Productivity of Potato Seed-tubers from Different Latitudes

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Mohamed Noorul Jazeem Wahab

Dedicated to

my father

The late Al-Haj. O.V.A. Wahab

and

my father-in-law

The late Mr. C.A.C. Marikar

ABSTRACT

Potato (*Solanum tuberosum* L.) seed-tubers from northern latitudes are usually more vigorous and higher yielding than seed from more southern latitudes. It is not clear whether the superiority of northern seed is due to physiological and/or disease related causes. This study was conducted to examine the relative growth and yield potential of Norland and Russet Burbank seed from different latitudes with the objective of relating seed-tuber vigour to physiological or pathological factors associated with seed production environment. In a five year study, comparisons were made for seed sources from Saskatchewan, Colorado, Minnesota, Nebraska and Wisconsisn that provided a range of environmental conditions.

Norland and Russet Burbank seed from Saskatchewan usually outyielded seed from Minnesota or Nebraska but was rarely better than Colorado seed. Tuber yields for the various Saskatchewan seed sources were similar. Lower yields for Russet Burbank from the southern sources was associated with reduced seed piece vigour and greater hill-to-hill variability. However, with Norland, yield increases

for northern seed was mainly due to increased seed piece vigour.

Northern seed lots produced more vigorous and persistent haulms than southern seed. Premature senescence of plants from southern seed was caused by reduced allocation of dry matter to shoots in favour of tubers. This differential allocation was, in turn, triggered by high levels of tuberizing stimulus present in the southern seed. Differences in shoot vigour, mainstem number, tuber initiation, tuber yield, and tuber dry matter concentration did not indicate that seed-tubers from cooler (northern) sites were physiologically younger than seed from relatively warmer (southern) sites. Rather, seed-tuber vigour appeared to be more closely related to the extent of diurnal temperature fluctuations at each seed production site.

Seed potatoes from Saskatchewan retained their productive vigour over Minnesota source for at least two generations. Cycling low yielding Minnesota seed through Saskatoon increased its productive capacity. However, cycling superior Saskatchewan seed through Minnesota reduced its yield potential but it was still superior to seed grown continuously in Minnesota. This is further evidence that the site related variability of seed stocks is due to physiological factors rather than disease conditions.

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As Carrie J. Bond penned:

Well, this is the end of the perfect day,
Near the end of the journey too;
But it leaves a thought that is big and strong,
With a wish that is kind and strong

'A Perfect Day'

Too many individuals to list encouraged and supported me in this journey. I am greatly indebted to all.

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CHAPTER 1

Introduction

INTRODUCTION

The potato (*Solanum tuberosum* L.) is commonly propagated by 'seed-tubers'. The productive capacity of the seed-tuber is dependent upon levels of seed-borne diseases and the physiological condition of the seed. The environment under which the seed crop is grown, the cultural practices employed in its production and conditions under which the seed is stored help determine the quality of seed-tubers and subsequent performance of the progeny (Wurr, 1978a). The importance of varietal purity as well as insect and disease control in potato seed production is well understood. Current 'Seed Certification' regulations (e.g. Canada Department of Agriculture, Seeds Regulations, 1991) govern only disease tolerances and genetic purity of the seed. By contrast, less well understood and appreciated is the influence of the physiological condition of the seed-tuber upon subsequent growth and yield of the crop (Harris, 1982).

The latitude and altitude of seed production appear to influence the productivity of the progeny. Potato seed-tubers originating from cooler northern latitudes and/or high altitudes usually produce more vigourous plants and higher tuber yields than seed obtained from southern latitudes or lower altitudes (Wurr, 1978a). This effect has been attributed to differences in seed-borne disease levels and/or to some beneficial changes in the physiology or vigour of the seed-tuber. Seed potato production in North America is focused in northern, north western and high altitude locations in U.S.A. and in Canada (Slack, 1993). This is, in part, due to lower populations of insect vectors of viral diseases at these sites (Slack, 1993).

Potato growers throughout the main potato producing areas of the U.S.A. consider seed from northern regions highly desirable due to the belief that northern grown seed is more 'vigorous' and free from seed-borne diseases than seed from southern regions (Hartz et al., 1980). More recently, potato growers from Oregon and Washington have been obtaining increasing amounts of seed from Alberta and British Columbia, again based on the perception that this 'northern' seed outperforms local seed sources.

The present project was designed to study the growth and productivity of potato seed-tubers grown at various sites in Saskatchewan and the U.S.A. under diverse latitudes, altitudes and climatic conditions. The environmental factors influencing seed vigour and the physiological basis for any growth and yield differences observed were also examined.

CHAPTER 2

Literature Review

2. LITERATURE REVIEW

Potato productivity is determined by the soil and climatic conditions at the production site and the 'quality' of seed used (Burton, 1966; Wurr, 1978a). The quality and productivity of potato seed-tubers depend on the physiological condition of the seed and the level of seed-borne diseases. Seed-borne disease can have a direct impact on yields and quality, but also can serve as the means for disease spread through subsequent generations or to adjacent fields. Physiological factors influencing the relative vigour of seed potatoes can influence all aspects of growth, development and yield. The objective of seed production is to deliver disease-free seed stock in prime physiological condition. Potato seed production involves specialized production practices, strict insect control measures, and suitable handling and storage techniques, all focusing on the primary objective of producing consistent seed quality.

It has long been recognized that seed potatoes produced in northern latitudes are potentially more productive than seed produced at southern latitudes (Fraser 1912; Grubb and Guildford, 1912; Stuart, 1913). This was attributed to lower levels of seed-borne diseases in the northern seed which in turn was attributed to lower populations of insect vectors responsible for transmission of virus diseases (Slack, 1993). Some beneficial physiological changes also appear to occur in seed-tuber tissues grown in cooler northern environments (Wurr, 1978a; Iritani and Thornton, 1993). Some attribute this superiority to younger physiological age of the seed produced in the cooler northern latitudes (Went, 1959; Bodlaender, 1973; Caldiz et al., 1985), while others say it is related to some physiological change in the seed other than physiological age effects (Goodwin et al., 1969b; Wiersema and Booth, 1985).

Following is a review of the influence of environmental conditions and cultural practices during seed production on growth and productivity of the progeny. Seed production and certification techniques which could potentially influence the vigour of the seed are also discussed.

2.1. Seed-tuber Production Conditions and Performance of the Progeny

2.1.1. Environmental Factors

2.1.1.1. Location

Potato seed-tubers originating in different locations exhibit varying levels of shoot vigour and productivity

(Sawyer and Cetas, 1962; Iritani, 1967; Wright and Mellor, 1976; Love et al., 1992). Iritani (1967) compared 22 lots of certified Russet Burbank seed from major seed growing areas in Idaho, and found yields ranging from 7.9 to 12.8 t ha^{-1} of US #1 tubers. Kunkel et al., (1977) compared virus-tested seed lots produced in British Columbia, Montana and Washington. They found significant yield differences among the different seed sources which were attributable to factors other than seed-borne virus diseases. Ohms (1974) observed a 15% variation in total yield among different virus-tested Russet Burbank seed lots, while Wright and Mellor (1976) found a 21% to 36% differences in yields among five lots of virus-free Russet Burbank seed in three out of four tests. Yield differences were also observed for PVX-free Katahdin potatoes from different seed sources (Sawyer and Cetas, 1962). Flack (1983) compared the productive potential of Desiree (at 55 test sites) and Pentland Crown (at 65 test sites) potatoes from Cumbria and Durham (U.K) sources. Significant yield increases were obtained for Pentland Crown from Cumbria relative to Durham seed in many of the sites. However, for Desiree, the two seed sources produced generally similar yields. These workers offered no explicit explanations for the differential yield responses for these two cultivars with respect to seed source effects. However, they suggested likely causes to be factors such as date of planting and maturity at harvest (Iritani, 1967), unexplained influence of seed growing environment (Flack, 1983) or clonal effects (Wright and Mellor, 1976 and Love et al., 1992). Flack (1983) observed that the Cumbria and Durham locations produced seed stocks of Pentland Crown that performed as if they were two distinct varieties.

2.1.1.2. Altitude

The altitude at which potato seed-tubers are grown can influence the morphological characters (Sacramella Petri, 1959) as well as productivity of the progeny (Wurr, 1978a). Yields of seed-tubers from higher elevations are generally superior to those obtained from relatively lower altitudes (Kozlowska, 1963; de Bokx and Mooi, 1974; Choudhury et al., 1984, Wiersema and Booth, 1985; Caldiz, 1991). Kozlowska (1963) obtained yield increases of 600-1000 g per plant from seed obtained from 1290 m elevation compared to seed from sea level. de Bokx and Mooi (1974) showed that seed from 1000 m altitude outperformed seed from 360 m altitude by 5%-15%. In a more recent study, Wiersema and Booth (1985) found a 30% yield superiority by using seed obtained from 3280 m altitude over seed from 240 m elevation. The relative productivity of seed-tubers from different altitudes can be inconsistent; e.g. Wurr (1979) in a two year study, observed higher yields for seed from higher elevations than seed from lower elevations only in one out of two years.

2.1.1.3. Latitude

The productive advantage of potato seed-tubers from northern latitudes compared to southern sources has long been recognized by potato growers in Europe and North America (Grubb and Guildford, 1912; Fraser, 1912; Stuart, 1913). Studies conducted in Rhode Island showed a yield depression of '66 bushels per acre' after using southern seed (Wessels and Hartwell, 1927). Stuart (1913), in a six year study comparing 13 potato cultivars obtained from England and Scotland, found a five-fold yield advantage in favour of seed from Scotland. Commercial growers from northern areas in the U.S, such as Idaho and Maine, traditionally grew their own seed (Went, 1959), while growers in southern and central states obtained better results using seed from northern sources (Thompson, 1939). Seed for New Jersey, Virginia, and the South Atlantic States generally came from Vermont, New York, and the Maritime regions of Canada.

At present, seed production in North America is centred around the northern states and Canada due to the belief that northern seed lots have low levels of seed-borne virus diseases (Slack, 1993) and are more productive (Hartz et al., 1980) than seed from southern regions. In the U.K, seed from Scotland is preferred over seed from England (Goodwin et al., 1969b; Wurr, 1978a). In Russia, northern seed is also preferred over southern seed (Korzunova, 1962).

In the southern hemisphere, southern seed has been found to be more productive than northern seed (Claver et al., 1971).

Growth and yield differences between northern and southern seed sources are not always consistent. Westover (1931) found that Smooth Rural potato seed-tubers obtained from Kentucky produced similar yields to seed grown in northern Minnesota. In Sweden, potato seed-tubers produced at different latitudes produced similar tuber yields although there were significant differences in growth characteristics and tuber dry matter concentration among the various seed sources (Hagman, 1973). In a two year study, Goodwin et al., (1969b) examined the influence of latitude of seed production (50°44'N-Efford, 52°54'N-Sutton Bonnington, 55°55'N-Edinburgh) on growth and productivity of potatoes. A progressive increase in tuber yield occurred with increasing latitude in one year, but did not observe any yield differences among the various seed sources in the next year.

2.1.1.4. Physiological Basis for Growth and Yield Responses Related to Latitude and Altitude of Seed Production.

The increased vigour of seed-tubers produced at northerly latitudes and at higher altitudes may be associated with reduced disease levels (Wurr, 1978a; Banttari, 1993) and/or to beneficial physiological changes in the seed-tuber tissue (Sawyer and Cetas, 1962).

In general, increasing latitudes and altitudes are associated with a decrease in mean temperatures. High temperatures during tuber initiation (Claver et al., 1975), tuber development (Sunoschi, 1981), or during the latter part of the season (Kawakami, 1962) can increase the physiological age of seed. Therefore, the seed-tubers originating from high altitudes or northerly latitudes may be physiologically younger than seed grown under relatively warmer (Went, 1959), southerly latitudes (Goodwin et al., 1969a) or lower altitudes (Wurr, 1978a). There is general consensus that physiologically younger seed-tubers produce higher yields at maturity than physiologically old tubers, given a sufficiently long growing season (Goodwin et al., 1969b; Wurr, 1978a; Knowles and Botar, 1992).

The enhanced vigour of seed-tubers from cooler environments can persist through several subsequent generations (Sacramella Petri, 1952; Went, 1959), while yields for potato seed-tubers multiplied through successive generations in warm climates degenerate rapidly (Stuart, 1913; Husain et al., 1978; Tien et al., 1982). When low vigour seed from warm sites was grown in a cooler region for one generation, a revitalizing effect on yields was observed (Stuart, 1913; Tien et al., 1982).

The mechanism(s) whereby environmental factors such as temperatures during seed production determine vigour of the progeny is not well understood. de Bokx and Mooi (1974) obtained more vigourous seed-tubers when the seed crop was grown under 17°C compared to 26°C. Went (1959) also found seed-tubers produced under low temperatures were higher yielding than seed grown under warmer temperatures. His data also shows that seed-tubers originating under treatments with greater diurnal temperature fluctuations were more productive than seed produced under lower diurnal temperature fluctuations. McCown and Kass (1977) studied the productive capacity of Katahdin seed by exposing mother plants to cool (20°C day/14°C night) and warm (26°C day/20°C night) temperatures at different growth stages. These workers did not find any effects of seed growing environment on productivity of the progeny.

Goodwin et al., (1969b) and Wiersema and Booth (1985) were unable to relate the differences in growth and productivity of potato seed-tubers from varying latitudes and altitudes to physiological age differences associated with the average temperature regimes of these locations. Goodwin et al., (1969a and 1969b) suggested that the effect of latitude on potato seed-tuber productivity is due to some unknown modification of the seed-tuber tissues besides its modifying influence on sprouting characteristics of the seed-tuber. According to Went (1959), the carry-over effects of seed-tuber productivity is unlikely due to any hormonal influence. Wiersema and Booth (1985) attributed the increased productivity of the highland seed to its higher dry matter content relative to lowland seed. Shaw and Booth (1982) also found that the dry matter content of seed-tubers produced at high elevations was greater than for seed produced at lower elevations. However, Hagman (1973) showed an increase in tuber dry matter content with decreasing latitude of production, without finding any latitude effects on tuber yields.

2.1.2. Cultural Practices

2.1.2.1. Soil Type

Kruger (1927) found seed grown on calcareous soils was of poorer quality than seed from sandy loams, although the basis of the differences was not clear.

Albert et al., (1939) demonstrated that potato seed-tubers produced in peat soils were more vigorous during the initial stages of the crop and produced higher yields than seed from silty-loam soils. Bardeva et al., (1956), Fillipov (1965) and Karavaeva et al., (1973) also showed that potato seed-tubers produced in peat soils were more productive than those grown in mineral soils. This response may be due to the low average soil temperatures (Karavaeva et al., 1973) or low diurnal temperature fluctuations (Wurr, 1978a) characteristic of peat soils relative to sandy soils.

2.1.2.2. Fertilizer Application

Potatoes have relatively high fertility requirements and respond well to manures and inorganic fertilizers (Harris, 1978; Beukema and van der Zaag, 1990; Schaupmeyer, 1992). Appropriate rates of fertilizers, applied on the basis of soil analyses, can improve yield and quality of the seed crop (Schaupmeyer, 1992). Nutrient deficiencies lead to premature senescence, increased susceptibility to early blight, and reduced yields, while excess nutrients, particularly nitrogen, can lower the specific gravity of tubers, increase the incidence of hollow heart, delay maturity, and produce over-sized tubers. Addition of phosphorus and potassium fertilizers produce tubers more resistant to bruising, which is beneficial for seed potatoes as it can reduce the spread of diseases.

The effect of fertilizers added to a potato seed crop on the performance of the progeny is inconsistent (Gray, 1974; Wurr, 1978a). In some instances, application of inorganic fertilizers (Pfeffer, 1959) and farmyard manure (Sharma and Sharma, 1981) have enhanced the productive capacity of the progeny tubers. Addition of nitrogen (Walker, 1968; Thow, 1970; Gray, 1974), phosphate (Sharma and Sharma, 1981), and potassium (Walker, 1968; Sharma and Sharma, 1981) produced more vigorous and higher yielding seed-tubers compared to seed raised in unfertilized plots. In other instances, application of inorganic fertilizer during seed production either had no effect on seed vigour (Reichard, 1964; Gray, 1973; Wurr, 1978a) or decreased the vigour (Drab, 1961) of the resulting seed-tubers.

The physiological basis for the influence of soil nutrient levels on potato seed-tuber productivity is not well understood. Gray (1973 and 1974) and Sharma and Sharma (1981) showed that the superior growth and yield potential of potato seed-tubers produced under high fertility conditions was due to the greater uptake of nutrients by the mother plants leading to higher levels of nutrients in the seed. Gray (1974) showed a 46% increase in tuber nitrogen content (on a dry weight basis) when soil nitrogen level was increased from 0 to 301 kg ha^{-1}. The increased nitrogen content in the seed promoted rapid sprout growth and early emergence which enhanced early yields (Walker, 1969; Thow, 1970). Gray (1974) suggested that the superior performance of seed from crops given high levels of nitrogen might be due to the nitrogen delaying senescence of the mother plant rather than to any direct influence on tuber nitrogen concentrations.

Wurr (1978a), citing several reports, indicates that treating potato seed-tubers with micro-nutrients (copper, iron, manganese, or zinc) enhanced their yield potential. It is assumed that the beneficial effects of such micro-nutrient treatments involved the correction of nutrient deficiencies in the mother plant rather than through direct physiological effects on the seed (Wurr, 1978a).

2.1.2.3. Irrigation

Yield and quality of table, processing, and seed potatoes are sensitive to soil moisture deficits (Beukema and van der Zaag, 1990; Schaupmeyer, 1992). Soil moisture levels below approximately 50% field capacity can cause considerable yield reductions (Harris, 1978). For seed potato production, sufficient moisture at tuber initiation is critical to the formation of large numbers of small tubers. A continuous moisture supply, compared to intermittent irrigation, is desirable for seed crops as it also increases the yield of the smaller tubers preferred for seed purposes (Schaupmeyer, 1992). Excessive irrigation results in increased haulm growth that can predispose the plants to foliar diseases and late season aphid attacks.

In the past, growers in some areas preferred seed-tubers raised under dryland conditions over seed from irrigated sources (Edmundson, 1930; Harrington, 1933). Consequently, some U.S. States only certified seed grown under dryland conditions (Harrington, 1933). The lower quality of seed-tubers produced under irrigation was attributed to increased disease levels caused by delayed haulm senescence relative to dryland production (Edmundson, 1930). However, studies conducted in Colorado (Edmundson, 1930) and in Montana (Harrington, 1933) showed no appreciable differences in performance of potato seed-tubers raised under either dryland or irrigated conditions provided fields were kept relatively free of diseases.

2.1.2.4. Time of Planting and Harvesting

Potato grown for seed are usually planted late and harvested early mainly as a means of controlling seed size and to minimize the spread of late season viral diseases (Schaupmeyer, 1992). Harvesting too early can reduce seed-tuber yields. Further, early harvesting under relatively warm environmental conditions creates difficulties in cooling tubers prior to long term storage.

Kawakami (1952, 1962) demonstrated that seed-tubers stored for five months after harvest were more vigorous and higher yielding than either younger or older seed. Beukema and van der Zaag (1990) similarly found that at 3-4 month post-harvest, seed-tubers were the most productive. However, the optimum storage periods for seed may vary between cultivars. Accordingly, planting and harvesting times can be manipulated to provide seed-tubers of the desired physiological state. In Sri Lanka, potato production in various regions is limited by temperatures. In the cooler mountain regions, two crops are grown each year, while in the warmer coastal regions, potato production is restricted to one crop in the winter months (Fig. 2.1). There is a well defined movement of seed potatoes among different potato growing regions designed to provide vigourous 3-4 month post-harvest seed for table production (Beukema and van der Zaag, 1990). The seed distribution scheme among the various regions in Sri Lanka is illustrated in Fig. 2.1.

The time of planting of seed crops can also be manipulated to obtain seed-tubers physiologically suited to specific production practices: e.g. in United Kingdom, physiologically old seed is utilized for early potato production. For early potato production, growers prefer seed from early plantings, as early planting of the seedcrop produces physiologically old seed which is preferred for early potato production (Wurr, 1978a).

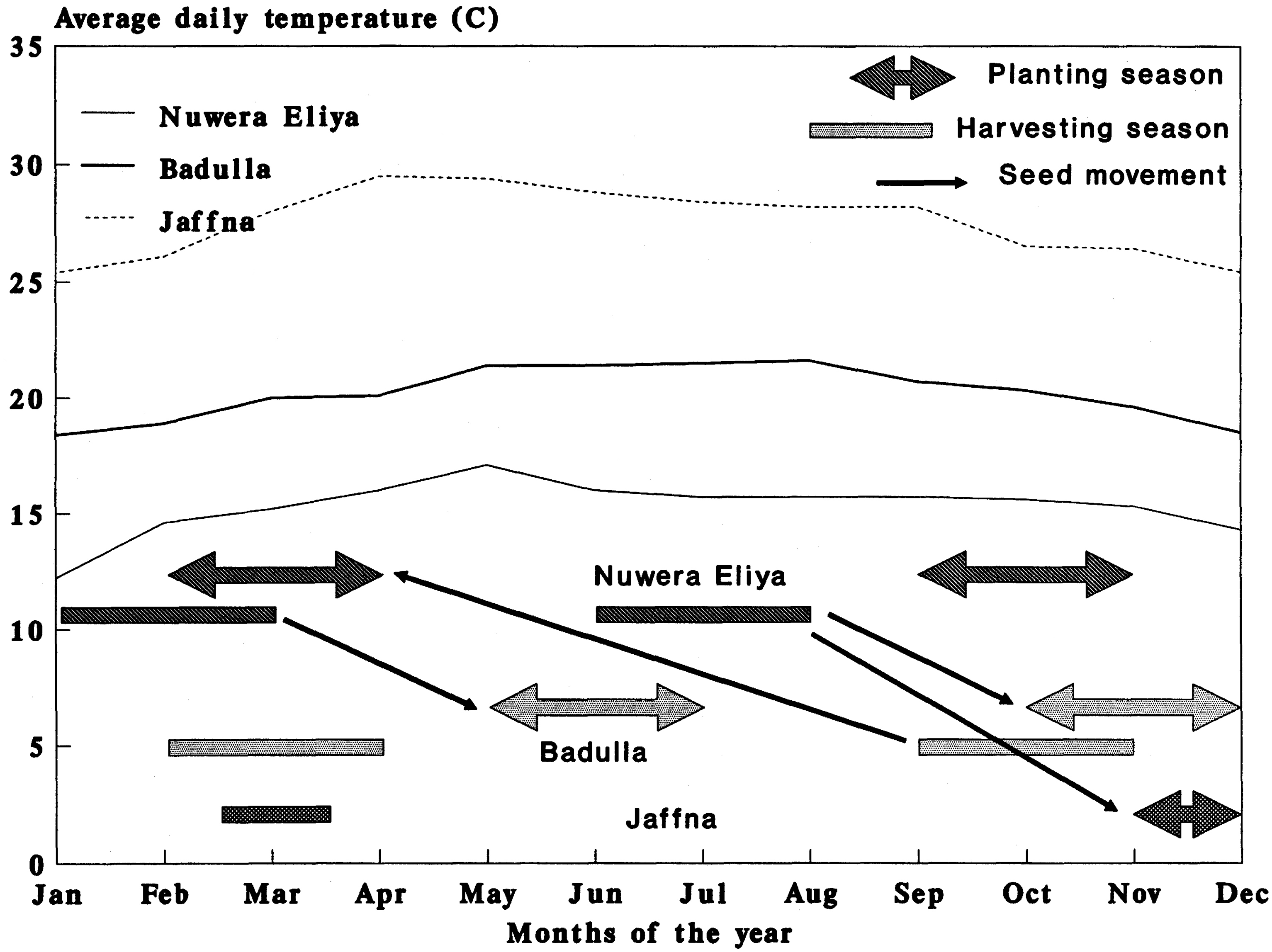


Fig. 2.1. Seasonality of potato production in different regions of Sri Lanka and inter-regional movement of seed potatoes. Source: Beukema and van der Zaag (1990).

2.1.2.5. Vine-Killing

Vine-killing is a commonly utilized practice in seed potato production (Wurr, 1978b and 1978c). Vine-killing controls tuber sizing, reduces spread of viruses during the late season influx of aphids, promotes skin set in the tubers, and facilitates mechanical harvesting (Schaupmeyer, 1992). Slow vine killing is generally preferred as it favours the translocation of metabolites from the tops to the tubers (Schaupmeyer, 1992) resulting in better yields and enhanced seed vigour (Postnikov et al., 1981).

Vine-killing must be performed at the appropriate growth stage, as it can affect yield of seed-tubers and the performance of the progeny. Early desiccation can lead to reductions in yield of the seed crop (Postnikov et al., 1981) as well as reduced seed vigour (O'Brien, 1978; Wurr, 1978b and 1978c). Holmes and Gray (1972) and Allen (cited by Wurr, 1978a) reported that premature vine-killing accelerated sprouting. Goodwin et al., (1969b) reported that early haulm destruction had no impact on vigour of potato seed-tubers obtained from different latitudes. Similarly, Burton (1963) and Iritani (1967) did not observe any differences in seed-tuber yield potential between early and late vine-killing treatments.

2.1.2.6. Herbicides

The effects of herbicide residues in the soil and herbicide drifts on potatoes has been well documented (Eberlein and Schaffers, 1993). However, information on carry-over effects of herbicides (and other agro-chemicals) used during seed production on productivity of the progeny tubers is limited. Haderlie et al., (1986) showed that dicamba and glyphosate drift on seed fields severely reduced the vigour and productivity of the progeny tubers. This was attributed to the herbicides reducing the vigour of the mother plants.

2.1.2.7. Mainstem Density

Seed potato growers usually opt for high density planting, as increased stem densities produce higher yields of the small tubers best suited for seed purposes (Beukema and van der Zaag, 1990; Schaupmeyer, 1992). Seed grown at higher densities produces smaller more roundish tubers with relatively few eyes per unit tuber weight (Wurr, 1978a). Consequently, for a particular weight of seed-tuber, the number of eyes and therefore, the number of stems will be less for seed grown at higher densities. Fewer eyes per unit seed weight can affect yield potential of the seed as tuber yields are generally positively related to mainstem density (Allen, 1978).

2.1.3. Disease Levels

The use of tubers for potato propagation necessitates maintenance of high seed 'quality' standards. The disease status of seed-tubers not only influences yields and quality of the plants arising from this seed, but also diseased plants can infect neighbouring plants and contaminate the soil. Consequently, seed growers strive to minimize all seed-borne diseases, with particular emphasis on the most damaging diseases. Seed-borne diseases may be caused by viral, bacterial and fungal agents, as well as nematodes (Harris, 1982; Beukema and van der Zaag, 1990; Banttari, 1993; Slack, 1993). Presently, nematodes are not a serious problem in seed potato production in Canada (Hodgson et al., 1974), but are very significant in many regions including adjacent states of the U.S.A. (Hooker, 1990; MacGuidwin, 1993).

2.1.3.1. Viruses and Viroids

Potato Virus S (PVS), Potato Virus X (PVX), Potato Virus Y (PVY), Potato Leaf Roll Virus (PLRV), and Potato Spindle Tuber Viroid (PSTV) are the most commonly encountered virus/viroid diseases of seed potato crops in Canada (Hodgson et al., 1974). The strain N of PVY (PVY^N) also called the Tobacco Veinal Necrosis Strain, which attained epidemic levels in Eastern Canada and the United States in 1990 (Banttari, 1993) has caused considerable economic losses for Maritime potato growers. Strict quarantine measures are being adopted to prevent the spread of this virus.

The effect of all potato viruses depends on the type and strain of the virus, the virus titre, degree of resistance of the potato genotype, and the stage of the crop at infection (Banttari, 1993). Virus infections typically reduce yields by restricting the assimilatory surface area of the plant and/or by lowering tuber quality (e.g. Net Necrosis in Russet Burbank caused by PLRV). Yield losses up to 80% have been reported for PVY and PLRV infections (Banttari, 1993). Mirza (1978) found a progressive increase in PLRV incidence from less than 0.1% to 58% in five years when adequate disease control measures were not practised. Potato Spindle Tuber Viroid can also cause severe yield reductions (Hodgson et al., 1974, Hooker, 1990; Banttari, 1993). Yield losses from 65%-80% have been recorded for virulent strains of this pathogen, while mild strains cause less loss, e.g. 15% to 25% (Banttari, 1993). PVX and PVS are less severe, with maximum yield reductions of up to 30% observed for PVX and up to 20% for PVS (Hooker, 1990). Co-infection with two or more viruses can cause more severe damage: e.g. PVX+PVY can cause severe Rugose Mosaic, while, PVX+PVA can cause Mild Mosaic (Hodgson et al., 1974; Hooker, 1990).

The primary source of virus infection is contaminated seed. Therefore, the possibility of virus spread is limited if disease-free seed is used. Viruses and viroids can be transmitted from infected plants mechanically and/or by aphids (Table 2.1). Consequently, the choice of equipment, cultural practices, and pest management procedures are designed to control insect vectors and to minimize mechanical spread of the pathogens. According to Radcliffe et al., (1993), the use of insecticides for aphid control should be undertaken with caution as: (i) most registered insecticides are ineffective against aphids, but do kill the predators which naturally control aphid populations. Insecticide induced outbreaks of aphids, particularly green peach aphid, can occur. (ii) aphids rapidly develop resistance to insecticides.

Short growing seasons and cooler temperatures slow the multiplication rates and check the movement of most insect vectors of potato viruses (Radcliffe et al., 1993). Consequently, in North America, potato seed production is concentrated in the northern states and Canada (Slack, 1993).

Table 2.1. Methods of transmission of common potato viruses and viroids.

Pathogen	Mechanical transmission	Vector	Mode of transmission
PVX	Yes	Insects	Non persistent
PVY	Yes	Aphid	Non persistent
PVS	Yes	Aphid	Non persistent
PLRV	No	Aphid	Persistent
PSTV	Yes	None	-

Source: Hooker, 1990; Banttari, 1993.

2.1.3.2. Bacteria

The seed-borne bacterial diseases of economic importance in potatoes are bacterial ring rot (BRR), black leg, and soft rot.

The causal organism of BRR is *Corynebacterium sepedonicum* (presently called *Corynebacterium michiganense* subsp. *sepedonicum* or *Clavibacter michiganense* subsp. *sepedonicus*). Bacterial ring rot can spread rapidly and cause considerable yield losses (Gudmestad and Secor, 1993). The organism is capable of overwintering in infected seed and can survive up to 2-5 years in dried slime on storage containers and harvesting and grading equipment. Infection occurs through wounds and the organism is readily transmitted throughout healthy tissues. Seed cutting knives and seed picks on planters are the common modes of contamination of seed-tubers. The BRR organism can also be disseminated through irrigation water and by chewing insects, e.g. Colorado potato beetles and flea beetles (Gudmestad and Secor, 1993).

The occurrence of BRR symptoms depends on the inoculum potential and the degree of resistance of the genotype. Low levels of infection can result in the disease being undetected during field inspections. Early-maturing cultivars generally exhibit symptoms earlier than late maturing cultivars. Cultivars resistant/tolerant to BRR (e.g. Merrimack, Teton, Belrus) are not preferred by growers and researchers as they can serve as symptomless carriers of the pathogen (Gudmestad and Secor, 1993). Potato growers from Western Canada are reluctant to grow any cultivar if it is a symptomless carrier for BRR.

Black leg and soft rot are caused by two closely related bacteria, *Erwinia carotovora* subsp. *atroseptica* and *Erwinia carotovora* subsp. *carotovora* respectively (Hooker, 1990). Black leg and soft rot have caused heavy losses to table and seed potatoes in Canada (Hodgson et al., 1974). Most seed lots are contaminated with low levels of the black leg pathogen, usually *Erwinia carotovora* subsp. *atroseptica*, but the bacteria remains dormant without causing disease until exposed to favourable environmental conditions (Gudmestad and Secor, 1993). High moisture conditions and cooler temperatures (18-19°C) are ideal for the spread of the disease (Hooker, 1990). Wet soils at 18-22°C at planting time are ideal for the spread of the disease. The expression of disease symptoms can be influenced by environmental conditions. Temperatures between 24-32°C favour the development of disease symptoms, while temperatures above 32°C retard expression of symptoms (Hooker, 1990). Foliar symptoms may be completely suppressed in cool wet weather or when daylength is greater than 14 h (Gudmestad and Secor, 1993)

2.1.3.3. Fungi

Black scurf (also called stem and stolon canker) caused by *Rhizoctonia solani* strain AG-3 (anastomosis group 3) is the most damaging seed-borne fungal disease of potatoes (Powelson et al., 1993). The greatest damage occurs when *Rhizoctonia* present in the seed or soil attack newly emerging sprouts. The resulting slow emergence and decreased vigour reduce crop growth and lead to premature senescence of the plant (Powelson et al., 1993). Losses due to *Rhizoctonia* average about 15% and in severe cases entire fields have been destroyed (Hodgson et al., 1974). The sclerotia of the pathogen can survive on tubers (black scurf) and in the soil for relatively longer periods (Powelson et al., 1993). The spread of the disease is rapid in cool (±18°C) moist soils (Hooker, 1990).

Late blight (caused by *Phytophthera infestans*) is infrequent in the Canadian prairies, but can be severely damaging under the prolonged cool and rainy conditions (Stevenson, 1993), characteristic of coastal British Columbia and the Maritimes. Infected seed-tubers are a major source of disease spread and complete crop losses can occur in uncontrolled late blight epidemics (Hooker, 1990).

Early blight (caused by *Alternaria solani*) is common in the prairies but is less destructive than late blight. The disease organism overwinters in potato debris and can affect the crop relatively early in the season. It can be very destructive late in the season under favourable weather conditions (Hodgson et al., 1974). The pathogen causes yield reduction normally by reducing assimilatory surface area of the crop and through rapid senescence of infected plants. Immature tubers are more likely to be damaged by early blight than mature tubers (Hooker, 1990).

2.1.4. Potato Seed Certification

The aim of seed potato growers is to produce vigorous disease-free seed. High quality seed ensures better plant stands, promotes rapid canopy closure, delays senescence and produces high yields. The essential prerequisite for production of high quality seed potatoes is to begin with 'clean', disease-free seed and to adopt cultural practices aimed at controlling insect and pest incidence throughout the production cycle.

Major potato seed producing countries have strict guidelines for seed potato certification aimed at controlling the spread of tuber-borne diseases as well as guaranteeing varietal purity.

The cornerstone of the Canadian seed certification programme is nuclear seed. Sophisticated tissue culture and disease-freeing techniques are used to ensure that nuclear seed stocks are completely free of any diseases. In the Canadian Seed Potato Certification Scheme, there are seven subsequent classes (Pre-Elite, Elite-I, Elite-II, Elite-III, Elite-IV, Foundation, and Certified) corresponding to successive generations in the multiplication cycle (Canada Gazette, Part II, Department of Agriculture, Seed Regulation Amendments, 1991). The Pre-Elite, Elite-I and Elite-II seed must be free of any visible diseases in the third field inspection. Subsequent classes have slightly higher disease tolerances (Table 2.2). The tolerance levels allowed for each disease depends on the potential impact of that disease and the grade of seed required. Potato seed certification procedures include field inspections and post-harvest inspections in storage. Disease identifications are done visually and by laboratory methods. Techniques such as test plant grafting, enzyme linked immuno-sorbent assay (ELISA), polyacrylamide gel electrophoresis (PAGE), etc. are used to assay various diseases. Samples of seed stocks also are grown out in California and Florida to diagnose late season infections.

Table 2.2. Disease tolerance levels[z] for seed potatoes allowed in the Canadian Seed Certification Scheme.

Disease[z]	Inspection First	Second	Third
		Elite-III	
PSTV	0.00	0.00	0.00
BRR	0.00	0.00	0.00
All viruses	0.25	0.10	0.01
Black leg, wilts, and viruses	0.50	0.25	0.25
Varietal mix	0.10	0.00	0.00
		Elite-IV	
PSTV	0.00	0.00	-
BRR	0.00	0.00	-
All viruses	0.50	0.10	-
Black leg, wilts, and viruses	1.00	0.25	-
Varietal mix	0.10	0.00	-
		Foundation	
PSTV	0.00	0.00	-
BRR	0.00	0.00	-
All viruses	0.50	0.20	-
Black leg, wilts, and viruses	1.00	0.50	-
Varietal mix	0.10	0.05	-
		Certified	
PSTV	0.00	0.00	-
BRR	0.00	0.00	-
Any one virus	1.00	0.50	-
All viruses	2.00	1.00	-
Black leg, wilts, and viruses	3.00	2.00	-
Varietal mix	1.00	0.05	-

[z]PSTV and BRR indicate potato spindle tuber viroid and bacterial ring rot respectively.
Source: Canada Gazette, Part II, Department of Agriculture, Seed Regulation Amendment (1991).
[z]Percentage infected plants or tubers.

2.1.5. Cultural Means of Maintaining Seed Crop Quality

Various cultural practices are adopted in seed potato production with the objectives of producing vigorous disease-free, seed-sized tubers.

Planting whole seed, compared to cut pieces, is beneficial as the use of whole seed reduces the spread of disease, encourages uniform plant stands and produces a greater proportion of seed grade tubers (Schaupmeyer, 1992). Use of whole seed also eliminates need for tuber unit planting. The use of cup-type instead of pick-type planters also can reduce the spread of mechanically transmitted diseases. Irrigation water and irrigation equipment can spread some diseases, such as black leg, wilts and PVX. Disinfection of all equipments used in seed potato production, including the wheels of irrigation equipment, is recommended (Schaupmeyer, 1992).

According to Schaupmeyer (1992), the performance of seed-tubers depends on their physical and physiological condition. Healthy seed-tubers perform better than damaged tubers as the damaged tubers are more susceptible to seed piece decay. Suitable harvesting techniques, storage, handling, and grading methods are crucial for production of high quality seed. This is particularly important to control degeneration of the seed stock.

2.2. Physiology of Growth and Tuber Yield

2.2.1. Tuber Initiation and Mother Tuber Effects

In the potato, tubers develop at the sub-apical region of the stolon through the thickening of the first internode behind the apex (Plaisted, 1957). Whether tuber initiation is due to cell division (Reeve et al., 1969), cell enlargement (Booth, 1963), or both is not well understood. The physiological condition of the mother tuber and environmental conditions (photoperiod and temperature) influence the timing and extent of tuber initiation and the subsequent rate of enlargement (Smith, 1977; Ewing, 1985; Struik et al., 1991).

The source of the tuberizing stimulus in potatoes has been investigated with conflicting results. Kumar et al., (1980) found that the tuberizing stimulus originated in the developing sprouts, while, Madec and Perennec (1959) and Bodlaender and Marinus (1969) showed that the mother tuber was partly responsible for tuberization. The stimulus provided by the mother tuber appears to act additively with the stimulus originating in the leaves (Madec and Perennec, 1959). The following observations illustrate the influence of the mother tuber on potato tuberization:

i. Tuber formation is earlier in plants with attached mother tubers than in plants where the mother tubers have been removed (Burton, 1966).

ii. Plants with attached mother tubers have a stronger tendency to set tubers even under non-inductive environments than plants separated from mother tubers (Burton, 1966).

iii. Stem cuttings separated later from the mother tuber showed a greater degree of tuberization compared to those separated relatively early (Madec, 1963; Simmonds, 1965; Murti and Banerjee, 1975; van den Berg et al., 1990).

iv. 'Secondary growth' in potato tubers, in the dark, in the absence of foliage is an indication that tuberizing stimulus is present in the mother tuber (Madec and Perennec, 1959; Burton, 1966).

The contribution of the mother tuber to tuberization may depend on the environment in which the plant is grown. Under inductive photoperiods and temperatures, the influence of the mother tubers may be insignificant (Ewing, 1985), while under non-inductive situations, the mother tuber may play a more significant role (Madec and Perennec, 1959; Ewing, 1985).

2.2.2. Photoperiod

Short photoperiods favour tuber initiation in potato, while long photoperiods either inhibit or delay tuberization (Garner and Allard, 1923; Chapman, 1958; Cutter, 1978; Wurr, 1978a; Ewing, 1981 and 1985; Menzel, 1985). Menzel (1985), citing several workers summarized that the critical photoperiod for tuberization by *Solanum andigena* was 11-13 h, while *Solanum tuberosum* had a critical daylength of 15h-17h. However, *S. andigena* also tuberized at a 20h critical photoperiod (Upadhya et al., 1972) and *S. tuberosum* at a 10h critical photoperiod (Ewing and Wareing, 1978). Different *S. tuberosum* cultivars exhibit varying critical photoperiods (Struik et al., 1988; Cao and Tibbits, 1991). The critical photoperiod for early maturing cultivars is generally longer than for late maturing types. The ability of early maturing cultivars to tuberize at longer photoperiods is an important factor in determining earliness of the crop (Ewing, 1981 and 1985).

Tuber induction in potatoes takes place only once a given number of short day cycles have occurred. The number of cycles required varies among genotypes (Gregory, 1956; Chapman, 1958; Murti and Banerjee, 1975).

Photoperiod influences other aspects of potato growth and yield in addition to tuberization. Short photoperiods advance tuber initiation (Demegante and van der Zaag, 1988), while reducing the tuber bulking period (Bodlaender, 1963). Short daylengths also encourage preferential dry matter partitioning to the tubers, thereby increasing tuber dry matter content (Pohjakallio, 1953). Short photoperiods reduce elongation (Murti and Saha, 1975) and weights of stems (Purohit 1970), leaf number, leaf weight (Murti and Saha, 1975) and photosynthetic efficiency (Cao and Tibbits, 1991).

2.2.3. Temperature

Temperature regulates many aspects of the growth and development of the potato (Bodlaender, 1963; Ewing, 1981; Cao and Tibbits, 1992). The temperature optima for potatoes varies with the plant part (Prange et al., 1990; Cao and Tibbits, 1992) and the growth stage (Ewing, 1981; Benoit et al., 1986). Tuber formation is favoured by low temperatures, while higher temperatures promote shoot growth (Benoit et al., 1986). The optimum temperature for tuber formation is between 15°-20°C; at higher temperatures, e.g. 30°C, tuberization may be delayed or completely inhibited (Menzel, 1985).

Potato plants exposed to diurnal temperature fluctuations (cool nights and warm days) outperformed those subjected to constant temperatures (Ewing, 1981). This was due to reduced respiratory losses at low night temperatures (Beukema and van der Zaag, 1990). Maintenance respiration contributed more to the night-time losses than growth respiration (Prange et al., 1990). The optimum night temperature is dependent on the day-time maximum. Higher day-time temperatures require increasingly low night-time temperatures for optimum growth (Benoit et al., 1986). *Solanum* cultivars and species respond differently to varying temperature regimes (Menzel, 1985; Bennett et al., 1991).

