Vine desiccation characteristics and influence of time and method of top kill on yields and quality of four cultivars of potato (*Solanum tuberosum* L.)

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Waterer, D. 2007. **Vine desiccation characteristics and influence of time and method of top kill on yields and quality of four cultivars of potato (*Solanum tuberosum* L.)**. Can. J. Plant Sci. **87**: 129–135. Potato crops are typically flailed or chemically desiccated several weeks prior to harvest to promote tuber maturity and facilitate harvest operations. This study evaluated how yields and processing quality of several potato cultivars responded to mechanical top kill versus chemical desiccation with diquat at four different treatment dates. The influences of year and cultivar on the rate and extent of vine desiccation were also evaluated in the chemically desiccated crop. The cultivar Ranger Russet was slower to desiccate than Russet Burbank, Shepody or Russet Norkotah, likely because of its larger canopy. Averaged over 3 yr and four treatment dates, flailing reduced yields of the four cultivars tested by an average of 4% relative to chemical desiccation of the tops. The yield difference between flailed and chemically desiccated crops increased if conditions after application of the desiccant favored a gradual die down of the canopy. Specific gravities of the chemically desiccated treatments were equal to or higher than treatments killed by flailing. Fry colors were not influenced by either the method or timing of top kill. Although chemical desiccation enhanced yields relative to a crop flailed at the same time, the dry down period required for the chemically treated crop was at least 3 wk in this study. By contrast, crops killed by flailing are ready for harvest immediately, as long as skin set is not critical. Early in the season, if flailing allowed top kill of Russet Burbank to be delayed by as little as a week, the result was a 9% yield gain. As growing conditions became less favorable later in the season, there was little potential for yield gain by opting to flail instead of using the chemical desiccant.

Key words: Diquat, flailing, Russet Burbank, Shepody, Ranger Russet, Russet Norkotah

Waterer, D. 2007. **Caractéristiques de la dessiccation des fanes et incidence du moment et de la méthode de défanage sur le rendement et la qualité de quatre cultivars de pomme de terre (*Solanum tuberosum* L.)**. Can. J. Plant Sci. **87**: 129–135. Habituellement, on met fin à la croissance des pommes de terre ou sèche les plants avec un produit chimique quelques semaines avant la récolte afin de favoriser la maturation des tubercules et de faciliter les opérations à la récolte. L'auteur a évalué la réaction du rendement et de la qualité de transformation de plusieurs cultivars de pomme de terre au défanage mécanique et à la dessiccation avec du diquat à quatre moments distincts. Il a également déterminé l'incidence de l'année et du cultivar sur la rapidité et l'importance de la dessiccation par traitement chimique. Ranger Russet met plus de temps à sécher que Russet Burbank, Shepody et Russet Norkotah, sans doute à cause du feuillage plus touffu. Les résultats des trois années et des quatre traitements révèlent que le battage diminue le rendement des quatre cultivars à l'étude d'en moyenne 4 % comparativement à celui obtenu avec le défanage chimique. L'écart s'élargit quand les conditions climatiques contribuent au dépérissement graduel du feuillage après application du dessiccant. La densité des plants tués chimiquement est égale ou supérieure à celle des plants tués mécaniquement. La couleur de friture n'est pas touchée par la méthode ni le moment du défanage. Bien que la dessiccation chimique donne un rendement plus élevé que le défanage mécanique quand ils surviennent en même temps, il faut au moins trois semaines pour que plantes traitées chimiquement sèchent. Celles tuées mécaniquement, en revanche, sont prêtes à être récoltées immédiatement, pourvu que la fermeté de la peau du tubercule ne soit pas un problème. Si les fanes des Russet Burbank mettaient à peine une semaine de plus à sécher après le battage, en début de saison, le rendement augmenterait de 9 %. Les conditions climatiques empirant à mesure que la saison avance, les gains de rendement deviennent de moins en moins probables quand on privilégie le battage au lieu du défanage chimique.

