EFFECTS OF TOPPING, STEM DENSITY, AND STAGE OF VINE CUTTING ON CANOPY GROWTH AND TUBER YIELD OF POTATO

(*SOLANUM TUBEROSUM* L.)

by

James Ajuoga Okeyo

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APPROVED:

Ronald D. Morse, Chairman

Charles R. O'Dell

David M. Orcutt

Jonathan D. Eisenback

Richard E. Veilleux

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James Ajuoga Okeyo

Committee Chairman: Ronald D. Morse

(ABSTRACT)

Seed tubers of 'Yukon Gold' potato (*Solanum tuberosum* L.) exhibit strong apical dominance, resulting in low stem density after planting. After emergence, the terminal buds reimpose apical dominance on the rest of the canopy leading to production of few secondary branches. Therefore, several experiments were conducted at the Virginia Polytechnic Institute and State University Kentland Research Farm, Blacksburg in 1992, 1993, and 1994 to evaluate the effects of topping [(excising 2-3 cm from the terminal buds at 1 to 2 weeks after the date of plant emergence (WAE)], stage of vine cutting at ground level, and main stem density on canopy growth, tuber bulking rate, and tuber yields of potato. Topping (3 years) and vine cutting (2 years) at 1 WAE resulted in more uniform plant stands and increased average yield of US No. 1 tubers of 'Yukon Gold' by 16 and 14%, compared to untopped and uncut plants, respectively. When plants of 'Kennebec', 'Superior', and 'Yukon Gold' were topped in 1994, yield of US No. 1 tubers increased by an average of 10%, indicating that topping could be used to improve tuber yield of potato cultivars exhibiting different growth habits. The increased tuber yields following topping resulted from a combination of increased leaf area duration and increased period of tuber bulking. Cutting vines of 'Yukon Gold' at 2, 4, and 6 WAE in 1992 and 1993, decreased yield of US No. 1 tubers by 11, 69, and 38% and by 19, 56, and 48%, respectively. Yield of US No. 1 tubers increased with increased stem density and increased in-row spacing. Interaction effects between in row spacing and topping were significant. Control plants of 'Yukon Gold' produced higher tuber bulking rates and yield of US No. 1 tubers than topped plants at 15 cm in-row spacing, while topped plants had higher tuber bulking rates and yield of US No. 1 tubers than control plants at 20, 25, and 30 cm in-row spacings. Neither topping nor in-row spacing increased the incidence of hollow heart of tubers in 1994. The results showed that the difference in tuber yield between topped and control plants was greater during long growing season and topped plants should be spaced at 25 cm in-row in order to obtain maximum tuber yield.

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Introduction

Potato (*Solanum tuberosum* L.) is the fourth most important crop in the world, after wheat, rice, and maize (Beukema and Van Der Zaag, 1990; Horton and Anderson, 1992; Spooner and Bamberg, 1994). Although potato originated from Central and South America, its cultivation has spread to every country in the temperate zone and many tropical and subtropical countries (Beukema and Van Der Zaag, 1990; Horton and Anderson, 1992; Midmore, 1992).

Based on a dry matter yield at the rate of 1.4-1.6 g/mega joules (MJ) of energy trapped by potato plants, Allen and Scott (1992) estimated that the potential tuber yield (20% DM) during the dullest and the brightest year is between 60 and 128 $t \cdot ha^{-1}$. Yields between 15 $t \cdot ha^{-1}$ (MacKeown, 1990) and 63 $t \cdot ha^{-1}$ (Rykbost and Maxwell, 1994) have been obtained under experimental conditions in the United States, indicating that approximately one-quarter to one-half of the potential tuber yield has been attained so far.

Tuber yield in potato is a product of three major processes: radiation interception by the canopy, conversion of intercepted radiation to dry matter, and the partitioning of dry matter between the tubers and the rest of the plant (Harris, 1992). Researchers have shown that under adequate water, mineral nutrition, and pest control, efficiency of radiation utilization and dry matter partitioning are relatively constant among cultivars and regions (Allen and Scott, 1992). Potato tuber yield in temperate climate is limited mainly by the amount of radiation intercepted by the canopy (Allen and Scott, 1992).

The amount of radiation intercepted by a crop is determined by the leaf area duration in relation to seasonal changes in incident radiation (Allen and Scott, 1992; Gardner et al., 1985; Hay and Walker, 1989). Any procedure which can increase leaf area index early in the season and or prolong leaf area duration will maximize radiation interception and lead to increased tuber yields (Allen and Scott, 1992; Hay and Walker, 1989; Nobel, 1992).

The two most important factors which contribute to decreased rate of canopy growth in potato are reduction in stem emergence as a result of apical dominance exerted on the rest of the buds by the apical-end of the seed tuber (Allen and Scott, 1992; McKeown, 1990; Chase et al., 1989) and reduction in development of secondary branches due to reimposed apical dominance on the rest of the canopy by terminal buds (Allen et al., 1992; Gill et al., 1989; Hay and Walker, 1989). Previous studies conducted to improve tuber yield in potato by improved cultural practices and breeding have increased canopy size. however they have had limited yield enhancement effects because they have been unable to increase leaf area duration (Allen and Scott, 1992).