The influence of temperature on plant growth and tuber yield is expressed through morphological and physiological changes, although genetic factors determine the extent of expression of temperature effects (Menzel, 1985; Manrique and Bartholomew, 1991). At high temperatures, dry matter is preferentially partitioned to the shoots at the expense of the tubers (Slater, 1969; Saha et al., 1974; Menzel, 1985; Wolf et al., 1991). High temperatures promote the growth of shoot apices through cell division and cell wall synthesis (Wolf et al., 1991) which results in the shoots remaining the dominant sink (Randeni and Ceaser, 1986; Basu and Minhas, 1991; Manrique and Bartholomew, 1991). By contrast, the temperature optimum for tuber growth is relatively lower than that for shoots (Ewing, 1981; Manrique and Bartholomew, 1991). Temperature, and particularly diurnal temperature fluctuations influence photosynthetic capacity and dry matter distribution patterns in potatoes. High temperatures decrease photosynthesis (Dwelle, 1985; Hammes et al., 1990), lower the activity of Photosystem II (Prange et al., 1990), reduce chlorophyll content (Nagarajan and Bansal, 1990), diminish stomatal conductance and inhibit dark reactions (Reynolds et al., 1990). These temperature mediated factors cause a reduction in transport of sugars to the tubers (Wolf et al., 1991; Basu and Minhas, 1991).

2.2.4. Photoperiod and Temperature Interactions

Day-length and temperature act in tandem to influence the growth and development of potatoes (Menzel, 1985). Non-inductive photoperiods can diminish the effects of inductive temperatures and vice versa. Non-inductive warm temperatures and long photoperiods are being utilized by researchers to evaluate genetic material for adaptation to warm tropical environments (Ewing, 1981; Nagarajan and Bansal, 1990; Tibbits et al., 1990).

2.2.5. Tuber Enlargement and Productivity

Tubers are formed over a period of two to four weeks, with late set tubers generally resorbed (Moorby, 1978). Tuber set and tuber size distribution are dependent upon the genotype (Cother and Cullis, 1985) and environmental conditions (Struik et al., 1991). The number of tubers that attain marketable size is determined shortly after tuber set

(Struik et al., 1991), with the size of each tuber determined by its 'sink strength' relative to its cohorts (Dwelle, 1985; Struik et al., 1991; Sattelmacher and Laidig, 1991). Tuber sink strength is particularly high during the linear growth phase (Ahmed and Sagar, 1981). Since the growth rate of individual tubers are different (Ahmed and Sagar, 1981; Schnieders et al., 1988; Struik et al., 1988), the largest tuber during the early stages may not be the largest later in the season (Moorby, 1968).

Potato yields are a function of photosynthetic capacity and dry matter distribution (Dwelle, 1985). The developing plant is dependent upon the mother tuber for carbohydrates (Moorby, 1978) and other nutrients (Kunkel et al., 1973; Gray, 1973 and 1974) during the initial stages of growth. The plant becomes autotrophic once it has produced about 200-400 cm^2 of leaf area (Moorby and Milthorpe, 1975; Moorby, 1978) which occurs approximately four weeks after planting.

Leaf area index (LAI): (leaf area per unit area of land) (Watson, 1952; Bremner and Taha, 1966; Khurana and McLaren, 1982; Lemaga and Ceaser, 1990); leaf area duration (LAD): a measure of persistence of assimilatory area over time (Moorby and Milthorpe, 1975; Allen and Scott, 1980; Chowdhury and Hodgson, 1982; MacKerron and Waister, 1983);

and unit leaf rate (ULR) or net assimilation rate (NAR): (rate of change of plant dry weight per unit leaf area) (Moorby and Milthorpe, 1975) are closely related to potato tuber yields. The persistence of actively growing shoots (stem and leaves) is critical to tuber development, as about 90% of the tuber dry matter is obtained through present assimilation (Zelitch, 1975; Moorby, 1978). Once tubers are initiated, the growth of other plant parts including leaves, stems, and roots is reduced as the tuber becomes the dominant sink for photosynthates.

Tuber set triggers a two to four-fold increase in photosynthesis and a doubling of basipetal export of assimilates (Moorby, 1968). The relative increase in photosynthesis is a function of the sink strength created by the developing tubers (Nosberger and Humphries, 1965; Burt, 1964 and 1966; Collins, 1977).

The rate of dry matter partitioning to the tubers changes with time. The proportion of assimilates diverted to the tubers is low during tuber initiation but as the tubers approach maturity, i.e. four to five weeks after initiation, they become the dominant sink for photosynthates (Gawronska et al., 1984). During the latter stages of tuber development, about 20-25% of the dry matter present in the tubers is supplied by remobilization of assimilates from the shoot rather than by photosynthesis (Moorby and Milthorpe, 1975). This results in a reduction of haulm dry weight and accelerates senescence of the tops.

Increasing stem numbers per unit area increases the tuber number per unit area, while the number of tubers per mainstem remains relatively constant (Allen, 1978; Moorby, 1978). As stem densities increase, the photosynthetic area per stem decreases, but the LAI remains relatively unchanged (Moorby, 1978). Consequently, increased stem densities result in the production of more small tubers (Bleasdale, 1965; Bremner and Taha, 1966; Thompson and Taylor, 1974; Moll, 1983). Lower stem densities reduce inter-plant competition which delays senescence and may result in larger total yields particularly during long growing seasons (Allen, 1978).

2.2.6. Tuberizing Stimulus

Presently, there is a consensus that the tuberizing stimulus in potatoes is hormonal (Gregory, 1956; Ewing, 1985; Stallknecht, 1985) similar to the flowering stimulus in plants (Ewing, 1981). The tuberizing stimulus is not a single compound, rather it is a balance between several compounds (Krauss and Marschner, 1982; Krauss, 1985). Numerous compounds have been identified with positive or negative influences on tuberization (Menzel, 1985; Ewing, 1985; Stallknecht, 1985). Cytokinins (Koda and Okazawa, 1971; Langille and Forsline, 1974; Ewing, 1985) and abscisic acid (Wareing, 1978; Menzel, 1985; Krauss and Marschner, 1986) appear to promote tuber induction, while gibberellic acid inhibits tuber induction (Okazawa, 1960; Kumar and Wareing, 1974; Ewing, 1981 and 1985; Stallknecht, 1985). Although the presence of auxins in potato stolons has been demonstrated (Booth and Wareing, 1958; Tizio and Maneschi, 1973; Stallknecht, 1985), there is no clear evidence of their involvement in tuber initiation (Menzel, 1985). The ratio between hormones (e.g. ABA:gibberellic acid) appears to be more important for tuber initiation than the concentrations of individual hormones (Krauss and Marschner, 1985; Menzel, 1985; Stallknecht, 1985).

2.3. Physiological Age

Hartmans and van Loon (1987) citing several authors reported that the growth and production potential of the developing potato plant is regulated by the physiological age of the mother tuber. Physiologically old mother tubers produce plants that emerge faster, initiate tubers earlier, bulk comparatively slower and senesce earlier than plants from young seed (van der Zaag and van Loon, 1987, Knowles and Botar, 1991). Consequently, physiologically old seed produces higher early yields and lower final (at maturity) yields than physiologically younger seed (Kawakami, 1962;

Iritani, 1968a and 1968b; Allen et al., 1979; O'Brien et al., 1983; Knowles, 1987; Szlavik and Ceaser, 1989; Knowles and Botar, 1991). The improved early yields obtained by using physiologically old seed are primarily due to accelerated emergence (Madec and Perennec, 1955; Wurr, 1978a), as the period between emergence and senescence are similar for the various maturity classes of potato (Moll, 1985). Tuber initiation also occurs at a relatively lower leaf area when older seed is used (Moorby, 1978). As the developing tubers become the dominant sink (Moorby and Milthorpe, 1975), there is limited subsequent partitioning of dry matter to the leaves. This results in restricted shoot growth and early haulm senescence (Moorby, 1978). The potential for increasing early yields by planting physiologically older seed-tubers has been utilized to raise crops for early markets (Wurr, 1978a; O'Brien et al., 1983; van der Zaag and van Loon, 1987) and in regions with a short growing season (Knowles and Botar, 1992).

Temperature is a key factor controlling the physiological age of potato seed-tubers (Bodlaender and Marinus, 1987). High temperatures during tuber initiation (Claver et al., 1957), tuber development (Carls and Ceaser, 1979; Caldiz, 1985) and particularly during the last month of growth (Krijthe, 1958; Wurr, 1978a; Sunoschi, 1981), and during storage (Goodwin et al., 1969a and 1969b; Wurr, 1978a; Hartmans and van Loon, 1987), as well as combinations of these factors (Carls and Ceaser, 1979; O'Brien et al., 1983) all increase the physiological age of seed-tubers. Gillison et al.,(1987) compared the effect of elevated temperatures at different storage phases on physiological age of seed. They found the most pronounced effect of ageing when the tubers were warmed late in the storage period.

2.3.1. Assessment of Physiological Age

Several physical and biochemical methods have been developed for assessing the physiological age of potato tubers. Day-degree sum during storage (Wurr, 1978a and 1979; Kawakami, 1980; O'Brien et al., 1983) and sprouting characteristics (Krijthe, 1962) are commonly used to estimate physiological age. Techniques such as chronological age, i.e. time between seed harvest and planting of seed (Kawakami, 1952); incubation period, i.e. the period between sprouting and tuber initiation (Madec and Perennec, 1955); and duration between planting and emergence (Cho et al., 1983) have been used as indicators of physiological age in potatoes. Biochemical methods assessing enzyme activity and substrate concentration have also been used as a means of evaluating and quantifying the relative age of potato seed-tubers (Appelbaum, 1984; Reust and Arney, 1985; Hartmans and van Loon, 1987; Mikitzel and Knowles, 1989).

CHAPTER 3

Vigour of Potato Seed-tubers from Different Latitudes: Growth and Tuber Yield.

ABSTRACT

Growth and yields of Norland and Russet Burbank potato seed-tubers from different sources were investigated in a five year (1986 to 1990) study. Seed production sites in Saskatchewan (La Ronge, Prince Albert, Saskatoon and Outlook), Minnesota (Becker), Colorado (Greeley and San Luis Valley), Nebraska and Wisconsin were selected to provide a range of latitudes and growing conditions. In 1986 and 1987, comparisons were made among commercial seed lots from the U.S.A. and Saskatchewan. The 1988 to 1990 tests were conducted using seed multiplied from a single original stock in the different Saskatchewan, Colorado and Minnesota locations. Yield trials were conducted at Saskatoon in 1986 and 1987 and at sites in Colorado, Minnesota and Saskatchewan in 1988 through 1990. Seed lots from different locations exhibited varying growth and yield potential; these trends were consistent across yield trial sites. Seed-tubers from the Minnesota site were less vigorous and lower yielding than the Colorado or Saskatchewan sources. This effect was more pronounced in Russet Burbank than Norland

seed. Vigour of the various seed lots did not appear to be associated with incidence of seed borne diseases. Based on stem densities, early shoot vigour and the relative yield differences between 90 and 120 DAP harvests, there were no indications that seed-tubers obtained from the relatively warmer southern sites were physiologically older than seed from cooler locations. Seed vigour appeared to be related to diurnal temperature fluctuations at the seed production sites rather than the average daily temperatures. Growth and yield responses for seed-tubers from contrasting environments are likely due to some physiological changes in the seed-tuber, unrelated to physiological age, that affected shoot vigour, tuberization and assimilate partitioning, thereby influencing tuber yields.

Productivity of potato (*Solanum tuberosum* L.) seed-tubers is dependent on levels of seed-borne disease and the physiological condition of the tuber. The environment in which the seed crop is grown (Goodwin et al., 1969b; Wurr, 1978a; Iritani and Thornton, 1993), cultural operations used during seed-tuber production (Jones et al., 1981) and storage conditions (Goodwin et al, 1969b; Carls and Ceaser, 1979; Wurr, 1978a; Iritani, 1981, Knowles and Botar, 1992) can influence seed vigour by influencing the physiological condition of the tubers as well as the incidence or levels of seed-borne diseases (Harris, 1978; Wurr, 1978a).

There is some evidence that potato seed-tubers grown at higher altitudes are more vigorous and higher yielding in the subsequent generation than those grown at lower altitudes (Hartz et al., 1980, Wiersema and Booth, 1985; Caldiz, 1990). Stuart (1913) and Went (1959) reported that 'Northern' seed was superior to 'Southern' seed, while Westover (1931) showed no yield difference between northern and southern tubers. Goodwin et al., (1969b) obtained variable results over two years with respect to the relative productive potential of northern and southern seed sources.

Potato growers from the southern U.S.A. regularly purchase seed from northern U.S.A. with the belief that this 'northern' seed is more vigorous, and has lower virus levels than southern seed (Hartz et al., 1980). Consequently, in North America, seed potato production is concentrated in the northern U.S.A. and Canada. More recently, table potato growers from the Pacific North Western States of the U.S.A. have been importing increasing quantities of potato seed-tubers from Western Canada due to a similar belief in 'Northern Vigour'.

Potato seed-tuber production practices and seed certification techniques are designed to ensure varietal purity and freedom from seed borne diseases (Harris, 1982; Hooker, 1990; Slack, 1993). Several virus diseases can cause substantial yield reductions in potato. Viruses of commercial significance on the Canadian prairies are potato leaf roll virus (PLRV), potato virus S (PVS), potato virus X (PVX) and potato virus Y (PVY). Prevention of virus diseases in seed potatoes is normally achieved by use of virus-free planting stocks and adoption of appropriate cultural practices, adequate isolation and routine pest and disease management programmes (Hodgson et al., 1974; Harris, 1982; Hooker, 1990; Slack, 1993). Relatively cool, short growing seasons in northern latitudes substantially lowers the activity and multiplication of virus-carrying insects, thereby improving the quality of seed-tubers produced in more northern latitudes (Slack, 1993).

The present project studied the effect of site of seed production on growth and yield potential of potatoes by comparing seed produced in Saskatchewan with seed from more southerly locations in the U.S.A. This paper will describe the influence of site of seed production on growth and tuber yields of the progeny. Seed-borne virus levels will also be examined. Seed source effects on plant growth characteristics will be discussed in more detail in a subsequent paper (Chapter 4).

MATERIALS AND METHODS

Seed Sources

Experiments were conducted in 1986 through 1990, using the locally important potato cultivars Norland and Russet Burbank. The seed sources used in the different years are described in Table 3.1. Monthly temperatures during the growing season for the different seed production sites are summarized in Appendix 3.1. Average daily temperatures during the growing season were lower at the northern sites than at the southern sites. Diurnal temperature fluctuations were higher at Prince Albert, Outlook and Saskatoon than La Ronge, Becker, Nebraska and Wisconsin. The 1986 and 1987 trials were conducted using equivalent generation certified seed-tubers obtained from commercial sources. In the 1988 to 1990 tests, Elite III seed derived from a single source for each cultivar was multiplied at the various locations and the resulting seed was evaluated in the following year. Standard seed production practices were employed at all locations. Disease control in the seed crop was accomplished through locally approved routine spray programmes. The seed-tubers were harvested at maturity (approximately 120 days from planting) and stored in

Table 3.1. Seed sources used in potato yield trials conducted in 1986 through 1990.

Year	Cultivar	Seed sources
1986	Norland	- Nebraska, Outlook, Prince Albert.
	Russet Burbank	- Becker, Outlook, Prince Albert.
1987	Norland	- Nebraska, Outlook, Prince Albert, La Ronge.
	Russet Burbank	- Wisconsin, Outlook, Prince Albert, La Ronge.
1988	Norland	- Becker, Outlook, Prince Albert, La Ronge.
	Russet Burbank	- Becker, Outlook, Prince Albert, La Ronge.
1989	Norland	- Becker, Outlook, Saskatoon, Prince Albert.
	Russet Burbank	- Becker, Outlook, Saskatoon, Prince Albert.
1990	Norland	- San Luis Valley, Greeley, Becker, Outlook, Saskatoon, Prince Albert.
	Russet Burbank	- San Luis Valley, Greeley, Becker, Outlook, Saskatoon, Prince Albert.

Seed production sites:-
Becker (Minnesota).
Greeley and San Luis Valley (Colorado).
Outlook, Prince Albert, La Ronge (Saskatchewan).

Saskatoon at 4°C for approximately seven months until the next growing season.

The 1986 and 1987 yield trials were conducted in Saskatoon using a randomized complete block design (RCBD) with six replications. The 1988 to 1990 yield tests were conducted at several sites in each year: 1988 - Becker in Minnesota, and Outlook, Saskatoon and Prince Albert in Saskatchewan; 1989 - Greeley in Colorado, Becker, Outlook, Saskatoon and Prince Albert; 1990 - Greeley, Becker, Saskatoon and Prince Albert. In these trials, the plots were laid out as a factorial combination of cultivar x seed source in a RCBD with six replications in 1988 and 1989 and four replications in 1990. Seed pieces weighing approximately 35 to 50 g were planted by hand at a 90 cm (between row) x 30 cm (within row) spacing. The crop was raised under irrigation at all locations except Prince Albert which received adequate rainfall. Fertilizer application and other cultural practices were performed according to commercial recommendations specific to the different regions. Ten guarded plants were harvested at 90 ('Early' harvest) and 120 ('Final' harvest) days from planting for yield estimations. Mainstem counts and haulm fresh weights were recorded at the 90 DAP harvest. Tubers were graded according to diameter. In the succeeding discussion, the term 'marketable' will be used to describe all tubers larger than 45 mm in diameter.

All growth and yield data were analyzed using analysis of variance (Minitab, Release 7). Combined analyses were performed for the 1988 to 1990 results considering replicates and test sites as random variables. Correction for heterogeneity in variances was done by reducing the corresponding degrees of freedom as described by Cochran and Cox (1967).

In 1988 and 1989, the crops grown at Outlook, Prince Albert and Saskatoon were assayed in late July for levels of the commercially important viruses; PLRV, PVS, PVX and PVY. Composite samples of 25 leaves were tested from each seed source for the two cultivars grown at each trial site. In 1988, virus tests were also conducted on greenhouse grown plants from the various seed sources. Composite leaf samples from 10 plants were utilized for the greenhouse assay. Virus testing was done at the Agriculture Canada Research Station, Lethbridge, Alberta using the ELISA (enzyme-linked immuno-sorbent assay) procedure. Duplicate wells were used for PLRV and PVY testing. A positive result occurred when test levels exceeded the mean values for virus-free samples by 3-4 standard deviations from the mean.

RESULTS

In 1988 through 1990, combined analyses over production sites for haulm characteristics and yield components showed significant cultivar x yield site interactions (Appendix 3.2). Hence, the data were reanalysed based on individual cultivars (Appendix 3.3).

HAULM GROWTH

Mainstem Density

The site of seed production often significantly influenced the number of above ground stems produced by the progeny of both cultivars (Table 3.2). In 1986, Norland seed from Prince Albert produced more mainstems than seed from Nebraska and Outlook, although the differences were not significant. With Russet Burbank, the Outlook seed source produced fewer mainstems than the Becker or Prince Albert sources. In 1987, Norland seed from the most northern source at La Ronge produced fewer mainstems than the other sources (Table 3.2). For Russet Burbank, in 1987, the Outlook and Wisconsin seed produced significantly higher stem numbers than the more northern Prince Albert and La Ronge sources. For Norland, in 1988, there were no distinct patterns in mainstem numbers between the northern and southern seed sources. By contrast, in 1989, Norland seed from Becker consistently produced fewer mainstems than any

Table 3.2. Number of mainstems per plant at 90 days after planting for Norland and Russet Burbank potatoes grown from different seed sources at various yield trial sites: 1987 to 1990.

Seed source	Number of mainstems per plant											
	1986	1987	1988			1989				1990		
	Sktn	Sktn	Outl	Sktn	PAlb	Grly	Outl	Sktn	PAlb	Beck	Sktn	PAlb
Norland												
Becker	-	-	3.03	6.08	2.24	2.45	2.65	2.88	2.05	4.30	4.23	3.05
Nebraska	3.58	3.90	-	-	-	-	-	-	-	-	-	-
Greeley	-	-	-	-	-	-	-	-	-	4.20	4.35	4.20
S.L.Valley	-	-	-	-	-	-	-	-	-	4.05	4.68	3.18
Outlook	3.50	3.71	2.63	4.72	2.26	2.65	3.95	4.55	4.08	3.20	3.83	2.73
Saskatoon	-	-	-	-	-	3.25	4.28	4.47	3.32	3.78	4.65	3.90
P. Albert	4.25	3.70	2.50	5.29	2.19	2.72	3.55	4.93	3.62	2.88	3.20	2.85
La Ronge	-	3.22	3.10	4.71	2.61	-	-	-	-	-	-	-
Significance	NS	**	**	**	NS	*	**	**	***	**	NS	***
LSD (5.0%)	1.30	0.58	0.53	0.77	0.36	0.07	0.88	0.98	0.81	0.63	0.96	0.55
Russet Burbank												
Becker	3.58	-	2.58	4.15	3.03	2.63	3.52	3.72	4.50	4.05	2.15	2.65
Wisconsin	-	3.02	-	-	-	-	-	-	-	-	-	-
Greeley	-	-	-	-	-	-	-	-	-	4.35	3.55	3.50
S.L.Valley	-	-	-	-	-	-	-	-	-	3.38	3.65	3.00
Outlook	2.25	2.91	1.94	3.53	2.19	1.58	2.57	2.92	2.38	3.18	2.88	2.75
Saskatoon	-	-	-	-	-	1.50	2.37	3.27	2.45	2.88	2.23	2.55
P. Albert	3.75	2.20	2.06	3.88	2.17	1.43	2.93	3.57	3.13	2.85	2.45	1.95
La Ronge	-	2.22	2.26	3.43	2.33	-	-	-	-	-	-	-
Significance	*	**	*	NS	**	***	**	NS	***	***	**	NS
LSD (5.0%)	1.20	0.48	0.43	1.08	0.57	0.30	0.61	1.24	0.40	0.49	0.69	0.86

[z]Recorded 90 days from planting.
*, **, ***, and NS indicate significance at P<0.05, 0.01, 0.001 levels of probability and not significant, respectively.
Sktn=Saskatoon, Outl=Outlook, PAlb=Prince Albert, Beck=Becker, S.L.Valley=San Luis Valley.

other source. In 1988 and 1989, Russet Burbank seed from the Becker site generally produced more mainstems than any of the Saskatchewan sources. This trend was consistent across test sites, although the differences were not significant in some instances. In 1990, Norland and Russet Burbank seed from the southern sources (Minnesota, Greeley and San Luis Valley) tended to produce more stems than seed from the Saskatchewan seed sources, with similar trends at the various yield trial sites (Table 3.2).

Haulm Fresh Weights

Significant seed source effects on haulm fresh weights were observed in 1987, 1989 and 1990 (Appendix 3.3) with source effects more apparent in Russet Burbank than Norland (Table 3.3). Russet Burbank seed from Becker tended to produce lower haulm weights than the other seed sources (Table 3.3). This phenomenon was particularly marked at the Outlook and Saskatoon test sites. The Saskatchewan seed sources usually produced similar haulm weights. In 1990, the San Luis Valley, Greeley, Outlook and Prince Albert seed sources produced comparable haulm weights, while the Becker and Saskatoon seed produced lower haulm weights than the other sources (Table 3.3).

Table 3.3. Haulm fresh weight per plant at 90 days after planting for Norland and Russet Burbank potatoes grown from different seed sources at various yield trial sites: 1987 to 1990.

Seed source	Haulm fresh weight per plant (kg)[z]								
	1987	1988	1989				1990		
	Sktn	Sktn	Grly	Outl	Sktn	PAlb	Grly	Sktn	PAlb
Norland									
Becker	-	1.13	0.33	0.54	0.85	0.35	0.55	0.76	0.26
Nebraska	0.88	-	-	-	-	-	-	-	-
Greeley	-	-	-	-	-	-	0.56	0.65	0.29
S.L Valley	-	-	-	-	-	-	0.56	0.64	0.37
Outlook	1.00	1.17	0.38	0.70	0.94	0.57	0.67	0.92	0.39
Saskatoon	-	-	0.39	0.68	1.06	0.55	0.71	0.80	0.39
P. Albert	1.09	1.36	0.44	0.72	0.97	0.56	0.80	0.79	0.40
La Ronge	0.96	1.29	-	-	-	-	-	-	-
Significance	NS	NS	NS	NS	NS	*	NS	NS	NS
LSD (5.0%)	0.17	0.21	0.59	0.19	0.24	0.17	0.21	0.33	0.12
Russet Burbank									
Becker	-	0.80	0.59	0.23	0.37	0.59	0.72	0.56	0.27
Wisconsin	1.13	-	-	-	-	-	-	-	-
Greeley	-	-	-	-	-	-	1.63	1.06	0.60
S.L.Valley	-	-	-	-	-	-	1.48	1.22	0.58
Outlook	1.05	1.72	1.44	1.04	1.49	0.86	1.45	1.29	0.54
Saskatoon	-	-	1.41	1.26	1.30	0.81	1.25	0.52	0.25
P. Albert	1.25	1.68	1.43	1.06	1.33	0.80	1.55	1.31	0.46
La Ronge	1.11	1.75	-	-	-	-	-	-	-
Significance	NS	***	***	***	***	NS	**	***	***
LSD (5.0%)	0.20	0.36	0.28	0.37	0.33	0.52	0.35	0.30	0.13

[z]Recorded 90 days from planting.

*, **, ***, and NS indicate significance at P<0.05, 0.01, 0.001 levels of probability and not significant, respectively.

Sktn=Saskatoon, Outl=Outlook, PAlb=Prince Albert, Grly=Greeley, S.L.Valley=San Luis Valley.

TUBER YIELDS

A summary of analyses of variance of the yield data in 1986 and 1987 and the combined analyses for 1988, 1989 and 1990are presented in Appendices 3.2 and 3.3 respectively. The error variance constituted only a small proportion of the expected mean square for the denominator in calculating 'F' for the seed source and its interactions with cultivar and test site. Therefore, in the combined analysis for test sites within each year, the error variances were considered homogeneous. The seed source (S) x trial site (L) interactions were generally significant only for Russet Burbank potatoes (Appendix 3.3).

Total Tuber Number per Plant

The effects of seed source on total tuber number per plant were variable and the responses were inconsistent for the two cultivars over the various years (Appendix 3.3). In 1986, seed of both cultivars from Prince Albert produced more tubers than the other sources at both harvests, but the differences were not significant for Russet Burbank at 90 DAP (Table 3.4). In 1987 Norland seed from the various sources produced comparable number of tubers, while Russet Burbank from Wisconsin produced more tubers than the Saskatchewan sources, although the differences were not significant in some instances (Table 3.4). In 1988, Norland and Russet Burbank from the various seed sources produced

Table 3.4. Total number of tubers per plant for Norland and Russet Burbank potatoes from different seed sources at 90 and 120 days after planting: 1986 and 1987 (Test site-Saskatoon).

Seed source	1986	1987
	---Total tuber number per plant[z]---	
	90 DAP	
Norland		
Nebraska	7.9	7.9
Outlook	7.5	9.1
Prince Albert	10.2	8.9
La Ronge	-	8.0
Significance	**	NS
LSD (5.0%)	1.5	1.2
Russet Burbank		
Becker/Wisconsin[y]	7.6	8.3
Outlook	7.6	8.1
Prince Albert	9.1	6.4
La Ronge	-	6.9
Significance	NS	*
LSD (5.0%)	1.5	1.6
	120 DAP	
Norland		
Nebraska	5.9	9.3
Outlook	6.5	10.1
Prince Albert	8.6	10.1
La Ronge	-	9.0
Significance	*	NS
LSD (5.0%)	2.1	1.8
Russet Burbank		
Becker/Wisconsin[y]	5.8	10.1
Outlook	7.1	10.0
Prince Albert	8.2	7.8
La Ronge	-	8.6
Significance	***	*
LSD (5.0%)	1.2	1.8

[z]Tubers larger than 25 mm diameter.
[y]Seed origin: Becker, Minnesota in 1986 and Wisconsin in 1987.
*,**, ***, and NS indicate significance at P<0.05, 0.001 levels of probability and not significant, respectively.

similar number of tubers (Table 3.5). In 1989, Norland seed from Becker produced fewer tubers than the Saskatchewan sources at both harvests, while Russet Burbank from the different sources produced similar number of tubers (Table 3.6). In 1990, Norland seed from the various sources produced comparable number of tubers, while Russet Burbank from the Becker source consistently produced fewer tubers than the other sources (Table 3.7). In 1990, seed-tubers from the Colorado and Saskatchewan sources generally produced comparable numbers of tubers.

The seed source x yield trial site interactions for tuber number per plant were significant in some instances (Appendix 3.3), but no identifiable trends were observed with respect to these interactions (Tables 3.5, 3.6 and 3.7).

Total Tuber Yields

For Norland, significant seed source effects on total tuber yields were observed only in 1986 and 1989 (Appendix 3.3), at which time the Saskatchewan sources significantly outyielded the southern sources at both the 90 and 120 DAP harvests (Tables 3.8 and 3.10). In 1987 (Table 3.8), 1988 (Table 3.9) and 1990 (Table 3.11), Norland seed from the various sources produced similar yields. In 1990, the Saskatchewan and Colorado seed sources generally produced

Table 3.5. Total number of tubers per plant for Norland and Russet Burbank potatoes from different seed sources at 90 and 120 days after planting at several locations: 1988.

Seed source	Test site				
	Becker	Outlook	Sktn	P.Albert	**Mean**
			90 DAP		
Norland					
Becker	12.3	6.6	10.6	4.1	8.4
Outlook	10.1	6.3	9.5	4.5	7.6
P.Albert	9.7	6.5	9.6	5.3	7.8
La Ronge	10.8	7.2	9.0	5.2	8.0
Significance	**	NS	NS	NS	NS
LSD (5.0%)	1.0	0.9	1.7	0.9	2.5
Russet Burbank					
Becker	10.3	6.1	7.4	4.5	7.1
Outlook	12.1	6.1	7.9	5.4	7.8
P.Albert	11.5	6.2	9.0	5.9	8.2
La Ronge	12.9	5.7	8.0	7.5	8.5
Significance	NS	NS	NS	NS	NS
LSD (5.0%)	1.3	0.5	1.3	1.4	1.9
			120 DAP		
Norland					
Becker	12.7	6.4	9.5	4.4	8.3
Outlook	11.4	6.0	7.6	5.4	7.6
P.Albert	12.6	6.8	8.5	5.0	8.2
La Ronge	11.1	6.9	8.3	6.1	8.1
Significance	NS	NS	*	NS	NS
LSD (5.0%)	1.6	0.6	1.4	1.7	1.6
Russet Burbank					
Becker	11.4	6.3	6.8	6.1	7.6
Outlook	11.8	6.0	7.6	6.5	8.0
P.Albert	13.9	6.2	7.7	6.3	8.5
La Ronge	13.3	5.9	6.9	6.6	8.1
Significance	NS	NS	NS	NS	NS
LSD (5.0%)	2.5	0.9	1.2	1.1	1.6

*, **, and NS indicate significance at $P<0.05$, 0.01 levels of probability and not significant, respectively.
Sktn=Saskatoon.

Table 3.6. Total number of tubers per plant for Norland and Russet Burbank potatoes from different seed sources at 90 and 120 days after planting at several locations: 1989.

Seed source	Test site					
	Beck	Grly	Outl	Sktn	PAlb	**Mean**
				90 DAP		
Norland						
Becker	8.8	14.5	6.2	7.9	3.7	8.2
Outlook	10.0	14.0	8.7	10.0	6.3	9.8
Saskatoon	9.6	14.9	8.5	9.9	5.8	9.7
P.Albert	8.7	14.4	7.9	9.1	5.2	9.1
Significance	*	NS	*	NS	*	**
LSD (5.0%)	1.1	0.6	1.7	1.9	1.6	0.7
Russet Burbank						
Becker	8.3	10.1	4.7	5.9	5.7	6.9
Outlook	9.8	8.9	7.8	8.2	4.9	7.9
Saskatoon	9.4	8.2	6.6	8.6	4.4	7.4
P.Albert	8.6	8.7	7.0	9.2	5.7	7.8
Significance	NS	NS	***	NS	NS	NS
LSD (5.0%)	2.1	1.9	1.3	2.8	1.2	1.5
				120 DAP		
Norland						
Becker	10.5	10.1	6.0	9.1	3.5	7.8
Outlook	11.7	11.6	10.3	10.8	6.0	10.0
Saskatoon	9.9	10.8	8.8	12.0	6.6	9.6
P.Albert	10.5	10.5	8.0	10.0	5.3	8.9
Significance	NS	NS	**	NS	***	**
LSD (5.0%)	2.1	2.0	2.0	2.4	1.3	1.1
Russet Burbank						
Becker	10.5	9.7	5.0	6.3	6.1	7.5
Outlook	11.7	7.5	8.6	8.5	5.4	8.3
Saskatoon	11.3	8.4	7.6	7.8	5.2	8.1
P.Albert	11.1	8.4	7.8	8.8	5.7	8.4
Significance	NS	NS	**	**	NS	NS
LSD (%)	2.1	1.4	1.9	1.5	1.8	1.4

*, **, ***, and NS indicate significance at P<0.05, 0.01, 0.001 levels of significance and non significant, respectively. Beck=Becker, Grly=Greeley, Outl=Outlook, Sktn=Saskatoon and PAlb=Prince Albert.

Table 3.7. Total number of tubers per plant for Norland and Russet Burbank potatoes from different seed sources at 90 and 120 days after planting at several locations: 1990.

Seed source	Test site: Becker	Greeley	Saskatoon	P.Albert	Mean
			90 DAP		
Norland					
S.L.Valley	9.5	11.7	7.1	6.0	8.6
Greeley	8.6	12.5	6.9	5.2	8.3
Becker	6.9	10.2	7.8	4.5	7.3
Outlook	7.9	9.6	6.8	5.5	7.4
Saskatoon	8.5	10.7	6.8	5.5	7.8
P.Albert	7.3	11.1	6.2	5.8	7.6
Significance	**	NS	NS	NS	NS
LSD (5.0%)	1.0	2.9	2.3	1.5	1.1
Russet Burbank					
S.L.Valley	11.6	11.8	7.2	6.6	9.3
Greeley	12.6	11.9	6.7	7.9	9.8
Becker	7.5	7.5	4.9	4.8	6.1
Outlook	9.6	12.3	5.9	6.1	8.5
Saskatoon	7.6	9.5	5.6	4.7	6.8
P.Albert	11.5	12.8	6.1	4.9	8.8
Significance	**	*	*	**	***
LSD (5.0%)	2.2	2.8	1.2	1.3	1.6
			120 DAP		
Norland					
S.L.Valley	10.5	11.4	8.3	4.9	8.8
Greeley	9.4	10.7	8.7	5.6	8.6
Becker	8.4	10.2	6.1	4.5	7.3
Outlook	9.8	10.6	6.4	4.7	7.9
Saskatoon	8.7	10.7	8.4	5.6	8.3
P.Albert	9.4	11.7	6.9	4.5	8.1
Significance	NS	NS	*	NS	NS
LSD (5.0%)	2.3	1.6	1.5	1.3	1.1
Russet Burbank					
S.L.Valley	11.7	12.5	7.8	5.8	9.4
Greeley	13.3	12.4	6.6	5.9	9.5
Becker	6.2	8.4	4.3	5.3	6.0
Outlook	12.5	12.1	7.1	6.3	9.5
Saskatoon	8.9	8.6	5.0	4.5	6.7
P.Albert	10.7	12.3	6.6	5.1	8.7
Significance	***	***	***	*	*
LSD (5.0%)	1.7	1.4	1.2	1.3	2.1

*, **, ***, and NS indicate significance at P<0.05, 0.01, 0.001 level of significance and not significant, respectively.

Table 3.8. Total tuber yields for Norland and Russet Burbank potatoes from different seed sources at 90 and 120 days after planting: 1986 and 1987 (Test site-Saskatoon).

Seed source	1986	1987
	---Total tuber yield (t ha^{-1})^{z}---	
	90 DAP	
Norland		
Nebraska	35.6	32.7
Outlook	43.0	37.7
Prince Albert	49.9	36.8
La Ronge	-	34.0
Significance	**	NS
LSD (5.0%)	7.6	5.9
Russet Burbank		
Becker/Wisconsin[y]	28.3	25.1
Outlook	34.6	24.1
Prince Albert	40.7	21.5
La Ronge	-	17.9
Significance	**	*
LSD (5.0%)	5.4	4.8
	120 DAP	
Norland		
Nebraska	35.2	58.5
Outlook	43.7	67.4
Prince Albert	42.9	61.3
La Ronge	-	61.3
Significance	*	NS
LSD (5.0%)	7.4	14.3
Russet Burbank		
Becker/Wisconsin[x]	28.8	60.4
Outlook	42.4	59.5
Prince Albert	43.7	55.3
La Ronge	-	52.9
Significance	***	NS
LSD (5.0%)	6.2	13.2

[z]Tubers larger than 25 mm diameter.
[y]Seed origin: Becker, Minnesota in 1986 and Wisconsin in 1987.
*, **, ***, and NS indicate significance at P<0.05, 0.01, 0.001 levels of probability and not significant, respectively.

Table 3.9. Total tuber yields for Norland and Russet Burbank potatoes from different seed sources at 90 and 120 days after planting at several locations: 1988.

Seed source	Test site				
	Becker	Outlook	Saskatoon	P.Albert	**Mean**
			---Total tuber yield (t ha^{-1})^{z}---		
			90 DAP		
Norland					
Becker	43.1	25.5	49.6	14.5	33.2
Outlook	43.1	27.9	49.4	22.5	35.7
P.Albert	42.8	28.1	52.7	21.8	36.4
La Ronge	41.6	28.2	41.5	17.1	32.1
Significance	NS	NS	*	**	NS
LSD (5.0%)	7.0	5.0	7.1	5.1	13.3
Russet Burbank					
Becker	22.1	16.6	16.8	11.1	16.7
Outlook	23.1	16.9	25.6	15.5	20.2
P.Albert	22.5	16.5	29.3	15.6	21.0
La Ronge	24.5	16.3	25.1	16.2	20.5
Significance	NS	NS	***	NS	NS
LSD (5.0%)	3.6	4.1	5.0	5.5	11.0
			120 DAP		
Norland					
Becker	52.9	28.6	71.9	16.8	42.5
Outlook	51.7	31.5	71.7	24.1	44.7
P.Albert	49.5	35.6	79.5	24.0	47.1
La Ronge	47.7	32.3	65.4	19.1	41.2
Significance	NS	NS	NS	NS	NS
LSD (5.0%)	10.1	6.4	10.1	6.5	14.5
Russet Burbank					
Becker	51.9	23.7	29.2	20.4	31.3
Outlook	50.6	26.7	48.6	28.2	38.5
P.Albert	56.5	25.0	50.5	22.3	38.6
La Ronge	55.7	26.5	44.8	21.6	37.1
Significance	NS	NS	***	NS	NS
LSD (5.0%)	8.0	6.0	7.4	6.3	19.2

^{z}Tuber larger than 25 mm in diameter.
*, **, ***, and NS indicate significance at P<0.05, 0.01, 0.001 levels of significance and not significant, respectively.

Table 3.10. Total tuber yields for Norland and Russet Burbank potatoes from different seed sources at 90 and 120 days after planting at several locations: 1989.

Seed source	Becker	Greely	Outlook	Saskatoon	P.Albert	**Mean**
	Test site					
			---**Total yield (t ha^{-1})^{z}**---			
			90 DAP			
Norland						
Becker	42.6	75.2	24.2	37.1	17.4	39.3
Outlook	59.4	73.0	38.2	57.9	34.1	52.5
Saskatoon	57.5	86.1	39.9	58.7	30.1	54.5
P.Albert	49.1	78.4	40.1	53.0	30.1	50.1
Significance	***	NS	***	*	**	***
LSD (5.0%)	5.7	11.2	7.6	15.2	8.6	6.0
Russet Burbank						
Becker	27.4	46.8	9.2	22.3	12.8	23.7
Outlook	37.0	61.6	24.8	34.4	33.0	38.2
Saskatoon	33.8	59.1	23.9	38.2	17.8	34.6
P.Albert	35.8	60.8	23.9	47.7	21.2	37.9
Significance	NS	*	***	**	*	***
LSD (5.0%)	8.1	9.6	4.0	13.2	12.9	6.1
			120 DAP			
Norland						
Becker	51.4	58.3	36.0	63.1	18.6	45.5
Outlook	70.4	66.3	53.3	59.0	34.5	56.7
Saskatoon	66.2	62.6	52.5	58.6	34.4	54.8
P.Albert	62.9	66.6	53.4	67.2	33.2	56.7
Significance	*	NS	**	NS	**	**
LSD (5.0%)	12.9	7.8	9.4	12.0	9.7	6.4
Russet Burbank						
Becker	60.9	43.9	12.6	20.0	20.2	31.5
Outlook	67.5	44.4	53.1	56.2	29.0	50.1
Saskatoon	64.5	50.9	47.5	45.5	26.9	47.0
P.Albert	71.6	54.0	48.6	57.2	30.6	52.4
Significance	NS	NS	***	***	NS	**
LSD (%)	14.7	8.6	9.2	10.4	13.8	11.4

^{z}Tubers larger than 25 mm in diameter.
*, **, ***, and NS indicate significance at P<0.05, 0.01, 0.001 levels of significance and not significant, respectively.

Table 3.11. Total tuber yields for Norland and Russet Burbank potatoes from different seed sources at 90 and 120 after planting at several locations: 1990.

