, and movement of the actual diseased portion of the plant.

Viruses can be described as a nucleic acid (DNA or RNA) surrounded by a protein coat; they are not visible without the use of an electron microscope. Viruses are reproduced by the host cell. Viruses can be spread by insects, nematodes, mechanically by contact between plants or plant sap, and movement by humans.

The choice of the proper disease control method or methods should be based on an accurate knowledge of the pathogen and the disease. The best time of control can be based on the life cycle of the pathogen, the portion of the plant under attack, the method of distribution of the pathogen, as well as environmental conditions. The judicious use of pesticides should always be a last resort to alternative measures. These include use of resistant cultivars, use of certified seed, use of appropriate cultural practices, and crop rotation. Table 19 lists common diseases encountered by growers in the United States and Canada, the causal organism, whether it affects the vine, tuber, or root, the most common method of spreading the source of disease from one year to the next, and a brief comment on control.

Table 19. Reference table of some potato diseases and physiological disorders.

Name	Causal Organism	Part of Plant Affected	Means of Spread	Source of Inoculum	Control
Bacterial Brown Rot (Southern Bacterial Wilt)	Bacterium *Ralstonia solanacearum*	Tubers, plants	Soil, seed	Soil, seed	Avoid infested fields.
Bacterial Soft Rot	Bacterium *Pectobacterium carotovorum* var. *carotovora*	Tubers	Soil, tuber contact	Soil, seed	Allow tubers to suberize after harvest; dry washed potatoes; minimize wounding.
Blackleg	Bacterium *Pectobacterium carotovorum* var. *atrosepticum*	Tubers, stems	Seed, soil, mechanical	Soil, seed	Use disease-free seed; prevent wounding; treat and suberize seed pieces; warm seed.
Blackdot	Fungus *Colletotrichum coccodes*	Tubers, stems, roots	Soil	Soil, tubers	Use disease-free seed; practice crop rotation; resistant cultivars; fungicides.
Calico	Virus alfalfa mosaic virus	Vines, tubers	Aphids, seed	Seed, alfalfa, clover	Eliminate volunteer alfalfa plants; use disease-free seed; control aphids.
Corky Ring Spot	Virus tobacco rattle	Tubers	Stubby root nematode *Paratrichodorus minor*	Soil, seed	Avoid infested fields; use resistant cultivars; control nematodes.

Dry Rot	Fungus *Fusarium* spp.	Tubers	Soil, tubers	Soil, seed	Prevent wounding at harvest; treat tubers with fungicide; allow tubers to suberize and then store at low temperatures.
Early Blight	Fungus *Alternaria solani* *Alternaria alternata*	Vines, tubers	Air, water	Soil; plant debris	Spray with fungicides; practice crop rotation and sanitation. Use tolerant cultivars.
Fusarium Wilt	Fungus *Fusarium solani* var *eumartii* *Fusarium oxysporum*	Vines, tubers	Soil, seed	Soil, seed	Use disease-free seed; practice crop rotation.
Late Blight	Chromistan *Phytophthora infestans*	Vines, tubers	Air, water, seed	Seed; cull piles; volunteers	Use resistant cultivars and disease-free seed; spray with fungicides; eliminate cull piles; kill potato foliage 10 days to 2 weeks before digging.
Leaf roll	Virus potato leaf roll virus	Vines, tubers (net necrosis)	Aphids, seed	Seed (minor weed hosts)	Use disease-free seed; control aphids; use resistant cultivars; rogue diseased plants; isolate from other potatoes.
Leak	Chromistan *Pythium debaryanum* *Pythium* spp.	Tubers	Soil	Soil	Prevent harvest injury; suberize in storage; cool tubers to 40°-45°F soon after harvest; avoid poorly drained soils. Use fungicides.
Mop-Top	Virus potato mop-top virus	Vines, tubers spraing	*Spongospora subterranea* seed	Seed (minor weed hosts)	Use disease-free seed; crop rotation; use resistant cultivars; rogue diseased plants;
Mosaic	Virus potato virus Y	Vines	Aphids, seed, mechanical	Seed (minor weed hosts)	Plant disease-free seed; control aphids; use resistant cultivars; rogue diseased plants early; sanitation.

Nematode (eelworm) diseases	Nematodes:				
	Golden *Globodera rostochiensis*	Roots	Soil, tubers	Soil, seed, equip-ment	For controlling all nematodes, fumigate or treat soil with nematicides; rotate crops or fallow fields; prevent
	Potato tuber rot *Ditylenchus destructor*	Tubers	Soil	Soil	movement of material from infested fields; use nematode-free seed; use resistant cultivars.
	Root knot *Meloidogyne* spp.	Tubers, roots	Soil, tubers	Soil, seed	For golden nematodes, observe quarantine regulations
	Columbia root knot *Meloidogyne chitwoodi*	Tubers, roots	Soil, tubers	Soil, seed	
	Root lesion, or Meadow *Pratylenchus penetrans*	Tubers, roots	Soil	Soil	
Pink rot	Chromistan *Phytophthora erythroseptica Phytophthora* spp.	Tubers, roots, vines	Soil, seed	Soil	Crop rotation; tolerant cultivars; fungicides; harvest in lower temperatures.
Purple-top wilt	Phytoplasma-like organism aster yellows	Vines	Leafhoppers	Crops, weeds	Control leafhoppers.
PVA	Virus potato virus A	Vines	tubers, aphids, mechanical	Seed	Plant disease-free seed; control aphids; use resistant cultivars; rogue diseased plants early; sanitation.
PVM	Virus potato virus M	Vines	tubers, aphids, mechanical	Seed	Plant disease-free seed; control aphids; use resistant cultivars; rogue diseased plants early, sanitation.
PVS	Virus potato virus S	Vines	tubers, aphids, mechanical	Seed	Plant disease-free seed; control aphids; use resistant cultivars; rogue diseased plants early; sanitation.