Research conducted in several crops has shown that the removal of apical dominance by topping results in improved development of lateral shoots and this in turn led to increased net photosynthesis and higher productivity (Ovaska et al., 1992; Wade, 1973; Yamashita and Fujino, 1986). Other benefits derived from topping which could be contributing to increased crop productivity include delay in plant senescence (Colbert and Beever, 1981; Satoh et al., 1977; Van stadden and Carmi, 1982) and increased amount and activity of ribulose bisphosphate carboxylase (oxygenase), the main carboxylating enzyme during photosynthesis (Carrasco et al., 1993; Heichel and Turner, 1983; Hoogesteger and Karlssom, 1992).

Large canopy size which results after topping may require that potato crops be spaced at wider in-row spacing than the conventional. Therefore, the following experiments were conducted to determine if small canopy size limits tuber yield and to determine the effects of topping alone and topping at different in-row spacings on canopy growth, tuber bulking, and tuber yield of a recently introduced potato cultivar, 'Yukon Gold', which exhibits strong apical dominance (Johnston and Rowberry, 1981). Two additional cultivars, 'Kennebec' (late maturing) and 'Superior' (early maturing) and 'Yukon Gold' (medium maturing) were topped in 1994 and assessed for canopy growth and tuber yield.

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Chapter one.

Effects of Vine Cutting Early in the Season on Canopy Regrowth and Tuber Yield of 'Yukon Gold'

Abstract

Seed tubers of 'Yukon Gold' potato (*Solanum tuberosum* L.) exhibit strong apical dominance, resulting in slow plant emergence and uneven stand establishment. After emergence terminal buds reimpose apical dominance on the developing shoots causing them to grow upright with few branches. Cutting seed tubers before planting to overcome apical dominance in 'Yukon Gold' often results in irregular, uneven stem emergence. Experiments were conducted in 1992 and 1993 to evaluate the effects of stage of vine cutting on canopy regrowth and tuber size and yield of 'Yukon Gold'. Vines were left intact or cut at ground level at 1, 2, 4, and 6 weeks after plant emergence (WAE) in both years. Cutting vines at 1 WAE produced more uniform canopy growth and increased yield of US No. 1 tubers by 16 and 11% in 1992 and 1993, respectively. Yield of US No. 1, however, decreased by 11, 69, and 38% in 1992 and by 19, 56, and 48% in 1993 following vine cutting at two, four,and six WAE, respectively. Compared to the control, yield and number of large tubers increased and yield and number of small tubers decreased significantly following vine cutting at 1 WAE, while the reverse occurred at 2, 4, and 6 WAE. Control plants and plants whose vines were cut at 1 WAE produced equal number of main stems during both years.

Regrowth of main stems, however, declined after vine cutting at two and four WAE and no regrowth occurred at six WAE. Number of total tubers declined following vine cutting after 1 to 5 WAE, while vine cutting at 6 WAE had no effect on number of total tubers produced. These results show that the stage of growth at which the vines are cut dramatically affects subsequent yield and size distribution of tubers and that tuber yield and size effects are related to the extent and distribution of shoot regrowth and tuber set following vine cutting.

Introduction

Several yellow-flesh potato cultivars were recently introduced to growers in the United States (Chase et al., 1989; Coffin et al., 1988a,b; Johnston and Rowberry, 1981; Young et al., 1988). One of the recently introduced yellow-flesh cultivars in United States and Canada is 'Yukon Gold' (Johnston and Rowberry, 1981).

Seed pieces of 'Yukon Gold', however, exhibit strong apical dominance which results in uneven and irregular stem emergence (Chase et al., 1989; Mckeown, 1990a,b). After emergence, terminal buds of developing stems reimpose apical dominance on the rest of the canopy, leading to erect-growing stems with few branches per plant (Johnston and Rowberry, 1981).

Research has shown that potato tuber yield in temperate climates is limited mainly by amount of radiation intercepted by the canopy (Allen and Scott, 1992; Bouman et al., 1992; Haverkort et al., 1991). The strong apical dominance exhibited by 'Yukon Gold' possibly results in reduced canopy growth and decreased tuber yields (Johnston and Rowberry, 1981; Chase et al., 1989; McKeown, 1990b).

Cutting vines immediately after plant emergence could break the apical dominance of seed tubers and this in turn could promote emergence of dormant buds resulting in more branches per plant and increased tuber yield.

The objective of this study was to evaluate the effects of vine cutting early in the season on canopy regrowth and tuber yields of 'Yukon Gold'.

Materials and Methods

Experiments were planted in 1992 and 1993 at the Virginia Polytechnic Institute and State University Kentland Farm in Blacksburg. Soil type was a Hyter loam (fine-loamy, mixed mesic,ultic, Hapludalf) with 2.7% slope and pH of 7.1 and 7.2 in 1992 and 1993, respectively. Whole seed pieces weighing between 70 and 80 g each were planted in 1992 and 1993.