Seed Source	Test site: Becker	Greeley	Saskatoon	P.Albert	**Mean**
			---Total yield (t ha^{-1})^{z}---		
			90 DAP		
Norland					
S.L.Valley	35.5	38.8	39.4	34.4	37.0
Greeley	31.1	45.2	34.8	30.1	35.3
Becker	24.4	39.2	36.7	22.0	30.6
Outlook	33.2	48.7	40.4	28.8	37.8
Saskatoon	37.1	41.2	34.3	35.9	37.1
P.Albert	34.2	50.1	36.4	31.5	38.0
Significance	**	NS	NS	NS	NS
LSD (5.0%)	5.8	13.0	15.8	8.8	5.6
Russet Burbank					
S.L.Valley	29.8	31.3	28.7	32.7	30.6
Greeley	30.4	34.8	28.2	34.9	32.1
Becker	15.1	22.6	15.8	18.0	17.9
Outlook	24.7	44.7	26.4	28.3	31.0
Saskatoon	17.3	33.6	18.0	17.0	21.5
P.Albert	27.1	34.4	26.5	22.9	27.7
Significance	***	*	*	**	***
LSD (5.0%)	4.9	15.1	10.3	8.7	5.8
			120 DAP		
Norland					
S.L.Valley	53.2	55.1	58.6	27.4	48.6
Greeley	46.6	56.3	40.1	30.8	43.5
Becker	45.8	54.8	40.3	27.0	42.0
Outlook	56.1	49.5	45.3	27.2	44.5
Saskatoon	44.6	59.1	51.9	29.3	46.2
P.Albert	53.4	61.6	45.1	29.3	47.3
Significance	NS	NS	NS	NS	NS
LSD (5.0%)	17.9	12.1	19.8	11.3	9.1
Russet Burbank					
S.L.Valley	74.4	48.2	53.9	31.9	52.1
Greeley	68.8	54.8	37.0	29.2	47.5
Becker	23.4	31.9	20.8	24.3	25.1
Outlook	70.6	51.9	41.6	33.0	49.2
Saskatoon	46.8	42.5	25.1	16.2	32.6
P.Albert	64.8	48.8	57.2	29.0	50.0
Significance	***	***	***	*	**
LSD (5.0%)	22.2	6.9	12.4	11.1	10.9

^{z}Tubers larger than 25 mm in diameter.
*, **, ***, and NS indicate significance at P<0.05, 0.01, 0.001 levels of significance and not significant, respectively.

similar yields (Table 3.11). The absence of seed source x trial site interactions (Appendix 3.3) indicates that the performance of the various seed sources was consistent across test sites.

Seed source effects for total tuber yields of Russet Burbank were significant in all years but at 120 DAP in 1987 and at both harvests in 1988 (Appendix 3.3). The Becker seed produced lower tuber yields than the other sources in 1986, 1988, 1989 and 1990 although the differences were not significant in 1988 (Tables 3.8, 3.9, 3.10 and 3.11). This trend was consistent across all yield test sites. In 1990, the Saskatchewan and Colorado sources generally produced similar tuber yields (Table 3.11). Differences between yield potentials of the various seed sources were consistent despite considerable differences in absolute yields across the test sites. Significant seed source x test site interactions occurred for Russet Burbank at the 90 and 120 day harvests in 1988 and at the 120 day harvest in 1989 and 1990 (Appendix 3.3). This was due to the exceptionally poor performance by the Becker source at the northern yield trial sites.

Analyses of variance were performed for the difference in total yield between the 90 and 120 day harvests for all 30 test sites and cultivar combinations in 1986 through

1990. All but four tests showed non-significant seed source effects and no consistent patterns were discernible among the various seed sources for the significant yield differences between the two harvests.

Marketable Tuber Yields

In 1986, Norland seed from Nebraska produced lower marketable yields than the Saskatchewan seed sources at both the 90 and 120 DAP harvests (Table 3.12). There were no significant effects of seed source on marketable yields for Norland in 1987 and 1988 (Tables 3.12 and 3.13), although Outlook and Prince Albert seed appeared to produce higher yields than Nebraska seed in 1987 and Becker and La Ronge seed in 1988. In 1989, Norland seed from Becker produced significantly lower marketable yields than the Saskatchewan sources at both harvests, while the various Saskatchewan sources produced similar yields (Table 3.14). In 1990, Norland seed from Becker tended to produce lower marketable yields than either the various Saskatchewan sources or the two Colorado sources at both 90 DAP and 120 DAP in 1990 (Table 3.15). The absence of seed source x trial site interactions (Appendix 3.3) is indicative of the consistency of the relative performance of the various seed sources across different test environments.

Table 3.12. Marketable tuber yields for Norland and Russet Burbank potatoes from different seed sources at 90 and 120 days after planting: 1986 and 1987 (Test site-Saskatoon).

Seed source	1986	1987
	---Marketable tuber yield (t ha^{-1})^{z}---	
	90 DAP	
Norland		
Nebraska	32.4	30.9
Outlook	40.6	34.9
Prince Albert	46.6	34.5
La Ronge	-	32.1
Significance	**	NS
LSD (5.0%)	7.7	6.3
Russet Burbank		
Becker/Wisconsin[y]	20.9	20.5
Outlook	28.5	20.0
Prince Albert	33.7	18.5
La Ronge	-	13.5
Significance	**	*
LSD (5.0%)	5.4	5.1
	120 DAP	
Norland		
Nebraska	32.6	55.1
Outlook	41.3	63.2
Prince Albert	38.9	56.9
La Ronge	-	57.9
Significance	*	NS
LSD (5.0%)	6.8	15.4
Russet Burbank		
Becker/Wisconsin[y]	24.0	51.0
Outlook	37.3	52.2
Prince Albert	37.5	49.9
La Ronge	-	44.1
Significance	**	NS
LSD (5.0%)	7.7	14.1

[z]Tubers larger than 45 mm diameter.
[y]Seed origin: Becker, Minnesota in 1986 and Wisconsin in 1987.
*, **, ***, and NS indicate significance at $P<0.05$, 0.01, 0.001 levels of probability and not significant, respectively.

Table 3.13. Marketable tuber yield for Norland and Russet Burbank potatoes from different seed sources at 90 and 120 after planting at several locations: 1988.

Seed sourcee	Test site				
	Becker	Outlook	Saskatoon	P.Albert	**Mean**
			---Marketable yield ($t\ ha^{-1}$)[z]---		
			90 DAP		
Norland					
Becker	41.7	24.3	47.1	13.5	31.7
Outlook	42.2	26.7	45.2	21.9	34.0
P.Albert	41.9	27.0	50.7	21.0	35.1
La Ronge	40.4	25.9	39.3	15.7	30.3
Significance	NS	NS	*	**	NS
LSD (5.0%)	6.8	5.3	7.2	5.4	12.1
Russet Burbank					
Becker	16.8	11.9	9.0	8.1	11.5
Outlook	18.2	12.8	17.1	11.6	14.9
P.Albert	17.7	11.9	19.2	11.8	15.2
La Ronge	18.0	12.1	15.3	12.8	14.5
Significance	NS	NS	***	NS	NS
LSD (5.0%)	3.8	5.2	4.3	5.3	9.6
			120 DAP		
Norland					
Becker	42.9	27.3	69.8	15.7	38.9
Outlook	42.5	29.9	70.7	23.1	41.5
P.Albert	38.6	34.6	75.1	23.4	43.0
La Ronge	39.3	31.2	63.8	17.5	38.0
Significance	NS	NS	*	*	NS
LSD (5.0%)	9.3	7.1	7.8	6.0	12.8
Russet Burbank					
Becker	46.2	20.4	21.9	17.8	26.6
Outlook	40.1	24.4	42.6	26.1	33.3
P.Albert	46.9	22.2	44.4	19.7	33.3
La Ronge	43.8	24.3	40.3	18.3	31.7
Significance	NS	NS	***	*	NS
LSD (5.0%)	7.9	6.4	7.7	6.3	17.7

[z]Tubers larger than 45 mm in diameter.
*, **, ***, and NS indicate significance at $P<0.05$, 0.01, 0.001 levels of significance and not significant, respectively.

Table 3.14. Marketable tuber yields for Norland and Russet Burbank potatoes from different seed sources at 90 and 120 days after planting at several locations: 1989.

Seed source	Test site					
	Becker	Greeley	Outlook	Saskatoon	P.Albert	**Mean**
			---Marketable yield (t ha^{-1})^{z}---			
			90 DAP			
Norland						
Becker	40.7	61.0	19.9	32.3	16.0	34.0
Outlook	58.5	61.5	33.3	55.1	32.2	48.1
Saskatoon	56.7	72.4	35.2	55.2	28.3	49.6
P.Albert	47.7	66.4	35.8	47.7	28.8	45.3
Significance	***	NS	**	*	**	***
LSD (5.0%)	5.5	9.5	7.9	17.0	8.4	5.8
Russet Burbank						
Becker	21.1	23.0	0.1	14.0	6.4	12.9
Outlook	30.6	46.8	9.1	23.3	30.5	28.1
Saskatoon	27.0	47.0	12.4	24.0	15.4	25.2
P.Albert	29.9	47.0	6.4	29.4	16.9	25.9
Significance	NS	***	***	NS	**	***
LSD (5.0%)	9.4	6.6	3.2	14.1	12.5	6.7
			120 DAP			
Norland						
Becker	48.6	53.1	33.8	60.2	17.0	42.5
Outlook	67.7	60.3	49.8	67.4	27.8	54.6
Saskatoon	64.5	56.9	49.8	68.3	30.4	54.0
P.Albert	59.7	61.9	51.2	64.1	31.7	53.7
Significance	*	NS	**	NS	*	***
LSD (5.0%)	13.7	7.2	8.6	11.4	9.5	4.5
Russet Burbank						
Becker	58.4	31.7	3.8	7.2	14.3	23.1
Outlook	64.4	37.0	41.9	46.7	25.7	43.1
Saskatoon	61.7	43.2	38.9	35.6	23.2	40.5
P.Albert	69.4	46.5	37.3	45.3	27.5	45.2
Significance	NS	**	***	***	NS	**
LSD (5.0%)	15.3	8.8	9.1	11.1	14.0	10.7

^{z}Tubers larger than 45 mm in diameter.
*, **, ***, and NS indicate significance at P<0.05, 0.01, 0.001 levels of significance and not significant, respectively.

Table 3.15. Marketable tuber yields for Norland and Russet Burbank potatoes from different seed sources at 90 and 120 days after planting at several locations: 1990.

Seed source	Test site: Becker	Greeley	Saskatoon	P.Albert	**Mean**
			---**Marketable yield (t ha^{-1})^{z}**---		
			90 DAP		
Norland					
S.L.Valley	33.2	38.4	36.6	32.5	35.2
Greeley	28.9	44.7	31.6	27.6	33.2
Becker	22.8	38.9	33.4	20.1	28.8
Outlook	31.0	48.5	38.5	26.6	36.2
Saskatoon	35.7	40.8	32.1	34.4	35.8
P.Albert	32.7	49.8	34.3	29.2	36.5
Significance	**	NS	NS	*	NS
LSD (5.0%)	6.2	13.0	15.2	8.9	6.3
Russet Burbank					
S.L.Valley	18.8	30.8	23.4	27.0	25.0
Greeley	18.5	34.2	22.3	27.3	25.6
Becker	8.6	22.2	12.0	12.7	13.9
Outlook	15.4	43.6	22.3	22.7	26.0
Saskatoon	10.8	33.2	13.1	11.8	17.2
P.Albert	15.7	33.5	20.8	19.0	22.3
Significance	*	*	*	**	***
LSD (5.0%)	6.2	15.2	10.4	8.7	5.2
			120 DAP		
Norland					
S.L.Valley	51.0	49.9	56.6	25.9	45.9
Greeley	45.0	50.7	35.7	29.2	40.1
Becker	44.4	50.0	38.1	25.6	39.5
Outlook	54.6	43.2	44.0	25.5	41.8
Saskatoon	43.3	54.7	48.1	27.0	43.3
P.Albert	51.8	56.0	43.0	28.2	44.7
Significance	NS	NS	NS	NS	NS
LSD (5.0%)	17.9	12.5	20.3	11.9	7.5
Russet Burbank					
S.L.Valley	71.1	30.7	50.8	27.5	45.0
Greeley	62.9	38.0	32.2	23.3	39.1
Becker	19.3	18.1	16.9	18.9	18.3
Outlook	65.8	36.3	38.2	28.0	42.1
Saskatoon	41.7	30.6	21.3	12.1	26.4
P.Albert	61.7	31.6	54.6	24.3	43.0
Significance	***	**	***	NS	***
LSD (5.0%)	22.3	10.3	14.2	12.4	7.3

^{z}Tubers larger than 45 mm in diameter.
*, **, ***, and NS indicate significance at $P<0.05$, 0.01, 0.001 levels of significance and not significant, respectively.

Russet Burbank seed from the Saskatchewan and Colorado sources outyielded the Wisconsin/Becker seed in three (1986, 1989 and 1990) out of five years (Appendix 3.3, Tables 3.12, 3.14 and 3.15). Russet Burbank seed from Wisconsin/Becker and La Ronge produced slightly lower (non-significant) marketable yields than the other sources at 120 DAP in 1987 (Table 3.12) and at both harvests in 1988 (Table 3.13). The Colorado and Saskatchewan sources produced similar marketable yields in 1990 (Table 3.15). Although marketable yields obtained at the different yield trial sites were variable, the relative superiority of the Saskatchewan seed sources was quite consistent across the different test sites in the different test-years. Tuber yields from the Becker seed were very inconsistent. For example, Becker seed produced quite low yields relative to the other seed sources at the Saskatchewan test sites while at the Becker and Colorado test sites, the Becker seed performed relatively well. This was reflected by the significant seed source x trial site interactions (Appendix 3.3).

The analyses of variance for the difference in marketable yields between the 90 DAP and 120 DAP harvests for the 1986 through 1990 trials generally showed no significant seed source effects.

Virus Levels

The results for the virus tests from the various seed sources taken from greenhouse grown plants in 1988 and from various field test sites in 1988 and 1989 are presented in Table 3.16. In 1988, no virus diseases were detected in greenhouse grown plants for all seed sources, yet in the field, all sources tested positive for at least one virus. This suggests that these viruses were acquired through primary (current season) infection from the field in the test year rather than through secondary infections carried over in the seed. The presence of PVS and PVY in Russet Burbank seed from Becker at all three test sites in 1989 suggests that the original seed stock was infected with these viruses.

DISCUSSION

Seed potato vigour is determined by the environmental conditions under which the seed is grown and management practices during seed production (Iritani and Thornton, 1993). In this study, the relative growth and yield characteristics of Norland and Russet Burbank seed potatoes produced at different latitudes were not absolutely consistent across test sites and test years. This is likely due to site to site and year to year variability in soil and climatic conditions and management practices during both seed production and yield testing (Burton, 1966; Harris,

Table 3.16. Virus levels in field grown Norland and Russet Burbank potatoes from different seed sources at several test sites: 1988 and 1989.

Seed source	Test site: Outlook	Saskatoon	P. Albert
		1988	
Norland			
Becker	S	S, LR	S, LR
Outlook	-	LR	-
Prince Albert	-	LR	(LR)
La Ronge	-	LR	LR
Russet Burbank			
Becker	S, LR	S, LR, (Y)	S, LR
Outlook	(LR)	LR	-
Prince Albert	LR	LR	-
La Ronge	LR	LR	LR
		1989	
Norland			
Becker	-	-	-
Outlook	(Y), LR	-	-
Saskatoon	-	-	-
Prince Albert	LR	(S)	S
Russet Burbank			
Becker	YY, S, LR	YY, S	YY, S
Outlook	X, (S)	-	(S)
Saskatoon	X, S	-	-
Prince Albert	-	-	S

Virus assay done using ELISA test.
Positive results exceeded the mean value of the virus-free standard by 3-4 standard deviations from the mean.
LR, S, X, Y, and YY indicate PLRV, PVS, PVX, PVY, and strong PVY reaction, respectively.
Letters within parenthesis indicates weak positive reaction to the corresponding virus.

1978; Beukema and van der Zaag, 1990, Rowe, 1993). Nonetheless, there were some clearly discernible patterns in the growth and yield potential of the different seed sources. Russet Burbank seed from the Becker and Wisconsin sources frequently produced lower marketable yields than Saskatchewan and Colorado seed sources. Similar, but less pronounced, trends were observed for Norland seed from the different northern and southern sources. Differential cultivar responses for differing seed sources have also been described by Flack (1983).

Stuart (1913) and Goodwin et al., (1969b) showed that potato seed-tubers from northern latitudes were more productive than seed from southern sources. Growing potato seed-tubers in cooler northern latitudes caused beneficial physiological changes in the seed-tuber tissue (Goodwin et al., 1969b) and reduced the levels of seed borne viruses (Hartz et al., 1980; Slack, 1993). In this study, the observed growth and yield responses were not clearly correlated with differing levels of seed borne viruses. For example, in 1989, Norland seed from Outlook and Prince Albert sources produced higher marketable yields than the Becker source despite testing positive for some viruses which were not found in the Becker seed. An exception might be the Russet Burbank seed from Becker in 1989 which performed very poorly and had high levels of PVY. The apparent lack of linkage between site of production, virus levels and yields suggests that the yield advantage of the Saskatchewan seed sources over the Becker seed was caused by some beneficial physiological changes in the seed-tuber tissue. Sawyer and Cetas (1962) and Kunkel (1977) also found that the differences in productivity of seed lots were due to factors other than the levels of seed-borne diseases.

The physiological basis of the productive superiority of potato seed-tubers grown in relatively cooler high altitudes (Kozlowska, 1960 and 1963; Wiersema and Booth, 1985; Caldiz, 1991) and higher latitudes (Westover, 1931; Goodwin et al., 1969b) compared to warmer lower elevations and lower latitudes is thought to be mediated through the influence of low temperatures on the physiological age of the seed (Bodlaender, 1973; Carls and Ceaser, 1979; Caldiz, 1985; Iritani and Thornton, 1993). Physiologically older seed-tubers produced under warm conditions give rise to less vigorous plants with more mainstems than physiologically younger seed. Plants from old seed set tubers early but senesce prematurely, resulting in lower tuber yields at maturity (Harris, 1978; Knowles and Botar, 1992). Artificially ageing seed increased stem numbers in late-maturing cultivars but reduced stem numbers in early-maturing cultivars (Moll, 1985). In this study, there was no clear evidence that the growth and yield responses for

Norland and Russet Burbank potatoes from the various seed sources were related to physiological age effects corresponding with the average growing season temperatures for the different locations. Both the early-maturing Norland and late maturing Russet Burbank failed to show any distinct patterns for stem numbers in relation to growing season temperatures. Seed from the various sites often produced similar stem numbers and in some situations, the responses were opposite to the expected trends.

In this study, the early (90 DAP) harvest was designed to examine seed source effects on the rate of crop development and maturity. Knowles and Botar (1992) found increased haulm weights and tuber yields at 90 DAP for physiologically old seed. However, in this study, the haulm weights for seed from the relatively warm Becker, Greeley or Wisconsin sites were comparable to the plants grown from the relatively cooler Saskatchewan and San Luis Valley sources. In fact, haulm weights from Becker seed were consistently lower compared to seed from the other cool sites. Again, these data do not support the concept that seed from the warmer sites was physiologically older than seed from cooler sources. Also, according to physiological age theory, the relative yield increase between the 90 and 120 DAP harvests should be higher for physiologically young seed than for older seed. In this study, the relative yield differences between harvests were similar for the various seed sources. A similar lack of response was also observed by Wiersema and Booth (1985) in their comparison of yields for highland and lowland seed.

The mature harvests, in this study, were taken approximately 120 days after planting. By this time, the early-maturing Norlands had naturally senesced. The 120 DAP harvest, therefore, accurately represents the maximum yield potential of the Norland seed. By contrast, the late-maturing Russet Burbank was still healthy at all sites at the 120 DAP harvest. Consequently, the 120 DAP harvest period does not necessarily represent the full yield potential of this cultivar. This is particularly true at the southern test sites where the average growing season is 150 days or more. Under favourable climatic conditions, Russet Burbank is capable of growing actively up to 180-190 days (Knowles and Botar, 1992). If the more vigorous Russet Burbank seed from the northern sources were allowed to grow to full maturity at the southern yield test sites, a greater differential between yields for northern and southern seed could be expected.

Early studies showed that potato seed-tubers produced in cooler high latitudes were more vigorous and higher yielding than seed from relatively warmer lower latitudes

(Stuart, 1913; Goodwin et al., 1969b; Hartz, 1980). The observed poor performance of the Minnesota, Nebraska and Wisconsin seed cannot be solely attributed to high temperatures at these sites. The average temperatures at the Greeley site were comparable to Becker, yet the Greeley seed was consistently more vigorous than Becker seed. A more important difference between the temperature characteristics of the low-yielding Becker, Nebraska and Wisconsin sites versus the high yielding Colorado and Saskatchewan sites may be diurnal temperature fluctuations. The high yielding sites had greater diurnal temperature fluctuations than the other sites. The unexpectedly low vigour of seed originating in the northern most La Ronge site might be attributed to low diurnal temperature fluctuations at that site, although this site also experienced low average daily temperatures. Went (1959) also found that productivity of potato seed-tubers was enhanced by greater day/night temperature differences. Temperature influences most aspects of potato growth and yields (Tibbits and Wheeler, 1987). Vegetative growth is favoured by warm temperatures, while cool temperatures favour tuber growth (Ewing, 1981; Manrique, 1984). This response is due to differential partitioning of photosynthates according to temperature (Khedar and Ewing, 1985; Manrique and Bartholomew, 1991; Gawronska et al., 1992). Warm days combined with cool nights enhance growth and tuberization in potato (Steward et al., 1981) compared to constant day/night temperatures (Ewing, 1981). A significant diurnal temperature fluctuation allows for efficient photosynthesis in the day while reducing respiration at night; thereby enhancing dry matter accumulation (Bennett et al., 1991). Relatively cool night temperatures may increase adenylate energy levels (e.g. Levitt, 1980) in the potato tuber similar to beans exposed cool temperatures (Wilson, 1978). Increased adenylate levels in seed-tubers from cooler sites could likely have a positive influence on seed vigour as has been observed in other crop species (Bewley and Black, 1985).

Bennett et al., (1991) found that growth and yield responses for early maturing Norland were less affected by diurnal temperature fluctuations than late maturing Denali potato. The more pronounced seed source effect observed in this study for late maturing Russet Burbank potatoes compared to Norland may be due to similar effects associated with the diurnal temperature differences in the seed growing sites.

It can be summarized that the growth and yield responses for seed-tubers from various locations are more related to physiological modifications in the seed-tuber tissue than to differences in their physiological age or levels of seed borne disease. The yield differences between the northern and southern sources appeared to be more pronounced in the more northern test sites than at the southern sites. It is possible that the lower average temperatures at the northern test sites favoured early tuberization, thereby increasing early partitioning of dry matter to the tubers (Manrique and Bartholomew, 1991; Gawronska, 1992). This trend taken in combination with the higher levels of tuberizing stimulus present in the Becker seed (Chapter 9) may have greatly restricted haulm growth of the Becker seed in favour of early tuber development (Ewing, 1985). Cool temperatures are also more favourable for the expression of virus disease symptoms (Hooker, 1990; Banttari, 1993) resulting in the loss of assimilatory surface area and corresponding reductions in tuber yields. Consequently, the negative effects of seed-borne viruses would be more pronounced at cool (i.e. northern) test sites.

The relative performance of seed-tubers from an array of germplasm sources raised under controlled temperature regimes should be evaluated in contrasting environments in order to provide information on (i) seed source x production environment interactions, (ii) the critical temperature limits for maximizing seed vigour and (iii) the physiological and biochemical factors determining seed potato vigour.

CHAPTER 4

Vigour of Potato Seed-tubers from Different Latitudes: Growth Analysis.

ABSTRACT

Growth and yield characteristics of potato seed-tubers from different latitudes were compared using growth analysis procedures. The study was conducted in Saskatoon, Saskatchewan, during the summers of 1986 through 1989. Growth and yield characteristics of Norland and Russet Burbank seed from several locations in Saskatchewan (La Ronge, Prince Albert, Outlook and Saskatoon) were compared with seed from southern Becker (Minnesota), Nebraska and Wisconsin. The performance of the seed sources were variable in the different years, but some consistent differences were observed between the northern and southern seed sources. Northern seed usually produced plants that were more vigorous (taller plants and higher shoot weights) which senesced relatively later (greater shoot biomass duration) resulting in greater tuber yields than plants from southern sources. Seed source effects were more pronounced in Russet Burbank than in Norland. Superior tuber yields produced from northern seed were associated with greater tuber bulking rates, despite a delay in tuber initiation as compared to

southern seed. Premature partitioning of dry matter to the developing tubers likely reduced the vigour of the crop derived from southern seed. Variables such as shoot growth, mainstem number, date of tuber initiation and tuber dry matter content did not indicate that seed-tubers from the southern locations were more physiologically advanced than seed from the cooler northern locations.

Physiological condition and tuber borne diseases are major determinants of potato (*Solanum tuberosum* L.) seed-tuber productivity. These factors are, in turn, influenced by the environment in which seed-tubers are produced. Potato seed-tubers originating in cool northerly latitudes (Went, 1959; Stuart, 1913; Goodwin et al., 1969a; Hartz et al., 1980) and high altitudes (Wiersema and Booth, 1985; Caldiz, 1991) frequently outperform seed from relatively warmer southerly latitudes or low altitudes. The physiological basis for these yield responses is not clear.

The effect of prevailing temperature regimes on the physiology of potato seed-tubers has been investigated with conflicting results. Bodlaender (1973), Wurr (1978a), Carls and Ceaser (1979) and Kawakami (1980) attributed the effects of seed production environment to impact on the physiological age of the seed-tubers. Cool environments are thought to produce physiologically young seed-tubers (Went, 1959; Bodlaender, 1973; Caldiz et al., 1985). Plants grown from physiologically young seed-tubers exhibit the following characteristics: slow emergence, few mainstems, relatively late tuber initiation, delayed haulm senescence, low early tuber yields and high yields at maturity (Mikitzel and Knowles, 1989). The expression of physiological age can be influenced by genotype (O'Brien, 1983; van der Zaag and van Loon, 1987); degree (Knowles and Botar, 1991 and 1992) and stage of ageing (Gillison et al., 1987) and the environment under which the crop is grown (Carls and Ceaser, 1979). By contrast, Wiersema and Booth (1985) and Caldiz (1991) were unable to find any physiological age differences between seed lots produced in different latitudes, yet seed-tubers from higher elevations were consistently more productive than those from lower elevations. Goodwin et al., (1969b) concluded that the growth and yield variability among potato seed-tubers originating from different latitudes in England was due to some modification in the seed-tuber tissue distinct from physiological age.

Growth analysis techniques have been used to study many aspects of the development of potato (Borah and Milthorpe, 1962; Milthorpe, 1963; Dawes et al., 1983; Knowles and Botar, 1992). Potato yields are determined by the efficiency of tuber bulking (Moorby and Milthorpe, 1975) and the ability of the shoot and foliage to provide sufficient photosynthates to the developing tubers. About 90% of the dry matter accumulated by the tubers is supplied by current assimilation (Moorby, 1970; Zelitch, 1975). High photosynthetic rates coupled with long leaf area duration and biomass duration are critical to potato yields (Dyson and Watson, 1971; Khurana and McLaren, 1982; Dwelle, 1985). Reported effects of tuber growth rates and duration of tuber development on yield are variable (Struik et al., 1991). According to different authors, the crucial considerations were: the date of tuber initiation (Sale, 1973), tuber bulking rate (Moorby and Milthorpe, 1975) and/or the length of the growing season (Moorby, 1978).

Although studies on the yield potential of potato seed-tubers from different locales, latitudes and altitudes are common, information on the basis for these yield responses is limited. The present investigation will use growth analysis techniques to examine growth and yield responses of potato seed produced at different latitudes.

MATERIALS AND METHODS

This study was carried out in Saskatoon during the summers of 1986 through 1989. Comparisons were made for Norland and

Russet Burbank seed obtained from locations in the U.S.A. (Minnesota, Nebraska, Wisconsin) and Saskatchewan (La Ronge, Outlook, Prince Albert, Outlook, Saskatoon). Seed sources tested each year are shown in Table 3.1. Seed production procedures and the cultural practices employed in producing the resulting crop were described in detail in Chapter 3. The experiments were laid out in a randomized complete block design with six replications. Seed pieces were planted at 90 cm (between row) x 30 cm (within row) spacing. The crops were raised under supplemental irrigation. Two guarded plants from each plot were carefully harvested at regular intervals for growth analysis. The sampling dates in the different years were as follows: 31, 47, 75, 89 and 108 DAP in 1986; 34, 41, 54, 68, 82 and 102 DAP in 1987; 31, 45, 59, 73, 89 and 101 DAP in 1988; 36, 49, 57, 70, 90 and 105 DAP in 1989. Mainstem counts, vine lengths and dry weights for various plant components were recorded at each sampling date.

The following growth parameters were calculated according to Hunt (1982):

Mean Relative Growth Rate (RGR) for shoot and tuber:

$$(\log_e W_2 - \mathrm{loge}_e W_1)/(T_2 - T_1)$$

where W_2 and W_1 are shoot or tuber dry weights at stages T_2 and T_1 respectively.

Shoot Biomass Duration:

Area beneath a response curve depicting the relationship between total shoot dry weight and time.

Harvest Index:

Total tuber dry weight expressed as a percentage of total (leaf + stem + tuber) dry weight of plant.

Statistical analyses were performed using the GLM procedure of Minitab (Version 7.0). Harvest indices and tuber dry matter percentages were analyzed following arcsine transformation of the data in order to fulfil the conditions required for analysis of variance (Steel and Torrie, 1982). Time of tuber initiation and tuber bulking rates were estimated from the linear relationship $Y = a + bX$ (where **X** is days after planting, **Y** is total tuber dry weight, **a** is the intercept and **b** is the regression coefficient) as suggested by Goodwin et al., (1969b) and Knowles and Botar (1992). Use of this linear relationship allowed for variance associated with individual data points (van Heemst, 1986). The regression coefficient represents tuber bulking rate and **-a/b** describes the time of tuber initiation. Homogeneity of regression coefficients for the different seed sources for each cultivar was tested according to Snedecor and Cochran (1980).

RESULTS

Average monthly temperatures during the growing season at the different seed production regions are summarized in Appendix 3.1. The temperature attributes for the Saskatoon test location during the 1986 through 1989 cropping seasons are presented in Appendix 4.1. Average daily temperatures during the growing season were lower at northern sites than at the southern sites. Diurnal temperature fluctuations were higher at Prince Albert, Saskatoon and Outlook than at La Ronge and the various southern sites. In subsequent discussions, seed-tubers produced in La Ronge, Prince Albert, Saskatoon and Outlook will be broadly categorized as 'northern' seed and those obtained from Minnesota, Nebraska and Wisconsin as 'southern' seed. Tuber dry weight records are not available for 1987 due to spoilage prior to data collection.

Vine Lengths

In 1986 and 1989, Norland plants derived from southern seed had shorter vine lengths in the early growth stages than northern seed (Fig. 4.1). In the latter stages, vine lengths for all seed sources were similar. No significant

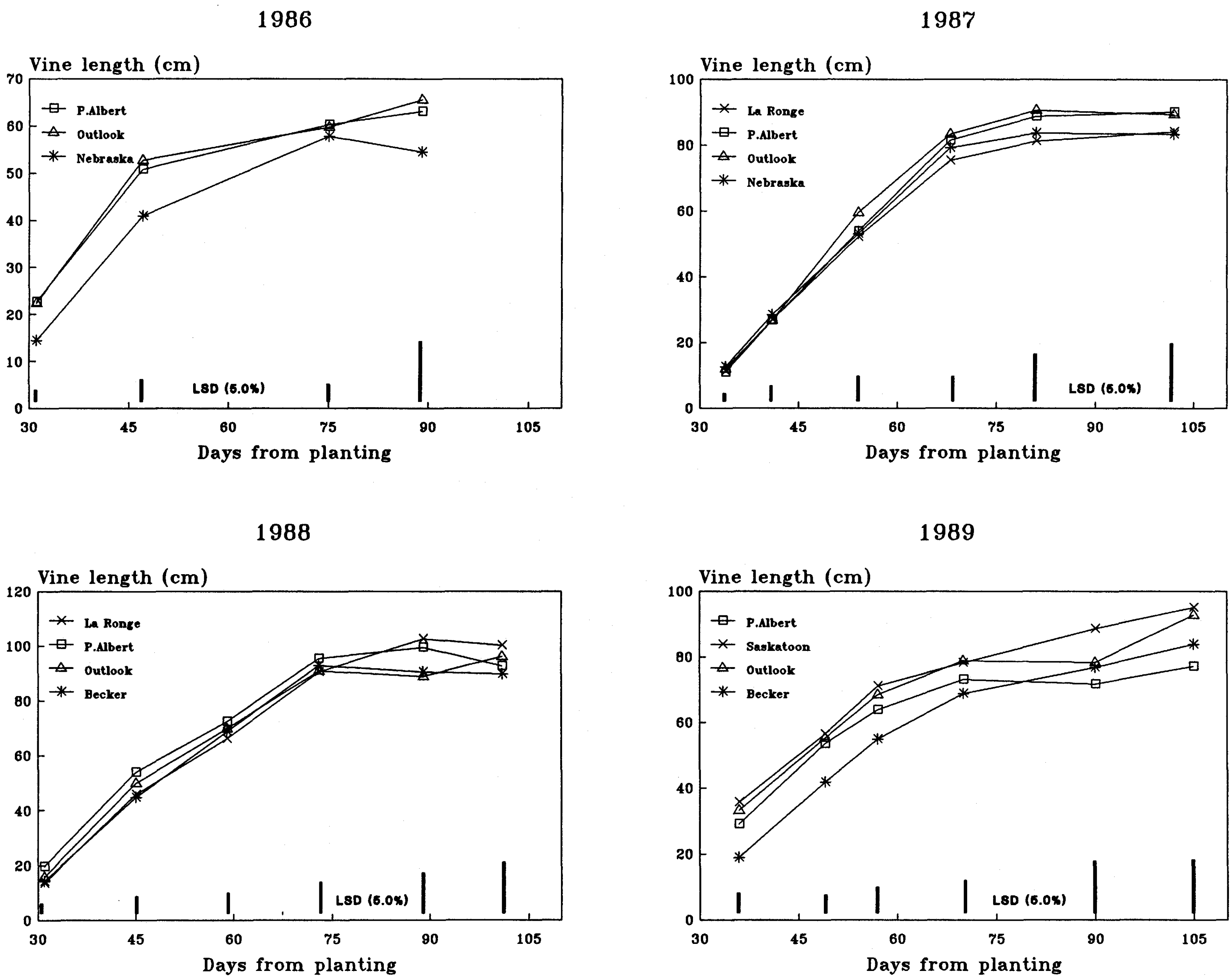


Fig. 4.1. Vine length for Norland potatoes from different seed sources: 1986 to 1989.

seed source effects on vine length for Norland were observed in 1987 and 1988.

In 1986, 1988 and 1989, vine lengths for Russet Burbank from all seed sources were similar at the initial sampling (Fig. 4.2). In 1987, La Ronge seed produced shorter vines than the other sources (not obvious in Fig. 4.2). In the subsequent harvests, vine lengths from the southern sources were often shorter than from the northern sources. This seed source effect was particularly marked during the latter growth stages.

Mainstem Numbers

The number of mainstems per hill remained relatively constant over the different sampling periods. Therefore, the mainstem count at the post-flowering stage was used to depict seed source effects. No seed source effects were observed for mainstem number for Norland in 1987 and 1988 or for Russet Burbank in 1986, 1987 or 1988 (Table 4.1). In 1989, Norland seed from Becker produced fewer mainstems than the three northern sources, while Russet Burbank from Becker produced more mainstems than the Prince Albert and La Ronge sources. Differences between the Outlook and Becker sources were not significant.

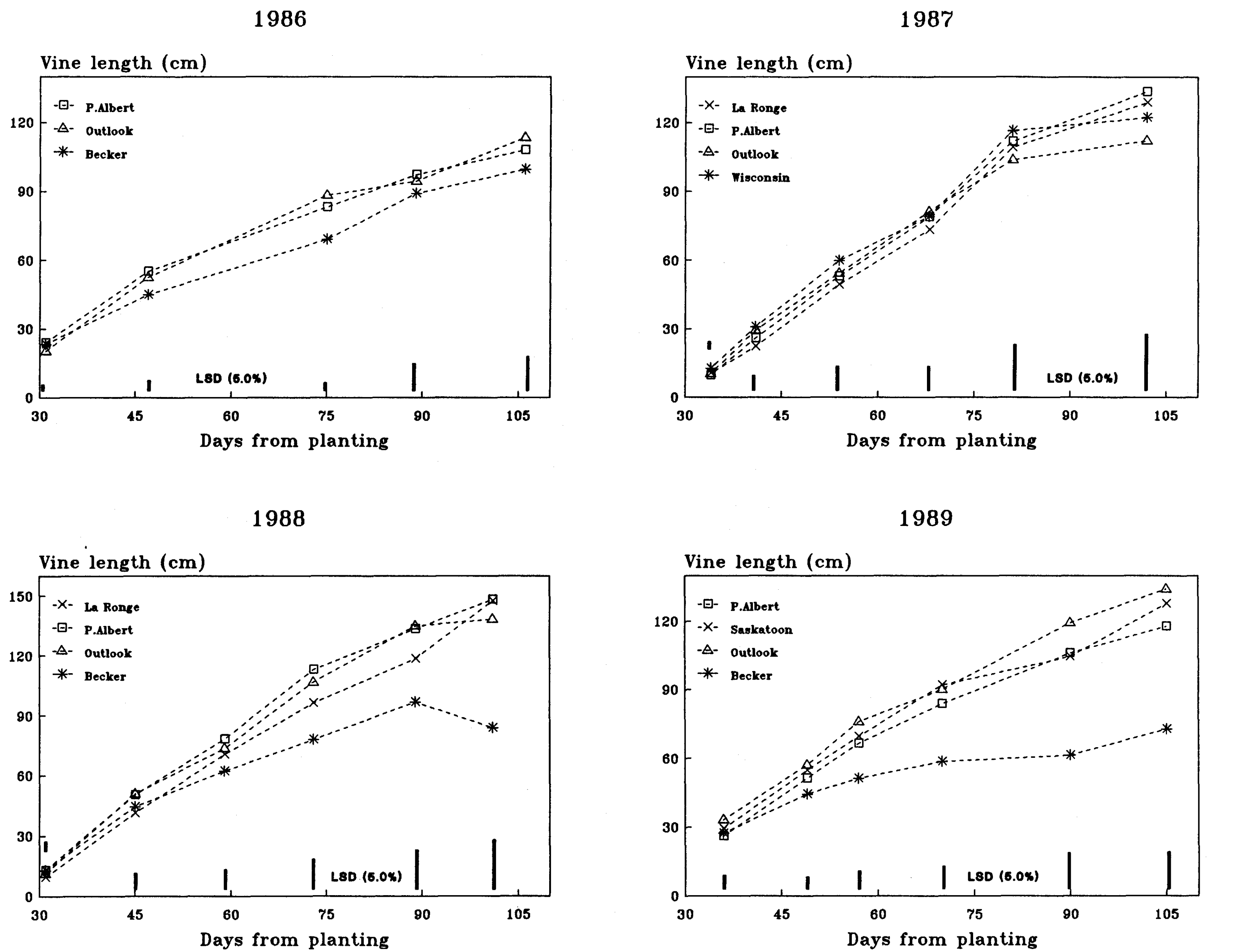


Fig. 4.2. Vine length for Russet Burbank potatoes from different seed sources: 1986 to 1989.

Table 4.1. Number of mainstems per plant in Norland and Russet Burbank potatoes from different seed sources approximately 70 DAP: 1986 to 1989.

Seed source	Norland	Russet Burbank
	---Number of mainstems per plant---	
	1986	
Prince Albert	4.8b[z]	3.8a
Outlook	2.8a	3.4a
U.S.A[y]	3.5ab	4.4a
	1987	
La Ronge	3.2a	2.1a
Prince Albert	4.9a	2.3a
Outlook	4.0a	2.7a
U.S.A[x]	4.6a	3.6a
	1988	
La Ronge	4.8a	3.3a
Prince Albert	5.6a	3.6a
Outlook	5.0a	3.0a
Becker	4.8a	4.3a
	1989	
La Ronge	4.5b	3.3a
Prince Albert	5.0b	3.3a
Outlook	4.7b	4.1ab
Becker	2.6a	5.1b

[z]Means for seed sources within cultivars followed by the same letter are not significantly different at $P<0.05$ level of probability.
[y]Norland from Nebraska and Russet Burbank from Minnesota.
[x]Norland from Nebraska and Russet Burbank from Wisconsin.

Dry Matter Distribution

Leaf Dry Weight: Significant effects of seed source on leaf dry weights were observed at several sampling dates in all four years (Appendix 4.2). The effects of seed source differed between the two cultivars.

Seed source had little influence on leaf dry weight of Norland potato in 1987 or 1988 (Fig. 4.3). In 1986, Nebraska seed produced lower leaf dry weights than the northern seed throughout the growing season, although the differences were not significant in the later growth stages. In 1989, the southern seed source again produced significantly lower leaf dry weights than the northern sources at the early sampling dates (Fig. 4.3).

Russet Burbank plants from all seed sources produced similar leaf dry weights at the initial sampling date in all test years (Fig. 4.4). In 1986 and 1987, the various seed sources continued to produce similar foliage dry weights at all subsequent harvest intervals, although in 1986, leaf dry weights from the Prince Albert source was slightly lower than the other sources. However, in 1988 and 1989, the northern seed sources consistently produced higher leaf dry weights than the southern sources at the later harvest dates.