PVX	Virus potato virus X	Vines	tubers, mechanical	Seed	Plant disease-free seed; use resistant cultivars; rogue diseased plants early, sanitation.
Rhizoctonia	Fungus *Rhizoctonia solani*	Stems, tubers, roots	Soil, seed	Soil, seed	Treat seed tubers; avoid planting in cold soils; disease-free seed.
Ring rot	Bacterium *Clavibacter michiganensis* subsp. *sepedonicus*	Vines & tubers	Mechanical, seed	Seed, equipment, storage	Plant disease-free seed; use whole seed; disinfect storages and equipment.
Rugose mosaic	Virus (PVY + PVX)	Vines	Aphids, seed, mechanical	Seed (minor weed hosts)	Plant disease-free seed; control aphids; use resistant cultivars; rogue diseased plants early; sanitation.
Scab, common	Filamentous bacterium *Streptomyces scabies* *Streptomyces* spp	Tubers	Soil, seed	Soil, seed	Avoid infested fields; use resistant cultivars; rotate crops; treat seed; control pH; maintain uniform moisture.
Scab, powdery	Plasmodium (slime mold) *Spongospora subterranea*	Tubers, roots	Soil, seed	Soil, seed	Avoid infested fields; use disease-free seed; rotate crops; uniform watering. Vector of Mop-Top.
Secondary growth	Physiologic	Tubers	Not transmitted	None	Provide adequate and uniform soil moisture; use resistant cultivars.
Silver scurf	Fungus *Helminthosporium solani*	Tubers	Soil, seed	Soil, seed, storage	Use disease-free seed; practice crop rotation; resistant cultivars; fungicides.
Verticillium wilt	Fungus *Verticillium* spp.	Vines & tubers	Soil, seed, debris	Soil, seed, other crop debris	Fumigate infested soil; use resistant cultivars; practice long rotations; plant disease-free seed.
Wart	Plasmodium (slime mold) *Synchytrium endobioticum*	Tubers	Soil	Soil	Do not plant in infested fields; resistant cultivars.
White mold	Fungus Sclerotinia sclerotiorum	Vines	Air	Soil	Tolerant cultivars; spray fungicides.

While prevention and control of the many diseases affecting potatoes vary widely, some practices apply generally to all diseases. These include the following:

1. Use certified seed.
2. Handle seed properly.
3. Follow a regular and rigorous sanitation program.
4. When applying fungicides, follow the instructions on the label as well as the local authorities' recommendations.
5. Irrigate uniformly and adequately, but not excessively.
6. Control aphids, leafhoppers, and nematodes.
7. Harvest and handle tubers gently.
8. Do not harvest when tuber temperatures are below 45°F (7°C) or above 85°F (30°C).
9. If storing, provide environment for wound healing, followed by proper temperature, humidity, and aeration.

Production Management

(Steven B. Johnson)

Potato production is being driven by consumer demands for safe and high quality processed potato products as well as fresh potatoes. Extensive recordkeeping of pesticide applications are now more than ever mandated. Environmental impacts of potato farming from soil erosion to pesticide fate are constant potato management issues.

Potatoes are in a global market. No longer does a potato producer only have competition from the local area, but both fresh and processed potato products may come from across the continent.

Many of the cultural practices used in potato production appear straightforward and uncomplicated. However, even the simplest-appearing task has to be performed properly with little margin for error. Implementing new and ever changing technology into production practices is required in the face of national and international competitive pressures.

To remain competitive and profitable, growers must deal with the increasingly complex nature of potato production. Potato producers must develop integrated management strategies to increase production efficiency while protecting and sustaining soil and water resources. Part of these management strategies will be evaluating the level of inputs such as fertilizer, pesticides, irrigation water, and energy. Reducing inputs can result in reduced costs and reduced potential for negative environmental impacts. Reducing inputs can also increase the risks associated with producing potatoes.

An integrated management strategy is based on grower knowledge of potato growth and how varied climatic factors affect potato growth, cultural practices used in potato production and how such cultural practices interact to affect tuber yield and quality as well as their affect on the soil and water resources. In many cases, growing the potato is only part of the challenge. Markets—processing, seed or fresh—demand high consistently quality potatoes delivered in a timely fashion. Proper harvesting, handling, and in particular, storage of the product are mandatory. Much of these factors are described in other chapters.

Recent research and grower experiences have provided considerable information on the interactions among the many cultural practices used to produce potatoes. The interaction of irrigation with other cultural practices provides some excellent examples of how such interactions can impact potato productivity and soil and water resources.

Irrigation is used in many potato production areas to ensure adequate soil moisture for potato growth and tuber development. Its use is essential for potato production on sandy soils which have low available water-holding storage capacity. Irrigation that exceeds crop use and soil water storage increases the potential for leaching nitrates and pesticides to ground water leading to contamination problems. The practice of hilling interacts with irrigation to further increase this leaching potential on sandy soils. In this interaction, hilling changes the water infiltration pattern by causing more water to enter the soil in the furrow area. The significance of this is related to the root system of potatoes. Potatoes are shallow rooted and the root density under the furrow is less than that within the hill. Thus water uptake from the furrow is less. Without plant uptake, water infiltrating the furrow becomes a source of leaching water and the potential for ground water contamination increases. Modifying the hill shape to increase water infiltration into the hill would reduce the leaching impact of this irrigation and hilling interaction.