Mots clés: Diquat, battage, Russet Burbank, Shepody, Ranger Russet, Russet Norkotah

Potato producers strive to maximize yields through liberal application of fertilizer and irrigation and careful control of insect pests or diseases. With long season indeterminent cultivars like Russet Burbank, these management practices result in the production of tops that stay vigorous until the onset of cold weather, unless some form of top killing is employed. In North America, several weeks prior to harvest, the tops are typically killed by mechanical means or by the application of chemical desiccants. Desiccation or destruction of the vines triggers maturation of the tuber periderm, which reduces skinning during harvest and moisture loss during subsequent storage (Halderson and Henning 1993). Vine killing also reduces the amount of vegetative material that must pass through the harvester, allowing faster harvester speeds and more efficient recovery of the tubers from crop debris (Hutchinson and Stall 2003). In seed potato production, vine killing may also be used to control tuber size (Sanderson et al. 1984) and to reduce the crop's susceptibility to several viral diseases spread by late-season infestations of aphids.

Timing of top killing becomes problematic when long season, processing-types of potatoes are grown in regions with a relatively short growing season. Although postponing top killing may increase yields in these areas (Giesel 1995; Ronald and Pritchard 1999) it may also leave insufficient time for completion of the harvest prior to damaging frosts. The magnitude of the yield gain associated with delaying harvest will vary with crop vigor, cultivar and prevailing growing conditions (Giesel 1985, 1995; Ronald and Pritchard 1999). The processing quality (specific gravity and product color) of potatoes also tends to improve as the crop matures (Ronald and Pritchard 1999; Essah et al. 2006) but processing quality may also be compromised if the tubers are exposed to excessively low temperatures due to a delayed harvest.

Mechanical treatments such as mowing, flailing or pulling result in instantaneous removal of the tops. The mechanically top killed crop is consequently ready for immediate harvest, providing that skin set is not a priority. Skin set typically takes 10–14 d, depending on the cultivar and prevailing soil conditions (Halderson et al. 1988). By contrast, it may take up to 3 wk for a chemically desiccated crop to dry down to the point where the vines will pass smoothly through the harvester (Terman et al. 1952; Halderson et al. 1988; Ivany and Sanderson 2001). If a mechanically top killed crop is ready for harvest sooner than one treated with chemical desiccants, this raises the possibility of delaying top kill (Bouman 1975). This delay may produce a significant yield and quality advantage, particularly in a well-managed crop under favorable growing conditions (Ivany and Main 2004). In southern Idaho, yields and tuber specific gravity of processing-type potatoes may be increasing by 450–550 kg ha^{-1} d^{-1} and 2 points per day, respectively, at the time of top kill (Halderson et al. 1985). Further north, in Manitoba, the rate of change in yield and specific gravity at the time of top kill was only 76–190 kg ha^{-1} d^{-1} and 0.5 point per day, respectively (Giesel 1985; 1988; 1995).

The rate and extent to which chemically treated tops die down can be influenced by the type (Ivany and Sanderson 2001; Pavlista 2001), amount, method and time of application of the top killer (Haderlie et al. 1989a), crop vigor at the time of top kill (Haderlie et al. 1989b), the cultivar (Renner 1991; Ivany and Sanderson 2001) and weather conditions prior to, during and after application of the top killer (Haderlie et al. 1989a). Although all commonly used desiccants result in rapid destruction of the photosynthetic capacity of the leaves (Haderlie et al. 1989a; Pavlista 2001), translocation of previously synthesized metabolites stored in the leaves and stems may continue during the dry down period (Halderson et al. 1988). Little information is available as to the magnitude of the yield change that can be expected during the dry down period for a chemically desiccated crop (Bevis 1985; Halderson et al. 1988; PAMI 2003). By contrast, yields of a mechanically top killed crop are effectively fixed at the moment that the tops are removed (Halderson et al. 1988).

This project evaluated how yields and processing quality of several commercially important potato cultivars responded to mechanical top kill versus chemical desiccation at four different treatment dates. The influences of year and cultivar on the rate and extent of desiccation were also evaluated in the chemically treated crop.