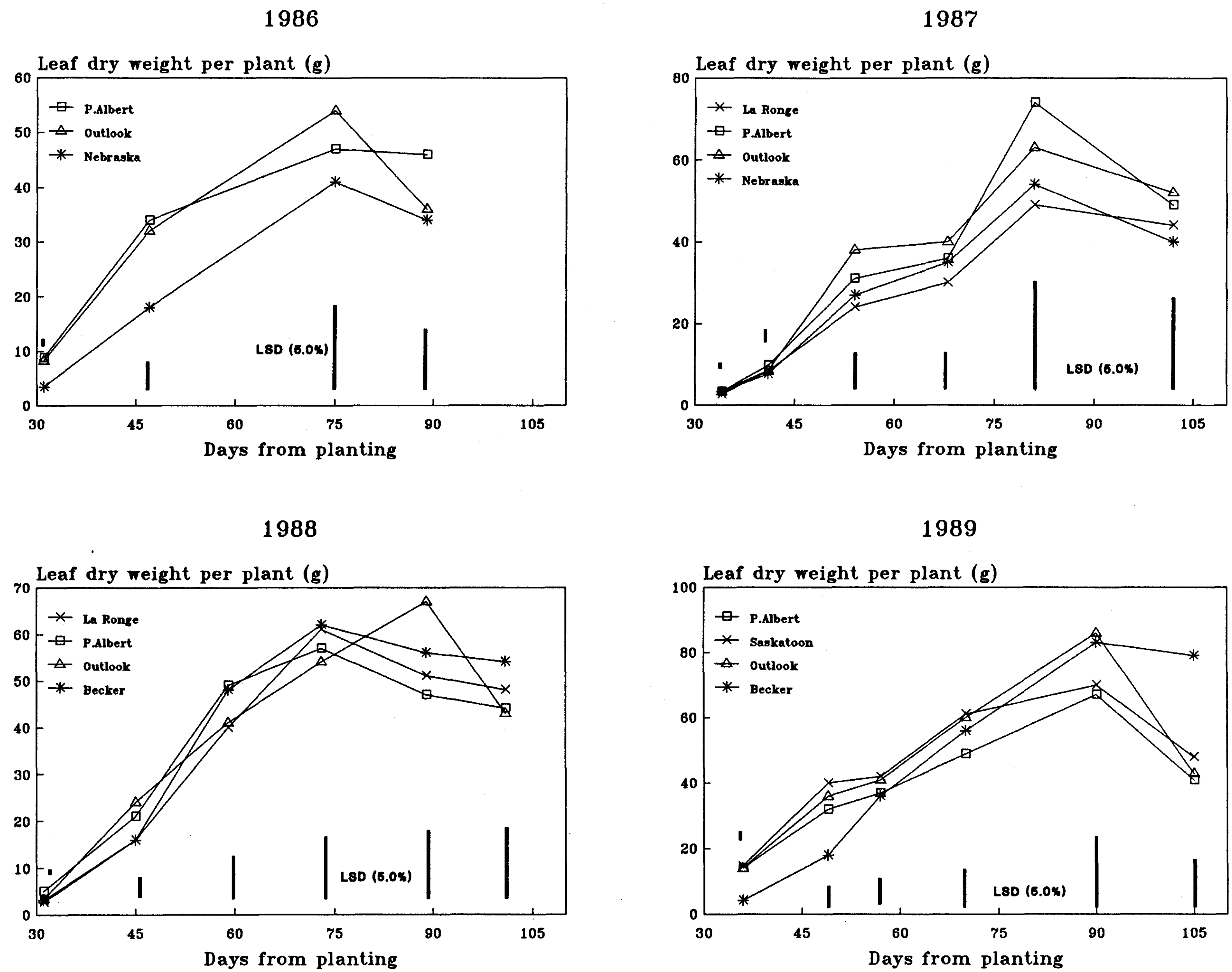


Fig. 4.3. Leaf dry weight per plant for Norland potatoes from different seed sources: 1986 to 1989.

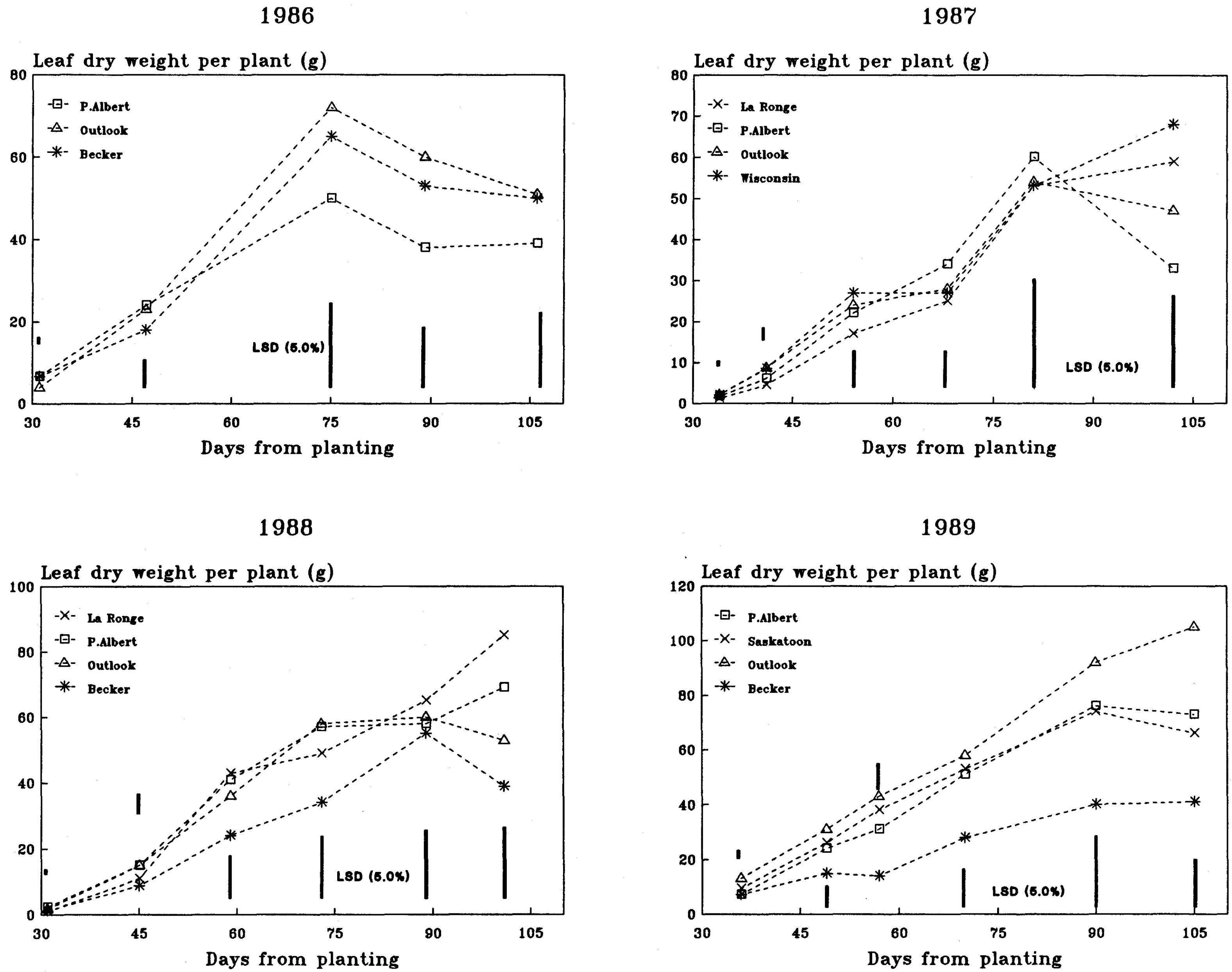


Fig. 4.4. Leaf dry weight per plant for Russet Burbank potatoes from different seed sources: 1986 to 1989.

Stem Dry Weight: The effects of seed source on stem dry weights were variable over the different years (Appendix 4.2). The effects of seed source were generally not significant for Norland potatoes, except in 1989, when in the early growth stages, the southern seed source produced lower stem dry weights than the northern sources (Fig. 4.5). Relatively high variances at the later growth stages likely obscured the treatment effects.

In all years, Russet Burbank seed from the various sources produced similar stem dry weights at the initial sampling (Fig. 4.6). In 1986, 1988 and 1989, northern seed produced higher stem dry weights than the southern sources at the later harvests. The differences in stem dry weights between northern and southern seed were particularly pronounced in 1988 and 1989.

Total Tuber Dry Weight: The effects of seed source on total tuber dry weight per plant were not consistent over the different sampling dates (Appendix 4.2). Norland seed from the southern sources produced lower tuber dry weights than the northern sources at the earliest harvest in 1986 and 1989 (Table 4.2). At later harvests, the various seed sources produced comparable yields throughout the growing season, except in 1989, where the Becker seed generally

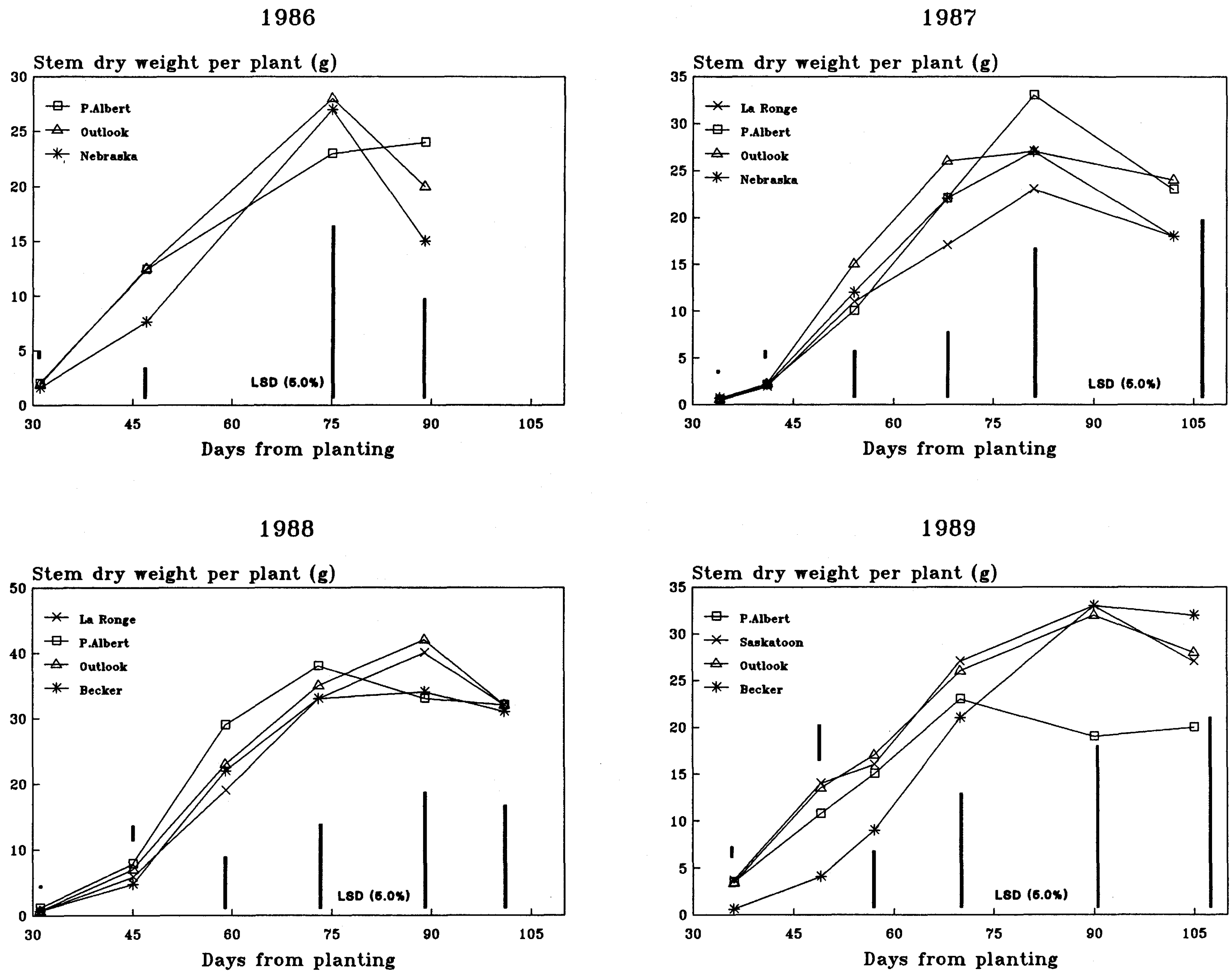


Fig. 4.5. Stem dry weight per plant for Norland potatoes from different seed sources: 1986 to 1989.

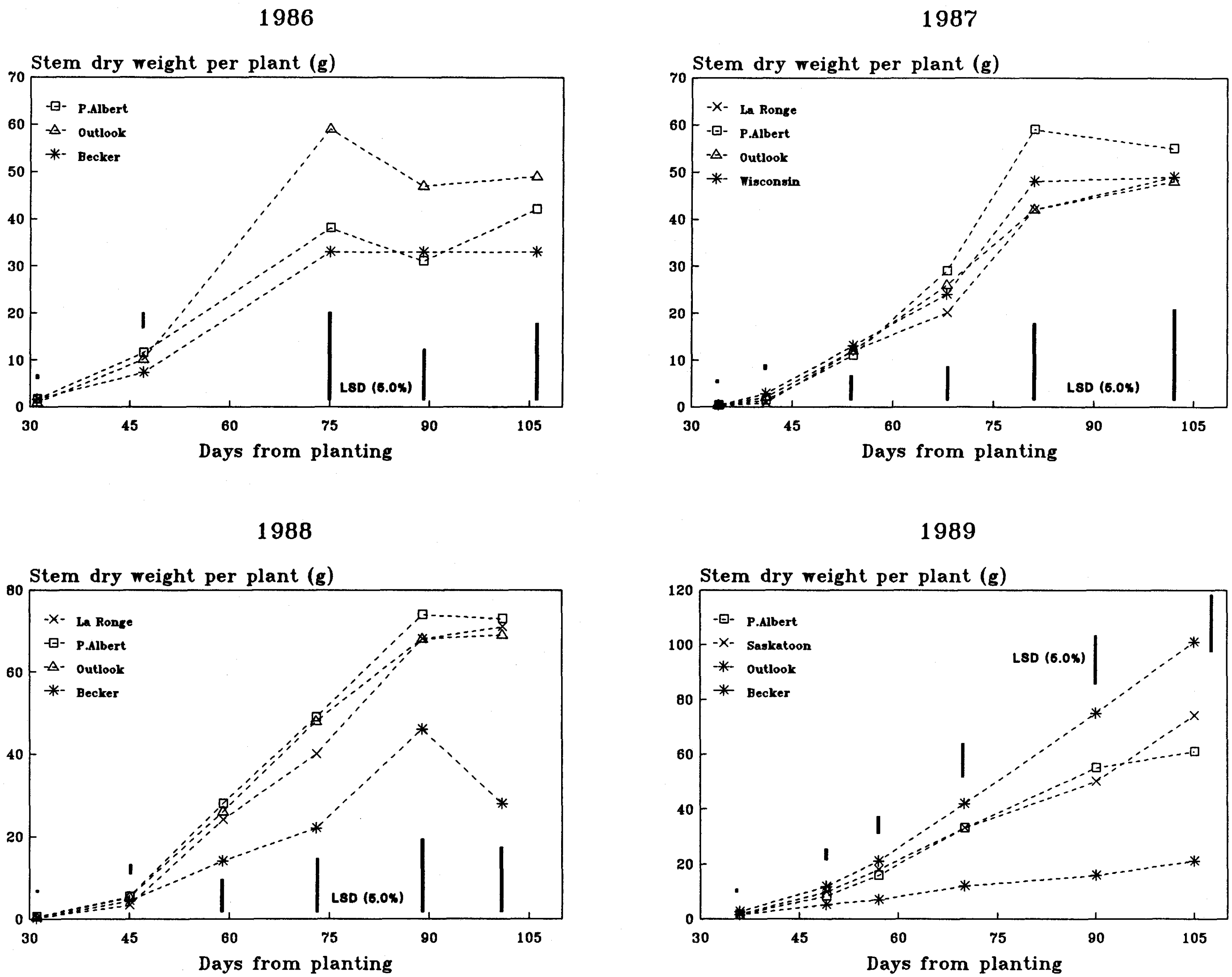


Fig. 4.6. Stem dry weight per plant for Russet Burbank potatoes from different seed sources: 1986 to 1989.

Table 4.2. Total dry weights of tubers produced by Norland and Russet Burbank potatoes from different seed sources at the sampling period when tuberization was first visible: 1986 to 1989.

Seed source	Norland	Russet Burbank
	---Total tuber dry weight per plant (g)[z]---	
	1986	
Prince Albert	6.4 b[y]	7.4 b
Outlook	6.9 b	4.3 a
U.S.A[x]	0.5 a	2.6 a
	1988	
La Ronge	7.6 a	11.6 a
Prince Albert	19.9 b	15.2 a
Outlook	16.8 b	9.3 a
Becker	18.3 b	12.7 a
	1989	
Prince Albert	13.1 b	5.2 a
Saskatoon	14.0 b	6.1 a
Outlook	15.3 b	8.8 a
Becker	1.2 a	5.4 a

[z]Observations were taken 47, 59 and 49 DAP in 1986, 1987, 1988, and 1989 respectively.
[y]Means for seed sources within cultivars followed by the same letter are not significantly different at $P<0.05$ level of probability.
[x]Norland from Nebraska and Russet Burbank from Minnesota.

produced lower tuber dry weights than the other seed sources (Fig. 4.7).

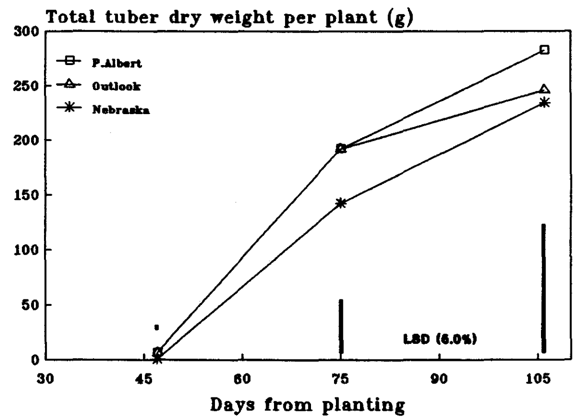
Russet Burbank seed from the different sources produced similar tuber dry weights at the initial harvest (Table 4.2). With time, the northern sources produced higher total tuber dry weights than the southern sources, although the differences were often not significant in the later harvests (Fig. 4.8).

Marketable Tuber Dry Weight:

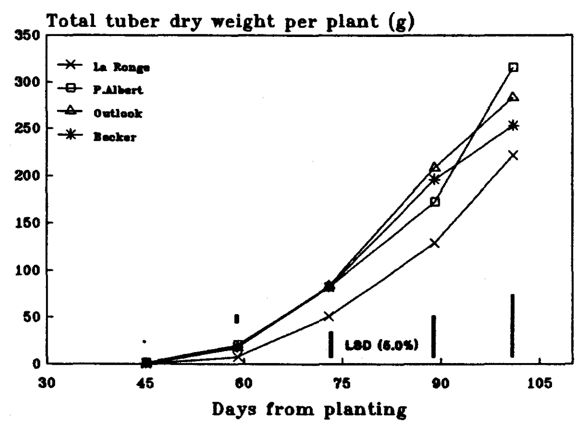
In 1986 and 1989, Norland seed from the northern sources produced significantly higher marketable tuber dry matter yields than the southern seed, particularly at the initial harvest dates but not at later harvest dates (Fig. 4.9). A notable exception was that, in 1988, the La Ronge seed produced lower marketable tuber dry weights than all other sources. At the final sampling, the Outlook and Prince Albert sources produced higher marketable tuber dry weights than the Becker source (Fig. 4.9).

For Russet Burbank, all seed sources produced comparable marketable tuber dry weights early in the season (Fig. 4.10). By the latter growth stages, marketable tuber dry weights from the northern sources were consistently

1986



1988



1989

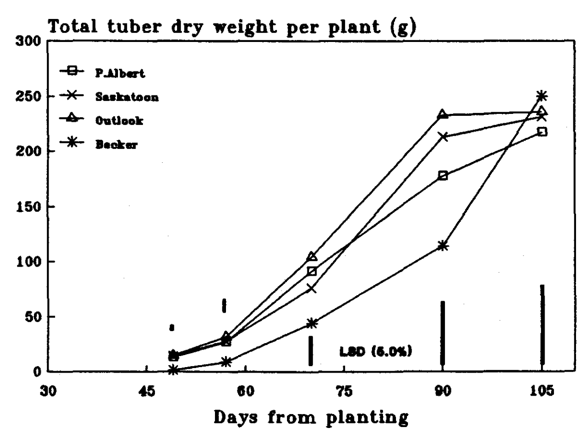
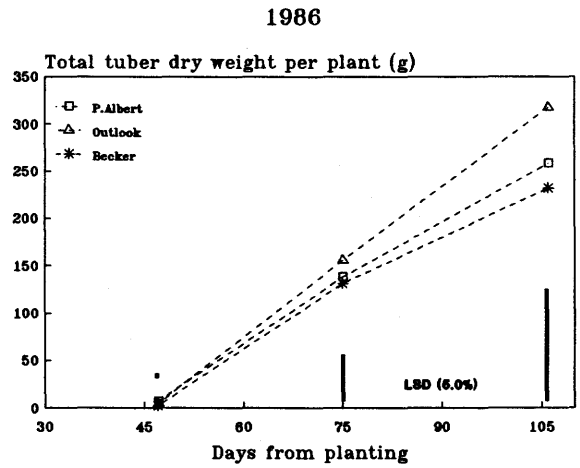
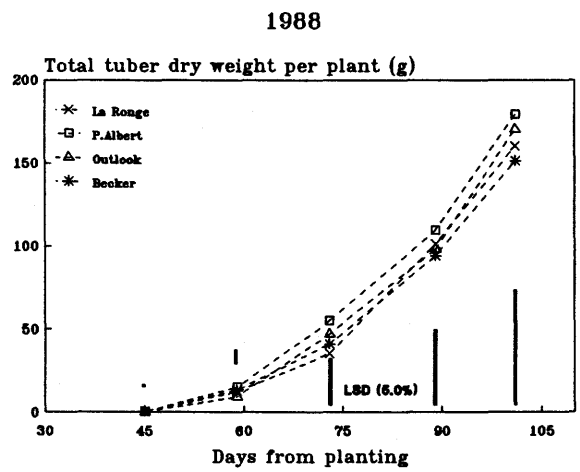


Fig. 4.7. Total tuber dry weight per plant for Norland potatoes from different seed sources: 1986, 1988, and 1989.





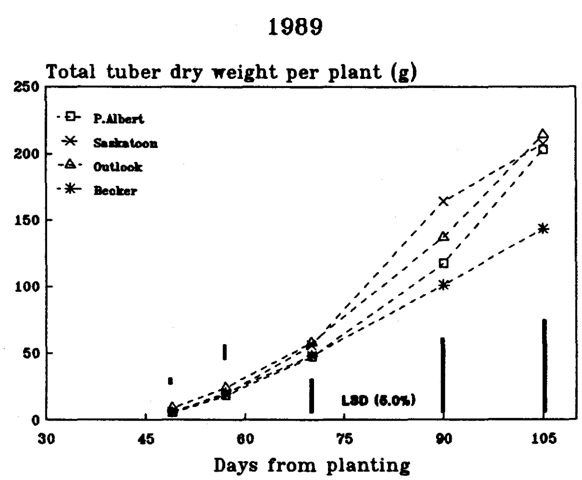


Fig. 4.8. Total tuber dry weight per plant for Russet Burbank potatoes from different seed sources: 1986, 1988, and 1989.

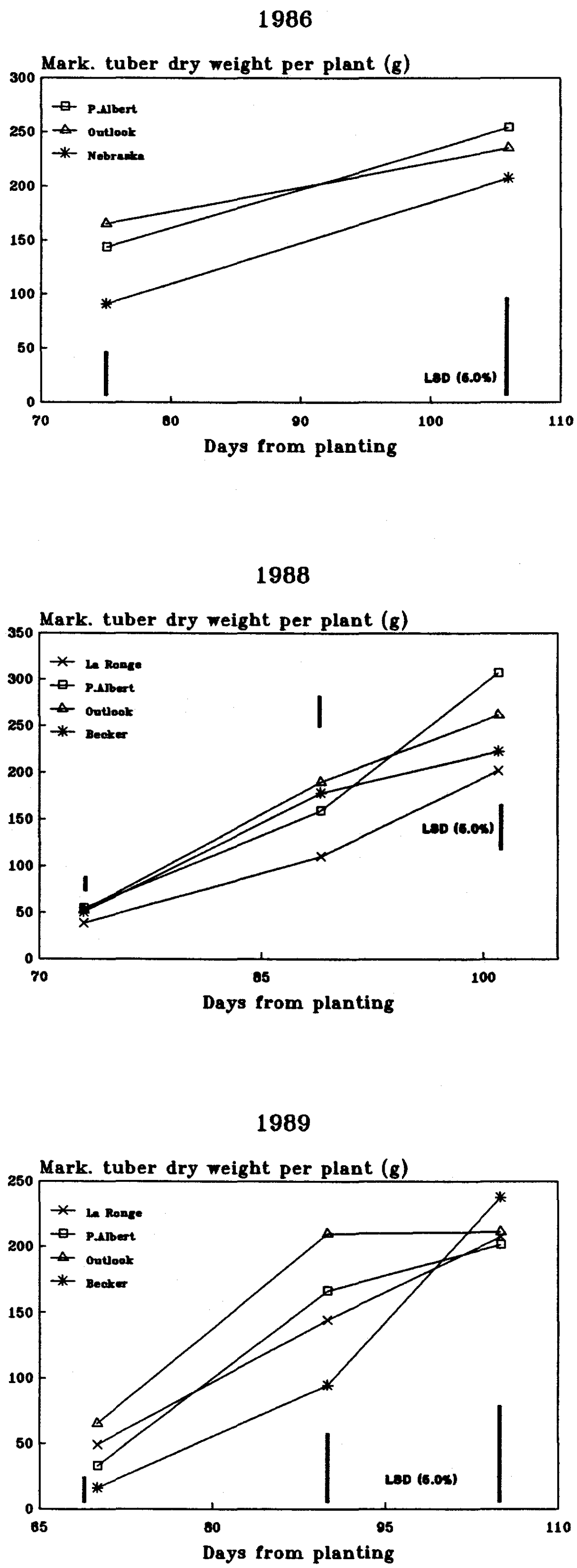


Fig. 4.9. Marketable tuber dry weight per plant for Norland potatoes from different seed sources: 1986, 1988, and 1989.

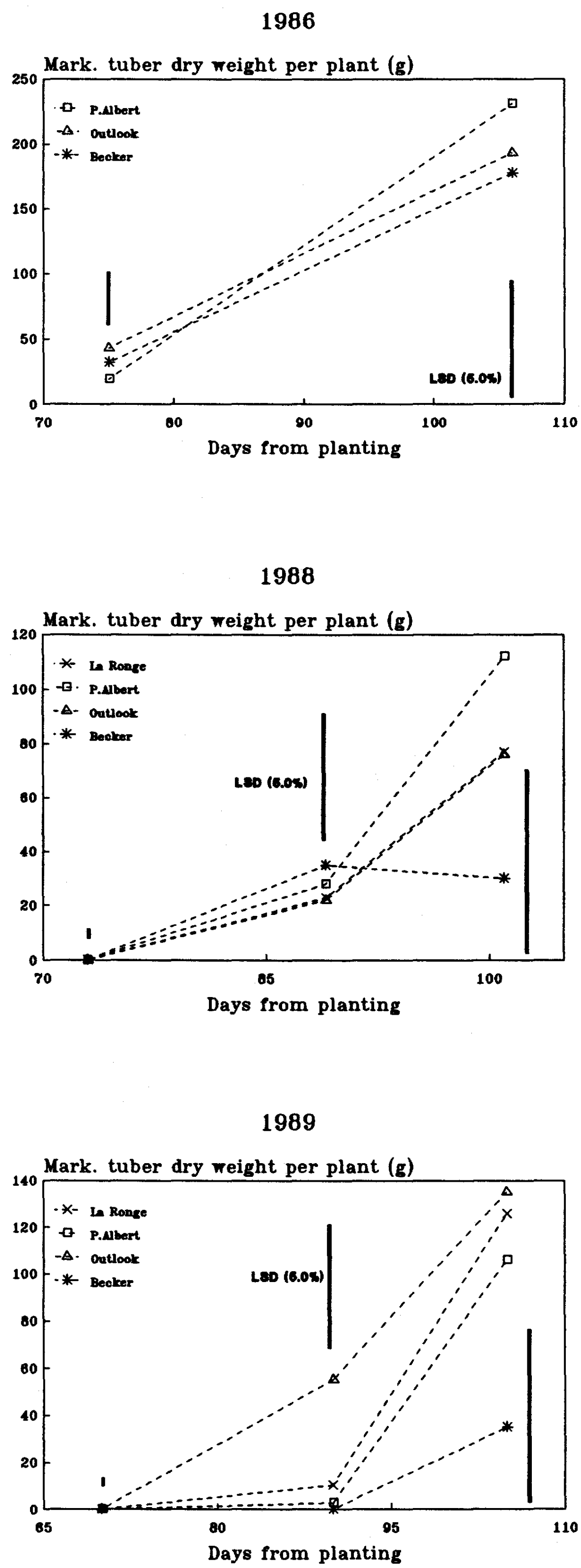


Fig. 4.10. Marketable tuber dry weight per plant for Russet Burbank potatoes from different seed sources: 1986, 1988, and 1989.

higher than the southern seed sources, although, the differences tended to be significant only in 1989.

Tuber Dry Matter Percentage: Dry matter content data for the different tuber size grades of Norland and Russet Burbank potatoes obtained using the various seed sources in 1988 and 1989 are presented in Tables 4.3 and 4.4, respectively. Tuber dry matter contents were generally similar for the northern and southern seed, except in 1989 where <25 mm Russet Burbank tubers from the southern source often had a higher dry matter content than comparable size potatoes grown from northern seed sources.

Harvest Index: Harvest indices for Norland and Russet Burbank seed from the various seed sources increased progressively with time (Table 4.5). In Norland, southern seed produced lower harvest indices than the northern sources in 1989, whereas in 1986 and 1988 the trends were inconsistent (Table 4.5). In 1988 and 1989, Russet Burbank potatoes grown from the southern sources had higher harvest indices than the northern seed sources at all harvest dates (Table 4.5).

Table 4.3. Dry matter concentration for tuber size grades of Norland and Russet Burbank potatoes from different seed sources at various growth stages: 1988.

Cultivar - seed source	Days from planting 45	59	73	89	101
			---Percent dry matter---		
			< 25 mm tubers		
Norland					
La Ronge	27.7 a[z]	11.5 a	16.2 a	17.4 a	15.7 a
P. Albert	23.7 a	16.8 a	19.2 b	16.5 a	16.5 a
Outlook	24.5 a	18.8 a	17.8 b	16.1 a	19.7 b
Becker	34.5 a	17.9 a	15.8 a	17.6 a	16.0 a
Russet Burbank					
La Ronge	24.3 a	14.3 a	16.0 a	16.6 a	15.4 a
P. Albert	27.4 a	15.7 a	17.2 a	16.9 a	14.7 a
Outlook	33.4 a	14.1 a	16.6 a	18.3 a	20.9 b
Becker	24.6 a	18.1 a	20.1 b	18.9 a	16.6 a
			25-45 mm tubers		
Norland					
La Ronge	-	14.7 a	16.4 b	16.6 a	20.0 bc
P. Albert	-	15.5 a	13.5 a	17.0 a	15.3 a
Outlook	-	15.0 a	16.6 b	18.4 a	19.6 b
Becker	-	14.7 a	15.7 b	18.0 a	18.2 b
Russet Burbank					
La Ronge	-	15.7 a	14.6 a	17.9 a	19.3 a
P. Albert	-	15.4 a	15.6 a	17.4 a	19.3 a
Outlook	-	13.8 a	15.7 a	17.2 a	20.1 ab
Becker	-	18.7 a	18.9 b	20.4 a	21.5 b
			>45 mm tubers		
Norland					
La Ronge	-	-	-	15.9 a	20.1 a
P. Albert	-	-	-	17.7 a	18.9 a
Outlook	-	-	-	17.9 a	19.6 a
Becker	-	-	-	18.3 a	18.6 a
Russet Burbank					
La Ronge	-	-	-	16.6 a	20.2 a
P. Albert	-	-	-	17.3 a	17.3 a
Outlook	-	-	-	17.3 a	20.5 a
Becker	-	-	-	18.2 a	20.7 a

[z]Within each growth stage and cultivar, means for seed sources followed by the same letter are not significantly different at P<0.05 probability according to analysis of variance using arcsine transformed values.

Table 4.4. Dry matter concentration for tuber size grades for Norland and Russet Burbank potatoes from different seed sources at various growth stages: 1989.

Cultivar - seed source	Days from planting 49	57	70	90	105
	---Percent dry matter---				
	< 25 mm tubers				
Norland					
P. Albert	16.7 b[z]	17.6 a	17.7 a	17.6 a	15.5 ab
Saskatoon	16.4 b	17.1 a	17.3 a	15.1 a	15.4 ab
Outlook	16.1 ab	16.7 a	17.6 a	16.9 a	14.3 a
Becker	15.5 a	14.8 a	16.0 a	16.8 a	17.5 b
Russet Burbank					
P. Albert	15.2 ab	15.0 a	15.6 a	13.9 a	16.6 ab
Saskatoon	14.6 a	16.8 a	16.5 a	13.8 a	15.6 a
Outlook	14.8 a	14.6 a	17.1 ab	15.0 a	16.0 a
Becker	15.9 b	36.3 b	18.7 b	22.8 b	19.5 b
	25-45 mm tubers				
Norland					
P. Albert	-	15.7 a	17.3 a	14.0 a	18.6 a
Saskatoon	-	15.5 a	16.7 a	21.4 b	17.6 a
Outlook	-	16.1 a	17.3 a	17.7 ab	16.5 a
Becker	-	14.7 a	15.6 a	18.1 ab	16.6 a
Russet Burbank					
P. Albert	-	20.6 a	16.6 a	18.6 a	17.8 a
Saskatoon	-	16.0 a	16.3 a	19.3 a	17.5 a
Outlook	-	19.2 a	15.3 a	16.4 a	17.4 a
Becker	-	37.4 b	19.1 b	21.5 a	22.4 a
	>45 mm tubers				
Norland					
P. Albert	-	-	17.3[y]	18.0[y]	18.1 b
Saskatoon	-	-	16.5	18.3	18.1 b
Outlook	-	-	16.8	18.2	16.1 a
Becker	-	-	17.1	15.7	17.8 b
Russet Burbank					
P. Albert	-	-	17.3[y]	18.2[y]	18.0 a
Saskatoon	-	-	16.5	18.3	17.5 a
Outlook	-	-	16.8	17.7	17.9 a
Becker	-	-	17.1	15.7	20.7 b

[z]Within each growth stage and cultivar, means for the seed sources followed by the same letter are not significantly different at $P<0.05$ probability according to analysis of variance using arcsine transformed values.
[y]Unable to calculate mean separations for cultivar x seed source interactions due to rank deficiency.

Table 4.5. Harvest indices at various growth periods for Norland and Russet Burbank potatoes from different seed sources: 1986, 1988, and 1989.

Cultivar - seed source	Sampling period 2	3	4	5	6
		---Harvest index (%)[z]---			
			1986		
Norland					
P. Albert	12.0 b[y]	-	-	86.3 b	-
Outlook	12.4 b	-	-	71.2 a	-
Nebraska	1.6 a	-	-	69.2 a	-
Russet Burbank					
P. Albert	16.2 b	-	-	60.3 a	-
Outlook	9.5 a	-	-	54.2 a	-
Becker	8.8 a	-	-	56.0 a	-
			1988		
Norland					
La Ronge	0.3 a	8.8 a	22.3 a	60.8 a	72.1 a
P. Albert	1.0 a	19.3 b	45.7 b	67.2 a	80.5 a
Outlook	0.3 a	17.8 b	48.1 b	67.2 a	79.1 a
Becker	1.4 a	19.8 b	44.6 b	67.9 a	74.3 a
Russet Burbank					
La Ronge	0.1 a	13.9 a	28.1 a	42.1 a	50.4 a
P. Albert	0.1 a	16.1 a	34.7 a	45.0 ab	55.9 a
Outlook	0.4 a	13.2 a	30.1 a	42.5 a	57.6 a
Becker	0.7 a	24.9 b	44.4 b	54.4 b	71.9 b
			1989		
Norland					
P. Albert	23.5 b	35.0 b	55.2 b	67.4 b	77.9 b
Saskatoon	19.1 b	33.1 b	45.9 b	67.7 b	75.2 b
Outlook	23.3 b	34.8 b	54.1 b	66.4 b	76.9 b
Becker	3.3 a	13.7 a	27.6 a	47.1 a	69.0 a
Russet Burbank					
P. Albert	13.8 a	26.8 a	32.9 a	48.0 a	60.9 b
Saskatoon	15.8 ab	24.6 a	39.1 a	56.9 b	60.4 b
Outlook	16.3 ab	26.8 a	37.5 a	45.0 a	51.5 a
Becker	23.1 b	47.6 b	53.3 b	67.4 c	71.4 c

[z]Harvest index = Total tuber dry weight/(Shoot dry weight + total tuber dry weight).

[y]Within each growth stage and cultivar, means for the various seed sources followed by the same letter are not significantly different at $P<0.05$ probability according to analysis of variance using arcsine transformed values.

Growth Characteristics

Shoot Biomass Duration: The effects of seed source on shoot biomass duration for Norland and Russet Burbank potatoes varied between the different years (Table 4.6). With Norland, biomass durations for the various seed sources were inconsistent in the different years.

In 1988 and 1989, Russet Burbank seed from the southern sources produced significantly lower shoot biomass durations than the northern sources (Table 4.6). The three northern sources produced similar biomass durations. In 1986, the Outlook seed produced greater biomass duration than both Prince Albert and Becker seed. In 1987, the northern and the southern seed generally produced similar biomass durations.

Relative Shoot Growth Rate: There were few identifiable trends in the RGR of the shoots for the different seed sources of either cultivar (Figs. 4.11 and 4.12). For Norland, in 1989, early season relative growth rates for southern seed sources tended to be higher than the RGR for northern seed (Fig 4.11).

Tuber Initiation: Time of tuber initiation was estimated using the linear relationship between total tuber weight and time (e.g Goodwin et al., 1969b; Knowles and Botar, 1992),

Table 4.6. Shoot biomass duration for Norland and Russet Burbank potatoes from different seed sources: 1986 to 1989.

Seed source	Norland	Russet Burbank
	---Biomass duration (g.days)---	
	1986	
Prince Albert	3240 a[z]	4500 a
Outlook	3348 a	6118 b
U.S.A[y]	2422 a	4849 a
	1987	
La Ronge	3154 a	3710 a
Prince Albert	4119 b	4479 a
Outlook	4134 b	3778 a
U.S.A[x]	3450 ab	4324 a
	1988	
La Ronge	4342 a	5301 b
Prince Albert	4629 a	5598 b
Outlook	4715 a	5313 b
Becker	4556 a	3410 a
	1989	
Prince Albert	4580 a	5723 b
Saskatoon	5437 ab	5907 b
Outlook	5574 ab	7799 b
Becker	6235 b	2743 a

[z]Within cultivars, means for seed sources followed by the same letter are not significantly different at $P<0.05$ level of probability.
[y]Norland from Nebraska and Russet Burbank from Minnesota.
[x]Norland from Nebraska and Russet Burbank from Wisconsin.

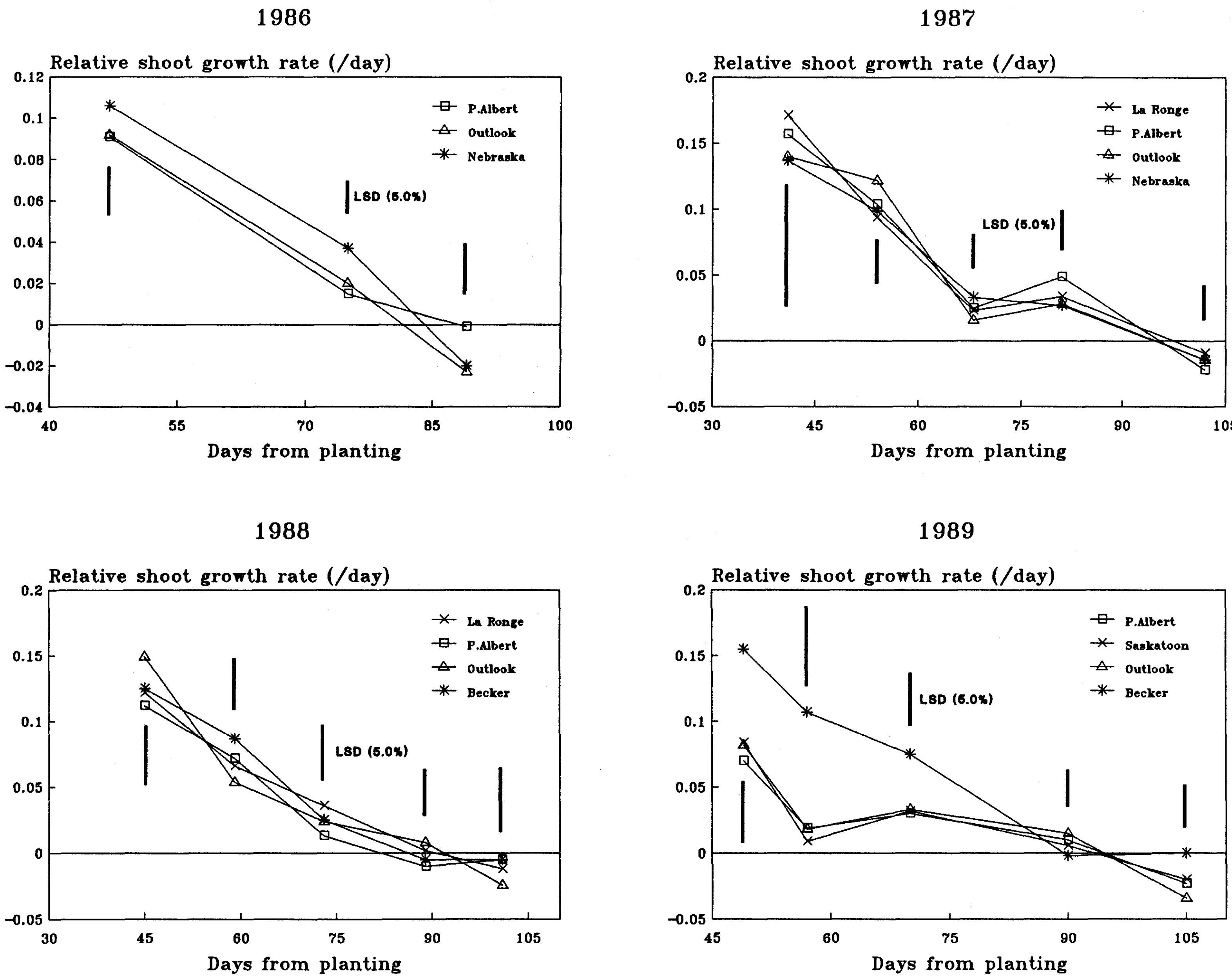


Fig. 4.11. Relative shoot growth rate for Norland potatoes from different seed sources: 1986 to 1989.