The leaching problem associated with excessive irrigation and hilling also interacts with fertility practices, especially nitrogen management. Potatoes use relatively large amounts of nitrogen, which in the nitrate form readily leaches. Leaching of nitrogen from the root zone can result in nitrogen deficiency and a potential for reduced yields. It also leads to nitrate contamination of ground water. Nitrogen deficiency also results in earlier senescence of the vines. This in turn increases plant susceptibility to early blight, which, if not controlled, can further reduce yields. Irrigation is also associated with other disease problems. Heavy irrigation and high soil moisture conditions increase problems with late blight, pink rot, white mold and aerial blackleg. Lack of irrigation and low soil moisture increases problems with scab and Verticillium wilt. These are just some of the interactions between only four cultural practices: irrigation, hilling, nitrogen fertility and disease management. Examples abound pertaining to cultural practice interactions and how they increase the complexity of potato production.

Understanding the complexities of potato production allows the producer to customize a management strategy that optimizes production efficiency while utilizing environmentally sound practices. These strategies may include selection of a pest resistant or tolerant cultivar or locating disease-sensitive cultivars in locations with a less disease-conducive microclimate. Customized rotations to reduce specific soil-borne pathogens or to provide additional fertility or soil structure characteristics can be implemented. Irrigation scheduling is being used to eliminate over-irrigation with benefits of reduced disease pressure and leaching. Adoption of integrated pest management practices can reduce pesticide inputs in addition to other environmental benefits. Potato producers need to understand and manage the impacts and interactions of varied cultural practices. Computer aided support systems are becoming available to aid in sorting out some of the interactions among the cultural practices involved with potato production. Increased computer applications in potato production are to be expected.

Physiological Disorders

(Mike Thornton)

Some of the most widespread defects that cause damage to potato vines and tubers are called “physiological disorders.” These disorders are not caused by insects, diseases or nematodes. Instead, they result from stressful environmental conditions or poor management practices. Often a disorder is caused by the combined effects of both environmental and management factors. Symptoms of physiological disorders can occur on the foliage while others can occur on either the outside or the inside of tubers. Foliar disorders mostly limit yield, while tuber disorders can decrease the market value of the crop.

Common physiological disorders of potato foliage include frost, hail, lightening, windburn and air pollution damage. Damage from these disorders can be distributed uniformly across a field, but may also occur in a pattern associated with a specific topographic feature such as low spots or ridges. Foliar disorders are often mistaken for insect, disease or herbicide damage.

Tuber physiological disorders are usually not detected until after harvest, which makes it difficult to identify patterns of occurrence in the field. Physiological disorders reduce marketability of tubers by damaging appearance or reducing processing quality. In some cases, these defects also make the tubers more susceptible to decay. Common disorders that produce symptoms on the outside of the tuber include growth cracks, secondary growth (also called knobs, dumbbells, and malformed) (Figure 20), heat sprouts, enlarged lenticels and greening. Growth cracks and secondary growth are associated with non-uniform growing conditions. Heat sprouts are caused by high soil temperatures that cause the stolons to

Figure 20. Secondary growth producing knobs on tubers. Tubers like these are not suitable for the fresh market, but can be used for processing into flakes or other products. (S. Johnson)

elongate and emerge from the soil (Figure 21). Lenticels may become enlarged when tubers are exposed for prolonged periods to very wet soil. Tubers turn green in response to light exposure in the field or after harvest.

Figure 21. Heat sprouts resulting from high soil temperatures causing stolons to elongate. (S. Johnson)

Disorders that produce symptoms on the inside of tubers include hollow heart, internal necrosis (also called heat necrosis and internal brown spot), sugar end (also called translucent end, dark end and jelly end rot) and blackheart. Hollow heart is caused by non-uniform plant growth early in the development of tubers, especially when accompanied by cool, wet soil conditions and excessive nitrogen fertility. Internal necrosis is associated with hot, dry weather and high soil temperatures during tuber bulking. Sugar end is associated with high soil temperatures and water stress during early tuber development. It most commonly occurs on the stolon end of the tuber and is not apparent until after processing. Blackheart occurs when tubers are exposed to low oxygen conditions. Improper storage ventilation, high temperatures after harvest, or extended low temperatures in storage can lead to blackheart.

Many of the defects discussed above are associated with extremes in environmental conditions that cannot be controlled by growers. However, proper cultural management can help promote uniform crop growth and minimize the impact of these environmental stresses. Establishing a uniform stand, monitoring soil moisture, applying irrigation in a timely manner, fertilizing based on soil tests for a reasonable yield goal, and establishing proper storage conditions will help reduce losses due to many of these physiological disorders.

HARVESTING THE CROP

(Steven B. Johnson)

Potatoes are grown to some extent in all states in the United States and all provinces of Canada. Across this area, potatoes are harvested every month of the year and probably every day of the year somewhere in North America. In some areas, potatoes are harvested while vines are still green and tubers comparatively immature. Such potatoes usually go directly from the field to the fresh market or into processing. This is especially true in the early producing areas—those designated as winter, spring, and summer.

Traditionally the fall crop is harvested when the vines and tubers are mature. The use of improved production and pest control techniques has tended to delay plant death and tuber maturity to a point where potatoes in many production areas benefit from vine killing to help set the tuber skins. Mature tubers are usually higher in dry matter, which makes them better quality for most processing uses. They also have tougher skins that are more resistant to skinning and bruising during the harvesting operation. Excessive skinning spoils appearance and predisposes tubers to rot-causing organisms resulting in an increase in weight loss during storage. In general, it is considered desirable for the vines to have died and dried up before harvest, especially where potatoes are to be stored for some length of time.

Vine Killing

(Steven B. Johnson)

Vine killing does not necessarily result in improved tuber quality but it can help achieve a desired skin set and may help reduce bruising and increase storability of the crop. Internal quality must be established before harvest through the proper production techniques.

In the past, it was not unusual for potato vines to have died and dried up from various causes before harvest. Pest damage, lack of fertility, or decreased moisture was often responsible for vine death. Foliar feeding insects, Verticillium wilt, and late and early blight diseases contributed to the death of vines well in advance of harvest.