MATERIALS AND METHODS

Trials were conducted in 1998 through 2000 on the University of Saskatchewan Plant Science Department Potato Research plots located in Saskatoon, SK. The site features a sandy loam soil, pH 7.2, EC < 1 dS, with 4% organic matter. Standard practices for production of irrigated commercial potatoes in western Canada were used in all trials (Western Potato Council 2003). Nitrogen as 46-0-0 was broadcast prior to planting to bring the total soil nitrogen level (residual + applied) to 175 kg ha^{-1}. Elite 2 seed of the processing-type cultivars Russet Burbank, Ranger Russet and Shepody and the table-type Russet Norkotah was planted in mid-May at a spacing of 25 cm within the row and 1 m between rows. Sufficient phosphorus (11-55-0) was applied in a band adjacent to the seed to raise soil P_2O_5 levels to 120 kg ha^{-1}. Weed control was achieved utilizing preplant applications of EPTC (5.90 kg ha^{-1}) and metribuzin (0.37 kg ha^{-1}) followed by linuron (1.80 kg ha^{-1}) prior to crop emergence. A rolling cultivator was used after ground crack and again 2 wk later for inter-row tillage and to throw hills. Soil moisture levels were monitored in the plots using electrical resistance meters. The plots were irrigated whenever soil water potentials at 23 cm depth fell below –60 kPa. No significant problems with insects or diseases were observed and the plots received no pesticides beyond those already described.

The crop was top killed at 2-wk intervals beginning the first week of August and continuing through to the third week in September. The first week of September approximates the standard date for chemical top kill of potatoes in Saskatchewan. Late September would approximate the time of mechanical top kill employed by growers of processing potatoes in Manitoba. At each date, a mechanical flail was used to remove the vines at or near the soil surface in half of each plot. The other half of each plot was sprayed with 0.73 kg ha^{-1} of the chemical desiccant diquat applied via ground sprayer in 250 L ha^{-1} of water. This rate of diquat corresponds to the high end of the recommended range (0.41 to 0.83 kg ha$^{-1)}$ and reflects local experience with top killing vigorously growing long-season-type cultivars. Seven days after the initial application of desiccant, a second application was made (0.30 kg ha^{-1} diquat in 250 L ha^{-1} water). Plots were harvested 3 wk after the initial top kill treatment using a small plot harvester. Tubers free of growth defects and with diameters exceeding 55 mm were considered as marketable. Twenty-five-kg samples of marketable tubers from each treatment replicate were cured for 4 wk at 10°C and then cooled to 6°C over the course of the next 3 wks. After 4 wk of storage at 6°C specific gravities were determined using 2.5-kg samples drawn at random from each treatment replicate. Ten randomly selected tubers from each treatment replicate were reconditioned for a week at 20°C and then fried using standard protocols. Fry colors were evaluated the UDSA visual rating system, which ranges from a score of 00 for very light through to a score of 5 for very dark fries.

To avoid uneven competition effects related to differences in growth rates and vigor, the cultivars were grown in separate trials. Factorial combinations of four top kill dates and two methods of top kill were arranged in a split plot design, with harvest dates as the main plot and top-kill method as the sub-plot. Each sub-plot consisted of four 8-m-long rows but only the two center rows were harvested. Treatments were replicated four times.

The rate of desiccation of the chemically treated vines (leaves + stems) was investigated in a separate trial. In early September, 6-m-long rows of each cultivar were treated with diquat as previously described. The moisture content of three randomly selected plants from each plot was determined just prior to application of the desiccant and at 10 and 20 d after treatment. The trial was conducted using a randomized complete block design with four replicates.

All data were analyzed using appropriate models in SAS (SAS Institute, Inc. 1999). Least significant difference or t-tests ($P = 0.05$) were used for means comparisons.

RESULTS AND DISCUSSION

In the fall (September and October) of 1998 there were no killing frosts (–2°C) until early October, while in 1999 the fall was cooler than normal with multiple killing frosts from Sep. 15 onward. Conditions in the fall of 2000 were excellent until Oct. 04, when temperatures dropped to –14°C and stayed below freezing for 72 h. This resulted in extensive low-temperature damage to any treatments still in the field at this time.