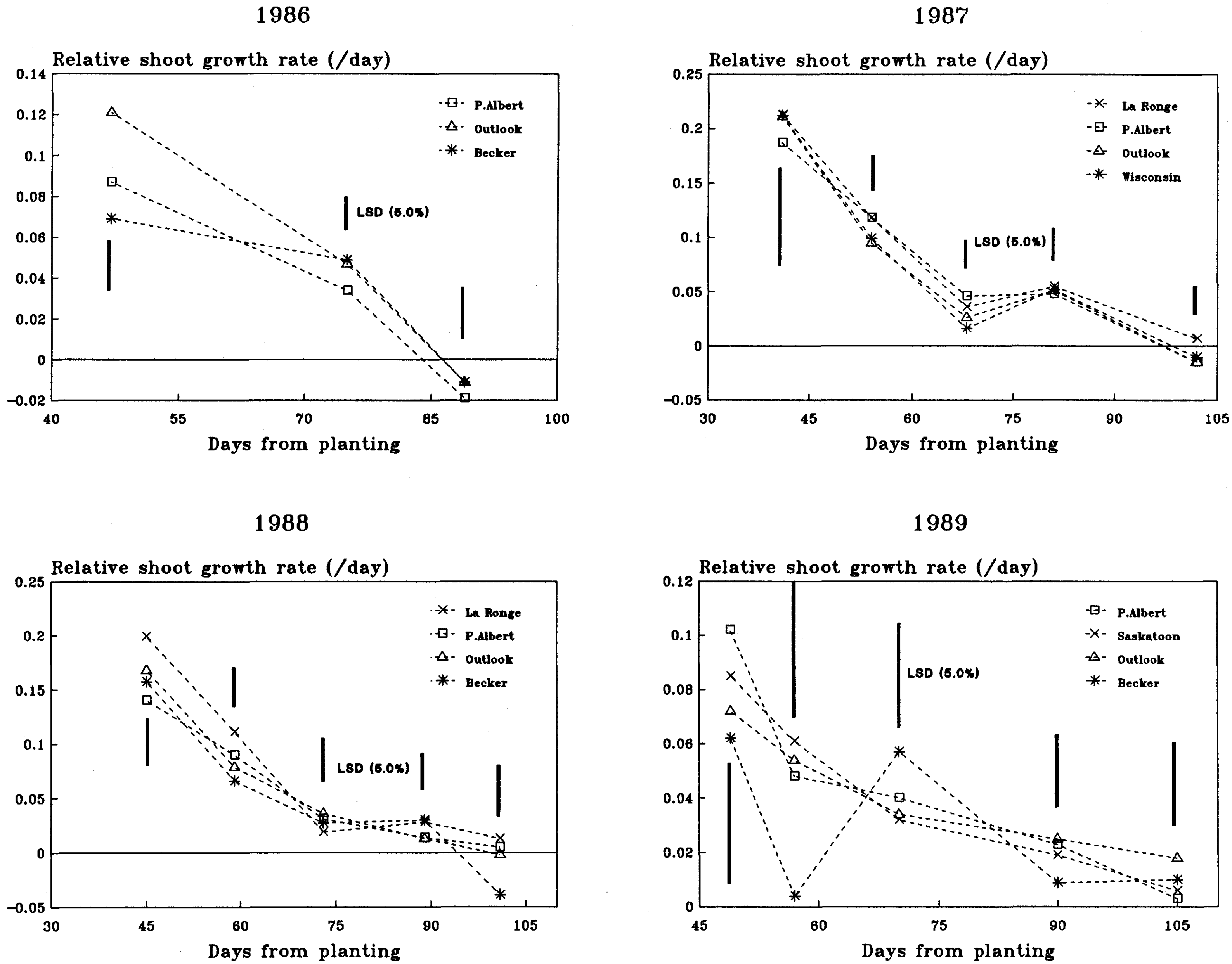


Fig. 4.12. Relative shoot growth rate for Russet Burbank potatoes from different seed sources: 1986 to 1989.

although in 1986, the yield versus time relationship was best described by an asymptotic function.

In Norland, seed sources had variable effects on the time of tuber initiation (Table 4.7). In 1987, the estimated tuber initiation time for the southern source was about 2 to 4 days earlier than the northern sources. By contrast, in 1986 and 1989, tuber initiation by the southern sources was delayed by 4 to 6 days relative to the northern seed. In Russet Burbank, tuber initiation by the southern sources consistently occurred 1 to 6 days earlier than for the northern seed (Table 4.7).

Tuber Bulking Rate: Tuber bulking rates for the various seed sources were estimated using the regression coefficients of the linear relationship between total tuber fresh weight and time. Homogeneity of regression coefficients for the seed sources were examined separately for the two cultivars in the different years. For Norland, tuber bulking rates for the various seed sources were similar (Table 4.8). For Russet Burbank, the northern seed sources exhibited higher tuber bulking rates than southern seed in 1986, 1988 and 1989, although the differences were not significant in 1986 (Table 4.8). In 1987, seed from La Ronge and Prince Albert had lower rates of bulking than the Outlook seed.

Table 4.7. Correlation coefficients for the linear relationships between total tuber fresh weight per plant and age of crop and estimated time of tuber initiation for Norland and Russet Burbank potatoes from different seed sources: 1986 to 1989.

Cultivar - seed source		Correlation coefficient	Estimated time of tuber initiation (DAP)
		1986	
Norland	- P. Albert	+0.96*[z]	41
	- Outlook	+0.92**	40
	- Nebraska	+0.98**	44
R. Burbank	- P. Albert	+0.99**	44
	- Outlook	+0.98**	43
	- Becker	+0.98*	41
		1987	
Norland	- La Ronge	+0.99**	56
	- P. Albert	+0.99**	55
	- Outlook	+0.99**	55
	- Nebraska	+0.99**	53
R. Burbank	- La Ronge	+0.99**	53
	- P. Albert	+0.98**	57
	- Outlook	+0.99**	55
	- Wisconsin	+0.99**	51
		1988	
Norland	- La Ronge	+0.97**	51
	- P. Albert	+0.96**	51
	- Outlook	+0.97**	50
	- Becker	+0.98**	50
R. Burbank	- La Ronge	+0.96**	51
	- P. Albert	+0.98**	50
	- Outlook	+0.97**	50
	- Becker	+0.97**	48
		1989	
Norland	- P. Albert	+0.96**	50
	- Saskatoon	+0.96**	49
	- Outlook	+0.94**	50
	- Becker	+0.94**	55
R. Burbank	- P. Albert	+0.94***	50
	- Saskatoon	+0.99***	50
	- Outlook	+0.99***	50
	- Becker	+0.99***	49

[z]*, ** and *** indicate regression analyses of variance for regression significant at P> 0.05, 0.01 and 0.001 levels of probability, respectively.

Table 4.8. Regression coefficients for the relationship between total tuber fresh weight and time from planting for Norland and Russet Burbank potatoes grown from different seed sources: 1986 to 1989.

Seed source	1986	1987	1988	1989
	---Regression coefficient (g d^{-1})---			
	Norland			
La Ronge	-	26.4 ±2.4	21.0 ±2.5	-
P. Albert	24.9 ±4.7	26.2 ±2.4	29.5 ±4.4	22.4 ±3.1
Saskatoon	-	-	-	23.3 ±3.1
Outlook	21.2 ±5.2	28.6 ±2.9	28.1 ±3.3	27.1 ±5.0
Becker	-	-	25.9 ±2.6	24.3 ±4.4
Nebraska	20.4 ±2.1	22.0 ±1.1	-	-
Significance	NS	NS	NS	NS
	Russet Burbank			
La Ronge	-	15.7 ±1.3	15.4 ±2.2	-
P. Albert	22.4 ±2.0	15.0 ±1.6	17.3 ±2.0	17.8 ±1.1
Saskatoon	-	-	-	21.1 ±1.3
Outlook	20.0 ±2.2	21.9 ±1.7	15.3 ±1.8	21.1 ±1.5
Becker	16.7 ±3.9	-	10.3 ±1.3	11.5 ±0.6
Wisconsin	-	17.1 ±1.3	-	-
Significance	NS	**	**	**

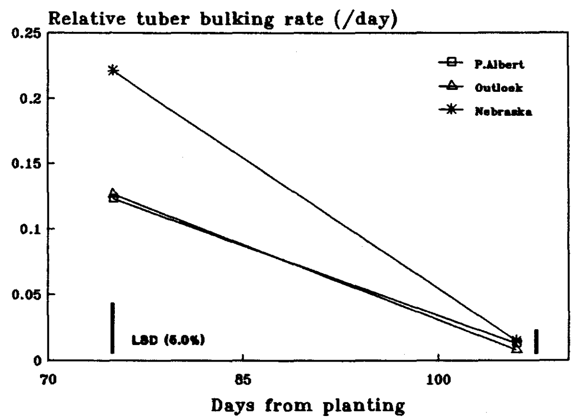
** and NS: Test of homogeneity of regression coefficients among different seed sources within each cultivar significant at $P<0.01$ level and not significant, respectively.

Relative Tuber Growth Rate: The efficiency of tuber bulking is described by the relative tuber bulking rate. The relative rate of tuber bulking for Norland (Fig. 4.13) and Russet Burbank (Fig. 4.14) were calculated on the basis of total tuber dry weights. Seed source had no effect on relative tuber bulking rates (Appendix 4.2) except in 1986, when Norland from the southern source had higher relative tuber bulking rates than the northern sources (Fig. 4.13).

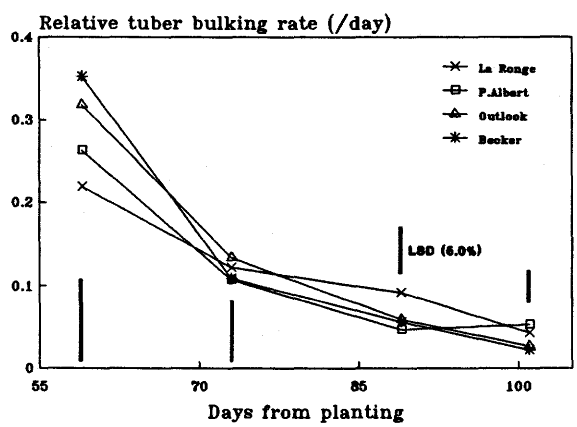
DISCUSSION

Soil and climatic variations and disease incidence during seed production can influence the vigour and yield potential of potato seed-tubers. Storage conditions and the growing environment during the following cropping season can also influence the expression of seed vigour (Bodlaender, 1963; Burton, 1966; Wurr, 1978a). In this study, the growth and yield patterns of Norland and Russet Burbank potatoes from different seed sources varied considerably from year to year and site to site. This variability likely reflects unavoidable differences in soil and climatic conditions as well as pest and disease levels from year to year and their interaction with seed sources and physiological condition of the seed (Burton, 1966; Harris, 1978; Carls and Ceaser, 1979). Year to year variability in growth and productivity of potato seed-tubers from different altitudes (Wurr, 1979) and latitudes (Goodwin et al., 1969b) have already been

1986



1988



1989

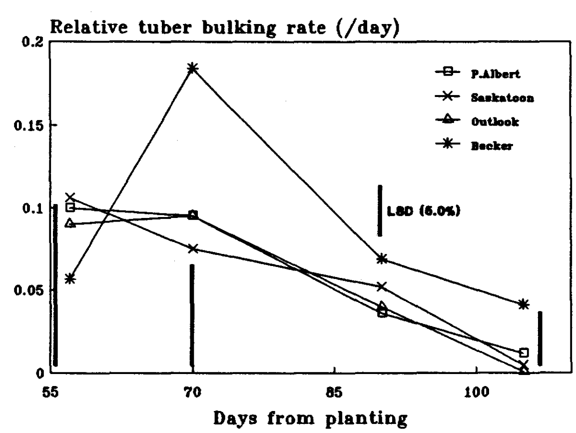


Fig. 4.13. Relative tuber bulking rate for Norland potatoes from different seed sources: 1986, 1988, and 1989.

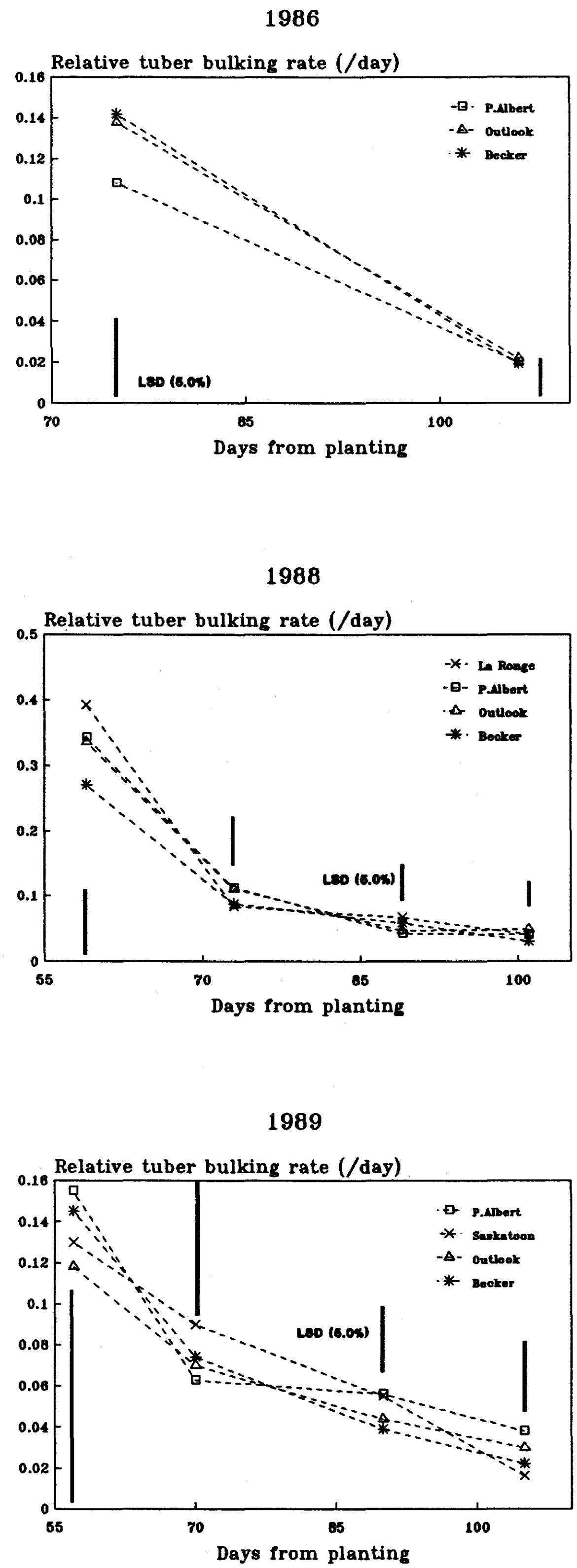


Fig. 4.14. Relative tuber bulking rate for Russet Burbank potatoes from different seed sources: 1986, 1988, and 1989.

observed. In this study, some differences in the growth and dry matter distribution patterns, e.g. vine lengths, leaf dry weights, and stem dry weights, of the northern and southern seed sources were quite stable across years. The differences were more pronounced for Russet Burbank relative to Norland potatoes. Similar cultivar specific differences were also observed by Wurr (1979) for sprouting habits and productivity in potato seed-tubers obtained from different altitudes.

The various seed production sites used in this study were chosen to provide a range of growing season temperatures. It was expected that seed-tubers produced in relatively warmer southern sites would be physiologically older than seed produced in northern sites (Bodlaender, 1973; Wurr, 1978a; Carls and Ceaser, 1979). In the present investigation, the growth and yield patterns of seed from the various seed sources often did not conform to prevailing hypotheses on physiological age. Some divergent observations were:

i. The observed similar or superior early season shoot growth and yields from northern seed is contradictory to physiological age hypothesis (O'Brien et al., 1983; Knowles and Botar, 1992).

ii. Physiologically older seed produces more mainstems than younger seed (Wurr, 1977; Iritani and Weller, 1987, Knowles and Botar, 1991). However, in this study, mainstem numbers in most instances were similar for the northern and southern seed.

iii. Tuber dry matter content increases with physiological maturity in potato (Hartz et al, 1980; Knowles and Botar, 1992). Early tuberization and higher early season bulking rates of physiologically older seed produce mature tubers with high dry matter content earlier than when young seed is planted (Knowles and Botar, 1992). In this study, the dry matter content of the different tuber grades of both Norland and Russet Burbank potato from the different seed sources were generally similar at all harvest dates.

iv. Plants produced from physiologically old Russet Burbank seed had low relative growth rates for shoot and tuber (Mikitzel and Knowles, 1989). In this study, there were no identifiable differences in the relative shoot growth rates and relative tuber growth rates among the various seed sources.

Wiersema and Booth (1985) and Caldiz (1991) also were unable to explain yield differences in potato seed-tubers grown at different latitudes in terms of physiological age effects.

As tubers that attain marketable grade are initiated within a period of two weeks (Moorby and Milthorpe, 1975), the period of tuber initiation has little impact on subsequent marketable yields (Struik et al., 1991). In this study, the early tuber initiation characteristic of southern seed, particularly Russet Burbank, did not translate to superior yields (Chapter 3). As observed for Russet Burbank, lower yields produced by southern seed can be attributed to reduced tuber bulking rates. Goodwin et al., (1969b) also attributed the lower productive capacity of Arran Pilot potato from southern locations to lower tuber bulking rates than for seed from northern centres.

Since more than 90% of tuber dry weight is derived from current photosynthesis (Moorby, 1970), potato yields are dependant on effective light interception, sustained photosynthesis and preferential partitioning of assimilates to developing tubers (Dwelle, 1985). Consequently, potato productivity can be described by assimilatory capacity (leaf area duration, biomass duration) and assimilatory efficiency (e.g. relative growth rates of plant components).

Leaf area duration is a frequently used measure of photosynthetic capacity of plant stands (Hunt, 1982). However, in potatoes, both leaves and stems are actively involved in photosynthesis (Dwelle, 1990). Therefore, the above ground biomass duration provides a more complete measure of photosynthetic capacity (Kvet et al., 1971). In this study, the biomass duration of the plants grown from southern seed sources were occasionally lower than plants grown from northern seed. This is primarily due to the premature senescence of plants grown from the southern seed. Early haulm senescence can be caused by seed-borne diseases (Hooker, 1990) or altered dry matter distribution patterns (Moorby, 1975; Ewing, 1985). In this study, early senescence of Russet Burbank plants from southern seed was likely due to preferential partitioning of dry matter to tubers rather than to shoots early in the growing season. This is evidenced by the higher harvest indices and greater relative tuber bulking rates for southern seed than northern seed at the early harvests. Another study in this project (Chapter 9), indicated that seed tubers produced in Becker, Minnesota contained higher levels of tuberizing stimulus than seed obtained from more northern locations. Ewing (1985) found a strong positive correlation between degree of tuberizing stimulus in stem cuttings and earliness of senescence in field grown potato. When tuberization occurs in the early stages of crop development, prior to establishment of sufficient leaf, it reduces crop vigour and tuber yields by restricting the shoot growth which is needed for efficient photosynthesis (Moorby, 1978). It is likely that the presence of higher levels of tuberizing stimulus in plants from southern sources causes increased diversion of dry matter to the tubers early in the season, thereby resulting in premature senescence.

Dry matter distribution is an important aspect of potato yields, as tuber development is dependant on the assimilate supply from shoot photosynthesis. In this study, it appears that greater tuber bulking of Saskatchewan seed relative to southern seed is due to superior assimilatory capacity (characterized by longer vines and higher shoot weights) rather than changes in component relative growth rates that signify assimilatory efficiency. Previous studies have also shown a positive influence of vine length (Moll, 1985) and shoot weight (Sale, 1973) on potato tuber yield. In this study, tuber bulking rates were comparable for the northern and southern seed sources. By contrast, Hartz et al., (1980) observed lower tuber bulking rates for plants grown from more vigorous seed produced at higher altitudes than seed from lower altitudes.

In this study, growth and yield patterns for Norland and Russet Burbank seed-tubers from northern and southern latitudes varied from season to season, although northern seed usually produced more vigorous plants than southern seed. Other studies in this project (Chapters 3, 5, 6, 7 and 8) also showed that for Norland and Russet Burbank, tuber yields were usually higher for seed from the relatively cooler northern locations than those obtained from the southern seed sources. The stability of increased vigour for northern seed across test sites and years is of significant economic importance as it indicates that northern seed can be expected to be superior under a wide array of agro-climatic conditions. The growth and yield responses of seed from various sources did not appear to be related to any distinct physiological age effects associated with average daily temperatures in the seed production regions. The growth and yield superiority of potato seed-tubers originating from the northern environments may be attributed to some beneficial physiological changes in the seed-tuber not associated with physiological age (Goodwin et al., 1969b; Wiersema and Booth, 1985). Further, evidence to support the contention that 'northern vigour' may be due to reasons other than physiological age also comes from experiments that showed artificial ageing did not affect the production potential of northern seed (Chapter 8) and from studies comparing levels of tuberizing stimulus present in northern and southern seed (Chapter 9). Additional research is needed to determine the physiological and/or biochemical basis for the growth and yield differences of potato seed-tubers produced in different environments.

CHAPTER 5

Vigour of Potato Seed-tubers from Different Latitudes: Hill-to-Hill Variability.

ABSTRACT

Potato seed-tubers from northern latitudes are often more productive than seed from southern latitudes. It is unclear whether this superiority is due to increased vigour of northern seed, to lower hill-to-hill variability in yields of northern seed or a combination of these factors. In this study, Norland and Russet Burbank seed lots produced at different latitudes were examined for their productivity and the degree of hill-to-hill variability in yield. Seed from several 'northern' (La Ronge, Prince Albert, Saskatoon and Outlook in Saskatchewan) and 'southern' (Minnesota and Wisconsin) sources were compared in field trials conducted in 1987 through 1989. The northern seed sources of both cultivars tended to produce higher marketable tuber yields than the southern seed. Yields from hills with similar numbers of mainstems were higher for the northern seed than the southern sources. Mainstem number and average number and weight of marketable tubers per seed piece from the different seed sources were not associated with seed piece weight. For Russet Burbank, northern sources had lower hill-

to-hill variability in tuber yields than southern seed. With Norland, the yield responses were not related to variability among seed pieces. In the absence of a direct influence of seed piece weight and mainstem number on tuber yield, it can be concluded that the superiority of Russet Burbank seed from northern relative to southern sources is due to the combined influence of superior productivity per mainstem and lower hill-to-hill yield variability. For Norland, the yield increase obtained with northern seed was mainly due to enhanced seed vigour rather than reduced hill-to-hill variability.

Yield potential of potato (*Solanum tuberosum* L.) seed lots is influenced by the inherent productive capacity of the seed-tubers (Silva and Andrew, 1985), storage management of the seed (Iritani, 1981; Iritani et al., 1983) and the size of seed piece planted (Allen, 1978; Wurr, 1979; Entz and La Croix, 1984). There is also considerable variability in the growth characteristics and productivity of individual seed-tubers (Hagman, 1973) or seed pieces (Silva and Andrew, 1984) within a seed lot. Hagman (1973) in comparing the productive capacity of seed lots from Sweden found that superior seed lots had lower variability in yield among individual seed-tubers than less productive seed lots.

Potato seed-tubers originating in cooler northern latitudes and higher altitudes often produce more vigorous, higher yielding plants than seed from relatively warmer, lower latitudes and altitudes (Stuart, 1913; Westover, 1931; Kozlowska, 1960; Hartz et al., 1980; Wiersema and Booth, 1985; Caldiz, 1991). The basis for this yield response has been attributed to a physiological age factor (Went, 1959; Bodlaender, 1973; Carls and Ceaser, 1979; Caldiz et al., 1985); tubers from cool environments being physiologically younger and consequently, more vigorous than seed from warmer environments. However, Goodwin (1969b) and Wiersema and Booth (1985) suggested that differences in productivity of potato seed-tubers from different altitudes could be due to some temperature mediated modifications of seed-tuber tissues unrelated to physiological age.

Studies conducted in the present project from 1986 through 1990 showed that Norland and Russet Burbank seed-tubers obtained from several Saskatchewan sources were often more productive than those obtained from certain southern (U.S.A) sources. The observed superiority of northern seed could be due to a general enhancement in vigour of northern seed lots and/or to reduced variability in yields among the individual seed pieces in northern seed lots compared to southern seed lots. The present paper is an attempt to study the productive potential of potato seed-tuber lots from different latitudes by examining the productivity of individual seed-tubers and the relative hill-to-hill variation within seed lots.

MATERIALS AND METHODS

Experiments were conducted in 1987, 1988 and 1989 at the field plots of the Department of Horticulture Science, University of Saskatchewan in Saskatoon, Saskatchewan using Norland and Russet Burbank seed obtained from different sources. In 1987, seed-tubers from Prince Albert, Outlook, Nebraska and Wisconsin were obtained from Certified commercial seed growers. The La Ronge seed-tubers were obtained by multiplying Foundation seed at Potato Lake near La Ronge in the previous year. Seed for the 1988 and 1989 tests were raised at Becker in Minnesota and at Outlook, Prince Albert and Saskatoon in Saskatchewan in the previous year from a single Elite III source for each cultivar. Standard seed production practices were used at all sites, with seed harvested at maturity and stored under standard seed storage conditions in Saskatoon until planting.

Mother tubers were cut by hand to produce seed pieces weighing approximately 40-80 g (similar to a commercial seed lot). Depending on the size of the seed-tuber, cuts were made longitudinally and/or transversely to obtain seed pieces of the desired size. Fifty seed pieces of varying sizes were selected from each source and the seed piece weights were recorded for each seed piece prior to planting. The seed pieces were treated with Agrox fungicide to control seed piece decay. Seed pieces from each treatment (cultivar x seed source) were planted in single rows, 1.0 m apart, with each seed piece spaced 1.0 m apart within the row. This wide spacing reduced inter-plant competition (Entz and La Croix, 1984) and facilitated expression of the maximum yield potential of each seed piece (Rex, 1990). The crop was raised under irrigation using recommended cultural practices. At maturity, individual plants were dug by hand for yield estimation. Mainstem numbers and marketable tuber (tubers larger than 45 mm in diameter) numbers and weights were recorded for each hill. Mainstem numbers were not recorded in 1988 due to haulm decay caused by early frost.

The variability of seed piece weight, growth and yield characteristics in a given seed lot was estimated using values of coefficients of variation for the various parameters. Regressions for the relationship between tuber yield components and mainstem number within the various seed sources were calculated by grouping data according to number of mainstems per hill. The correlations between seed piece weight, mainstem number and marketable yield per hill and the effects of number of mainstems on marketable yield components were estimated using the corresponding values of the correlation coefficients (Mintitab, Version 7). Homogeneity of correlation coefficients, based on X^2 tests, were estimated for the seed source combinations within each cultivar in the different years according to Steel and Torrie (1980). In the succeeding discussion, the terms 'northern' and 'southern' will be used to describe seed sources from Saskatchewan and U.S.A., respectively.

RESULTS

Seed Piece Weights

Over the three test years, the average seed piece weight for Norland ranged from 42 to 84 g for the different seed sources, with the corresponding coefficients of variation ranging between 16.5% and 50.2% (Table 5.1). Average seed weights for Russet Burbank varied between 39 g and 85 g and the coefficients of variation for seed weight ranged from 17.2% to 42.0% in the three test years (Table 5.1). There were no apparent trends in seed size or their variability among the various seed sources for either cultivar. The variability in a given seed lot had no relationship with the average weight of the individual tubers within that seed lot.

Number of Mainstems per Plant

The average number of mainstems per hill for the various seed sources ranged from 3.3 to 4.9 for Norland and from 2.1

Table 5.1. Descriptive statistics for seed piece weight and number of mainstems per plant for Norland and Russet Burbank potatoes from different seed sources: 1987 to 1989.

Seed source	Number of plants	Seed piece weight (g) Mean	Seed piece weight (g) C.V.(%)	Mainstem No. per hill Mean	Mainstem No. per hill C.V.(%)
		Norland - 1987			
La Ronge	48	52	35.5	3.7	35.0
Prince Albert	49	63	28.3	3.9	43.6
Outlook	49	88	26.3	3.9	35.7
Nebraska	47	42	21.0	3.3	27.5
		Norland - 1988			
La Ronge	41	59	32.2	-	-
Prince Albert	45	62	22.4	-	-
Outlook	37	84	29.3	-	-
Becker	41	59	16.5	-	-
		Norland - 1989			
Prince Albert	50	49	27.5	3.5	45.7
Outlook	50	63	31.0	4.6	61.2
Saskatoon	50	48	50.2	4.3	41.9
Becker	47	75	31.6	4.9	57.1
		Russet Burbank - 1987			
La Ronge	50	40	33.8	2.3	33.2
Prince Albert	48	39	30.1	2.1	43.3
Outlook	48	47	30.2	2.6	34.6
Wisconsin	49	55	42.0	3.1	43.5
		Russet Burbank - 1988			
La Ronge	43	49	25.4	-	-
Prince Albert	45	85	27.5	-	-
Outlook	40	63	21.2	-	-
Becker	42	54	31.2	-	-
		Russet Burbank - 1989			
Prince Albert	50	35	28.0	2.3	49.1
Outlook	50	70	48.1	4.3	51.6
Saskatoon	50	53	30.5	3.6	44.4
Becker	47	75	17.2	4.8	37.5

to 4.8 for Russet Burbank. There were no distinct trends in number of mainstem or the corresponding coefficients of variation for the different seed sources in any of the test years (Table 5.1).

The number of mainstems per hill was generally positively correlated with seed piece weight, although, the correlations were relatively weak (Table 5.2). Heterogeneity of the corresponding correlation coefficients for the different seed sources of Russet Burbank were observed in 1987 and 1989 and in 1989 for Norland (Table 5.3). This was mainly due to relatively low correlations for Norland from Becker in 1989 and for Russet Burbank from Prince Albert in 1987 and from Becker in 1989.

Tuber Yields

The trends in marketable tuber number and tuber weight produced by the various seed sources (Table 5.4) were generally similar to the trends observed for total yields (Appendix 5.1). Consequently, discussions in this paper will be limited to marketable tubers only.

Number of Marketable Tubers per Hill

Norland plants from different seed sources produced an average of 10.5 to 14.1 marketable tubers per hill with coefficients of variation ranging from 20.6% to 40.4%

Table 5.2. Correlation coefficients for the relationship between seed piece weight and the number of mainstems per plant, and the number and weight of marketable tubers per hill for Norland and Russet Burbank potatoes from different seed sources: 1987 to 1989.

Seed Source	No. mainstems per hill	Marketable[z] tubers per hill	
		Number	Weight (kg)
	Norland - 1987		
La Ronge	+0.36	+0.50	+0.15
P. Albert	+0.63	+0.53	+0.38
Outlook	+0.32	+0.15	+0.20
Nebraska	+0.25	+0.28	+0.33
	Norland - 1988		
La Ronge	-	+0.03	+0.04
P. Albert	-	+0.40	+0.24
Outlook	-	+0.07	+0.17
Becker	-	+0.16	+0.05
	Norland - 1989		
P. Albert	+0.57	+0.46	+0.33
Outlook	+0.37	+0.36	+0.34
Saskatoon	+0.69	+0.32	+0.26
Becker	+0.08	+0.02	+0.15
	Russet Burbank - 1987		
La Ronge	+0.35	+0.36	+0.32
P. Albert	-0.06	+0.21	+0.22
Outlook	+0.31	+0.52	+0.39
Wisconsin	+0.47	+0.43	+0.52
	Russet Burbank - 1988		
La Ronge	-	+0.29	+0.29
P. Albert	-	+0.40	+0.30
Outlook	-	+0.36	+0.36
Becker	-	-0.30	-0.31
	Russet Burbank - 1989		
P. Albert	+0.08	+0.21	+0.29
Outlook	+0.56	+0.53	+0.57
Saskatoon	+0.30	+0.15	+0.33
Becker	-0.01	-0.20	+0.21

[z]Tubers larger than 45 mm in diameter.

Table 5.3. X^2 estimates for homogeneity of correlation coefficients for the relationship between seed piece weight and number of mainstems per plant and yield components for different seed sources of Norland and Russet Burbank potatoes: 1987 to 1989.

Category	Norland			Russet Burbank		
	1987	1988	1989	1987	1988	1989
			---Estimated X^2---			
Mainstem No. /plant	6.34	-	14.78	8.05	-	11.30
Mark. tuber No./plant	7.56	3.77	5.50	3.15	13.77	5.75
Mark. tuber Wt./plant	1.85	1.16	1.17	3.02	12.45	4.94

Table X^2 for (n-1) df at $P<0.05$ = 7.81, where n is the number of seed sources included in each estimation.

Table 5.4. Descriptive statistics for marketable yield components per hill for Norland and Russet Burbank potatoes from different seed sources: 1987 to 1989.

Seed source	Number of plants	Mark. tuber[z] No. per hill Mean	Mark. tuber[z] No. per hill C.V.(%)	Mark. tuber[z] Wt per hill (kg) Mean	Mark. tuber[z] Wt per hill (kg) C.V.(%)
		Norland - 1987			
La Ronge	48	12.3	28.1	4.1	30.2
Prince Albert	49	11.0	32.6	3.1	29.5
Outlook	49	11.5	25.3	3.1	21.2
Nebraska	47	10.9	25.4	2.9	30.8
		Norland - 1988			
La Ronge	41	12.4	30.5	3.3	35.2
Prince Albert	45	12.0	22.7	3.5	18.3
Outlook	37	13.6	29.3	3.8	23.4
Becker	41	14.1	20.6	3.7	20.4
		Norland - 1989			
Prince Albert	50	10.5	32.1	3.0	29.5
Outlook	50	13.4	39.2	3.7	33.8
Saskatoon	50	11.9	29.4	3.3	29.3
Becker	47	10.7	40.4	2.6	42.9
		Russet Burbank - 1987			
La Ronge	50	11.3	22.8	4.6	21.9
Prince Albert	48	8.7	27.7	3.9	29.1
Outlook	48	11.6	23.7	4.4	13.0
Wisconsin	49	11.0	30.9	3.8	24.5
		Russet Burbank - 1988			
La Ronge	43	9.5	34.8	2.9	31.2
Prince Albert	45	11.0	27.7	3.9	21.7
Outlook	40	9.9	36.9	3.4	42.2
Becker	42	6.9	72.2	1.8	93.2
		Russet Burbank - 1989			
Prince Albert	50	7.1	33.4	1.6	34.7
Outlook	50	8.5	32.9	1.8	34.6
Saskatoon	50	8.8	26.4	2.1	29.7
Becker	47	0.3	190.9	0.1	200.0

[z]Tubers larger than 45 mm in diameter.

(Table 5.4). No consistent differences between seed sources were observed for tuber number per hill or their coefficients of variation (Table 5.4). For Russet Burbank, the average number of marketable tubers per plant varied from 6.9 to 11.6 except for the Becker source in 1989 which produced only 0.3 tubers per hill. Russet Burbank seed from the northern Prince Albert source in 1987 and the southern sources in 1988 and 1989 produced relatively few marketable tubers and had higher coefficients of variation for tubers per hill than the other seed sources (Table 5.4).

The number of marketable tubers per hill was positively, but weakly, correlated with seed piece weight except for Russet Burbank from Becker which had a negative correlation in both 1988 and 1989 (Table 5.2). The correlation coefficients for the relationship between seed piece weight and tuber number per hill for the various seed sources were homogenous for Norland potato in all three years (Table 5.3). For Russet Burbank, the corresponding correlation coefficients were homogenous in 1987 and 1989 but not in 1988. The heterogeneity in 1988 was due to the negative correlation between tuber number and seed piece weight for the Becker seed as opposed to the positive relationships for the various Saskatchewan sources.

In 1987, the correlation between number of mainstems per hill and marketable tuber number per hill was positive for all the seed sources of both cultivars (Table 5.5). In 1989, the corresponding correlations were positive in five out of eight comparisons (Table 5.5). Except for Norland in 1987, the number of marketable tubers in hills with a comparable number of mainstems were generally lower for the southern seed than for the northern sources (Fig. 5.1).

Marketable Tuber Weight per Hill

Marketable tuber weights ranged from 2.6 to 4.1 kg per hill for Norland, with yields from the southern sources lower than from the Saskatchewan sources in 1987 and 1989 (Table 5.4). Coefficients of variation for individual hill tuber yields among the northern and southern seed sources did not follow any identifiable patterns (Table 5.4).

For Russet Burbank, marketable yields for the various seed sources ranged from 0.1 to 4.6 kg per hill (Table 5.4). Seed from Wisconsin (1987) and Becker (1988 and 1989) produced lower yields than seed from the three Saskatchewan sources (Table 5.4). The yield advantage from the Saskatchewan seed over the southern sources ranged between 3% to 21% in 1987 and between 61% and 117% in 1988. In 1989, Russet Burbank from Becker yielded exceptionally poorly due to high levels of PVY in the seed (Chapter 3).

Table 5.5. Relationship between marketable yield components and number of mainstems per hill for Norland and Russet Burbank potatoes from different seed sources: 1987 and 1989.

Seed source	Tuber number: Relationship	Tuber number: Correl. Coeff.	Tuber weight: Relationship	Tuber weight: Correl. Coeff.
		Norland - 1987		
La Ronge	Quadratic	+0.97	Quadratic	+0.97
P. Albert	Asymptotic	+0.94	Asymptotic	+0.94
Outlook	Asymptotic	+0.98	Asymptotic	+0.95
Nebraska	Linear	+0.97	Asymptotic	+0.99
		Norland - 1989		
P. Albert	Asymptotic	+0.98	Asymptotic	+0.96
Outlook	-[z]	-	-[z]	-
Saskatoon	Linear	+0.80	Linear	+0.81
Becker	Linear	+0.94	Linear	+0.71
		Russet Burbank - 1987		
La Ronge	Linear	+0.81	Linear	+0.62
P. Albert	Linear	+0.93	Linear	+0.66
Outlook	Linear	+0.80	-[z]	-
Wisconsin	Linear	+0.91	Asymptotic	+0.96
		Russet Burbank - 1989		
P. Albert	-[z]	-	-[z]	-
Outlook	Linear	+0.94	Linear	+0.86
Saskatoon	Linear	+0.80	-	-
Becker	-[z]	-	-[z]	-

[z]No relationships were evident for tuber yield versus number of mainstems per hill.
Regression equations: Linear, Y=a+bX; Asymptotic, Y=a+b.1/X; Quadratic, $Y=a+bX+cX^2$ (where X is number of mainstems per hill, Y is tuber yield components, and a, b, and c are constants).

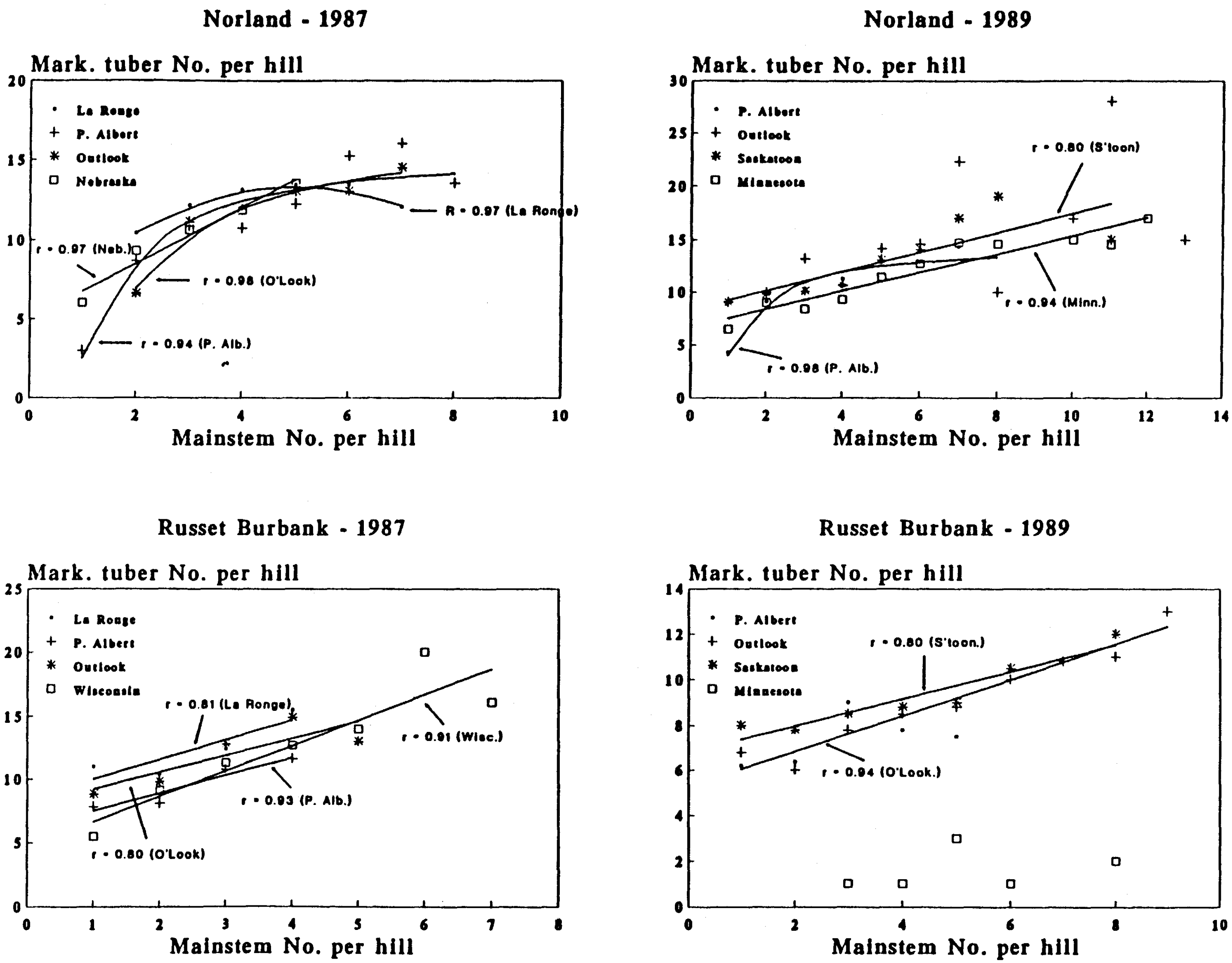


Fig. 5.1. Relationship between number of marketable tubers per hill and number of mainstems for Norland and Russet Burbank potatoes from different seed sources: 1987 and 1989.

The coefficient of variation for tuber yields was higher for Prince Albert seed than the other sources in 1987 and in 1988 and 1989, Becker seed showed considerably higher variability than the Saskatchewan seed sources (Table 5.4).

Marketable tuber weights per hill of both cultivars were weakly correlated with seed piece weight (Table 5.2). In Norland, the seed source had no effect on this relationship (Table 5.3). This suggests that, for Norland, the relationship between seed piece weight and tuber yield was similar for the various seed sources. For Russet Burbank, the relationship was homogenous in 1987 and 1989 but not in 1988 (Table 5.3). The heterogenous effect in 1988 was due to contrasting correlations between the Becker and Saskatchewan sources. The relationship between tuber yield and seed piece weight was positive for the Saskatchewan seed sources and negative for the Becker seed (Table 5.2).