New pest control materials and strategies have reduced the insect and disease effects on potato plants. Better irrigation and fertilizer practices also contribute to maintaining healthy green vines later into the season. The improvement in these and other cultural practices has resulted in increased yields and has enhanced the economics of potato production. It also has made it necessary to include the practice of artificial vine killing to bring about vine death in preparation for harvest. In areas that produce late fall potatoes, frost sometimes kills the vines, especially during the late part of the harvest season; but during the early part of the harvest, even in these areas, artificial killing of the vines may be necessary. The length of time between the application of vine-killing materials and vine desiccation and skin set depends on a number of factors.

Two general methods used for vine killing are mechanical and chemical. Flail beaters and rotary choppers are popular mechanical methods. Machines should be adjusted to avoid disturbing the soil so tubers will not be exposed to sunlight, frost or mechanical damage. Propane gas or oil flames are used in some areas to burn vines. Rolling vines before killing can lead to virus spread and tuber damage. Because conditions vary from area to area, local recommendations for methods and rates and timing of materials must be understood and followed.

Harvesting is easier when vines are dead. Under some conditions, vine killing is necessary to control tuber size. This can be especially important for growers of seed potatoes. Early vine killing can be used to prevent the spread of virus diseases when there is a late-season aphid infestation.

Timely vine killing allows the skins of tubers to toughen so the tubers can be harvested with a minimum of skinning and bruising. Bruised and skinned areas detract from potato appearance, an important quality parameter for the fresh market. These tuber blemishes also increase waste and costs when they are processed.

When late blight or pink rot is present at harvest, a higher amount of tuber rot in storage can result. The organisms can enter the tubers through harvest damage such as skinned and bruised areas. In storage, infected tubers continue to break down. Presence of these diseases is not always readily apparent at harvest. The safest precaution is to have potato vines dead and dry and the tuber skins set at harvest time.

Vines are difficult to kill when soil moisture is high or plants are large, green and vigorously growing. It takes more time for these plants to die than plants that are naturally maturing. Cool and cloudy weather conditions also retard vine death. Vines need to be killed two to three weeks before harvest. Cultivar, fertility and growth conditions can have an effect on vine killing.

Vine killing is an added cost and has been known to adversely affect internal quality of the tubers. Discoloration of the vascular ring at the stem end of tubers can occur when vines are killed rapidly. Usually the discoloration is confined to the stem end but on occasion it extends the entire length of the tuber. The problem is usually more severe when soil conditions are dry and weather is hot at the time vine-killing chemicals are applied. Chemicals that result in rapid death of the plant are more likely to cause discoloration than those that cause a slow kill. Removing vines by cutting, burning, or pulling seldom results in discoloration of the vascular tissue.

Vascular discoloration may be severe enough to reduce fresh market tuber grade. Tubers with a discolored vascular ring do not make good chips or French fries as the discolored area shows up as a dark area in the finished product. This discoloration has no effect on seed quality but often causes concern since it resembles the vascular discoloration caused by Verticillium wilt or Fusarium wilt.

To reduce the danger of severe vascular ring discoloration from vine killing, the following practices are suggested:

- Avoid using a chemical vine killer during hot weather, particularly if the soil is dry.
- If vines must be killed when soil is dry and weather is hot, reduce the rate of material used and use a chemical that tends to kill the vines more slowly.
- If irrigation is available, have soil moisture adequate at the time of vine killing.

Effectiveness of vine killing can be increased by practicing the following:

- Do not apply vine-killing chemicals during cool, damp, or extremely hot, dry weather.
- Under some conditions, split applications of chemical vine killers may be more effective than a single application. If the labeled use permits, use less than the full application rate, followed by a second application several days later.
- Use spray adjuvants that are recommended.
- Increased effectiveness has been shown with applications late in the day.

Harvesting Equipment

(Robert Thornton and Steven B. Johnson)

Most potatoes grown in North America are harvested with mechanical harvesters. Single-row harvesters are not common with most harvesters straddling two or in some cases, four potato rows (Figure 22).

Figure 22. Potatoes are harvested with two-row or four-row harvesters. Windrowers which place two or four rows of potatoes in the center of un-dug rows increase the efficiency of harvesters. Tubers are placed in bulk-bodied trucks and transported to grading areas, storages, or processing plants.
(W. Bohl)

In most areas windrowing is a common practice. With this method, two, four or more rows are harvested with a windrower and the tubers are placed in the furrow between two unharvested rows. The unharvested rows are then dug with a conventional harvester and the windrowed rows are picked up simultaneously. With windrowers, harvesting 12 rows together is not uncommon. Windrowing increases the acres that can be harvested with one machine during a harvesting season, reduces machine traffic over the soil, and increases the volume of potatoes within the harvester. Windrowers must be operated using the same bruise reduction concepts as the harvester, i.e., all conveyors must be kept full of potato tubers at all times.

Most harvesters deliver directly into trucks. Field trucks are often used to transport potatoes from the field to packing sheds, processing plants, warehouses or storages.

Potato Bruising

(Duane Preston)

It is difficult to fully measure all losses caused by bruising while potatoes are being harvested. Losses come from reduced potato value, increased shrink in storage, reduced return from processing contracts, as well as the direct loss caused by bruising itself. Studies in some areas have shown that growers may lose up to 20 percent of their income through potato injury at harvest.

Types of Bruising

Black spot Bruise—This is an internal discoloration resulting from impact that damages cells in tissue beneath the skin without causing an observable break in the skin. Black spot bruise can occur whenever tubers are handled. The symptoms normally develop over a period of 1 to 3 days with the development faster with higher temperatures. These discolored areas are not visible until a potato is peeled. Black spot bruise usually does not penetrate deeper than one-quarter inch and usually does not rupture the potato skin.