Vine Desiccation

In all 3 yr, all four cultivars were still growing vigorously, with no visual indications of impending senescence, at the time of desiccation. The rate and extent to which the vines dried down after treatment with the chemical desiccant varied over the 3 test years. In 1998, the vines had a higher water content at the time of application of the desiccant than in 1999 or 2000 (Table 1). At 10 d after application of the desiccant, vine moisture content in 1999 was lower than in 1998 or 2000. The degree of vine desiccation obtained after 20 days from initial treatment was lower in 2000 than in the other years. The difference in vine moisture content from time of application through 20 d of dry down was greatest in 1998 and lowest in 2000. The four cultivars had comparable vine moisture contents prior to application of the top killer. After 10 d, Russet Norkotah had lost more moisture than the other cultivars, while the Ranger Russet vines were slow to dry. By 20 d after treatment, the tops of the Burbank, Norkotah and Shepody crops had reached a moisture content of 23–26%. At this moisture content, the vines appeared to be in equilibrium with their surroundings, as no further moisture loss was observed (data not shown). In other studies of the activity of chemical desiccants, within 2–3 wk of treatment the level of vine desiccation commonly approach 90% (Haderlie et al. 1989b; Ivany and Sanderson 2001; Pavlista 2001), suggesting more complete desiccation than was observed in this study. Although the efficacy of top kill may be influenced by cultivar (Renner 1991) and weather conditions (Mroczek and Gastrol 1979), the primary difference between this study and those conducted previously is in the method of evaluating vine desiccation. In this study the moisture content of the vines was actually measured, while in the other studies it was estimated based on visual appearance of the vines. This suggests that visual estimates of vine desiccation may actually over-estimate the degree of desiccation that has been achieved. The fact that apparently dry vines still retain a significant amount of moisture may be of little practical significance, as along as they are dry enough to pass smoothly through the harvester. Despite differences in weather conditions, crop management practices and the method of evaluation of the degree of vine desiccation, the rate of desiccation (% change/day) for Russet Burbank observed in this study (Table 1) was similar to that observed elsewhere (Haderlie et al 1989).

At 20 d after treatment with the chemical desiccant, vines of Ranger Russet retained more moisture than the other cultivars tested in this trial. Cultivar differences in response to chemical desiccants have been reported (Renner 1991, Ivany and Sanderson 2001) and Ranger Russet is regarded by growers as difficult to kill. Over 50% of the variability in vine moisture content observed at 20 d after treatment could be attributed to differences in vine size at the time of application of the desiccant (Fig. 1). A larger canopy is difficult to fully desiccate, particularly with contact-type desiccants like diquat. When vigorous indeterminate cultivars like Ranger Russet are grown under near-optimal conditions, the canopy may be so dense that even multiple applications of contact-type desiccants may not provide complete top kill. Rolling the canopy prior to application of the desiccant may increase the degree to which the difficult to kill stem tissues are exposed to the spray (Renner 1991). Alternatively a portion of the canopy may be removed by flailing prior to application of the desiccant. Problems with adequate coverage are reduced when desiccants with systemic activity are employed (Ivany and Sanderson 2001). However, slower rates of dry-down coupled with concerns about translocation of these products into the tubers have limited adoption of systemically active desiccants.

Yields and Processing Quality

Averaged across years and harvest dates, yields from the chemically desiccated plots were significantly higher than the flailed plots for all cultivars (Fig. 2a). The previous trial had demonstrated differences between cultivars in the rate and extent at which their vines died down following application of a chemical desiccant. However, this trial showed little difference between the cultivars in their yield response to chemical versus mechanical top kill treatments. Yields increased substantially with each delay in the timing of top kill, but the yield advantage obtained with chemical desiccation was fairly consistent across the four top kill dates tested (Fig. 2b) The higher yields obtained with chemical desiccation were almost entirely attributable to an increase in average tuber weight (data not shown).