There was a positive correlation between marketable tuber weight and the number of mainstems per hill for the majority of cultivar/seed source comparisons (Table 5.5). For hills with similar stem densities, the Saskatchewan seed sources consistently outyielded seed from Becker or Wisconsin (Fig. 5.2).

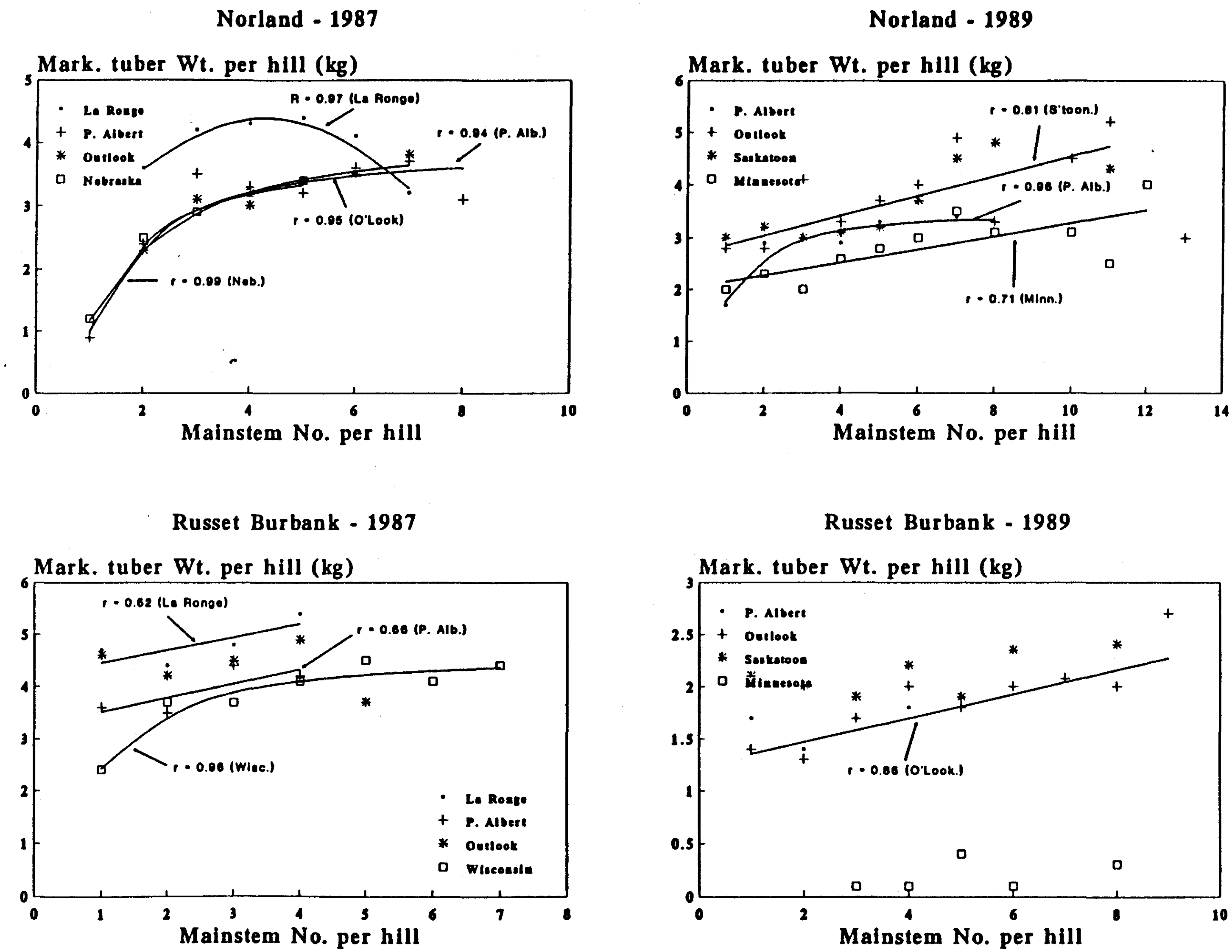


Fig. 5.2. Relationship between marketable tuber weight per hill and number of mainstems for Norland and Russet Burbank potatoes from different seed sources: 1987 and 1989.

DISCUSSION

Variability in seed piece performance has considerable impact on the economics of potato production. Some variability in seed piece size is unavoidable when cutting by hand or by machine. Schotzko et al., (1983) found that seed lots containing more than 46% of 42-56 g seed pieces provided higher returns than seed lots containing greater proportions of either larger or smaller seed pieces. In this study, there was considerable variability in seed piece weights for all seed lots tested. However, the degree of variability observed for seed piece weights conforms to expectations for standard seed lots graded according to tuber diameter. For example, Hagman (1973) found that seed-tuber weights graded to fit a 40-50 mm size grade varied in weight from 30-120 g.

Seed piece weight has considerable influence on potato growth and productivity (Allen, 1978; Iritani and Weller, 1987). For Russet Burbank, 57 g seed pieces appeared to be more productive than 43 g or 28 g seed pieces (Iritani et al., 1972). However, the increase in productivity obtained by using larger seed was not proportional to the change in seed weight (El Saeed et al., 1963). According to Schaupmeyer (1992), planting seed weighing greater than 60 g increases seed costs while providing no yield advantage. Further, the greater variability in shape and size found in larger size seed lots lowers planter efficiency, thereby producing poor plant stands. Allen (1987), also found large seed was less productive than smaller seed. This was attributed to higher within-hill competition as the larger seed produced more stems and more tubers which eventually restricted tuber bulking. In this study, mainstem numbers, marketable tuber numbers and marketable tuber weights were generally positively, but weakly, correlated with seed piece weights. The weak relationship between seed piece weight and mainstem numbers or tuber yields has also been observed by Sahota and Sawle (1984), Silva and Andrew (1985) and Kleinhenz and Bennett (1992). Hagman (1973) also found that the yield potential of seed lots from different latitudes appeared to be influenced by factors other than differences in seed piece weight.

Hagman (1973) reported that superior seed lots had lower variability in tuber yields among individual seed-tubers than less productive seed lots. Variation in tuber yields for individual seed pieces within the various seed sources tested in this study ranged from as low as 13% to as high as 200%, although the average ranged between 20% and 30%. Hagman (1973) obtained coefficients of variation for tuber yields per hill ranging from 19%-79%, while Silva and Andrew (1985) reported coefficients of variation ranging from 24% - 35% for Norland and from 33% - 47% for Russet

Burbank. In this study, the low yielding lots of Russet Burbank from the southern sources had considerably greater hill-to-hill variation for marketable tuber yields (C.V. of 93% in 1988 and 200% in 1989) than the higher yielding northern seed. With Norland potatoes, there was no consistent relationship between the yield potential of a given seed lot and its hill-to-hill variability. The high hill to hill variability in yield for Russet Burbank from the southern sources could be due to premature senescence of plants infected from seed-borne PVY (Chapter 3).

Further studies are required to examine the basis for the variability among different seed sources. Comparisons should be made between the variability exhibited by whole seed tubers versus cut pieces for the various seed sources. The cut seed pieces should be planted in a manner that would allow for identification of seed portion effects within the individual tubers. If the variability displayed by whole-tubers coming from the various seed sources were similar, but had specific trends for seed portions, it would suggest that the variability was related to some seed portion effects rather than seed source effects.

This study examined the productive potential of various Norland and Russet Burbank seed sources for their inherent vigour and hill-to-hill variability in yields. Differences in tuber yields per hill for different seed sources could not be attributed to the direct influence of either seed piece weight or mainstem number per hill. When comparing plants with similar stem numbers, plants grown from northern seed generally outperformed plants from southern seed. In addition, the lower hill-to-hill variability in the northern seed sources, particularly with Russet Burbank, further enhanced the productive potential of northern seed lots compared to southern seed. Potato growers strive to reduce hill to hill variability as uniform ground cover results in efficient light interception, thereby producing higher yields. Uniform seed lots also produce better tuber grades with a higher proportion of uniform tubers. A uniform plant stand makes tillage and weed control practices simpler and more effective.

CHAPTER 6

Seed-type Effects on Growth and Productivity of Russet Burbank Potatoes from Different Latitudes

ABSTRACT

Potato seed-tubers produced in cooler northern environments are often more vigorous and higher yielding than seed from relatively warmer southern locations. It is not known whether the increased productivity of the northern seed is due to increased vigour of specific portions of the seed piece (i.e. apical or basal portions) or simply reflects increased vigour of the whole seed-tuber. This study examined the growth and productivity of Russet Burbank potato seed-tubers from Outlook Saskatchewan (northern site) and Wisconsin (southern site) in relation to the performance of specific seed-tuber portions. Comparisons were made among various types of seed piece, including apical, central and basal; and whole, half, one-third and quarter seed-tubers. Seed piece weights were maintained at approximately 50 g in all cases. Outlook and Wisconsin seed produced similar shoot growth and marketable yields early in the season (90 DAP). Although, Outlook seed emerged slowly, it outyielded the Wisconsin seed at maturity (120 DAP) through the retention of active shoot growth for a longer period of time.

Generally, apical seed portions emerged more rapidly and produced higher yields at 90 DAP than basal portions, but at maturity both seed portions produced similar marketable yields. Otherwise the various cutting methods and seed portion compositions did not have any significant effect on growth or yields. Seed source x seed type interactions were not significant for any of the growth and yield characteristics tested. It can be summarized that the productive superiority of Russet Burbank seed produced in Outlook, compared to seed from Wisconsin, was due to the beneficial contributions of the entire seed-tuber rather than due to any specific effect of seed portion.

Potato (*Solanum tuberosum* L.) yields are a function of the vigour of individual seed pieces and the variability among them (Silva and Andrew, 1984). Seed vigour is influenced by seed piece size (Allen, 1978; Wurr and Morris, 1979; Nelson and Thorenson, 1982; Iritani and Thornton, 1993), number of cut surfaces on the seed piece (Schaupmeyer et al., 1989) and the physiological condition of the mother tuber from which the seed piece was derived (Wurr, 1978a; Ewing, 1985).

Larger seed usually produces higher yields than smaller seed (Allen, 1978). The yield superiority of larger seed has been attributed to the greater initial vigour of the resulting plant compared to smaller seed (Bremner and El Saeed, 1963). However, excessively large seed does not offer any added advantage (Allen, 1978) while substantially increasing seed costs. Seed pieces weighing approximately 50 g were found to be more productive than either smaller or larger seed pieces (Iritani, et al., 1972; Kleinhenz and Bennett, 1992).

The influence of seed portion on growth and productivity of potatoes has been extensively studied. Wurr (1974) showed that whole tubers were more productive than cut pieces. Welch (1963), conversely, found that cut seed outyielded whole tubers, while Ing (1966) found no yield differences between whole tubers and cut seed. More recently, McKeown (1990a and 1990b) found that the growth and yield differences between whole seed and cut pieces were cultivar dependant. Apical seed portions of Jemseg and Yukon Gold potatoes emerged more rapidly and produced higher tuber yields than basal portions, but with Superior, the rates of emergence and tuber yields were similar for both apical and basal seed portions (McKeown, 1990a and 1990b). Russet Burbank plants grown from apical and basal seed portions also showed no differences in productivity (Wilson and Murphy, 1970).

The general consensus is that seed pieces with more cut surfaces are less productive than seed pieces with fewer cut surfaces (Schaupmeyer et al., 1989) due to increased losses to seed-tuber rot originating at the cut surfaces (Beukema and van der Zaag, 1990).

The physiological age of potato seed-tubers is one of the major determinants of their productivity. Several studies have shown that physiologically old seed-tubers are less vigorous and lower yielding at maturity than physiologically young seed (Harris, 1978, van der Zaag and van Loon, 1987, Knowles and Botar, 1992). Potato seed-tubers originating in cooler climates are frequently more productive than seed from relatively warmer locations (Stuart, 1913; Went, 1959; Goodwin et al., 1969b; Wurr, 1978a; Wiersema and Booth, 1985; Caldiz, 1991). Increased vigour of potato seed-tubers from cooler environments has been attributed to lower physiological age of these seed-tubers compared to seed produced in warmer locations.

Arthur (1892) showed that in potato tubers, the vigour of eyes decreased progressively from the apical to the basal region. Knowles (1984) showed that the apical region of Russet Burbank potatoes aged more rapidly than the basal region. Therefore, it is possible that the lower yields of seed lots from warmer southern sources may be due to the reduced vigour of the apical seed portions as a result of rapid ageing.

The objective of this study was to examine growth and productivity of potato seed-tuber lots produced in different locations with particular emphasis on the performance of seed pieces derived from different positions on the seed-tuber. Comparisons were made among uniform sized whole tubers, cut pieces, (half, one-third and quarter) and different seed positions (apical, central and basal) with the view of providing a wide array of seed piece types for comparison of the effects of seed source. Treatments containing equal proportions of different seed portions were included to simulate standard commercial seed lots.

MATERIALS AND METHODS

The experiment was conducted using 'certified', Russet Burbank seed-tubers grown in Outlook, Saskatchewan (Canada) and Wisconsin (U.S.A.) in the summer of 1987. Differing seed piece types were obtained by cutting seed tubers in different planes (Fig. 6.1). The categories of seed pieces tested in this study were:

1. Whole tuber
2. Half tuber, basal
3. Half tuber, apical
4. Half tuber, basal + apical (1:1)

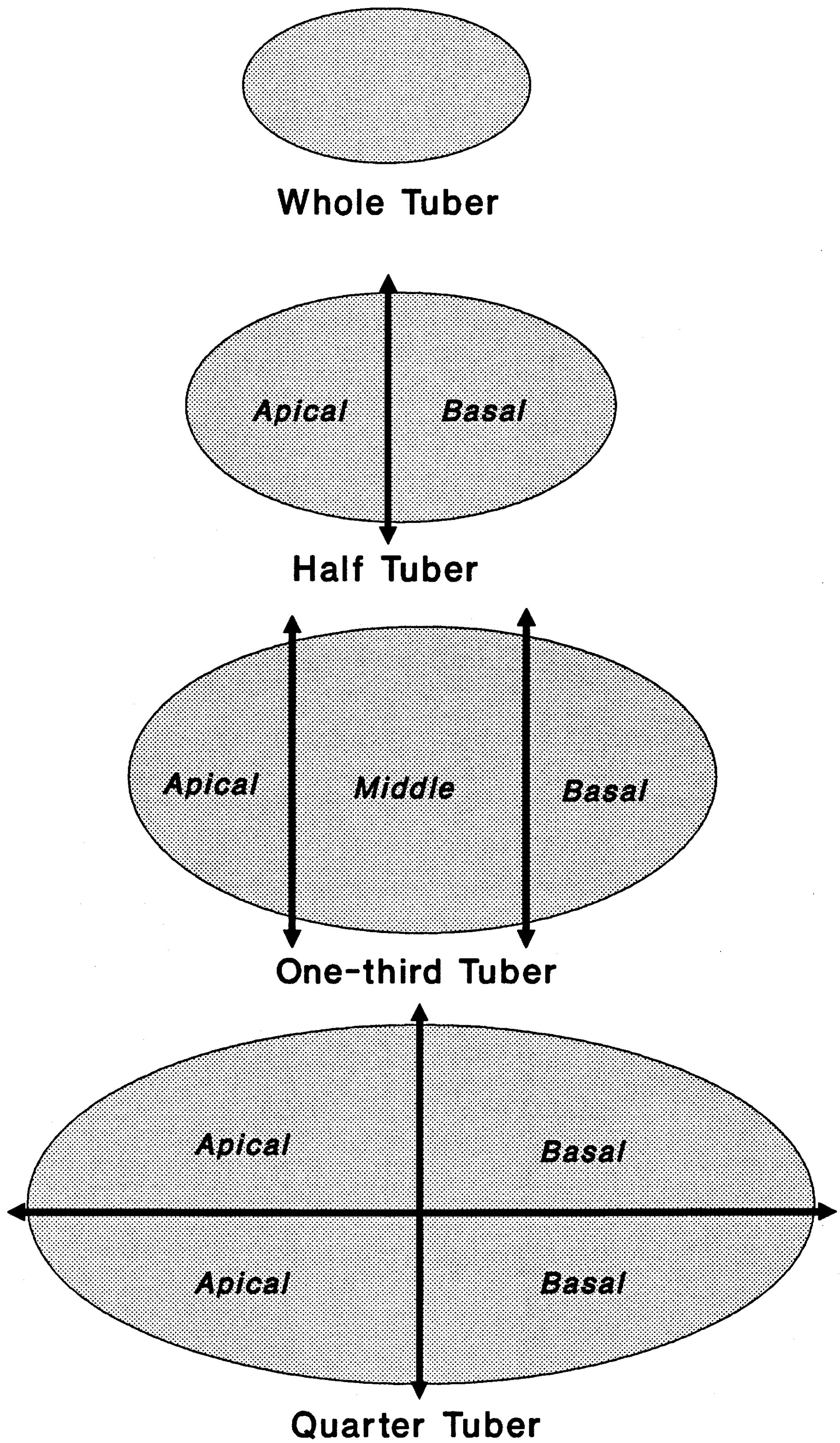


Fig. 6.1. Methods of cutting potato seed-tubers.

5. One-third tuber, basal
6. One-third tuber, middle
7. One-third tuber, apical
8. Quarter tuber, basal
9. Quarter tuber, apical
10. Quarter tuber basal + apical (1:1)

Seed-tubers weighing approximately 100, 150, or 200 g were cut longitudinally and/or laterally to obtain 'half', 'one-third' and 'quarter' seed pieces weighing approximately 50 g (commercially recommended seed piece weight). Whole tubers weighing approximately 50 g were also tested. Equal proportions of apical and basal segments were used in the treatments where apical and basal seed portions were evaluated together (treatments 4 and 10). The seed pieces were dusted with Captan fungicide to control seed piece decay.

The seed piece trials were conducted at the plots of the Department of Horticulture Science, University of Saskatchewan at Saskatoon, Saskatchewan in the summer of 1987. The experiment was laid out as a two (seed source) x 10 (seed piece type) factorial in a randomized complete block design with four replications. Ten seed pieces were planted in each plot at a spacing of 90 cm between row x 30 cm within row. The crop was raised under irrigation.

Fertility and other cultural practices were performed in accordance with commercial recommendations.

Emergence counts were taken 24, 26, 28,and 32 days from planting. Vine lengths (average of five plants per plot) were recorded at 100 days from planting at which time the plants were fully grown. The crop was harvested at 90 and 120 days from planting. Mainstem counts were taken at the first harvest period, while haulm fresh weights were recorded at both harvest dates. Tubers were graded according to their diameter, with tubers >45 mm diameter considered as 'marketable'.

Results were analyzed using the analysis of variance procedure (Minitab Release 7). Group comparisons for different seed types were made using orthogonal contrasts. The percent emergence data were analyzed after arcsine transformation in order to correct for heterogeneity of variance (Steel and Torrie, 1980).

RESULTS

The average temperature regimes during the growing season at the Outlook and Wisconsin seed production sites are given in Appendix 3.1. Outlook experienced relatively lower average temperatures and greater diurnal temperature fluctuations during the growing season than the Wisconsin site.

Emergence

The Wisconsin seed had higher rates of emergence at 24, 26 and 28 days from planting than the Outlook seed (Table 6.1). By 32 days from planting, both seed sources reached approximately 100% emergence.

There were significant differences for emergence rates among the seed piece types at the first three recording dates (Table 6.1). The whole tubers emerged earlier than the cut seed and the apical portions emerged earlier than the basal portions. The emergence rates of the central seed portion was intermediate between the apical and basal portions at the initial stages. At the final count, all seed piece types had approximately 100% emergence. Orthogonal comparisons showed that the emergence rates of the half and one-third tubers were significantly higher than the quarter tubers at 24 DAP (Table 6.1, Appendix 6.1). At the later sampling dates, the differences became less significant. Within the various cutting treatments, an equal blend of apical and basal pieces showed emergence characteristics comparable to basal portions but had poorer performance than the strictly apical portions (Table 6.1, Appendix 6.1). Seed source x seed type interactions were not significant (Table 6.1).

Table 6.1. Effects of seed source and seed portion on percent emergence for Russet Burbank potatoes at different periods from planting.

Treatment	Days from planting			
	24	26	28	32
	---Emergence (%)---			
Seed source[z]				
Outlook	7.1	70.4	91.7	99.8
Wisconsin	42.0	89.8	98.8	99.8
Sig. (Source main effect)	**	**	*	NS
LSD (5.0%)	6.7	5.3	3.7	-
Seed portion[y]				
Whole tuber	51.5	96.2	99.9	100.0
Basal (Bas) half	15.9	74.0	91.8	99.6
Apical (Ap) half	50.2	99.2	99.1	100.0
Bas.half + Ap.half	12.8	72.2	96.6	99.9
Basal one-third	4.9	57.3	88.8	99.9
Centre one-third	15.7	67.1	93.6	99.9
Apical one-third	56.4	98.1	99.8	99.8
Basal quarter (qrt)	4.4	45.0	84.7	98.4
Apical quarter	19.1	89.1	99.6	99.6
Bas qrt. + Ap qrt.	12.8	77.5	90.9	99.4
Sig.(Portion main effect)	*	*	*	NS
LSD (5.0%)	15.0	11.8	8.2	-
Sig. (Source x Portion)	NS	NS	NS	NS

[z]Average of different seed portion treatments.
[y]Average of seed sources.
*, ** and NS indicate significance at P<0.05, <0.01 levels of significance and not significant, respectively.

Main Stem Number

There were no significant effects of seed source, cutting methods or their interactions on mainstem numbers (Table 6.2, Appendix 6.2).

Vine Length

At 100 DAP, the vine lengths for plants originating from the Outlook seed lots were, on the average, 5 cm longer than plants from the Wisconsin seed source (Table 6.3). Seed piece type had no significant effect on vine length (Appendix 6.2). Seed source x seed portion interactions for vine lengths were not significant (Table 6.3).

Haulm Fresh Weight

Outlook and Wisconsin seed produced similar haulm fresh weights at the 90 day harvest, but at the 120 day harvest, plants grown from Outlook seed had 20% higher haulm weights than plants originating from Wisconsin seed (Table 6.4). Haulm weights for the Wisconsin seed source actually decreased by 20% between the 90 and 120 DAP harvests, reflecting loss of leaves and moisture as the tops senesced. By contrast, the plants from the Outlook source showed no change in haulm fresh weight between the two harvests.

Orthogonal comparisons showed no significant effects of seed piece type on haulm fresh weight at 90 DAP

Table 6.2. Effects of seed source and seed portion on number of mainstems per plant for Russet Burbank potatoes at 90 days from planting.

Treatment	Mainstems per plant
Seed source[z]	
Outlook	2.8
Wisconsin	2.7
Significance (Source main effect)	NS
Seed portion[y]	
Whole tuber	2.8
Basal half	2.7
Apical half	2.3
Basal half + Apical half	3.1
Basal one-third	2.9
Centre one-third	2.8
Apical one-third	3.1
Basal quarter	2.3
Apical quarter	3.0
Basal quarter + Apical quarter	2.8
Significance (Portion main effect)	NS
Significance (Source x Portion)	NS

[z]Average of different seed portion treatments.
[y]Average of seed sources.
NS indicates treatment effects are not significant.

Table 6.3. Effects of seed source and seed portion on vine lengths for Russet Burbank potatoes at 100 days after planting.

Treatment	Vine length (cm)
Seed source[z]	
Outlook	103
Wisconsin	98
Significance (Source main effect)	*
LSD (5.0%)	4
Seed portion[y]	
Whole tuber	99
Basal half	100
Apical half	105
Basal half + Apical half	101
Basal one-third	101
Centre one-third	97
Apical one-third	101
Basal quarter	98
Apical quarter	104
Basal quarter + Apical quarter	98
Significance (Portion main effect)	NS
Significance (Source x Portion)	NS

[z]Average of different seed portion treatments.
[y]Average of seed sources.
* and NS indicate significance at P<0.05 level of significance and not significant, respectively.

Table 6.4. Effects of seed source and seed portion on haulm fresh weight per plant for Russet Burbank potatoes at two harvest dates.

Treatment	90 DAP	120 DAP
	--Haulm fresh weight per plant (kg)--	
Seed source[z]		
Outlook	1.2	1.2
Wisconsin	1.2	1.0
Sig. (Source main effect)	NS	***
LSD (5.0%)	0.1	0.1
Seed portion[y]		
Whole tuber	1.2	1.1
Basal half	1.2	1.2
Apical half	1.1	1.3
Basal half + Apical half	1.3	1.2
Basal one-third	1.0	1.0
Centre one-third	1.3	1.2
Apical one-third	1.2	1.1
Basal quarter	1.1	1.0
Apical quarter	1.3	1.1
Basal quarter + Apical quarter	1.1	1.2
Sig. (Portion main effect)	NS	NS
Sig. (Source x Portion)	NS	NS

[z]Average of different seed portion treatments.
[y]Average of seed sources.
*** and NS indicate significance at P<0.001 level of significance and not significant, respectively.

(Appendix 6.2). At 120 DAP, the apical portion and half tubers produced higher haulm weights than did the basal seed portion or the one-third or quarter seed respectively (Table 6.4, Appendix 6.2). Seed source x seed portion interactions for haulm weight were not significant.

Yield Components

Outlook and Wisconsin seed sources produced similar marketable tuber yields at the 90 day harvest, but at the 120 day harvest, Outlook seed outyielded Wisconsin seed by 11% (Table 6.5). Analysis of variance for the yield differences between the 90 and 120 day harvests showed highly significant ($P < 0.01$) seed source effects. The increase in marketable yield from 90 to 120 days of the Outlook seed was 42.0 t ha^{-1}, whereas the yield increase from the Wisconsin seed source was only 35.1 t ha^{-1}.

Marketable yields were not significantly different for the various seed piece types at either harvest except at the 90 DAP harvest where the apical seed pieces outyielded the basal seed pieces by 14.1% (Table 6.5, Appendix 6.3).

Seed source had no significant effect on the number of marketable tubers per plant at either harvest (Table 6.5). Apical seed pieces tended to produce plants with more marketable tubers compared to basal seed portions, although

Table 6.5. Effects of seed source and seed portion on marketable yield components for Russet Burbank potatoes at two harvest dates.

	Marketable tubers[z]					
	90 DAP			120 DAP		
Treatment	Yield (t/ha)	Num. per plant	Aver. wt. (g)	Yield (t/ha)	Num. per plant	Aver. wt. (g)
Seed source[y]						
Outlook	26.7	5.7	127	68.7	6.9	270
Wisconsin	26.7	5.7	127	61.8	6.9	245
Sig. (Source)	NS	NS	NS	**	NS	***
LSD (5.0%)	-	-	-	4.4	-	13
Seed portion[x]						
Whole tuber	30.2	6.4	128	69.3	7.7	244
Basal (Bas) half	22.3	4.8	126	63.1	6.7	256
Apical (Ap) half	27.0	5.9	127	65.0	7.1	247
Bas half + Ap half	26.9	6.0	122	67.5	7.0	260
Basal one-third	26.3	5.8	127	63.1	6.8	252
Centre one-third	26.7	5.2	138	64.2	6.9	253
Apical one-third	27.7	6.2	120	67.5	7.4	249
Basal quarter (qrt)	24.4	5.1	131	59.3	6.1	263
Apical quarter	28.6	6.2	127	67.2	6.8	272
Bas qrt + Ap qrt	26.9	5.7	127	66.6	6.5	277
Sig.(Portion)	NS	NS	NS	NS	NS	NS
Sig.(S x P)	NS	NS	NS	NS	NS	NS

[z]Tubers >45 mm in diameter.
[y]Average of different seed portion treatments.
[x]Average of seed sources.
, *, and NS indicate significance at P<0.01, <0.001 levels of significance and not significant, respectively.

the difference reached significant levels only at the 90 DAP harvest (Appendix 6.3). At the 'final' harvest, whole seed produced more marketable tubers per plant than did cut seed (Table 6.5, Appendix 6.3).

The average weights of the marketable tubers were similar for the Outlook and Wisconsin seed sources at the 90 DAP harvest (Table 6.5), but by 120 DAP, Outlook seed produced tubers that averaged 10% heavier than Wisconsin seed. Seed piece type had no significant effects on the average marketable tuber weights at the 90 DAP harvest. By 120 DAP, plants from quarter seed produced larger tubers than plants grown from half or one-third tubers (Table 6.5, Appendix 6.3). Seed source x seed type interactions were not significant for any yield components at either harvests (Table 6.5).

DISCUSSION

In this study, seed from a relatively cool, northern source (Outlook) produced similar growth and yields during early growth stages as seed from a warmer southern site (Wisconsin). However, at maturity, the northern seed produced larger plants and higher tuber yields than the southern seed. Wiersema and Booth (1985) observed a similar absence of source effects at early harvests for seed originating under different temperature regimes. The similarity in shoot weights, stem numbers and tuber yields observed in this study for the two seed sources at the 90 day harvest do not correspond with the prevailing hypotheses on physiological age. Seed from the warmer southern site is presumed to be physiologically older than the northern seed and was expected to produce more mainstems (Iritani and Weller, 1987; Knowles, 1987; Knowles and Botar, 1991), greater early shoot growth (Knowles and Botar, 1991) and higher tuber yields at 'early' harvests (Knowles and Botar, 1992). It is likely that increased vigour of northern seed compared to the southern seed was caused by factors other than physiological age effects. This vigour difference is probably associated with the temperature conditions at the seed growing sites (Goodwin et al., 1969b; Wiersema and Booth, 1985).

The superior marketable yields for the northern seed at maturity was due to larger tuber size rather than due to differences in marketable tuber numbers. This greater tuber size may be attributed to the northern seed producing larger, more vigorous shoots that persisted longer than the tops from the southern seed. Previous studies comparing effects of seed source have also shown a positive relationship between tuber yields and shoot vigour, with shoot vigour characterized by taller plants (Hartz et al.,

1980) and retention of greater shoot biomass (Wurr, 1977; Wiersema and Booth, 1985; Caldiz, 1991).

Within a potato seed-tuber, the vigour of eyes tends to decrease progressively in a basipetal direction (Arthur, 1892). Consequently, if basal portions of potatoes are used as seed pieces they tend to be less productive than apical portions (McKeown, 1990b). In this study, apical seed portions emerged earlier and produced higher tuber yields than did basal seed portions. Similar observations were also made for Jemseg and Yukon Gold potatoes but not for Superior (McKeown, 1990b). As expected, a blend of equal proportions of various seed forms, a situation similar to a regular seed lot, showed growth and yield responses which were intermediate between either purely apical or basal seed lots.

Fifty gram seed pieces are considered to be optimum for potato production (Allen, 1978; Schaupmeyer et al., 1992). Previous studies had shown that increasing the number of cuts per seed piece reduced tuber yields (Schaupmeyer et al., 1989). Seed pieces obtained by multiple cuts from larger mother tubers produced lower yields due to a greater frequency of 'blind' seed pieces (Reeves and Hunter, 1980; Schaupmeyer et al., 1989). In this study, where seed piece weights were maintained at approximately 50 g, the various forms of cutting (one, two, or three cuts) had no significant effects on growth and yields of the resulting crop. The various cutting treatments did not produce excessive blind seed pieces, as evidenced by similar mainstem numbers produced by the differing seed piece types. In this study, the seed pieces were treated with Captan fungicide to prevent seed piece decay. However, in situations if the seed was not treated or cool wet conditions occurred at planting, the slow emerging basal portions (McKeown, 1990a) might be more susceptible to decay resulting in poor plant stands than when apical seed portions are planted.

It could be assumed that the superior yields obtained from the Outlook seed, compared to the Wisconsin seed, was due to increased vigour of either the entire seed-tuber or due to some differential effect of latitude on the relative vigour of the apical or basal seed portions. The absence of significant interactions between seed source and seed portion for the various growth and yield parameters is an indication that seed source effects were constant across the various seed piece types. More vigorous growth and the yield advantages obtained for northern seed appeared to be caused by some physiological changes in the seed tuber that were different from physiological age effects. Goodwin et al., (1969b) suggested that the increased vigour of potato seed-tubers produced in more northern locations was due to some beneficial physiological changes that occurred throughout the seed-tuber tissues. Wiersema and Booth (1985) also attributed the superior performance of potato seed-tubers produced in cooler higher elevations to changes in tuber dry matter content and not to any physiological age effects. Increased levels of tuber borne diseases have been found to reduce quality of potato seed-tubers produced in southern U.S.A. compared to seed produced in more northern latitudes (Went, 1959; Hartz et al., 1980). It is unlikely that in this study the yield reductions in the southern (Wisconsin) seed were caused by greater incidence of tuber borne diseases than the northern (Outlook) seed, as both seed lots were from certified disease-free stocks.

Further study is necessary to examine the influence of the climate in which seed is produced, the physiological and biochemical changes in the seed-tuber tissue and its influence on subsequent growth and yield of the progeny. It is possible that adenylate energy levels and/or plant growth regulators may influence the relative growth and yields of potato seed-tubers produced in varying environments.

CHAPTER 7

Carry-over Effect of Seed Growing Environment on the Productivity of Potato Seed-tubers

ABSTRACT

The carry-over effect of the environment in which potato seed-tubers were raised on productivity of the progeny was investigated. Norland and Russet Burbank potato seed-tubers grown in Outlook, Saskatoon, and Prince Albert in Saskatchewan produced higher marketable tuber yields in year-one of the study than did seed-tubers obtained from Becker, Minnesota. Propagating seed originating from Becker at Saskatoon in the following year improved the productive capacity of that seed relative to seed continually propagated at Becker. The re-vitalizing influence of the Saskatoon environment was more pronounced in Russet Burbank potato than in Norland potatoes. Cycling Saskatchewan grown seed through Becker reduced the vigour of that seed compared to seed that was continuously multiplied at the northern sites. The yield responses attributed to the initial seed source and the second generation seed production site involved differences in both number and size of marketable tubers in Russet Burbank. In Norland, the treatment effects were predominantly due to the differences in marketable tuber numbers rather than tuber size. It appears that 'northern vigour' is carried over for at least one season although exposure of northern seed to southern environments reduced the yield potential of the northern seed. The fact that southern seed can be revitalized by a single season exposure to the cooler northern seed growing environment suggests that this response was due to some physiological effect rather than any disease conditions. If the yield responses were due to seed borne diseases, the negative influence of the southern environment would persist even when cycled through the northern site. The advantage of using northern seed for commercial potato production is discussed.

Quality and yield potential of potato (*Solanum tuberosum* L.) seed-tubers depends on freedom from tuber borne diseases and the physiological state of the tubers. In turn, both the disease status and physiological condition of tubers depend upon the seed production environment (Harris, 1982; Wurr, 1978a; Wiersema and Booth, 1985), cultural practices (Jones et al., 1981; Caldiz et al., 1985), storage temperature (Knowles and Botar, 1991), and handling procedures prior to planting (Wiersema and Booth, 1985; Caldiz, 1991).

Potato seed-tubers originating in cooler northern climates are usually more productive than those from relatively warmer southern environments (Stuart, 1913; Goodwin et al., 1969b; Wurr, 1978a). Some very early studies conducted in the U.K with several cultivars, cited by Stuart (1913), showed that seed from more northern Scotland was superior to seed grown in a more southerly site near Cambridge. Seed from Scotland subsequently multiplied in Cambridge was less productive than the original seed from Scotland. By contrast, propagating Cambridge seed in Scotland substantially increased its vigour relative to the original Cambridge seed. For example, seed-tubers of Factor obtained from Scotland initially produced 45% higher marketable yields than seed raised in Cambridge. Cycling the Cambridge seed through Scotland in the following season elevated the productive potential of the original Cambridge seed stock by 42%. The devitalizing influence of the Cambridge environment on Scotland seed was less marked. Channelling seed from Scotland through Cambridge resulted in a yield decline of only 4% compared to the original seed.

Some researchers indicate that the productive advantage gained by raising potato seed-tubers in cooler environments may persist through several generations (Stuart, 1913; Went, 1959). However, O'Brien et al., (1986) reported that the carry-over effect of potato seed-tubers between successive generations was negligible and was of no commercial importance. The absence of source effect in the previous study was believed to be due to the divergent physiological status of the seed stocks from Scotland that were received over a period of four months (mid-October to mid-February).

Results previously reported in this project (Chapters 3, 4 and 5) showed that potato seed-tubers from Saskatchewan sites were often more vigorous and higher yielding than seed from a more southern source near Becker, Minnesota. It could be argued that the lower productivity of Becker seed reflected a greater incidence of seed borne diseases due to increased activity of insect vectors in the long, warm growing season at Becker. Channelling Becker seed through a relatively cooler site should not affect the yield potential of that source appreciably if the yield differences were related to tuber borne diseases. However, if the differences in yield potential of seed-tubers originating at the various sites were due to environment mediated differences in the physiology of the seed, growing Becker seed at Saskatoon should rejuvenate that seed stock. The present study describes the influence of seed growing environment on productivity of Norland and Russet Burbank potato seed-tubers obtained from different seed stocks, with the objective of determining whether there were significant 'carry-over' effects of site-of-origin on yield of the second generation.

MATERIALS AND METHODS

The seed increase and yield evaluation scheme used in this experiment is shown diagrammatically in Fig. 7.1. Elite-III seed-tubers of Norland and Russet Burbank potatoes from the Pemberton Valley (British Columbia) were initially multiplied during the summer of 1988 at Becker (Minnesota) and at Outlook, Saskatoon, and Prince Albert (Saskatchewan). The geographic and climatic characteristics of these sites are presented in Appendix 3.1. In 1989, seed lots from all four seed sources were again grown in Becker or in Saskatoon. In both years, the seed crops were raised using recommended cultural practices and precautions were taken to minimize the introduction and spread of virus diseases. Seed-tubers were harvested at maturity and stored under uniform conditions in Saskatoon until replanted. A yield test was conducted in 1990 at Saskatoon to compare the productivity of the original Becker, Outlook, Saskatoon, and Prince Albert seed sources subsequently multiplied at either the Becker or Saskatoon sites. The field plot was laid out as a 2 (cultivar) x 4 (initial seed source) x 2 (site of second generation propagation) factorial in a Randomized Complete Block Design with four replications. The trial was planted in May and harvested in September. Approximately

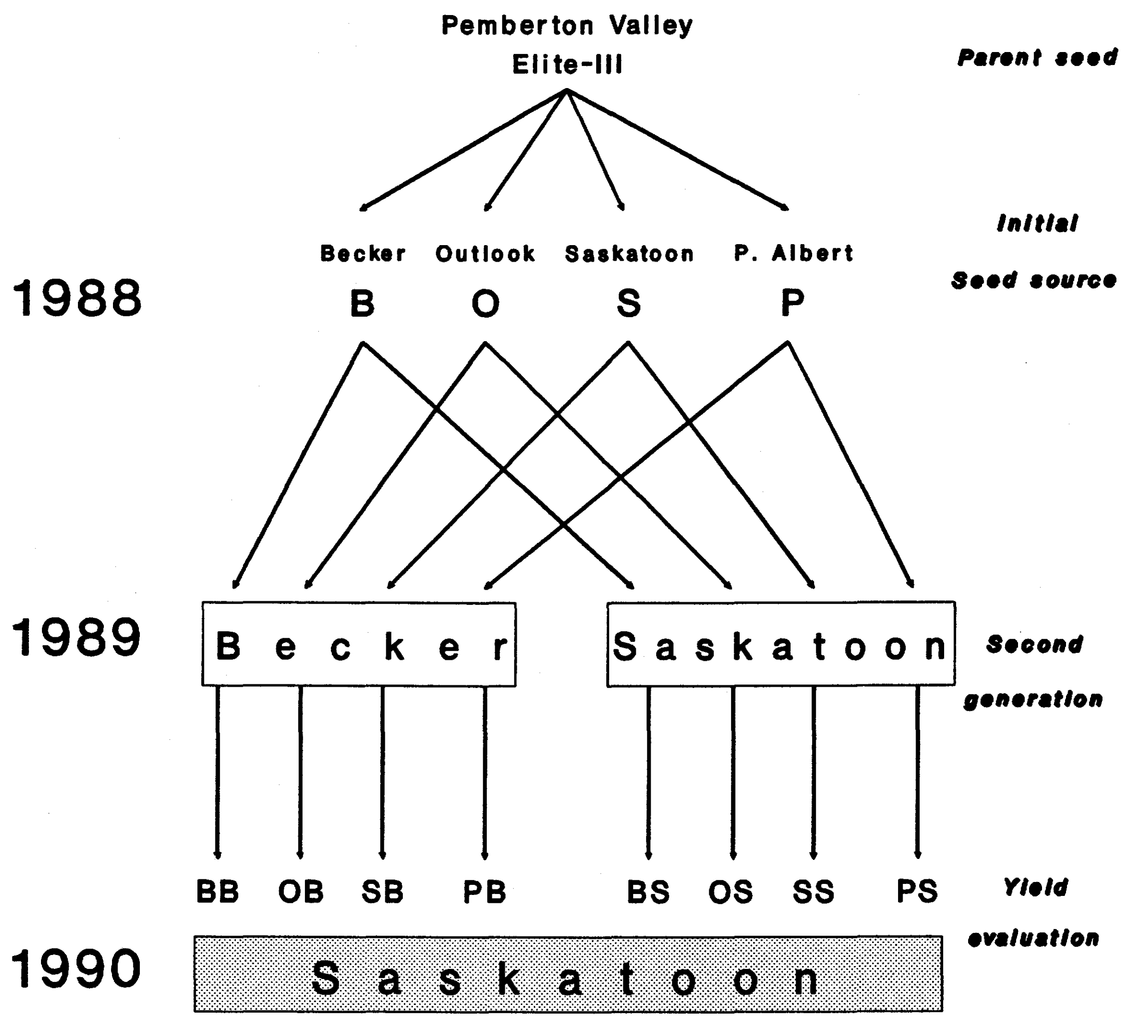


Fig. 7.1. Schematic representation of potato seed-tuber multiplication and evaluation procedure.

50 g seed pieces were planted with a 30 cm in-row x 90 cm between-row spacing. The crop was raised under irrigation using standard cultural practices for table potato production. Ten guarded plants were harvested at 120 days from planting for yield estimation. Grading was done according to tuber diameter with sound tubers larger than 45 mm in diameter considered as marketable.