Shatter Bruise—This injury is the result of a mechanical impact sufficient to cause splitting or cracking of the outer surface or skin of the tuber. The severity of the shatter bruise can vary with the cultivar, tuber maturity, internal tuber turgor, and the magnitude of the impact. The injury is most severe when the tubers are turgid and at low temperatures.

White Knot—This bruise is similar to black spot bruise, but does not discolor like black spot. This is more of a crushed cell effect on immature tubers.

Factors that Influence Bruising

Four general factors determine the amount of bruise during harvest: 1) soil condition, 2) tuber condition, 3) tuber temperature, and 4) harvester operation.

Soil Condition—The soil condition at harvest determines the ease with which potatoes can be separated from the soil. Heavy, compacted and very wet soil is difficult to separate from tubers, while medium to light, loose and moist soil separates easily. Proper soil moisture for harvest is between 60 and 80 percent of field capacity for loam and sandy soils. Heavy, dry cloddy soil increases damage to tubers as they are carried through the harvester. The more difficult the separation, the more the harvester chains (conveyors) must shake, which in turn causes more damage to the tubers. In some areas, stones present in the soil increase the amount of bruise.

Tuber Condition—The condition of tubers is influenced by fertility level, insect and disease control, irrigation, tuber maturity, and timing of vine kill. Other cultural practices undoubtedly are important but have not been studied in depth. The relationship between tuber condition and bruise susceptibility is not completely understood. Delaying harvest up to 20 days after vine kill encourages tuber skin set and resistance to skinning. Delaying harvest also appears to reduce susceptibility to serious bruise damage through increased tuber maturity. Many aspects of tuber maturity are still not understood. Cultural practices that influence tuber hydration are an important factor in the type and amount of damage tubers sustain during harvesting. Hydrated (crisp) tubers are susceptible to shatter bruise and resistant to black spot. Dehydrated (soft) tubers are resistant to shatter bruise and susceptible to black spot. At any given temperature there is a tuber hydration level at which bruise damage (both black spot and shatter bruise) is at a minimum (Figure 23).

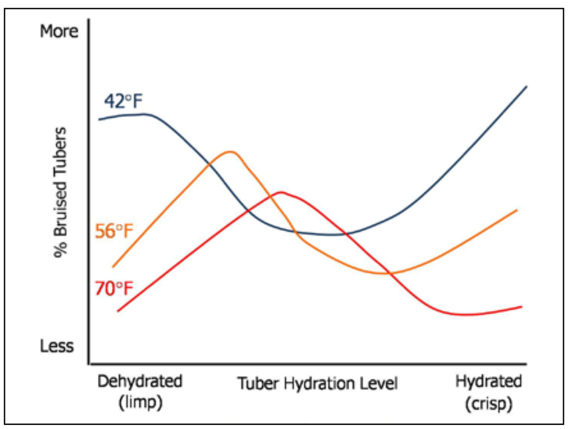

Figure 23. Tuber temperature and hydration levels have an impact on black spot and shatter bruise susceptibility. Dehydrated tubers are most susceptible to black spot while hydrated tubers are susceptible to shatter bruises. Generally, soil temperatures should be between 45 and 65°F at harvest time.

(Adapted from: Smittle, D.A., et al. 1974. Harvesting Potatoes with Minimum Damage. Am. Potato J. 51: 153-164.)

Tuber Temperature—At harvest, tuber pulp temperature should be between 10 and 15ºC (50 and 60ºF). When possible, avoid harvesting if tuber pulp temperatures are below 7ºC (45ºF) and above 18ºC (65ºF). Optimum harvest situation occurs when the potato tuber temperature in the field and the soil temperature are the same. Soil temperature lags behind air temperature. The lowest air temperature occurs about 6:00 a.m. but the lowest soil temperature at tuber level and therefore, tuber temperature, occurs about 9:00 a.m. This is normally about a 3- to 4-hour delay. A similar delay holds true for high temperature. Highest air temperature occurs at about 3:00 p.m. but the highest soil temperature does not occur until about 6:00 p.m. As soil temperature changes, the temperature of the tubers also changes. A 12-hour harvest period for soil temperature warm enough to reduce tuber bruising would be from about 11:00 a.m. to 11:00 p.m. Harvesting during these times would help in bruise reduction when night temperatures drop below 7ºC (45ºF). In spring and summer harvest areas, where high temperatures are to be avoided, afternoon and evening harvest should be avoided.

Harvester Operation—Probably the major factor in minimizing tuber bruise damage is harvester operation. Detailed suggestions on proper harvester operation are available from agricultural authorities and machinery manufactures in major potato producing areas. These suggestions are based upon local soil and climate conditions. To harvest effectively with a minimum of bruising, harvester and conveyor speed adjustment should be based upon local conditions. However, certain general recommendations to reduce bruising can be made.

Check all equipment well in advance of harvest and replace broken or worn parts. Breakdowns delay harvesting and can cause anxiety leading to the tendency to hurry harvesting operations. Unnecessary harvesting speed can cause more breakdowns. Equipment that continually breaks down makes for inefficient labor use.

Instruct and train operators so they understand their role in reducing tuber damage during harvest. The training should include explanation of local recommendations for low damage harvesting. The volume of potatoes harvested per unit of time must be balanced against the quality of the potatoes harvested. Harvesting potato tubers with little or no bruising is largely dependent on the operator. Operating a harvester is not easy and requires a person who is conscientious, responsible and well trained. There are many adjustments that need continual refining during the harvesting operation.