The magnitude of the effect that the method of top kill exerted on yields varied with the year and the treatment date. Data for Russet Burbank (Fig. 3) illustrate this interaction. In the 1998 trial, weather conditions in late August through September were near ideal for both potato growth

Table 1.Percent moisture content of the vines of several potato cultivars at 0, 10 and 20 d after application of the chemical desiccant diquat

Days after treatment	Russet Burbank	Russet Norkotah	Ranger Russet	Shepody	1998	1999	2000	Mean
0	86*a*	83*a*	85*a*	83*a*	91*A*	81*B*	83*B*	85
10	68*b*	59*b*	77*a*	68*b*	73*C*	59*D*	74*C*	69
20	25*c*	23*c*	30*b*	26c	24*F*	24*F*	33*E*	27
% Moisture loss/day	3.6	3.5	3.1	3.4	3.4	2.9	2.5	

a–b Values within columns for each cultivar followed by the same letter are not significantly different ($P = 0.05$).
A–F Values for each year × time after treatment combination followed by the same letter are not significantly different ($P = 0.05$).

and dry down of the tops treated with the desiccant. Consequently, initial vine moisture content was high in 1998 (Table 1) but a very thorough dry down was achieved following chemical desiccation at all four treatment dates. In the 3 wk it took for the tops treated with chemical desiccants to die back in 1998, the crop continued to support tuber bulking. By contrast, flailing the tops stopped bulking instantaneously. Consequently in the 1998 trial, for all four dates of top kill, yields for the chemically desiccated crop were higher than for a crop flailed on the same date (Fig. 3). Yields obtained from plots chemically desiccated beginning Sep. 08 were equivalent to plots flailed 2 wk later. As indicated by the lower initial vine water content (Table 1), the crop canopy was less vigorous in 1999 and the chemical top killer consequently worked rapidly. Yield gains associated with chemical desiccation compared with flailing were limited in 1999, particularly in the later treatments where frosts supplemented the activity of the chemical top killer. Nonetheless, yields for a crop chemically desiccated on Aug. 21 in 1999 were equivalent to a crop flailed as late as Sep. 22. The first fall frost in 2000 did not occur until late September. The substantial increases in yields for the second and third top kill dates in 2000 illustrate that conditions were still suitable for growth of the potato crop during this time. At the three later treatment dates in 2000, chemically desiccating the crop resulted in significantly higher yields than if the crop was flailed.

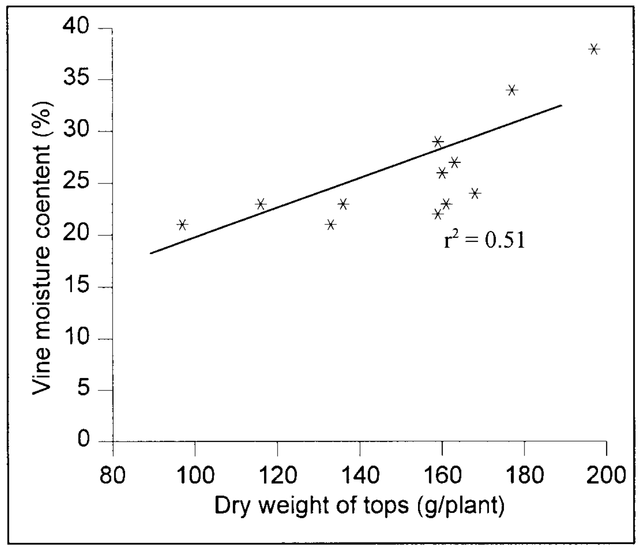

Fig. 1. Relationship between the size of the canopy prior to desiccation and the % moisture content of the vines 20d after application of the chemical desiccant diquat.

Top killing triggers stolon release and reduces the bulk of the tops, factors which both facilitate the harvest operation