RESULTS

Analyses of variance for the marketable yield components as influenced by cultivar, initial seed source, subsequent propagation site main effects and their interactions are summarized in Table 7.1. All main effects, cultivar x seed source, and cultivar x seed source x production site interactions were significant for marketable tuber yields. For marketable tuber number, all main effects and all first and second order interactions, except for the cultivar x production site interaction were significant. For the average tuber weight, significant effects were observed only for the cultivar and production site main effects and their interactions.

Marketable Tuber Yields

The yields of the various original seed sources (year-one) as observed in 1989 at the Saskatoon site (Chapter 3) and those seed lots following multiplication at Becker and

Table 7.1. Summary of analyses of variance of marketable yield components for carry-over effects of seed-tuber propagation site on Norland and Russet Burbank potatoes: Test location - Saskatoon, 1990.

Source of variation	df	Mean square (marketable tubers[z])		
		Yield	Tuber Number	Avg. weight
Cultivar (C)	1	13278***	192.5***	42048***
Source (S)	3	427***	4.2**	9449NS
Prop.site (P)	1	3706***	58.5***	15379*
C x S	3	702***	6.8***	5677NS
C x P	1	238NS	2.0NS	21158*
S x P	3	158NS	4.1**	3106NS
C x S x P	3	438***	6.5***	7906NS
Error	45	63	0.9	3584

[z]Tubers larger than 45 mm diameter.
*, **, ***, and NS indicate significance at 0,05, 0.01, 0,001 levels of probability and not significant, respectively.

Saskatoon (year-two, 1990) are presented in Table 7.2. Norland seed increased in Saskatoon during the second year generally produced higher tuber yields than corresponding seed lots increased in Becker during the second multiplication phase (Table 7.2).

Norland seed-tubers from the various original seed sources once multiplied in Saskatoon outperformed seed produced at Becker during the second generation by an average of 28% (mean of seed sources). Norland seed increased at Becker during two successive years produced marketable yields which were, on the average 31% lower than for seed grown in Saskatchewan in year-one and subsequently propagated in Becker. The three Saskatchewan seed sources produced similar yields following cycling through the Becker site. Norland seed originating from Becker and subsequently cycled through Saskatoon had a productive potential comparable to seed obtained from either Outlook or Saskatoon in year-one. Norland seed originating from Prince Albert or Saskatoon and subsequently raised at either Becker or Saskatoon produced similar marketable yields (Table 7.2).

Russet Burbank seed from all four original seed sources subsequently multiplied in Becker produced substantially lower marketable yields than seed increased at Saskatoon

Table 7.2. Marketable tuber yields for Norland and Russet Burbank potatoes from different seed sources subsequently multiplied at either Becker or Saskatoon: Test location - Saskatoon: 1990.

Seed source (Year-one)[y]	Norland Year - two Becker	Norland Year - two S'toon	Russet Burbank Year - two Becker	Russet Burbank Year - two S'toon
	---Marketable[z] tuber yield (t ha^{-1})---			
Becker	29.8	54.5	3.1	7.2
Outlook	41.2	60.8	1.3	29.3
Saskatoon	48.2	50.2	8.1	23.5
Prince Albert	40.4	39.5	16.5	45.3
Mean	39.9	51.3	7.2	26.3
Standard error		3.9		

Yield of the original seed sources (Year-one)[y] at Saskatoon.

	Norland	Russet Burbank
Becker	32.3	14.0
Outlook	55.1	23.3
Saskatoon	55.2	24.0
Prince Albert	47.2	29.4
Mean	47.5	22.7

[z]Tubers larger than 45 mm diameter.
[y]Source: Chapter 3, Saskatoon site.

during the second year (Table 7.2). Seed-tubers channelled through Saskatoon in year-two, on average, outyielded seed multiplied in Becker in year-two by about a three-fold margin (Table 7.2). Russet Burbank seed originating from Saskatoon or Prince Albert and subsequently multiplied at Becker produced higher marketable yields than the corresponding Becker and Outlook seed sources. Seed originating from Becker produced significantly lower tuber yields than the seed from the three Saskatchewan sources when the seed was subsequently increased in Saskatoon (Table 7.2). The seed lot obtained from Prince Albert produced the highest yields when channelled through both Becker and Saskatoon. The yield potential of the Outlook and Saskatoon seed sources were intermediate between the original Becker and Prince Albert seed.

Marketable Tuber Number per Plant

Norland and Russet Burbank plants grown from seed multiplied in Saskatoon in year-two produced, on average, two more marketable tubers than seed increased in Becker during the second year (Table 7.3). Norland seed originating from Becker and subsequently cycled again through Becker produced fewer marketable tubers than the three original Saskatchewan seed sources multiplied in Becker, as well as all seed sources, including Becker, channelled through Saskatoon in year-two. Norland seed originating in Becker and Outlook

Table 7.3. Marketable tuber number per plant for Norland and Russet Burbank potatoes from different seed sources subsequently multiplied at either Becker or Saskatoon: Test location - Saskatoon: 1990.

Seed source	Norland		Russet Burbank	
	Year - two		Year - two	
(Year - one)	Becker	S'toon	Becker	S'toon
	---Marketable[z] tuber number per plant---			
Becker	3.4	6.5	0.6	1.4
Outlook	4.6	8.1	0.2	3.4
Saskatoon	6.0	6.2	0.9	3.0
Prince Albert	4.7	4.2	1.7	4.7
Mean	4.7	6.2	0.8	3.1
Standard error		0.5		

[z]Tubers larger than 45 mm diameter.

raised in Saskatoon during year-two produced significantly more marketable tubers than the corresponding seed sources multiplied in Becker (Table 7.3). Plants derived from the original Prince Albert and Saskatoon sources produced a similar number of marketable tubers when cycled through both Becker and Saskatoon.

Russet Burbank seed originating from Prince Albert produced the highest number of marketable tubers irrespective of which site it was cycled through in year-two (Table 7.3). The three Saskatchewan seed sources produced more marketable tubers than the original Becker seed when propagated at Saskatoon. Seed obtained from the different sources in year-one and multiplied in Becker during year-two generally produced similar numbers of tubers. Seed from all original sources when cycled through Saskatoon produced significantly more marketable tubers than when the same seed sources were channelled through Becker during the second generation.

Average Weight of Marketable Tubers

The average weight of the marketable tubers produced by seed multiplied at Becker during the second generation was lower than for the crop derived from seed channelled through Saskatoon. However, the difference was significant only for Russet Burbank (Table 7.4).

Table 7.4. Average weight of marketable tubers for Norland and Russet Burbank potatoes from different seed sources subsequently multiplied at either Becker or Saskatoon: Test location - Saskatoon, 1990.

Seed source (Year - one)	Norland, Year - two: Becker	Norland, Year - two: S'toon	Russet Burbank, Year - two: Becker	Russet Burbank, Year - two: S'toon
	---Average marketable[z] tuber weight (g)---			
Becker	240	232	131	143
Outlook	244	206	78	246
Saskatoon	222	221	176	209
Prince Albert	236	261	205	262
Mean	235	230	147	215
Standard error		25		

[z]Tubers larger than 45 mm diameter.

DISCUSSION

This study demonstrated that the yield potential of Norland and Russet Burbank potato seed-tubers depended on both the original seed source and the environment under which further multiplication was undertaken. Irrespective of the site of second generation multiplication, the seed-tubers originating from the Saskatchewan sites were generally more productive than seed obtained from the relatively warmer Becker site. This phenomenon is consistent with previous observations that cooler growing temperatures (Stuart, 1913; Iritani, 1968a, de Bokx and Mooi, 1974), particularly, lower night temperatures (Went, 1959) produced highly productive potato seed-tubers.

In this study, the average temperatures during the growing season, particularly during the latter stages of development, were considerably higher in Becker than at the three Saskatchewan sites. The daily mean temperatures at the Saskatchewan seed production sites were about 4°C lower than at the Becker site, while diurnal temperature fluctuations at the three northern sites were about 3°C higher than at Becker. The relatively low yield potential of seed originating from Becker could be attributed to this temperature effect. However, it is also possible that the poor yield potential for Becker seed could be attributed to some other site related characteristics, such as disease incidence. Smith (1977) and Slack (1993) indicated that potato seed-tuber production in the U.S.A is concentrated in the northern U.S.A. adjoining Canada mainly due to reduced spread of viral diseases that can affect the quality of seed-tubers.

The greater productivity of potato seed-tubers originating in cooler environments had previously been found to persist through several successive generations (Stuart, 1913; Went, 1959). Goodwin et al., (1969b) showed that management factors such as stage of lifting of the seed crop and chitting of seed-tubers could negate the benefits gained through 'place effects'. By contrast, Wiersema and Booth (1985) showed that post harvest manipulations, such as high temperature (12°C) storage, did not affect the superior productive potential of potato seed-tubers originating from higher altitudes. In this study, when the yield potential of the seed lots multiplied in Saskatoon and Becker in year-two were compared with the potential of the original seed lots, a vitalizing influence of the Saskatoon environment and degenerative effect of the Becker site became evident. The increased vigour of potato seed-tubers acquired by growing them in the cooler Saskatchewan environment persisted for at least two generations. However, a single season at the southerly locale did result in a reduction in yield potential relative to fresh seed from the north. This suggests that U.S growers purchasing Canadian grown seed potatoes would probably benefit from obtaining seed from the north regularly rather than attempting to carry it over. The fact that low yielding southern grown seed could be revitalized by multiplying it under northern conditions is strong evidence that the site related variability in yield potential is due to a transitory physiological factor rather than some persistent pathological condition. Further studies to evaluate the degree of persistence of seed production site related yield responses through several successive generations would be useful.

CHAPTER 8

Accelerated Ageing Effects on Growth and Yield Characteristics of Potato Seed-tubers from Different Sources

ABSTRACT

High temperatures during development and storage of potato seed-tubers can increase their physiological age, causing early senescence and reduced yield potential at maturity of the resulting crop. The objectives of this study were to determine: (i) if previously observed differences in growth and yield of potato seed-tubers from different sources were related to differences in physiological age associated with the growing season temperature regimes at the seed production sites; and (ii) to examine the ability of different seed sources to tolerate accelerated ageing via high temperature storage. Norland and Russet Burbank seed-tubers produced in Saskatchewan, Minnesota and two Colorado locations were subjected to accelerated ageing by storing seed at 15°C for one month prior to planting. Control treatments were stored at 4°C until planting. Field evaluations of seed vigour were conducted in Saskatoon (1989) and Outlook (1990), Saskatchewan. The effect of site of seed production on the vigour and yield potential of the progeny differed between the two cultivars.

For Norland, the marketable yield trend was: Becker < Colorado < Saskatchewan and for Russet Burbank the trend was: Becker < Colorado = Saskatchewan. The growth and yield responses of seed from the different sources could not be attributed to differences in the physiological age of the seed related to the average temperature of the seed production sites. Accelerated ageing had no significant effect on the yield potential of any of the seed sources.

Productivity of potato (*Solanum tuberosum* L.) seed-tubers can be influenced by numerous factors including the environmental conditions under which the seed crop is grown (Goodwin et al., 1969b, Wurr, 1978a). Cooler climates (Went, 1959; Wurr, 1979a) associated with higher altitudes (Kozlowska, 1960 and 1963; Wiersema and Booth, 1985; Caldiz, 1991) and more northerly latitudes (Stuart, 1913; Westover, 1931, Hartz et al., 1980) generally produce more vigorous and higher yielding seed-tubers than seed originating in the relatively warmer environments characteristic of more southerly latitudes or lower altitudes. This phenomenon has been attributed to the cooler environments producing physiologically young seed-tubers (Bodlaender, 1973; Caldiz, 1985; Carls and Ceaser, 1979). The general consensus (Wurr, 1979; Iritani, 1983; Knowles, 1987; van der Zaag and van

Loon, 1987) is that younger seed emerges more slowly and produces fewer mainstems than old seed and that plants derived from young seed maintain active shoot growth longer than plants from older seed. Consequently, physiologically young seed produces lower 'early' yields and higher 'final' yields than physiologically old seed. Physiologically young seed is considered to be better suited to regions with longer growing seasons than is physiologically older seed (Knowles and Botar, 1992). In practice, this is evidenced by the growing demand for northern seed-tubers from commercial growers in the southern U.S.A. (Hartz et al., 1980).

Storage temperatures (Iritani, 1981; Iritani et al., 1983) and combinations of production and storage conditions (Carls and Ceaser, 1979) can markedly affect the physiological age of potato seed-tubers. High temperature storage of seed caused considerable yield reductions in Russet Burbank potato (Iritani et al., 1983; Iritani and Weller, 1987) and several European cultivars (O'Brien et al., 1986). Goodwin et al., (1969b) showed that early harvesting of the seed crop and subsequent chitting reduced the yield potential of Arran Pilot seed-tubers from a northern source (55°54'N) to a level comparable to seed from a southern source (50°44'N). However, Wiersema and Booth (1985) and Caldiz (1991) found that post-harvest manipulations, such as higher storage temperatures, did not lower the yielding capacity of highland seed. This suggests that highland tubers might be more capable of withstanding factors such as high temperature storage that decrease seed vigour.

Previous components of this project indicated that Norland and Russet Burbank seed-tubers produced at Saskatchewan sites were often more vigorous and higher yielding than seed from more southerly sites (Chapters 3 and 4). The physiological basis of this yield difference was not clear. It is possible that the growth and yield differences among the different seed sources could be related to differences in their physiological age caused by temperatures at the seed production sites. This study was conducted to determine whether: (i) the growth and yield characteristics of Norland and Russet Burbank potato seed-tubers from different sources were related to physiological age responses attributable to the temperatures at the seed production sites; and (ii) the effect of high temperature storage on vigour, yield potential and physiological age attributes of seed from different sources. The degree of tolerance of the northern seed source to ageing compared to the southern sources was of particular interest.

MATERIALS AND METHODS

Elite-III seed-tubers of the cultivars Norland and Russet Burbank from uniform genetic stocks were used to produce seed at Becker, Minnesota and at Outlook, Saskatoon and Prince Albert in Saskatchewan during the summer of 1988. In 1989, seed was raised at Greeley and San Luis Valley, Colorado in addition to the sites employed in 1988. The latitudes, altitudes and temperature characteristics during the growing season (30 year average) for the different seed increase sites are presented in Appendix 3.1. Cultural practices employed for seed increase were in accordance with recommendations for the different production sites. The seed-tubers were harvested at maturity (approximately 120 days from planting) and stored under uniform conditions, at 4°C, in Saskatoon until planting (about 8 months). To determine the effect of accelerated ageing on seed performance, small lots of seed were held at 15°C for one month prior to field planting, while non-aged seed was retained at 4°C. Ageing treatments were based on work by Knowles and Botar (1991) who found significant effects of short term storage at 15°C on growth and yield potential of seed. Ageing treatments are more effective when performed during the latter stages of storage compared to early stages (Gillison et al., 1987). In this study, the ageing treatment had to be limited to 30 days, otherwise sprout growth became excessive.

Field tests of the seed from the various sources and ageing treatments were conducted during 1989 and 1990. The 1989 trial was conducted at the Department of Horticulture Science field plots in Saskatoon, Saskatchewan. The experiment was laid out as a 4 (seed source) x 2 (ageing treatment) x 2 (harvest dates) factorial in a randomized complete block design with 3 replications for each cultivar. The 1990 test was conducted at the Saskatchewan Irrigation Development Centre, in Outlook, Saskatchewan. Separate trials were conducted for each cultivar, with field plots laid out as a 6 (seed source) x 2 (ageing treatment) x 2 (harvest dates) factorial with four replications. Seed pieces weighing approximately 50 g were planted at a spacing of 90 cm (between rows) x 30 cm (within rows). Fertilizer applications were based on soil tests to provide 200 kg N ha^{-1} and 75 kg P_2O_5 ha^{-1}. All the phosphorus and half the nitrogen were broadcast prior to planting, with the balance of the nitrogen applied at the first hilling. In both years, sprinkler irrigation was used to maintain adequate soil moisture levels throughout the growing season.

Ten guarded plants were collected for analysis of growth and yield variables at 94 and 120 days from planting in 1989, and after 90 and 120 days from planting in 1990. The harvested tubers were graded according to their diameter, with tubers >45 mm in diameter categorized as 'marketable'. The data were analyzed using analysis of variance procedures (Minitab Release 7).

RESULTS

Number of Mainstems per Plant

Norland seed from Saskatoon produced significantly more mainstems than Becker seed in 1989, otherwise stem numbers for the various seed sources were not significantly different (Table 8.1). In 1990, Norland seed from San Luis Valley produced the highest number of mainstems followed by Greeley, Prince Albert and Saskatoon, with Outlook and Becker producing the fewest mainstems per plant (Table 8.1).

The number of mainstems produced by Russet Burbank seed-tubers from the three Saskatchewan sources were consistently lower than for the Becker seed in 1989 and lower than for all three southern sources in 1990 (Table 8.1).

Ageing produced a slight but non-significant reduction in stem number in Norland, while it slightly increased stem number in Russet Burbank (Tables 8.1 and 8.2). A significant seed source x ageing interaction was observed for both cultivars in 1989 but not in 1990 (Table 8.1). There were no identifiable trends for the different seed sources in response to the ageing treatments (Table 8.2).

Table 8.1. Effects of seed source and accelerated ageing on the number of mainstems per plant for Norland and Russet Burbank potatoes from different seed sources: 1989 and 1990.

Seed source /Ageing	Norland 1989	Norland 1990	Russet Burbank 1989	Russet Burbank 1990
	---Mainstems per plant[z]---			
San Luis Valley	-	4.6	-	4.2
Greeley	-	4.0	-	3.7
Becker	3.1	3.5	4.6	3.9
Outlook	4.0	3.7	3.0	3.1
Saskatoon	5.0	4.1	3.0	2.9
Prince Albert	3.7	3.9	3.0	2.8
LSD (5.0%)	0.9	0.3	0.8	0.3
Non-aged	4.1	4.1	3.2	3.3
Aged	3.8	3.8	3.6	3.6
C.V. (%)	32.4	15.6	19.4	15.6

Summary of ANOVA

Source of variation				
Seed source (S)	**	*	**	*
Ageing (A)	NS	NS	NS	NS
S x A	**	NS	**	NS

[z]Data taken at 94 and 90 days from planting in 1989 and 1990 respectively.
*, **, and NS represent significance at P<0.05, <0.01 levels, and non significant, respectively.

Table 8.2. Effect of accelerated ageing on the number of mainstems per plant for Norland and Russet Burbank potatoes from different seed sources: 1989.

Seed source	Norland Non-aged	Norland Aged	Russet Burbank Non-aged	Russet Burbank Aged
	---Mainstems per plant[z]---			
Becker	3.2	3.1	4.3	4.9
Outlook	5.1	2.9	2.9	3.1
Saskatoon	4.1	5.8	2.4	3.5
Prince Albert	4.1	3.3	3.1	2.9
S x A - LSD (5.0%)	1.6		0.8	

[z]Data taken 94 days from planting.

Haulm Fresh Weights

Norland seed from the various sources produced similar haulm weights in 1989, but in 1990 the Becker source produced lower haulm weights than all other sources (Table 8.3). In 1989, Russet Burbank seed from Becker produced lower haulm weights than the three Saskatchewan sources (Table 8.3). In 1990, Russet Burbank from Becker again produced lower haulm weights than all other sources except the Saskatoon seed. The accelerated ageing treatment did not affect haulm fresh weights of either cultivar in either year (Table 8.3).

Marketable Tuber Yields

In 1989, the average (mean of two harvest dates) yields for Norland seed from Saskatoon was significantly higher than the Becker or Prince Albert sources (Table 8.4). In 1990, Becker seed produced lower tuber yields than all Saskatchewan and Colorado sources but the differences were not significant in some instances. On the basis of group comparisons, the average (mean of ageing and harvest date treatments) productivity of Saskatchewan seed (32.1 t ha^{-1}) was significantly higher than the average yield for the Colorado sources (28.9 t ha^{-1}). The estimated F value for the comparison was 6.42 which was significant at the 5.0% level.

Table 8.3. Effects of seed source and accelerated ageing on haulm fresh weight for Norland and Russet Burbank potatoes from different seed sources: 1989 and 1990.

Seed source /Ageing	Norland 1989	Norland 1990	Russet Burbank 1989	Russet Burbank 1990
	---Haulm fresh weight per plant (kg)[z]---			
San Luis Valley	-	0.45	-	0.54
Greeley	-	0.44	-	0.53
Becker	1.00	0.38	0.36	0.31
Outlook	0.99	0.47	1.65	0.51
Saskatoon	1.16	0.46	1.64	0.34
Prince Albert	1.03	0.47	1.66	0.54
LSD (5.0%)	-	0.03	0.28	0.06
Non-aged	1.11	0.45	1.34	0.47
Aged	1.19	0.44	1.31	0.46
C.V. (%)	14.4	14.0	16.8	23.8

Summary of ANOVA

Source of variation	Norland 1989	Norland 1990	Russet Burbank 1989	Russet Burbank 1990
Seed source (S)	NS	*	**	*
Ageing (A)	NS	NS	NS	NS
S x A	NS	NS	NS	NS

[z]Data taken 94 and 90 days from planting in 1989 and 1990 respectively.
*, **, and NS represent significance at P<0.05, 0.01 levels and not significant, respectively.

Table 8.4. Mean marketable tuber yields for Norland and Russet Burbank potatoes from different seed sources at two harvest dates: 1989 and 1990.

Seed source	1989 94 DAP	1989 120 DAP	1989 Mean	1990 90 DAP	1990 120 DAP	1990 Mean
	---Mean[z] marketable[y] yield (t ha^{-1})---					
			Norland			
San Luis Val.	-	-	-	27.3	32.2	29.8
Greeley	-	-	-	28.8	27.4	28.1
Becker	40.8	64.6	52.7	24.6	27.2	25.9
Outlook	51.5	66.5	59.0	31.0	35.3	33.1
Saskatoon	54.6	74.3	64.4	30.7	33.8	32.2
P. Albert	40.8	58.2	49.5	30.9	31.3	31.1
Mean	46.9	65.9		28.9	31.2	
LSD (5.0%) Source main effect			10.8			3.9
C.V. (%)			23.0			18.3
			Russet Burbank			
San Luis Val.	-	-	-	16.3	25.1	20.7
Greeley	-	-	-	17.3	24.9	21.1
Becker	4.3	10.9	7.6	6.9	10.4	8.6
Outlook	21.3	42.8	32.1	15.3	25.7	20.5
Saskatoon	23.9	50.1	37.0	15.5	22.8	19.1
P. Albert	23.6	46.2	34.9	16.8	28.2	22.5
Mean	18.3	37.5		14.7	22.9	
LSD (5.0%) Source main effect			5.6			3.6
- D x S interaction			8.0			-
C.V. (%)			24.3			27.3

Summary of ANOVA

Source of variation	Norland 1989	Norland 1990	Russet Burbank 1989	Russet Burbank 1990
Harvest date (D)	***	NS	***	**
Seed source (S)	*	**	***	**
Ageing (A)	NS	NS	NS	NS
S x A	NS	NS	NS	*
D x S	NS	NS	**	NS
D x A	NS	NS	NS	NS
D x S x A	NS	NS	NS	NS

[z]Average of ageing treatments.
[y]Tuber >45 mm in diameter.
*, **, ***, NS represent significance at P<0.05, 0.01, 0.001 levels and not significant, respectively.

Russet Burbank seed from Becker produced significantly lower average (mean of two harvest dates) yields than all other seed sources in both test years (Table 8.4). In 1989, the Saskatchewan seed outyielded the Becker source by 4 to 5 fold, with the three Saskatchewan sources producing similar yields. In 1990, the Colorado and Saskatchewan sources outperformed the Becker seed by 2 to 3 fold. Partitioning the seed source sum of squares using orthogonal contrasts indicated that the Colorado and Saskatchewan seed sources had similar productivity (estimated F value for the comparison was <1).

With Norland in 1989, yields at the late harvest were higher than the early harvests, however in 1990, no differences were found between yields at the two harvests (Table 8.4). The relative yield increases between the two harvests observed in 1989 were similar for the various seed sources. In 1989, Russet Burbank yields for the three Saskatchewan seed sources were significantly higher at the 120 DAP harvest than at 94 DAP (Table 8.4). For the Becker source, yields at 120 DAP were not significantly different than at 94 DAP. In 1990, the non-significant seed source x harvest date interaction is an indication that the relative yield increase for the different seed sources between the two harvests was similar.

The ageing treatment did not significantly influence yields for Norland in either test year (Table 8.4). With Russet Burbank, accelerated ageing had no effect on yields in 1989 but there was a significant ageing x seed source interaction in 1990 (Table 8.4). The trends in the data were inconsistent relative to northern versus southern seed. Ageing significantly decreased tuber yields for Becker (37%) and Saskatoon (30%) seed, but increased yields for Outlook seed (22%) (Table 8.5). Ageing had no effect on the other seed sources.

DISCUSSION

The vigour and yield potential of potato seed-tubers have been shown to be negatively correlated with the temperature regimes experienced by the seed crop (Went, 1959; Kozlowska, 1960, 1963; Wurr, 1978a and 1979; Carls and Ceaser, 1979; Wiersema and Booth, 1985). High temperatures during tuber initiation (Claver, 1975), tuber development (Kawakami, 1962; Iritani, 1968a; Carls and Ceaser, 1979; Perennec and Madec, 1980; Sunoschi, 1981) and during storage (Iritani, 1981; Knowles and Botar, 1991 and 1992) increase the physiological age of the seed-tubers while decreasing their yield potential.

Many of the growth and yield variables measured for seed produced in different environments in this experiment

Table 8.5. Effects of accelerated ageing on mean marketable tuber yields for Norland and Russet Burbank potatoes from different seed sources: 1989 and 1990.

Seed source	Norland		Russet Burbank	
	Non-aged	Aged	Non-aged	Aged
	Mean[z] marketable[y] yield (t ha^{-1})			
	1989			
San Luis Valley	-	-	-	-
Greeley	-	-	-	-
Becker	52.4	53.1	12.2	3.1
Outlook	60.1	58.0	34.7	29.4
Saskatoon	65.4	63.5	37.0	37.0
Prince Albert	52.3	46.7	35.1	34.7
Mean	57.5	55.3	29.7	26.1
LSD 5.0% (Source x Ageing)	-		-	
C.V. (%)	23.0		24.3	
	1990			
San Luis Valley	31.8	27.5	21.4	20.1
Greeley	27.4	28.3	19.9	22.3
Becker	27.1	24.3	10.6	6.7
Outlook	34.9	31.1	17.9	23.1
Saskatoon	31.3	32.9	22.5	15.7
Prince Albert	32.2	29.1	24.1	20.9
Mean	31.0	29.1	19.4	18.1
LSD 5.0% (Source x Ageing)	-		3.6	
C.V. (%)	18.3		27.3	

[z]Average of harvest dates.
[y]Tubers >45 mm in diameter.

did not conform to expected physiological age responses. Early growth, as indicated by haulm weights at the 'early' harvest, was lower for plants grown from seed produced at warmer locations than from the cooler sites. It was expected that if seed from the southern sites was physiologically old, it would produce rapid early haulm growth. Physiologically young seed generally produces fewer mainstems than old seed (Iritani and Weller, 1987; Knowles, 1987; Knowles and Botar, 1991) particularly in late maturing cultivars such as Russet Burbank. In this study, Russet Burbank seed from the southern sites produced more mainstems than the three Saskatchewan seed sources which agreed with the expected relationship between site and mainstem number. However, seed from the cool San Luis Valley site produced as many or more stems than seed from much warmer sites; this contradicts the physiological age hypothesis. In early maturing cultivars, such as Norland, aged seed generally produces fewer mainstems than younger seed (Moll, 1985). There were no indications in this study that Norland seed from the warmer sites produced fewer mainstems than seed from the cooler sites. According to the physiological age theory, physiologically old seed should produce higher 'early' yields and lower 'final' yields than younger seed. In this study, 'early' marketable yields for Saskatchewan grown seed of both cultivars were consistently higher than seed from the relatively warmer Becker site.

Physiologically young seed from cooler environments should produce a greater relative yield increase between 'early' and 'mature' harvests than older seed. In this study, the yield increases observed between the 90/94 DAP and 120 DAP harvests were no greater for the seed from the cool northern sources than for seed from the warmer southern sources.

The present study does not support a linkage between the average temperatures in the seed growing environment and the physiological age and yield potential of the seed. Mean growing season temperatures at Greeley (21.5°C) were higher than at Becker (19.0°C) (Appendix 3.1). Based on mainstem numbers, Greeley seed was apparently similar to Becker seed in physiological age and yet Greeley seed significantly outyielded Becker seed. It is perhaps significant that the low yielding Becker site had a lower average diurnal temperature fluctuation (10.9°C) compared to the higher yielding Colorado (15.3-21.2°C) and Saskatchewan (12.3-13.9°C) sites. Went (1959) showed that potato seed-tubers raised under low temperatures were more vigorous than seed derived from higher temperature conditions, with the highest yielding seed lots grown under the greatest diurnal temperature fluctuations. Went's (1959) greenhouse experiments showed that with a constant daytime temperature (23°C), decreasing night temperatures (from 23°C to 14°C) progressively increased the yield potential of seed lots.

It was found that the growth and yield characteristics of the different seed sources varied considerably between the two years. This variability is likely due to year to year and site to site variation in soil and climatic conditions both in the seed production locations and at the yield assessment sites (Burton 1966). However, it is important to note that the relative performance of the various seed sources were generally similar in the different years.

Physiological ageing is a standard means of evaluating crop vigour including potatoes (Knowles, 1987; Knowles and Botar, 1992; van der Zaag and van Loon, 1987). High temperatures during seed production (Bodlaender, 1973; Carls and Ceaser, 1979; Caldiz, 1985) and during storage (Iritani, 1981) increased the physiological age of potato seed-tubers. Ageing of potato seed accelerates tuber set and enhances 'early' yields. Some researchers (e.g. Knowles and Botar, 1992) are advocating the use of aged seed for regions with short growing seasons. The high temperature ageing treatment used in this study involved the accumulation of 330 degree-day (d-d) at a base temperature of 4°C. Knowles and Botar (1992) showed that ageing Russet Burbank seed for 359 d-d above a 4°C base significantly increased 'early' yields, however, Haydock (1989) did not observe any significant yield responses to ageing for 400 d-d in several potato cultivars. This study showed few significant effects of ageing on any of the growth parameters examined and no effects on 'early' or 'final' yields for either cultivar tested. Seed from the various sources showed a fairly uniform lack of response to the ageing treatments and the yield differences observed between sources in the non-aged seed were generally comparable to the aged seed. The reason for the lack of response to accelerated ageing in this study is unclear. Ageing effects might be more pronounced if seed was aged to a greater degree, perhaps by a longer exposure to higher temperatures. Problems with excess sprout growth during ageing treatments might be overcome by treating the seed immediately after harvest when the tubers are still dormant (Knowles and Botar, 1992).

In this study, significant differences were observed for growth and productivity among seed-tubers produced at various locations. However, these differences could not be explained by the differences in environmental temperatures during seed production nor during storage. The physiological basis for the differential yield responses for seed-tubers from different sites is still unclear. It appears that raising seed-tubers in cooler environments produces some beneficial changes in the physiology of the seed-tuber tissue, unrelated to physiological age (Goodwin et al., 1969b; Wiersema and Booth, 1985) that results in increased vigour compared to seed produced in relatively warmer climates. Additional research, perhaps, using different cultivars, ageing techniques, or means of growth and yield assessment are required to: (i) quantify the interaction between environmental variables, such as temperature and day length to vegetative growth, tuber set and the bulking of the seed crop; and (ii) to examine the effects of post-harvest handling on the vigour of seed from different sources.

CHAPTER 9

Single-Leaf Nodal Cuttings as a Model System to Study Tuberization Stimulus in Potatoes from Different Seed Sources.

ABSTRACT

The tuberization stimulus present in Norland and Russet Burbank potato (*Solanum tuberosum* L.) seed-tubers from different sources was studied using single-leaf, sub-apical nodal cuttings as a model system. Plants were grown from seed-tubers from Becker in Minnesota and Outlook, Prince Albert and Saskatoon in Saskatchewan. The plants were grown under 8 h or 18 h photoperiods for 30 and 35 days prior to excision of sub-apical nodal cuttings. These cuttings were subsequently grown under a 17 h non-inductive photoperiod. Most of the cuttings obtained from plants raised under the 8 h photoperiod produced axillary tubers, while only a few cuttings grown from the 18 h photoperiod plants produced tubers. Cuttings from the Becker source had a higher percentage of tuberization and produced larger axillary tubers than cuttings obtained from the three Saskatchewan seed sources. This indicates that seed from Becker possessed a greater degree of tuberization stimulus than seed from Saskatchewan. The effect of the mother tuber on tuberization of axillary buds was more pronounced when the developing plant remained attached to the mother tuber for a longer period.

Potato seed-tubers produced in cool climates (Went, 1959; de Bokx and Mooi, 1974; Wurr, 1979) at higher altitudes (Kozlowska,1960, 1963; Wiersema and Booth, 1985; Caldiz, 1991) or latitudes (Westover, 1931; Hartz et al., 1980) are often more productive than those from relatively warmer southerly latitudes or lower altitudes. The beneficial influence of cool weather on the yielding ability of potato seed-tubers has been attributed to the cool sites producing physiologically young seed-tubers relative to warmer climates (Goodwin et al., 1969b; Bodlaender, 1973; Caldiz, 1985). Physiologically young seed sprout more slowly, produces more vigorous shoots and higher yields at maturity than physiologically old seed (Harris, 1982; van der Zaag and van Loon, 1987; Knowles and Botar, 1992). Ewing (1985) reported that the early tuberization characteristic of physiologically older seed may be caused by higher levels of tuberizing stimulus present in the mother tuber.

Tuber formation in potato is controlled by a hypothetical 'tuber forming stimulus' (Madec, 1963; Cutter, 1987; Ewing, 1985). The stimulus is believed to originate in the leaves (Cutter, 1978; Kahn et al., 1983; Ewing, 1985) and the mother tuber (Madec and Perennec, 1959) and is distributed throughout the entire plant (Gregory, 1956; Chapman, 1958) by basipetal (Burton, 1966), acropetal (Mingo-Castel et al., 1976) or two-way movement (Kumar and

Wareing 1974; Ewing, 1985). Development of this tuberizing stimulus in the leaves is favoured by short photoperiods and cool temperatures (Ewing and Wareing, 1978). The mother tuber also contributes to the stimulus and the degree of influence of the mother tuber is particulary strong under non-inductive external conditions (Madec and Perennec, 1959; Ewing, 1985). However, Bodlaender and Marinus (1969) reported that neither the mother tuber nor short photoperiods were required for tuber formation in potato.

Cuttings offer a simplified and convenient model for examining tuberization in potato (Ewing, 1985; van den Berg et al., 1990), as tuber induction in the whole plant can be detected in cuttings taken from induced plants (Ewing, 1985). The degree of tuber induction in single-leaf nodal cuttings of potato can be assessed by examining the development of buried axillary buds (Ewing, 1985). Cuttings taken from strongly induced plants form sessile tubers, while cuttings from non-induced plants show no growth from the axillary bud (Ewing and Wareing, 1978). At intermediate levels of induction, a negatively geotropic vegetative shoot may be produced while formation of stolons or a stolon ending in a tuber illustrates a progressively higher level of induction (Ewing, 1985).

The objective of this study was to use single-leaf sub-apical cuttings as a system for examining: (i) the level of tuberizing stimulus present in potato seed tubers produced at different latitudes; and (ii) the contribution of the mother tuber towards tuberization.

MATERIALS AND METHODS

Elite III seed-tubers of Norland and Russet Burbank potatoes were multiplied at Becker in Minnesota and Outlook, Saskatoon and Prince Albert in Saskatchewan during the summer of 1988. The location and growing season temperature characteristics of the various seed production sites are presented in Appendix 3.1. Seed-tubers from the different sources were stored at 4°C until planting. Ten medium sized tubers of each cultivar and seed source were desprouted and planted in a greenhouse, at Saskatoon, Saskatchewan in a moist peat potting medium. The plants were grown with either 8 h or 18 h photoperiods using fluorescent and incandescent lighting at approximately 115 lux to augment light levels and extend the photoperiod. Eight uniform single-leaf cuttings were taken from the 3rd or 4th nodes from the shoot apex at 30 and 35 days from planting of each treatment (2 cultivars x 4 seed sources x 2 photoperiods). These cuttings were planted in trays containing a peat/vermiculite mixture (1:1 by volume) taking care to ensure that the axillary bud was properly buried below the surface of the growing medium. The trays were placed under intermittent mist with a non-inductive 17 h daylength and a day/night temperature regime of 25/12°C. The developmental characteristics of the axillary buds were recorded 21 days from each planting date. Dry weights of the plant components were obtained by oven drying at 105°C for 24 hours.

RESULTS

Almost all the cuttings obtained from the Becker seed source produced axillary-tubers and/or tuber-forming structures (stolons) when the mother plants from which the cuttings were taken had been grown for either 30 or 35 days under the inductive 8 h photoperiod (Table 9.1, Figs. 9.1 and 9.2). Under the same inductive photoperiod, the percentage of cuttings taken at 30 DAP that formed tubers from the Outlook, Prince Albert and Saskatoon seed sources ranged from 25% to 63% for Norland and 0% to 50% for Russet Burbank (Table 9.1, Figs. 9.1 and 9.2) . Similar responses were observed for cuttings taken at 35 DAP, except that the percentage tuberization was relatively higher than that observed for cuttings taken at 30 DAP (Table 9.1).

None of the cuttings taken from the 18 h non-inductive photoperiod treatment produced tubers or tuber-forming structures when the cuttings were taken at 30 DAP. When

Table 9.1. Percentage of single-leaf stem cuttings taken from plants exposed to 8 h or 18 h photoperiods for 30 or 35 days producing axillary tubers[z].

	Percent tuberization (%)			
	30 days		35 days	
Cultivar/ Seed source	8 h	18 h	8 h	18 h
Norland				
Becker	100	0	100	38
Outlook	50	0	75	25
Saskatoon	25	0	0	25
Prince Albert	63	0	88	50
Russet Burbank				
Becker	100	0	88	25
Outlook	38	0	88	0
Saskatoon	0	0	50	0
Prince Albert	50	0	63	0

[z]Total of sessile-tubers, stolon-tubers and stolons.

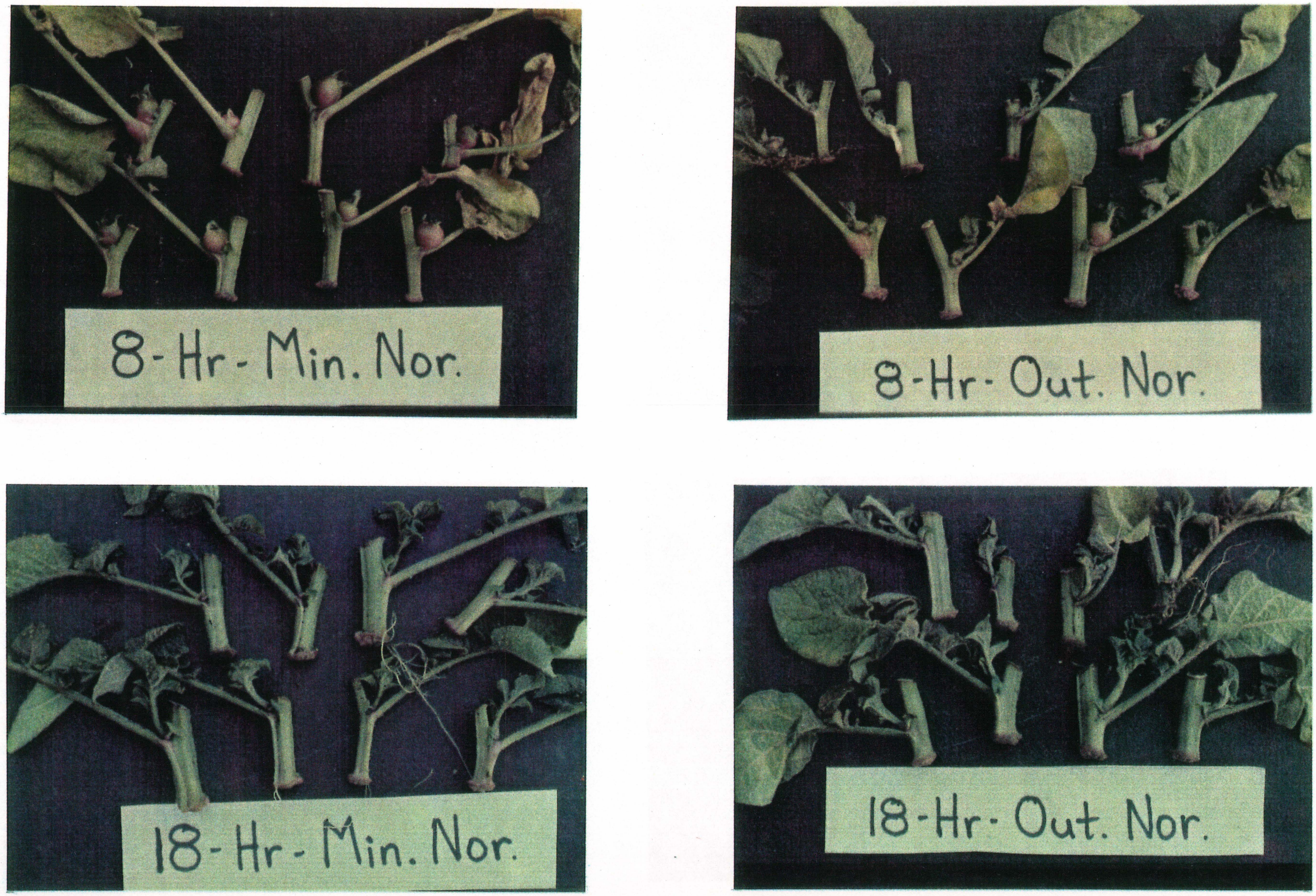


Fig. 9.1. Single leaf nodal-cuttings of Norland potatoes produced from Becker (Min) and Outlook (Out) seed grown under 8 h or 18 h photoperiods for 30 days prior to excision of cuttings.

Fig. 9.2. Single leaf nodal-cuttings of Russet Burbank potatoes produced from Becker (Min.) and Outlook (Out) seed grown under 8 h or 18 h photoperiods for 30 days prior to excision of cuttings.

cuttings were taken at 35 DAP, 25% to 50% of Norland from the different seed sources formed tubers (Table 9.1). In Russet Burbank, cuttings from the three Saskatchewan seed sources taken at 35 DAP failed to tuberize, whereas 25% of cuttings from the Becker seed formed tubers.