The harvester blade should be aligned so that the rear of the blade delivers tubers onto the front of the primary conveyor, not in the front of it. This can best be achieved by elevating the entire blade rather than raising the rear of the blade. Raising only the rear of the blade, can produce a blade angle steep enough that there will be a plowing effect. The harvester must be operated so that the blade is deep enough to lift the maximum number of potatoes with a minimum of damage. Operating the blade too deep can overload the beds with soil and reduce the separation of tubers from soil. Operation of equipment with the blade too shallow results in sliced potatoes and insufficient soil on the primary conveyor to cushion the potatoes. New, automatic, hydraulic depth control devices are available to regulate blade depth.

Pitch is the distance from hinge point to hinge point of two individual links in the harvester conveyor bed. Bed pitches from 1.56 to 2 inches (40 to 51 mm) are common. When harvesting in wet soil conditions, a bed with a wide pitch with is advisable. Wider pitch beds are more suitable for round cultivars of potatoes than for the long or flat cultivars.

Bed agitation should be avoided unless absolutely required to achieve minimum acceptable soil separation. An alternative to shakers for improved separation is reducing the flow of soil and potatoes, especially onto the primary bed. This can be done by reducing forward speed while maintaining bed speed. Combinations of high bed speed and high magnitude agitation should be avoided, especially when bed links are bare. Belted and rubber padded bed lags are now available. Where soil separation or roll back of tubers is a problem, various offset lag combinations of the conveyor links (i.e., up, down, and straight) can be used. Clod and stone separating equipment is now available for those conditions where separation of soil and tubers proves to be extremely difficult.

The forward speed of the harvester is determined by the digging conditions and varies accordingly. The key to the proper forward speed is to keep the beds filled to capacity. All beds should be operated so that the volume of material on them is equal to the capacity of that bed. Techniques for calibrating the bed speeds to forward harvesting speeds for various tuber yields have been developed in different production areas. Consult local agricultural authorities for the approach that has been the most successful in your area.

Spill-out losses of tubers at the harvester blade are variable and difficult to measure. Corrective measures include running the blade deep and cleaning and polishing the blade. Use of coulters on the harvester to cut the vines and narrow the hill is practiced by some producers. Spill-out loss can indicate a primary bed speed traveling slower than the forward speed of the harvester.

Padding placed wherever potato bruising might occur to soften the landing of tubers and the use of rubber-covered bed links helps reduce tuber bruising. Limiting drop height to six inches (15 cm) or less will also help. Padding placed in areas of the truck where loading begins, such as on the sides and bottom is of additional benefit. When loading the truck, build the load to full height in the padded areas first, then continue loading on previously built mounds to reduce the distance the potatoes fall.

The use of new technology, such as the Instrumental Sphere and similar electronic equipment helps identify and measure impacts that may lead to potato bruising. This helps inform the operator as to where bruising may be occurring in the operation.

At the Storage

(Nora Olsen)

Careful storage loading can reduce bruising. Drops and roll down can lead to skinning and bruising. Damage from storage loading is seldom noticed until potatoes are removed from storage. The height of the receiving hopper should be adjustable to keep the drop of potatoes from the truck or transport vehicle to a minimum, preferably less than 6 inches (15 cm). The hopper should be large enough and the apron (conveyor) operated at a speed fast enough to prevent spilling over. The hopper edges and surfaces should be padded to reduce damage to the potatoes. Rubberized chain conveyors and cleated belt conveyors may reduce tuber roll back and subsequent damage. All chain and belt speeds should be such that equipment is operated at full capacity. Conveyors, even-flow bins, sand machines and dirt eliminators may be implemented prior to loading potatoes into storage and should be maintained at levels to minimize potato drop heights and areas of impact. The boom should be able to swing in a wide arc, be easily adjusted to keep the drop from the boom to the pile to a minimum, and operated at full capacity.

STORAGE

(Nora Olsen)

In the northern production areas a large percentage of the potato crop is stored for processing and fresh market through the winter, spring and summer months. Many modern potato storages are entirely above ground, of concrete or corrugated metal exterior, insulated and equipped with a system of temperature, humidity and forced-air ventilation control (Figure 24). This control system is often a sophisticated computerized system capable of monitoring temperature in various areas of the storage, and relative humidity and carbon dioxide levels. Some storage facilities are equipped with refrigeration to maintain desired temperatures in late spring and summer months. Storage capacity can range from 500 ton to over 20,000 ton. A storage facility should be built to hold and ventilate the desired capacity. Most potatoes are stored in bulk piles, but box storages are utilized in some areas.

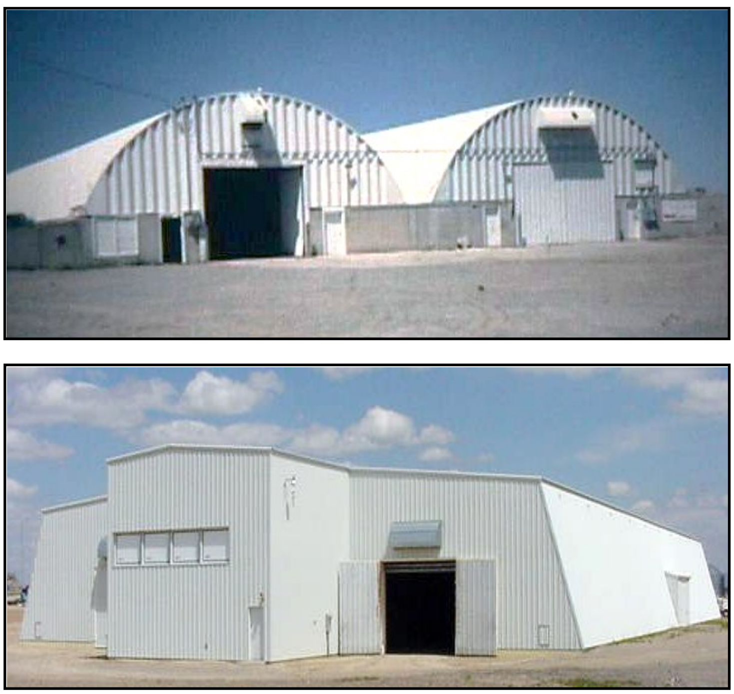

Figure 24. Modern potato storage facilities used to store potatoes in northern potato-production areas. Storage capacity can range from 500 ton to over 20,000 ton. Storage facilities are generally insulated and equipped with a forced-air ventilation system to control temperature and humidity. Most potatoes are stored in bulk piles, but box storages are utilized in some areas. (W. Bohl)

The design of storage structures varies considerably depending on location, climate, and market use of the potatoes. A storage structure should be well insulated, have adequate strength to withhold pressure the potato pile, wind and snow, and be equipped with a good ventilation system. It should also be easy to clean and have convenient access for loading and unloading potatoes.