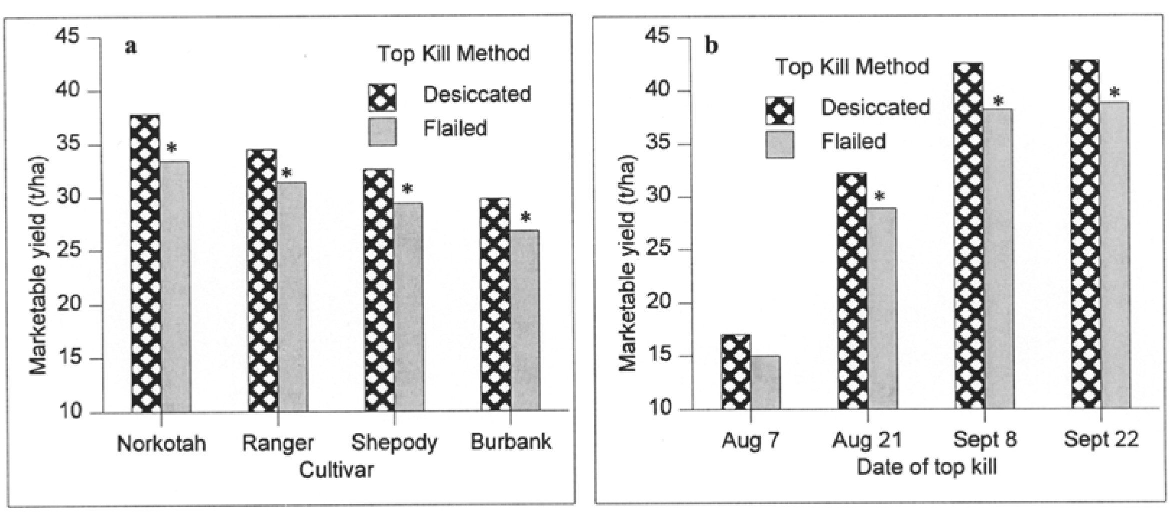

Fig. 2. Influence of method of top kill on marketable yields of four potato cultivars (a) and for four times of top kill (b). * indicates the difference between desiccated and flailed was significant at $P = 0.05$.

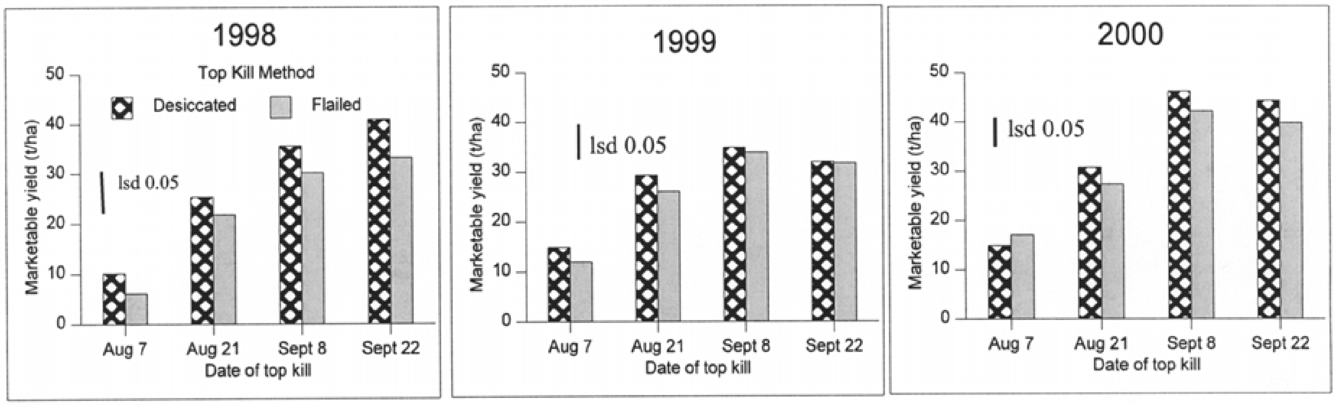

Fig. 3. Influence of method of top kill on marketable yields of Russet Burbank potatoes at four harvest dates over three growing seasons. Diquat was used as the desiccant. Vertical bars represent LSD $P = 0.05$.