The effect of photoperiod on the dry weights of axillary tubers, axillary shoots and roots were determined by analysis of variance (Table 9.2). The inductive 8 h photoperiod treatment produced greater tuber dry weights than cuttings raised under the 18 h non-inductive photoperiod (Table 9.2). The dry weights of the different components were slightly higher in cuttings taken at 35 DAP than at 30 DAP. The axillary tubers produced by Norland and Russet Burbank cuttings from the Becker source were consistently heavier than tubers produced by the other seed sources (Table 9.2). Cuttings taken from the three Saskatchewan seed sources produced similar tuber dry weights in both cutting date treatments. Cuttings taken at 35 DAP generally produced heavier axillary tubers than cuttings taken at 30 DAP (Table 9.2). In the 8 h photoperiod treatment, tuber dry weights for Norland from Becker increased three-fold between the two sampling periods, whereas tuber weights for Russet Burbank from Becker decreased as time from planting increased. The differences in tuber dry weights between the 30 and 35 day cuttings from

Table 9.2. Effects of seed source on axillary-tuber dry weights produced by Norland and Russet Burbank single-leaf cuttings taken from plants exposed to 8 h or 18 h photoperiods for 30 and 35 days prior to excision.

Photop.	Cultivar	Beck.	Outl.	Stoon.	P.Alb.	**Mean**
		----Axillary tuber dry weight (mg)---				
				30 day-old plants		
8 h	Norland	25	9	7	11	13
	R. Burb.	56	8	0	4	17
	Mean	**40**	**9**	**4**	**8**	**15**
18 h	Norland	0	0	0	0	0
	R. Burb.	0	0	0	0	0
	Mean	0	0	0	0	0
				35 day-old plants		
8 h	Norland	74	24	0	28	32
	R. Burb.	31	12	16	3	17
	Mean	**53**	**18**	**8**	**16**	**25**
18 h	Norland	18	0.3	0	1	5
	R. Burb.	0	0	0	0	0
	Mean	**9**	**0.1**	**0**	**0.5**	**2**

ANOVA

Factor	30 DAY Sig.	30 DAY LSD(5.0%)	35 DAY Sig.	35 DAY LSD (5.0%)
Cultivar (C)	NS	-	***	4
Source (S)	***	6	***	8
Photoperiod (P)	***	3	***	4
C x S	***	8	***	11
C x P	NS	-	*	8
S x P	***	8	***	11
C x S x P	**	12	*	16

***, **, * and NS represent significance at P< 0.001, 0.01, 0.05 levels of probability and not significant, respectively.

Becker were not as marked as for the three Saskatchewan seed sources.

Vegetative shoots originated from the axillary buds in cuttings that did not form tubers or stolons. In some cases, when the axillary buds tuberized, the adjacent ancillary buds developed into shoots. Cuttings taken from the 18 h photoperiod produced significantly higher shoot dry weights than cuttings from the 8 h photoperiod (Table 9.3). Cuttings from Becker seed usually produced smaller axillary shoots than the Saskatchewan seed sources. This difference in shoot dry weight was more marked in cuttings exposed to the 8 h photoperiod compared to the 18 h photoperiod (Table 9.3).

Cuttings raised under the 18 h photoperiod produced more vigorous roots than cuttings subjected to the 8 h photoperiod (Table 9.4). The Russet Burbank cuttings produced a strong adventitious root system while the Norland cuttings produced either a weak root system or no roots at all (Figs. 9.1 and 9.2). Under 8 h photoperiod, Norland and Russet Burbank cuttings taken from Becker seed at 30 DAP did not form roots, whereas cuttings of both cultivars from most other seed sources produced varying amounts of roots. On average,

Table 9.3. Effects of seed source on shoot dry weights produced by Norland and Russet Burbank single-leaf cuttings taken from plants exposed to 8 h or 18 h photoperiods for 30 and 35 days prior to excision.

Photop.	Cultivar	Beck.	Outl.	Stoon.	P.Alb.	**Mean**
			----Shoot dry weight (mg)---			
			30 day-old plants			
8 h	Norland	0.4	1.5	8.1	1.2	2.8
	R. Burb.	0.0	3.6	4.0	1.6	2.3
	Mean	**0.2**	**2.6**	**6.1**	**1.4**	**2.6**
18 h	Norland	4.1	10.2	6.2	8.9	7.4
	R. Burb.	12.5	10.4	8.9	6.2	9.5
	Mean	**8.3**	**10.3**	**7.6**	**7.6**	**8.5**
			35 day-old plants			
8 h	Norland	0.0	3.5	0.0	0.0	1.0
	R. Burb.	0.0	0.6	3.2	21.7	6.4
	Mean	**0.0**	**2.0**	**1.6**	**10.9**	**3.7**
18 h	Norland	12.8	31.1	0.0	7.5	12.9
	R. Burb.	16.6	9.0	15.0	6.4	11.8
	Mean	**14.7**	**20.0**	**7.5**	**7.0**	**12.3**

ANOVA

Factor	30 DAY Sig.	30 DAY LSD(5.0%)	35 DAY Sig.	35 DAY LSD (5.0%)
Cultivar (C)	NS	-	NS	-
Source (S)	*	1.9	NS	-
Photoperiod (P)	***	1.0	**	4.3
C x S	*	2.7	*	12.0
C x P	NS	-	NS	-
S x P	**	2.7	NS	-
C x S x P	**	3.8	NS	-

***, **, * and NS represent significance at P< 0.001, 0.01, 0.05 levels of probability and not significant, respectively.

Table 9.4. Effects of seed source on root dry weights produced by Norland and Russet Burbank single-leaf cuttings taken from plants exposed to 8 h or 18 h photoperiods for 30 and 35 days prior to excision.

Photop.	Cultivar	Beck.	Outl.	Stoon.	P.Alb.	**Mean**
			----Root dry weight (mg)---			
			30 day-old plants			
8 h	Norland	0.0	0.0	0.4	1.5	0.3
	R. Burb.	0.0	8.8	5.1	1.9	4.0
	Mean	**0.0**	**4.4**	**2.8**	**1.7**	**2.2**
18 h	Norland	1.0	0.3	0.0	1.3	0.7
	R. Burb.	10.2	13.2	10.5	8.8	10.7
	Mean	**5.6**	**6.8**	**5.3**	**5.1**	**5.7**
			35 day-old plants			
8 h	Norland	0.0	2.9	0.0	4.5	1.9
	R. Burb.	4.2	5.9	8.9	6.3	6.3
	Mean	**2.1**	**4.4**	**4.4**	**5.4**	**4.1**
18 h	Norland	0.2	3.8	4.5	3.6	3.0
	R. Burb.	18.7	9.2	9.0	3.6	10.1
	Mean	**9.5**	**6.5**	**6.8**	**3.6**	**6.6**

ANOVA

Factor	30 DAY Sig.	30 DAY LSD(5.0%)	35 DAY Sig.	35 DAY LSD (5.0%)
Cultivar (C)	***	1.1	***	1.5
Source (S)	NS	-	NS	-
Photoperiod (P)	***	1.1	*	1.5
C x S	**	3.0	**	4.3
C x P	***	2.1	NS	-
S x P	NS	-	*	4.3
C x S x P	NS	-	*	6.1

***, **, * and NS represent significance at P< 0.001, 0.01, 0.05 levels of probability and not significant, respectively.

cuttings taken 35 DAP developed slightly heavier root systems than cuttings taken at 30 DAP (Table 9.4).

DISCUSSION

The tuberization capacity of buried axillary buds of potato cuttings grown under non-inductive (16-18 h) photoperiods is a reflection of the level of tuberizing stimulus present in the cuttings prior to excision from the mother plant (Ewing, 1985). The level of tuberizing stimulus in the mother plant is in turn a function of the level of stimulus supplied by the mother tuber (Ewing, 1985), the duration of association between the parent plant and the mother tuber (Madec, 1963) and the photoperiod under which the plants were raised before removal of cuttings (Cutter, 1978; Ewing and Wareing, 1978). In this study, the cuttings obtained from the various treatments were raised under a non-inductive (17 h) photoperiod. Therefore, tuberization of these cuttings is predominantly a manifestation of the contribution of the mother tuber and the effect of the photoperiod under which the plants were raised prior to excision of the cuttings.

The greater frequency of tuberization and larger size of the axillary tubers formed by potato cuttings are characteristics of higher levels of tuberizing stimulus present in the parent plant from which the cuttings are taken (Ewing, 1985). Greater frequency and larger axillary tubers in Norland and Russet Burbank cuttings from the Becker seed source indicate that seed-tubers originating at that site possessed higher levels of tuberizing stimulus than the seed obtained from Outlook, Prince Albert or Saskatoon. Alternatively, the Becker mother plants might have been more sensitive to the inductive photoperiod. The three Saskatchewan grown seed-tubers appeared to possess similar levels of tuber forming stimulus.

High levels of tuberizing stimulus in the seed-tubers are thought to indicate advanced physiological age (Ewing, 1985). The physiological age of seed is influenced by climatic factors and cultural practices during growth and storage of the seed crop (Wurr, 1978a; Caldiz, 1991). Potato seed-tubers produced in relatively warmer climatic conditions tend to be physiologically older than those grown in cooler environments (Goodwin et al., 1969b; Bodlaender, 1973; Caldiz, 1985). In this study, the Becker site had higher average temperatures and lower diurnal temperature fluctuations during the growing season than the other seed production sites. This temperature regime during seed production may have rendered the Becker seed physiologically older than the other sources. The greater tuberization exhibited by the single-leaf nodal cuttings from Becker plants compared to cuttings from the three Saskatchewan seed sources suggests an advanced age for Becker seed. The reduced production of axillary shoots and roots by the Becker cuttings is further evidence that the Becker seed had a higher level of tuberization stimulus than the Saskatchewan sources. Several previous studies (Hammes and Nel, 1975; Ewing and Wareing, 1978; Kahn et al., 1983) also observed restricted root and shoot growth in highly induced potato cuttings.

In this study, cuttings taken from plants exposed to an 8 h (inductive) photoperiod produced axillary tubers more frequently than cuttings taken from plants grown under an 18 h (non-inductive) photoperiod. Similar observation have been reported by Cutter (1978), Ewing and Wareing (1978) and Ewing (1985). Axillary tuber growth occurred at the expense of axillary-shoot and root growth. Similar trends were also noted by Ewing and Wareing (1978) and Kahn et al., (1983).

Cuttings taken from older plants (35 DAP) had a higher frequency of tuberization and produced larger tubers than cuttings taken from younger plants (30 DAP). Similar age effects were observed by Madec (1963) and van den Berg et al., (1990). Madec (1963) attributed this phenomenon to a 'specific' tuber forming substance supplied by the mother tuber to the developing shoot through prolonged association with the mother tuber. Norland cuttings from all sources and Russet Burbank cuttings from Becker seed taken at 35 DAP produced tubers even when the plants were raised under the non-inductive 18 h photoperiod. This may be an indication of the contribution of the mother tuber towards tuberization. The high frequency of tuberization in Norland cuttings obtained from plants raised under the non-inductive 18 h photoperiod and again grown under a non-inductive 17-h daylength is an indication of the ability of this early maturing cultivar to form tubers even under unfavourable long photoperiods. Kopetz and Steineck (1954) and Krug (1960a and 1960b) also showed that early-maturing potato genotypes were capable of tuberization under relatively longer daylengths compared to late-maturing cultivars. The fact that the Russet Burbank cuttings from the three Saskatchewan seed sources taken at 35 DAP failed to tuberize under non-inductive conditions may also reflect the relatively low levels of tuberizing stimulus present in Saskatchewan seed compared to the Becker seed.

This study demonstrated that single leaf sub-apical cuttings represent a simple and convenient method for examining the level of tuberizing stimulus present in potato seed-tubers from different seed sources. Cuttings taken from seed obtained from the warmer Becker site contained greater levels of tuberizing stimulus than seed from the relatively cooler Outlook, Prince Albert or Saskatoon sites. The three Saskatchewan sources had similar tuberizing responses with no consistent trends among them. This may be due to the small differences in temperatures among the three seed production sites in Saskatchewan. Sub-apical cuttings could also prove useful for studying how production practices, disease and storage conditions influence tuberization in potatoes.

CHAPTER 10

Summary

SUMMARY

In potatoes, the procedures associated with vegetative propagation of the crop and the requirements for large quantities of seed for planting pose significant problems with respect to maintenance of superior seed 'quality'. Seed vigour is influenced by: (i) seed-borne diseases; (ii) harvesting, storage, handling and transportation systems; and (iii) the influence of environmental conditions during seed production. Aspects of varietal purity, pest control measures and seed handling procedures are well understood. Potato seed certification techniques ensure varietal purity and freedom from tuber-borne diseases. However, less understood and even less appreciated by both the seed grower and the purchaser is the 'carry-over' effect of the physiological condition of the seed-tuber upon subsequent growth and yield of the progeny (Harris, 1982).

The potential significance of the seed production environment on growth and productivity of the progeny tubers have long been recognized. As early as 1912, Grubb and Guildford concluded that seed potatoes produced in higher altitudes and more northern latitudes were superior to seed from lower elevations and southern latitudes. These authors attributed this phenomenon to the relative immaturity of the

seed produced at northerly latitudes and higher altitudes as the haulms were destroyed by early frost. They observed that "partially matured seed keeps better and makes stronger growing plants that are less liable to diseases". According to Fraser (1912), "it is often advised that potatoes be obtained from another soil and from more northern latitude if vigour and delayed maturity are desired, but from southern latitudes if earliness is sought". Stuart (1913) found that fresh seed stock from Scotland outperformed seed lots from England by a 4-5 fold margin and the seed from Scotland maintained its superiority over the England seed for six consecutive generations.

At present, it is widely held that seed produced in cooler northern latitudes and higher altitudes is more vigorous and higher yielding than seed obtained from relatively warmer southern latitudes and lower elevations (Kozlowska, 1963, Goodwin et al. 1969b; Wurr, 1978a; Hartz et al. 1980; Wiersema and Booth, 1985). It is claimed that the increased vigour of seed produced in cooler climates is due to lower levels of seed-borne viruses (Slack, 1993) or to some beneficial physiological changes in the seed-tuber tissue (Goodwin et al. 1969b; Wiersema and Booth, 1985). Consequently, seed potato production in North America is centred around the northern U.S.S. and Canada. In recent years, potato growers from the Pacific North Western U.S.A.

have been purchasing increasing quantities of seed potatoes from several Western Canadian sources on the anecdotal evidence that Canadian seed is more vigorous and higher yielding than seed produced in the Pacific North West.

It is not known whether the purported superiority of Canadian seed was associated with the physiological state of the seed-tubers and/or was due to lower levels of seed-borne diseases compared to seed produced in more southern locations. Sawyer and Cetas (1962) and Kunkel (1977) found that differences in productivity of seed-tubers from different sources were associated with factors other than seed-borne diseases. Further, recent studies examining the effects of latitude on seed-tuber productivity (e.g. Iritani, 1967; Goodwin et al. 1969b) were conducted using disease-free seed. The productive capacity of potato seed-tubers produced in different latitudes appears to be associated with some physiological changes in the seed-tuber. Seed-tubers produced in more northern cooler environments are thought to be physiologically younger than seed produced in relatively warmer lower latitudes (Wurr, 1978a). Other studies found that potato seed-tubers produced in contrasting environments did not exhibit typical physiological age-related characteristics associated with average temperatures at the seed production sites (Goodwin et al, 1969b; Wiersema and Booth, 1985).

The present project was conducted to examine the relative growth and yield potential of potato seed-tubers from different latitudes with the objective of relating seed-tuber vigour to climatic factors and/or build up of seed-borne diseases associated with seed production sites. Growth and related physiological aspects were also examined. Comparisons were made for early-maturing Norland and late-maturing Russet Burbank seed from sites in Saskatchewan and U.S.A. specifically chosen to provide a range of temperature related conditions.

In preliminary trials (1986 and 1987), seed potatoes from commercial certified sources from Saskatchewan, Minnesota, Nebraska and Wisconsin, were compared. In the later studies (1988-1990), to insure genetic uniformity, all tests used seed multiplied from a single source in the previous year. In 1988 and 1989, seed sources from Outlook, Prince Albert, and Saskatoon in Saskatchewan and Becker in Minnesota were evaluated. The 1990 tests included seed from Greeley and San Luis Valley in Colorado, in addition to the Saskatchewan and Minnesota sources. The Saskatchewan seed production sites of Outlook, Prince Albert and Saskatoon represent typical seed production areas in Saskatchewan. La Ronge in northern Saskatchewan is not a commercially viable seed production region, but it was included to provide an extreme northern seed production environment. The site in

Becker is a typical seed and table potato producing area in the North Cental U.S.A.. The San Luis Valley and Greeley are at essentially the same latitude as Becker but San Luis Valley is situated approximately 2300 m above the sea level. San Luis Valley is one of the premier seed growing regions in the U.S.A..

Seed lots from the different locations exhibited varying growth and yield characteristics in the different years. This reflects the interactive effect of soil and climatic factors and management conditions on growth and productivity. However, there were consistent trends in the relative vigour of the seed lots, and these trends were quite consistent across yield test sites. Both Norland and Russet Burbank seed from the northern sources usually outyielded seed from the Minnesota (Becker) and Nebraska sources but was rarely better than the Colorado seed. The seed source effects were more pronounced for Russet Burbank than Norland. In 1986, the lowest yielding northern source (Prince Albert) of Norland seed outyielded the southern Nebraska seed by 19%, while, Russet Burbank from Outlook outperformed the Becker seed by 55%. In 1989, the lowest yielding Saskatchewan source outyielded the Becker seed by 26% for Norland and by 75% for Russet Burbank. In 1990, Norland seed from the Saskatchewan and Colorado sources outyielded Becker seed by 1.5-16%, while Russet Burbank seed from the various Colorado and Saskatchewan seed sources outperformed the Becker seed by approximately a two-fold margin. The relative yield potential of the Colorado and Saskatchewan seed was similar, despite very significant differences in the geography and climatic variables at the seed production sites. Surprisingly, there appeared to be no significant differences between seed grown at the higher altitudes of San Luis Valley and seed from the relatively lower altitudes at Greeley. The yields obtained from the various Saskatchewan seed sources were quite similar. This is of commercial significance, as it means that buyers of Saskatchewan seed can be confident of the vigour of seed regardless of the specific locale of production.

In this study, there were no indications that the observed differences in shoot vigour, mainstem numbers, tuber initiation, tuber yield and dry matter distribution among the various seed sources were related to differences in physiological age of seed. Nor was seed vigour determined by the average environmental temperatures during seed production. It appears that seed vigour was more closely correlated with the extent of diurnal temperature fluctuations experienced at each seed production site. For example, the average temperatures at the low yielding Becker site were similar to those for the relatively high yielding Greeley site. However, the diurnal temperature fluctuations were considerably lower at the Becker site than at Greeley. The relatively low vigour of seed originating from the northern most La Ronge site could also be related to the low diurnal temperature fluctuations at that site, although this site experienced low average daily temperatures. Comparable yields of seed from the Colorado and Saskatchewan sites can be associated with somewhat similar diurnal temperature fluctuations at these locations, although the critical limits are still not known.

Accelerated ageing (at 15°C for one month prior to planting) of seed-tubers did not lower the productive potential of northern seed. This suggests that northern seed is tolerant to ageing and similar stresses. The lack of response of northern seed to ageing again suggests that growth and yield differences among the various seed sources are due to factors other than physiological age effects.

Due to its rapid growth and maturity, physiologically old seed produced in warmer regions are thought to be better suited for short growing season environments (e.g. the prairies) than physiologically young seed produced in more northern cooler locations (Fraser, 1912; Wurr, 1978a; Knowles and Botar, 1992). Physiologically young seed, originating in the cooler regions, that produce more vigorous plants which senesce relatively late are capable of expressing maximum potential in the longer growing seasons of the southern latitudes. Results of this study contradict this theory: e.g. northern seed outyielded southern seed at all the short season northern yield test sites. The poor performance of the southern seed, particularly in the northern regions was related to reduced production of assimilatory surface area by the southern seed. Higher levels of tuberizing stimulus present in southern seed (Chapter 9) may have restricted haulm development in favour of early tuberization (e.g. Ewing, 1985). Further, greater early dry matter partitioning to the tubers under cooler temperatures (Manrique and Bartholomew, 1991; Gawronska, 1992) may have restricted haulm growth, thereby further reducing yields (Moorby, 1978). Cool temperatures are also more favourable for the expression of virus symptoms (Hooker, 1990, Banttari, 1993) with corresponding loss of assimilatory surface area or photosynthetic efficiency lowering yields. Consequently, the negative influence of seed-borne viruses would be more pronounced under cooler environments similar to the northern yield test sites.

In this study, final yield harvests were taken approximately 120 days from planting, although the late-maturing Russet Burbank cultivar is capable of growing up to 180-190 days under favourable environmental conditions (Knowles and Botar, 1992). Therefore, the more vigourous, slow senescing Russet Burbank seed from Saskatchewan may have considerably outperformed the southern sources under longer growing seasons. Delayed senescence of northern seed, relative to southern seed, is an added advantage for the southern potato growers who can utilize their longer growing season to maximum benefit by using northern seed. Based on the poor performance of southern seed at northern yield test sites, it is preferable for Saskatchewan potato growers to use home-grown seed rather than importing seed from southern locations.

The observed superiority of seed from northern locations has been attributed to a general enhancement in vigour (Goodwin et al. 1969b) and/or to reduced hill-to-hill variability in northern seed compared to southern seed (Hagman, 1973). In this study, the superiority of Russet Burbank seed from the northern sources over Becker seed appeared to combine both factors. However, for Norland, the yield increase for northern seed was mainly due to increased seed piece vigour rather than due to reduced hill-to-hill variability. The late-maturing Russet Burbank is more prone to late season virus infections than the early-maturing Norland potatoes. The greater hill-to-hill variability for Russet Burbank from the southern seed sources could have been caused by premature senescence of virus-infected plants obtained from the southern seed sources.

Seed piece vigour is a function of several factors including seed piece size (Allen, 1978; Wurr and Morris, 1979; Nelson and Thorenson, 1982; Iritani and Thornton, 1985) and seed portion (McKeown, 1990a and 1990b). Seed pieces used in this project were cut to correspond with commercial seed piece weights. Within this size range, neither seed piece size nor seed portion had any effect on productivity at maturity, although apical seed portions of Russet Burbank outyielded the basal portions at 'early' harvest (90 DAP). The performance of the different seed portions were generally similar for northern and southern seed sources. This suggests that the 'factor' responsible for the greater vigour of northern seed was likely distributed through the entire seed-tuber.

Growth analysis studies showed that higher yielding northern seed lots produced more vigorous plants than southern seed lots. The limited top growth of plants grown from southern seed was likely due to preferential partitioning of dry matter to the tubers at the expense of shoot growth. The increased partitioning of dry matter to the tubers in plants from the southern sources was likely triggered by higher levels of tuberizing stimulus present in the southern seed.

This study showed that Norland and Russet Burbank seed from cooler Saskatchewan sources retained their superior vigour over Becker seed for at least two generations. Cycling high yielding Saskatchewan seed through Becker reduced its productive potential, but it was still superior to seed grown continuously in the south. This suggests that it is advantageous for the U.S. potato growers to purchase Canadian seed regularly rather than attempting to carry seed stocks over. By contrast, cycling low yielding Becker seed through Saskatoon increased its productive capacity. The fact that the low yielding seed from warmer southern Becker site could be revitalized by multiplying it in the relatively cooler Saskatoon site is strong evidence that the site related variability in yield potential is due to transitory physiological factors rather than permanent pathological conditions.

Temperature has significant effects on growth and yield on the current potato crop and vigour of the progeny. The role of temperature on growth and tuber production of the current crop has been extensively studied. No recent studies, except for Went (1959) and McCown and Kass (1977) have examined the influence of temperature during seed production on the performance of the progeny tubers. From this investigations, it is evident that seed growing temperatures, particularly diurnal temperature fluctuations, affected the performance of the progeny. However, the critical temperature limits during seed production responsible for the observed responses of the progeny have yet to be determined. More controlled studies are necessary to examine the physiological and biochemical basis of growth and productivity of potato seed-tubers produced in contrasting environments. In light of the differential response of Norland and Russet Burbank potatoes to seed source effects, several varieties with divergent growth habits should be included in these studies. Quantifying these production variables would enable the seed grower to select suitable areas for producing high quality seed and the seed buyer can be confident of the productive potential of the seed stock he/she purchases. Better information on the effects of seed growing environments on the performance of the progeny, would allow seed growers to choose suitable growing areas and production practices to produce seed for specific market classes.

Demonstrating that potato seed-tubers from cool regions such as Saskatchewan are more vigorous than seed from more southern locations for these effects could have a major economic impact on the seed potato industry. Saskatchewan is well suited geographically and economically for major expansions in seed potato acreage and for production of high quality seed. For example:

i. The limited extent of potatoes grown in the province enables effective isolation for seed production.

ii. Large irrigable land base (approximately 80,000 ha) ensures stability in supply.

iii. Large land base also enables suitable crop rotations.

iv. Severe winters in Saskatchewan serve as effective means for control of various insect pests and diseases.

v. Cooler environments favour better expression of disease symptoms, thereby facilitate effective rouging of diseased plants.

vi. The existing seed potato industry in the province could be of assistance in expansion efforts.

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Appendices

Appendix 3.1. Latitude, altitude, and growing season temperatures (°C) at the different seed production sites[z].

	May	June	July	August	September	**Season Av.**
La Ronge: Latitude = 55°09'N, Altitude = 379 m						
Maximum	14.5	20.1	22.6	20.6	14.1	18.4
Minimum	1.4	7.8	10.8	9.4	4.1	6.7
Mean	8.0	14.0	16.7	15.0	9.1	12.6
Difference	13.1	12.3	11.8	11.2	10.0	11.7
Prince Albert: Latitude = 53°13'N, Altitude = 428 m						
Maximum	17.4	21.5	24.2	22.8	16.4	20.5
Minimum	2.6	7.7	10.6	8.9	3.4	6.6
Mean	10.0	14.6	17.4	15.9	9.9	13.6
Difference	14.8	13.8	13.6	13.9	13.0	13.9
Saskatoon: Latitude = 52°10'N, Altitude = 501 m						
Maximum	18.1	22.3	25.4	24.2	17.7	21.5
Minimum	4.2	8.9	13.9	14.1	4.7	9.2
Mean	11.1	15.7	18.5	17.2	11.2	15.4
Difference	13.9	13.4	13.9	14.1	13.0	12.3
Outlook: Latitude = 51°29'N, Altitude = 541 m						
Maximum	18.6	22.8	25.8	25.1	18.5	22.2
Minimum	4.3	9.4	11.9	10.5	5.5	8.3
Mean	11.5	16.1	18.9	17.8	12.0	15.3
Difference	14.0	13.4	13.9	14.5	13.0	13.9
Becker: Latitude = 46°47'N, Altitude = 253 m						
Maximum	20.0	25.0	28.3	26.7	22.2	24.4
Minimum	8.9	14.4	17.2	16.1	11.1	13.5
Mean	14.4	19.7	22.8	21.4	16.7	19.0
Difference	11.1	10.6	11.1	10.6	11.1	10.9
Wisconsin[y]: Latitude = 43°05'N, Altitude = 297 m						
Maximum	19.4	24.4	27.2	26.1	21.7	23.8
Minimum	9.4	15.0	17.8	18.7	12.2	14.3
Mean	14.4	19.7	22.5	21.4	16.9	19.1
Difference	10.0	9.4	9.4	9.4	9.5	9.5
Nebraska[y]: Latitude = 41°18'N, Altitude = 298 m						
Maximum	22.2	27.2	30.0	28.9	24.4	26.5
Minimum	11.7	16.7	19.4	18.3	13.9	16.0
Mean	16.9	21.9	24.7	23.6	19.2	21.3
Difference	10.5	10.5	10.4	10.6	10.5	10.5
Greeley: Latitude = 40°25'N, Altitude = 1417 m						
Maximum	23.9	30.0	33.3	31.7	26.7	29.1
Minimum	8.9	13.9	17.7	16.7	11.7	13.8
Mean	16.4	21.9	25.6	24.2	19.2	21.5
Difference	15.0	16.1	15.6	16.7	11.7	15.3
San Luis Valley: Latitude = 37°27'N, Altitude = 2298 m						
Maximum	20.5	26.7	29.4	27.8	23.3	25.5
Minimum	0.6	3.9	7.2	7.2	2.8	4.3
Mean	10.6	15.3	18.3	17.5	13.1	14.9
Difference	19.9	22.8	22.2	20.6	20.5	21.2

[z]Source: Environment Canada, Atmospheric and Environment Service, Saskatoon, (30 year average).
[y]Approximate values for temperature and location.

Appendix 3.2. Summary of analyses of variance for haulm and yield variables in potato cultivar and seed source evaluation trials: 1986 to 1990.

	90 DAP					120 DAP		
Source of variation	Mainstem number	Haulm weight	Tot.tub. no./pl	Total yield	Mark. yield	Tot.tub. no./pl	Total yield	Mark. yield
				1986				
C (Cultivar)[z]	-	NS	NS	***	***	NS	NS	**
S (Source)	-	NS	***	***	***	***	***	***
C x S	-	NS	NS	NS	NS	NS	NS	NS
				1987				
C	-	*	**	***	***	NS	NS	NS
S	-	*	NS	NS	NS	NS	NS	NS
C x S	-	NS	NS	NS	NS	NS	NS	NS
				1988				
C	NS	-	NS	*	*	NS	NS	NS
S	NS	-	NS	NS	*	NS	NS	NS
C x S	NS	-	NS	NS	NS	NS	NS	NS
L (Site) x C	***	-	*	***	***	*	***	***
L x S	NS	-	NS	NS	NS	NS	NS	NS
L x C x S	(*)	-	(*)	NS	NS	NS	NS	NS
				1989				
C	*	NS	NS	***	***	NS	NS	NS
S	NS	***	NS	***	***	*	***	***
C x S	***	**	NS	NS	NS	NS	NS	NS
L x C	NS	**	***	*	*	**	NS	***
L x S	NS	NS	NS	NS	NS	NS	NS	NS
L x C x S	(*)	(*)	NS	NS	(*)	NS	(**)	(**)
				1990				
C	NS	NS	NS	**	**	NS	NS	NS
S	**	**	***	***	***	***	***	**
C x S	*	**	*	*	*	***	**	**
L x C	**	***	*	NS	*	**	**	***
L x S	NS	NS	NS	NS	NS	NS	NS	NS
L x C x S	NS	NS	NS	NS	NS	NS	NS	NS

[z]ANOVA results are from individual tests in 1986 and 1987, and from combined analyses in 1988 through 1990.

*, **, ***, and NS indicate significance at the 0.05, 0.01, 0.001 levels of probability, and not significant, respectively.

(*) denote items becoming non-significant with F tests using reduced degrees of freedom for correcting site x treatment interaction heterogeneity (Cochran and Cox, 1957).

Appendix 3.3. Summary of analyses of variance for haulm and yield variables of Norland and Russet Burbank potatoes in the seed source evaluation trials: 1986 to 1990.

Source of variation[z]	90 DAP					120 DAP		
	Mainstem number	Haulm weight	Tot.tub. no./pl	Tot.tub. yield	Mark. yield	Tot.tub. no./pl	Tot.tub. yield	Mark. yield
				1986 - Norland				
S[z]	NS	NS	**	**	***	*	*	*
				1986 - Russet Burbank				
S	*	NS	NS	**	***	**	***	**
				1987 - Norland				
S	NS	NS	NS	NS	NS	NS	NS	NS
				1987 - Russet Burbank				
S	**	***	*	*	*	NS	NS	NS
				1988 - Norland				
S	NS	-	NS	NS	NS	NS	NS	NS
L x S	***	-	**	NS	NS	NS	NS	NS
				1988 - Russet Burbank				
S	NS	-	NS	NS	NS	NS	NS	NS
L x S	**	-	NS	**	NS	NS	***	***
				1989 - Norland				
S	**	***	**	***	***	**	**	***
L x S	*	NS	NS	NS	NS	NS	NS	NS
				1989 - Russet Burbank				
S	**	***	NS	***	***	NS	**	**
L x S	*	*	**	NS	*	***	***	***
				1990 - Norland				
S	**	*	NS	NS	*	NS	NS	NS
L x S	NS	NS	NS	NS	NS	NS	NS	NS
				1990 - Russet Burbank				
S	**	**	***	***	***	***	***	**
L x S	NS	*	NS	NS	NS	**	***	***

[z]Sources of variation: seed source, and test site represented by S, and L respectively.
*, **, ***, and NS indicate significance at the 0.05, 0.01, 0.001 levels of probability and not significant, respectively.

Appendix 4.1. Growing season temperatures for Saskatoon: 1986 to 1989.

Month		1986	1987	1988	1989
		---Temperature (°C)---			
May	Maximum	19.6	21.2	23.1	17.6
	Minimum	6.5	6.6	7.1	4.8
	Mean	13.1	13.9	15.1	11.2
June	Maximum	23.2	25.9	28.7	22.8
	Minimum	8.8	11.4	13.6	9.9
	Mean	16.0	18.7	21.2	16.4
July	Maximum	23.4	24.8	26.7	27.6
	Minimum	11.5	12.0	11.7	13.4
	Mean	17.5	18.4	19.2	20.5
August	Maximum	24.9	21.0	22.3	24.0
	Minimum	9.8	7.9	10.6	11.7
	Mean	17.4	14.4	16.5	17.9
September	Maximum	13.6	21.9	18.1	17.9
	Minimum	3.7	5.9	4.7	5.5
	Mean	8.7	13.9	11.4	11.7

Source: Environment and Atmospheric Services Canada, Saskatoon.

Appendix 4.2. Summary of analyses of variance on growth and yield characteristics of Norland and Russet Burbank potatoes from different seed sources: 1986 to 1989.

		Sampling period[z]					
Year	Treatment	1	2	3	4	5	6
		Average vine length					
1986	C[y]	***	**	***	***	-	-
	S	***	***	*	NS	-	-
	C x S	***	NS	NS	NS	-	-
1987	C	NS	NS	NS	NS	***	***
	S	*	*	NS	*	NS	NS
	C x S	NS	NS	NS	NS	NS	NS
1988	C	***	NS	NS	*	***	***
	S	**	***	**	***	***	***
	C x S	NS	NS	NS	***	***	***
1989	C	NS	NS	NS	**	***	***
	S	**	NS	NS	**	***	***
	C x S	**	NS	NS	**	***	***
		Number of mainstems per plant					
1986	C	**	NS	NS	NS	NS	-
	S	*	***	NS	*	NS	-
	C x S	*	NS	NS	NS	NS	-
1987	C	***	***	***	***	***	***
	S	**	**	NS	NS	NS	NS
	C x S	NS	NS	NS	NS	NS	NS
1988	C	***	***	***	***	***	***
	S	*	NS	NS	NS	NS	NS
	C x S	NS	NS	NS	NS	NS	NS
1989	C	NS	NS	NS	NS	NS	NS
	S	NS	NS	NS	NS	NS	NS
	C x S	***	***	***	***	***	***
		Leaf dry weight per plant					
1986	C	*	**	**	***	-	-
	S	***	***	NS	NS	-	-
	C x S	***	NS	NS	***	-	-
1987	C	***	*	**	**	NS	NS
	S	NS	NS	*	NS	NS	NS
	C x S	NS	NS	NS	NS	NS	NS
1988	C	***	***	**	NS	NS	**
	S	***	***	**	NS	NS	**
	C x S	NS	NS	**	NS	NS	**
1989	C	**	***	*	*	NS	***
	S	***	***	***	*	NS	NS
	C x S	***	NS	*	NS	*	***

contd:

Stem dry weight per plant

1986	C	NS	NS	**	***	-	-
	S	NS	**	NS	*	-	-
	C x S	NS	NS	NS	*	-	-
1987	C	***	NS	NS	NS	***	***
	S	*	**	NS	*	NS	NS
	C x S	NS	*	NS	NS	NS	NS
1988	C	***	**	NS	NS	***	***
	S	**	*	**	**	*	***
	C x S	NS	NS	NS	*	NS	***
1989	C	**	*	NS	*	***	***
	S	***	***	***	**	***	***
	C x S	**	NS	NS	*	***	***

Total tuber dry weight per plant

1986	C	-	NS	**	-	NS	-
	S	-	***	NS	-	NS	-
	C x S	-	NS	NS	-	NS	-
1988	C	-	**	NS	***	***	***
	S	-	NS	*	*	NS	NS
	C x S	-	NS	NS	NS	NS	NS
1989	C	-	***	NS	***	***	**
	S	-	***	**	***	***	NS
	C x S	-	**	*	*	NS	NS

Marketable tuber dry weight per plant

1986	C	-	-	***	-	NS	-
	S	-	-	**	-	NS	-
	C x S	-	-	*	-	NS	-
1988	C	-	-	-	-	***	***
	S	-	-	-	-	NS	*
	C x S	-	-	-	-	NS	NS
1989	C	-	-	-	***	***	**
	S	-	-	-	**	***	NS
	C x S	-	-	-	**	NS	*

Relative shoot growth rate

1986	C	-	NS	NS	***	NS	-
	S	-	***	NS	*	NS	-
	C x S	-	***	***	NS	NS	-
1987	C	***	***	NS	NS	*	NS
	S	NS	NS	NS	NS	NS	NS
	C x S	NS	NS	NS	NS	NS	NS
1988	C	***	***	NS	NS	**	NS
	S	***	NS	NS	NS	NS	NS
	C x S	NS	NS	NS	*	NS	***
1989	C	NS	NS	NS	NS	NS	***
	S	***	NS	NS	NS	NS	NS
	C x S	***	NS	***	NS	NS	NS

contd:

Relative tuber bulking rate

1986	C	-	-	**	-	NS	-
	S	-	-	***	-	NS	-
	C x S	-	-	***	-	NS	-
1988	C	-	-	NS	NS	NS	NS
	S	-	-	NS	NS	NS	NS
	C x S	-	-	*	NS	NS	NS
1989	C	-	-	*	**	NS	NS
	S	-	-	NS	NS	NS	NS
	C x S	-	-	NS	NS	NS	NS

[z]Sampling periods 1, 2, 3, 4, 5, and 6 represent:- sampling at 31, 47, 75, 89, and 106 days from planting in 1986; 34, 41, 54, 68, 81, and 102 in 1987; 31, 45, 59, 73, 89, and 101 in 1988; 36, 49, 57, 70, 90, and 105 in 1989.
[y]Treatments: C = cultivar, S = seed source.
*, **, ***, NS indicate significance at 0.05, 0.01, 0.001 levels of probability and not significant, respectively.

Appendix 5.1. Descriptive statistics for total yield components per hill for Norland and Russet Burbank potatoes from different seed sources: 1987 to 1989.

Seed source	Number of plants	Total tuber No. per hill Mean	Total tuber No. per hill C.V.(%)	Total tuber Wt per hill (kg) Mean	Total tuber Wt per hill (kg) C.V.(%)
		Norland - 1987			
La Ronge	48	20.6	50.7	4.4	25.8
Prince Albert	49	15.6	37.4	3.3	29.2
Outlook	49	15.7	29.6	3.3	21.3
Nebraska	47	14.8	40.5	3.1	28.8
		Norland - 1988			
La Ronge	41	20.7	42.4	3.7	30.3
Prince Albert	45	16.9	23.0	3.7	17.3
Outlook	37	21.2	23.0	4.1	22.7
Becker	41	20.8	27.4	4.0	18.3
		Norland - 1989			
Prince Albert	50	14.8	34.9	3.1	28.9
Outlook	50	16.9	30.5	3.5	28.6
Saskatoon	50	17.7	37.1	3.8	33.1
Becker	47	16.6	41.0	2.8	40.7
		Russet Burbank - 1987			
La Ronge	50	14.5	25.9	4.8	20.5
Prince Albert	48	13.7	41.1	3.9	29.1
Outlook	48	14.4	33.1	4.5	17.9
Wisconsin	49	13.3	32.5	3.9	24.1
		Russet Burbank - 1988			
La Ronge	43	12.7	41.6	3.1	29.7
Prince Albert	45	13.8	32.8	4.1	20.4
Outlook	40	12.9	31.2	3.6	38.4
Becker	42	11.4	43.2	2.1	78.8
		Russet Burbank - 1989			
Prince Albert	50	10.4	37.8	1.8	29.2
Outlook	50	12.4	30.0	2.2	25.8
Saskatoon	50	12.9	35.0	2.0	32.1
Becker	47	8.2	42.4	0.3	56.3

[z]Tubers larger than 45 mm in diameter.

Appendix 6.1. Summary of orthogonal comparisons for plant emergence percentages at different times after planting for various seed piece types in Russet Burbank potatoes.

Category	24 DAP	26 DAP	28 DAP	32 DAP
Whole vs cut	***	***	***	NS
Apical vs basal	***	***	***	NS
Half vs one-third	NS	NS	NS	NS
Half vs quarter	*	**	NS	NS
One-third vs quarter	*	NS	NS	NS

*, **, ***, and NS indicate significance at P<0.05, <0.01, <0.001 levels of significance and not significant, respectively.

Appendix 6.2. Summary of orthogonal comparisons for shoot characteristics associated with different seed piece types in Russet Burbank potatoes.

Category	Stems per plant[z]	Vine length[y]	Haulm wt/plant 90 DAP	Haulm wt/plant 120 DAP
Whole vs cut	NS	NS	NS	NS
Apical vs basal	NS	NS	NS	*
Half vs one-third	NS	NS	NS	*
Half vs quarter	NS	NS	NS	*
One-third vs quarter	NS	NS	NS	NS

[z]Stem counts taken at 90 days after planting.
[y]Vine lengths measured at 100 days after planting.
* and NS indicate significance at $P<0.05$ level of significance and not significant, respectively.

Appendix 6.3. Summary of orthogonal comparisons for marketable yield components associated with different seed piece types in Russet Burbank potatoes at two harvest dates.

Category	Marketable yield	Marketable tubers/plant	Average tuber weight
		90 DAP	
Whole vs cut	NS	NS	NS
Apical vs basal	*	*	NS
Half vs one-third	NS	NS	NS
Half vs quarter	NS	NS	NS
One-third vs quarter	NS	NS	NS
		120 DAP	
Whole vs cut	NS	*	NS
Apical vs basal	NS	NS	NS
Half vs one-third	NS	NS	NS
Half vs quarter	NS	NS	*
One-third vs quarter	NS	NS	*

* and NS indicate significance at P<0.05 level of significance and not significant, respectively.