The ventilation system typically consists of large air plenums located on either or both sides of the potato pile or in the middle with ducts running across or lengthwise, depending on shape and size of the storage. A common type of duct is galvanized corrugated pipe located above ground, although air ducts can be located below ground. Dirt floors are the most popular in some areas of North America, some areas have storages with concrete floors with wood-covered or metal-covered flumes in the floor. The wooden covers can be removed as potatoes are flumed out. Moisture proof barriers with insulation are required on the walls and ceilings. The thickness of the insulation should be based upon climate and location. In most of the northern production areas and in areas of high elevation, an insulation R-value of 30 to 40 is needed for outside walls and ceiling. Because high humidity is required for potatoes in storage, condensation of water on the ceiling sometimes occurs. Proper design, adequate insulation, presence of a vapor barrier and air flow directed across the ceiling keeps this problem to a minimum. Requirements for storage in a specific geographic area should be obtained from the agricultural resource people in that area.

Physiological and Biochemical Changes in Storage

(Gale Kleinkopf)

The objective of the storage environment is to maintain the external and internal quality of potato tubers. Potato quality coming out of storage can be no better than the quality of the potatoes placed into storage. Long term storability of potatoes is influenced considerably by production and harvesting practices. The maintenance of potato quality in storage is enhanced by care in growing, harvesting and placement of tubers into storage.

The storage period can be divided into three periods. The first is the curing period or the period of suberization and maturation. The second, lengthier phase is the holding period, and the third is the warming period prior to removing tubers from storage. During the curing period, cuts, scrapes and bruises incurred during the harvest operation are suberized and a wound periderm is formed to prevent entry of rot organisms. Immature tubers are allowed to mature (set and thicken the periderm) during the curing period. Temperatures of 50° to 58°F (10 to 14.4°C) are used, depending upon eventual use of the tubers, cultivar, relative maturity and conditions of growth. Curing temperatures of approximately 50°F (10°C) are used when most of the potatoes are processed into frozen French fries, made into dehydrated products or sold on the fresh market. When potatoes are processed into chips, higher curing and holding temperatures may be used because of differences in cultivars and a lower maximum allowance of reducing sugars. Too much reducing sugars in tubers will result in dark-colored fries when cooked, which is not a desirable consumer characteristic. Length of the curing period is generally 10 to 14 days. Relative humidity above 90 percent and fresh air is important for the suberization process and helps to keep tuber weight loss to a minimum.

Proper curing of tubers is necessary to ensure storage without loss of quality. In areas with relatively warm fall temperatures, a considerable amount of field heat along with the heat of respiration must be dissipated requiring forced ventilation with cool air. Removing tuber heat is necessary to keep rot to a minimum and to keep tubers from physiologically aging, which eventually results in greater development of reducing sugars and premature sprouting. If tubers are relatively immature, they should be kept at curing temperatures for longer periods to ensure maturation of the skin for minimum weight loss.

Tubers are kept at holding temperatures between 40 to 50°F (4.4 to 10°C) depending on ultimate use. Chip potatoes are generally stored at 50 to 55°F (10 to 12.8°C) while those used for making French fries are kept at 45 to 48°F (7.2 to 8.9°C) and fresh market and seed potatoes are maintained near 40°F (4.4°C). The accumulation of reducing sugars precludes storage of processing potatoes at low temperatures. Constant storage temperatures are more desirable than fluctuating temperatures. High relative humidity (90 to 95%) is desirable to keep weight loss to a minimum and to prevent the occurrence of pressure bruises, especially in cultivars with low specific gravity. When potatoes have been kept at low holding temperatures, they should be warmed to approximately 50°F (10°C), before removing from storage to reduce bruising.

Ventilation and Humidity Control

(Stephen Belyea)

The primary purpose of ventilating potato storages is to remove field heat and the heat of respiration from the pile. Forced movement of air through potatoes maintains uniform temperature and humidity throughout the pile. A good ventilation system can also be used to dry out tubers harvested under wet conditions and to control progress of tuber wet rots by drying out damp or wet areas of the pile. Excessive accumulation of carbon dioxide given off from tubers, especially during the high respiration period of wound healing and suberization, can be prevented by adequate ventilation. Continuous airflow during the storage season is used to provide the constant temperature, low carbon dioxide concentration, and normal oxygen levels within the storage facility. These factors optimize tuber quality for potato processing.

Computer-based ventilation control panels provide the storage manager with precise control of temperatures and a multitude of management options. Temperatures are monitored and controlled to tenths of a degree. Specific programming of the computers provides specialized management options for different phases of the storage season, i.e. fall cooling, winter holding, spring warming, and refrigeration. Computerized controls are capable of monitoring storage conditions and storing the data for future download and analysis, or can be accessed by remote computer. Historical data for storage temperatures and carbon dioxide levels have proven to be especially useful.