and increase harvest recovery (Hutchinson and Stall 2003). Top kill also leads to changes in the biochemistry of the tuber that enhance storage potential and processing quality (Giesel 1988; Ronald and Pritchard 1999). For a vigorous cultivar grown under irrigation, this study and others (Haderlie et al. 1989b; Ivany and Sanderson 2001; Pavlista 2001) have shown that it takes 2 or more weeks following chemical desiccation for the tops to dry to the point that they can be efficiently handled. By contrast, flailing instantaneously eliminates the tops. If skin set is not critical, the flailed crop can be harvested almost immediately. Even if skin set prior to harvest is important, this process may be completed before dry down of the tops of a chemically desiccated crop (Hutchinson and Stall 2003). Consequently, a crop that is to be killed by flailing can be left to grow for a week or more longer than when chemical desiccants are used. In situations where the crop is still growing vigorously, this delay can result in a substantial yield increase. Averaged over the 3 yr of this study, a Russet Burbank crop chemically desiccated during the third week of August produced 27.8 t ha^{-1} of marketable tubers by the second week of September, at which time the tops were dry enough to allow harvest (Fig. 3). An untreated Russet Burbank crop gained, on average, 360 kg ha^{-1} d^{-1} from the third week of August through to the second week of September. If flailing allowed the top killing step to be delayed by as little as a week, this would result in a yield of 30.3 t ha^{-1} or a 9% increase over the chemically desiccated treatment. In situations where the crop was no longer growing vigorously, due to adverse growing conditions or impending crop maturity, relying on flailing as a means to delay the date of top kill provided little yield advantage. Averaged over the 3 yr of this study, Russet Burbank plots chemically desiccated during the second week of September actually yielded 4 t ha^{-1} more than a crop flailed 3 wk later (Fig. 3). Previous studies from the Canadian prairies (Giesel 1995; Ronald and Pritchard 1999) have shown that growing conditions in late September typically do not support further increases in potato yields. The lower yields for the flailed crop in the late harvests may reflect incomplete harvest recovery as a result of

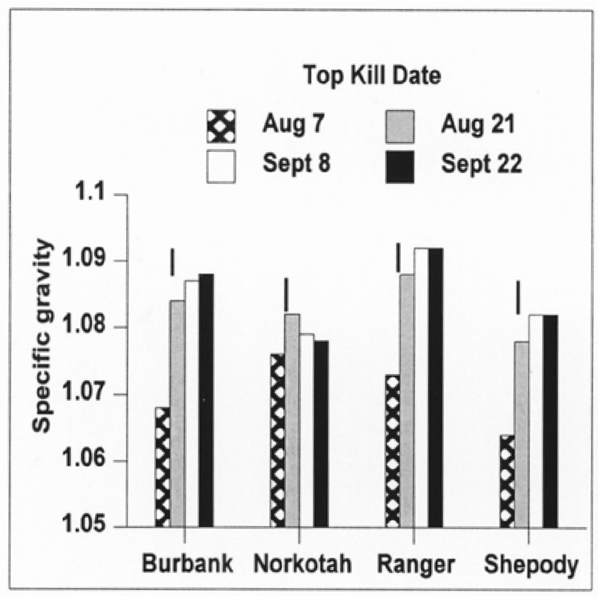

Fig. 4. Specific gravities averaged over 3 yr and two top kill methods for four potato cultivars top killed at four dates. Vertical bars represent LSD ($P = 0.05$) for each cultivar.

incomplete stolon release in the flailed crop.

Specific gravity of cv. Russet Norkotah peaked relatively early; this is consistent with the early-maturing nature of this cultivar (Fig. 4). Specific gravities of the other longer-season, processing-type cultivars increased markedly between the first and second top kill dates, but had effectively plateaued by the third top kill date. Averaged over the 3 test years, there was no clear relationship between time of top kill and fry colors of any of the four cultivars tested (data not shown). As illustrated by the data for Russet Burbank (Fig. 5a and b), for each top killing date in this study, the specific gravities and fry colors of the chemically desiccated crop were either equivalent to or better than those of the flailed crop. The gradual die down of the tops associated with chemical desiccation appeared to allow the crop to

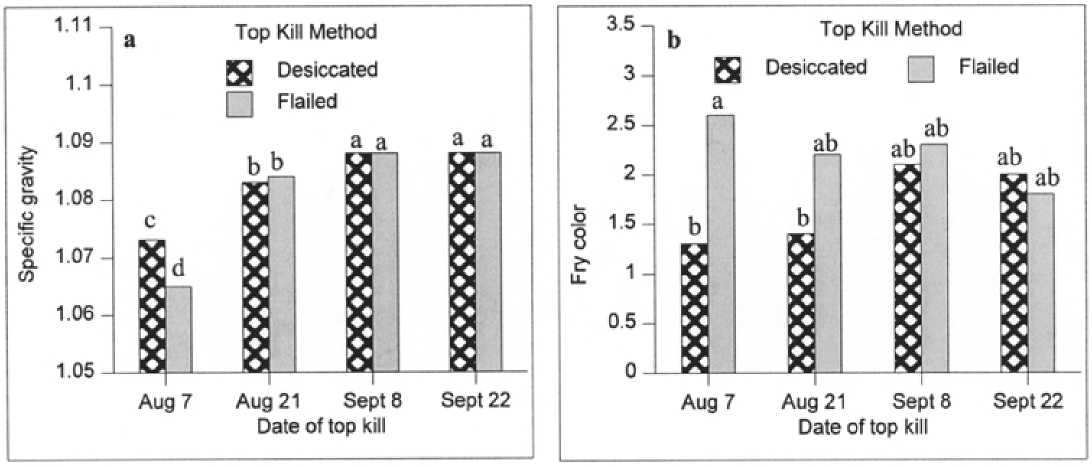

Fig. 5. Influence of date of top kill and top kill method on specific gravity (a) and fry color (b) of Russet Burbank potatoes averaged over three growing seasons. Diquat was used as the chemical desiccant. Low color scores signify light fry color. Means with the same letter are significantly (P = 0.05) different.

achieve a greater degree of tuber maturity, as reflected by the higher specific gravities and lighter fry colors. Other studies have found little consistent difference in the specific gravities of flailed versus chemically desiccated crops (Halderson et al. 1988; PAMI 2003). This may again reflect differences in crop vigor, top killing methods and environmental conditions. Delaying top killing Russet Burbank until early September resulted in a significant increase in tuber specific gravities (Fig. 5). As high gravities improve recovery percentages during frying, opting to deal with the tops by flailing just prior to harvest might be expected to improve the processing quality of an early harvested crop. However, any difference in specific gravity would have been minimal if the crop was flailed sufficiently in advance of harvesting in order to achieve skin set. Typically, fry colors also improve as the crop matures, as long as the later-harvested crop is not exposed to chilling temperatures (Sabba and Bussan 2005). However, in the 3 yr of this study there was no consistent improvement in fry color as the crop matured; therefore, any delay in top killing that may be possible by choosing to flail the crop would have had no beneficial impact on fry quality. Under the conditions encountered in this study, any improvements in fry colors associated with increasing crop maturity were apparently counterbalanced by the adverse effects on fry color caused by extended exposure to low temperatures in the field. A similar lack of consistent improvements in fry color with delayed harvest has been noted in previous studies conducted on the Canadian prairies (Giesel 1985; 1995; Ronald and Pritchard 1999).

When evaluating the relative merits of chemical versus mechanical top-killing, a range of additional factors must be considered beyond the basic differences in yield and processing quality. Estimated cost/unit area of desiccating a potato crop using diquat may be similar to (Haderlie et al. 1989a) or substantially greater than (PAMI 2003) flailing, depending on the rate and method of application of the desiccant and the type of flailing equipment used. Flailing reduces problems with vine wrapping during harvest (PAMI 2003), but if the crop is harvested soon after flailing, a special blower system must also be installed on the harvester to eliminate the large amounts of crop debris left after flailing (Hutchinson and Stall 2003). While chemical desiccation effectively stops the progression of many foliar diseases of potatoes, flailing may actually spread late blight and bacterial soft rot. The complete removal of the vines achieved via flailing leaves the hills exposed to wind and water erosion and renders shallow tubers more susceptible to sunburn and frost damage (Hutchinson and Stall 2003). Finally, as flailing results in the instantaneous elimination of the vines, it may allow growers to delay the top killing step and thereby achieve greater yields. However, if the flailed crop has not achieved an adequate skin set prior to harvest, any yield advantage would be quickly lost due to the greater moisture loss and decay during storage (Love and Pavek 1989).

This study suggests that growers must tailor their top killing strategy and corresponding harvest schedule to fit the top killing method used, the growth habit and relative vigor of the cultivar grown, the environmental conditions anticipated after top kill and the end-use planned for the crop.

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