The capacity of ventilation systems varies depending on the availability of low night temperatures for cooling and on the need for tuber drying capacity. The variation in capacity typically ranges from 0.6 cfm/cwt (cfm=cubic ft per min; cwt=100 lbs) (0.37 m^3 min^{-1} Mg^{-1}) to 2.4 cfm/cwt (1.5 m^3 min^{-1} Mg^{-1}). Higher airflow capacity is needed where there is little nighttime cooling air available. High airflows are commonly used to control soft rot and for drying tubers harvested damp or wet. From a seasonal management standpoint, highest airflow is required during the wound healing and cooling periods of storage. Once wound healing and cooling are accomplished, high airflow volumes are not generally required.

Axial flow fans typically are used to provide airflow, with ratings ranging from 3 horsepower to 30 horsepower (Figure 25**.** There may be one fan or multiple fans depending on the storage or bin capacity and airflow rate required. Ventilation air is moved from the fan room to the lateral distribution ducts by a main plenum. The plenum may be located along the side of the bin or across one end of the bin, depending upon bin width and length and type of lateral distribution duct used. Variations of this basic distribution system exist in the different producing areas.

Figure 25. Modern potato storage facility with axial flow fans used to move air from the fan room to the lateral distribution ducts to maintain a constant temperature of the potato tubers.
(S. Belyea)

Air distribution through potato piles is attained by several common methods. Some production areas have preferentially adopted distribution methods unique to their area. Distribution methods include cast-in-floor concrete ducts; steel, aluminum or plastic corrugated pipes; steel, aluminum, or plastic half-pipes; and various configurations of wood ducts. Air distribution ducts are typically spaced from six to ten feet apart beneath the potato pile. Ventilation air outlets are designed into the lateral distribution ducts to deliver the ventilation air to the pile. Air outlets in the lateral distribution ducts are unique for each storage building and are designed to provide uniform air distribution throughout the pile.

In most production areas, the addition of moisture to ventilation cooling air is a necessity, particularly during the wound healing and initial cooling periods. High relative humidity cooling air encourages rapid wound healing and minimizes the loss of moisture from the tubers in storage. Evaporation of moisture in the ventilation air also provides additional cooling capacity and, thus, can aid early cooling. Examples of humidification equipment include evaporative media, centrifugal humidifiers, air washers, high-pressure nozzles, and air-water nozzles.

Evaporative media is a specially treated corrugated pad that is constantly being saturated with water (Figure 26). Moisture is evaporated from the pad as ventilation air passes through. Evaporative media humidifiers are relatively low maintenance and use little energy to operate. They also produce little free water in the plenum and distribution ducts.

Figure 26. An evaporative cooling pad is constantly saturated with water while air is moved through the pad to provide humidity and cooling to potato tubers in storage.
(S. Belyea)

Centrifugal type humidifiers use a spinning disk to create a fine mist in the ventilation air stream. Centrifugal humidifiers generally provide good humidification but may be inadequate when large amounts of dry cooling air are brought in during the cooling period. Centrifugal humidifiers also can produce large amounts of free water in the plenum and distribution ducts, which must be drained away.

High-pressure nozzles and air-water nozzle humidifiers can provide good humidification of the ventilation air but are relatively expensive to operate and maintain. They also can produce large amounts of free water in the plenum and distribution ducts.

Large air washers are popular in some areas and provide adequate humidification. Refrigerated water chiller units can give additional cooling capacity to air washers if necessary.

The advent of computerized ventilation control systems has enabled system manufacturers to develop reliable electronic humidity sensors. Most computerized control panels provide direct relative humidity readout and automatic control of relative humidity in the storage plenum by modulating humidifier output.

Refrigerated storages are used to keep potatoes for prolonged periods into the summer months. Once outside air warms and can no longer be used as ventilation cooling air, refrigeration is required to maintain desirable temperatures in the storage. Refrigeration capacity needed depends upon anticipated outside air temperatures, insulation values in the storage shell, air tightness of the storage shell, storage capacity and storage temperature. Refrigeration systems are relatively expensive to install and operate.

Sprout Control in Storage

(Gale Kleinkopf)

Most common cultivars of potatoes have a natural dormancy period of 60 to130 days depending on the holding temperature in storage. Potatoes stored for longer periods must be treated with a sprout suppressant or inhibitor. The most common inhibitor used in storage is chlorpropham (CIPC). CIPC inhibits sprout development by preventing cell division. It is applied as a thermal aerosol after wound healing but before dormancy break. Potatoes treated with labeled amounts of CIPC in storage can be sprout-free for 6 to 12 months depending on the storage holding temperature.

Another commonly used sprout inhibitor is maleic hydrazide (MH). MH is field-applied to green potato foliage as recommended by the manufacturer. The chemical is translocated to the tubers and can prevent sprout development in shorter-term storage. Potatoes treated with MH can be stored for 3 to 5 months after normal dormancy break before sprouting occurs. For longer-term storage, a second sprout inhibitor, mainly CIPC, must be applied to prevent late-season sprout growth in storage. MH is used on both processing and fresh potatoes.

Several other sprout suppressants are available for short-term storage. Plant extracts, peppermint and clove oil, and some naphthalenes are used to give 20 to 30 days sprout-free conditions in storage. However, repeat applications are necessary for continued sprout control. These alternative suppressants are mainly used for potatoes in specialized markets such as organic trade or where chemical application of CIPC is not permitted.

Seed potatoes are not treated with chemical inhibitors for sprout control. Storages of seed potatoes are maintained sprout-free by holding tubers at colder storage temperatures, usually 38 to 40°F (3.3 to 4.4°C). At these colder temperatures, seed potatoes can be stored for 5 to 8 months in storage or until the planting season deliveries are made. Although processing potatoes can be stored sprout-free for several months at these colder temperatures, reducing sugar accumulation in cold stored potatoes usually prevents their use in the processing industry.