Each year, the experimental design was a randomized complete block with four replications. Treatments were vine cutting at 1, 2, 4, and 6 weeks after emergence, compared to uncut plants (Control). Seed pieces were treated with manganese ethylene bisdithiocarbamate (maneb) at the rate of 0.08 kg a.i/100 kg seed and stored for two days before planting. Each plot consisted of three rows each measuring 3.5 m long and surrounded by one guard row on each side. Plant spacing of 91 cm between the rows and 20 cm within the row was used each year. Granular fertilizer containing 101N-

43P-84K kg·ha^{-1} was incorporated in the furrow bottoms prior to planting. Experiments were planted on 18 April 1992 and on 20 April 1993. Weed control was done by pre-emergent application of a mixture of 2-chloro-N-(2-ethyl-1-6-methylphenyl) acetamide (metolachlor) at 1.96 kg a.i/ha and 3-(3.4-dichlorophenyl)-1-methoxy-1-methylurea (linuron) at 0.84 kg a.i/ha.

Pest control and other cultural practices were performed based on recommendations for white potato production in Virginia (Baldwin et al., 1992). Percent plant emergence was determined at four weeks after the date of planting (WAP). Sixteen plants in each replication were left intact (control) or cut with a knife at ground level at the end of 1, 2, 4, and 6 WAE in 1992 and 1993. After cutting, plant materials were placed in paper bags, weighed, dried in the oven at 75C for 3 to 5 days and reweighed.

Six plants in each replication were harvested at eight WAP then main stems/plant were counted (Allen et al., 1992; Firman et al., 1991). The remaining ten plants per replication were harvested after 151 and 133 days in 1992 and 1993, respectively, and the tubers were separated into size grade categories according to the United States Department of Agriculture (USDA) standards (USDA, 1991), counted, and weighed. For each factor measured, data were analyzed across years by analysis of variance (Gomez and Gomez, 1984; SAS, 1988). Treatment means were separated by Tukey's HSD test ($P \leq 0.05$) according to (SAS, 1988). Graphs were drawn using CoPlot and CoDraw (CoHort Software, Minneapolis, MN).

Results

Year affected all variables studied except yield of US No. 1 tubers and numbers of main stems and large tubers produced (Table 1). Stage of vine cutting, however, affected all the variables tested. Year x stage interactions were significant for all variables tested, except number of large tubers.

Compared to uncut plants (control), marketable tuber yield (US No. 1) varied dramatically in response to cutting plants at 1, 2, 4, and 6 weeks after planting (WAP). The three major yield-response patterns following vine cutting and their relative canopy growth responses were:

Maximum yield (1 WAE). Compared to control plants, when vines were cut at 1 WAE in 1992 and 1993, yield of US No. 1 (Fig. 1A), yield of large (Fig. 1C), and number of large (Table 2) tubers increased, while numbers of small and total tubers (Fig. 2) decreased. Yield of small tubers for plants cut at 1 WAE, however, decreased in 1992 but was similar to control plants in 1993 (Fig. 1B). Shoot regrowth (number of main stems/ha) of control plants and plants cut at 1 WAE was similar in both years (Fig. 3). However, the plant canopy which resulted after regrowth was bushier, greener and senesced two weeks after the canopy of control plants. At one WAE, the average dry weight of shoots was 6.4 and 7.8 g/plant in 1992 and 1993, respectively (Fig. 4).

Intermediate yield (2 WAE). When plants were cut at 2 WAE in 1992, yields of US No. 1 (Fig. 1A), small (Fig. 1B), and large (Fig. 1C) tubers were similar to yields of control plants. In 1993, however, yields of US No. 1 and large tubers declined compared to control plants. Yield of small tubers increased in 1993 following vine cutting at this stage, but were similar to control plants in 1992 (Fig. 1B). Number of large tubers for plants whose vines were cut at 2 WAE was similar to control plants (Table 2). Number of small tubers declined following vine cutting at this stage in 1992, but was similar to control plants in 1993 (Fig. 2). Total number of tubers produced in 1992 declined compared to control. In 1993, however, the total number of tubers produced after vine cutting at two WAE was intermediate between control and plants cut at one WAE (Fig. 2). Shoot regrowth occurred after vine cutting at 2 WAE and the resulting number of main stems produced declined compared to control plants (Fig. 3). Average shoot dry weight at this stage was 13.0 and 15.6 g per plant in 1992 and 1993, respectively (Fig. 4).

Minimum yield (4-6 WAE). When plants were cut at four and six WAE, yields of US No. 1 tubers declined drastically (Fig. 1A). Greatest yield of small tubers were produced after vine cutting at four WAE (Fig. 1B). Plants whose vines were cut at six WAE in 1992 and control plants produced similar yield of small tubers. In 1993, however, yield of small tubers for plants cut at 6 WAE were higher than control plants. Least yield of large tubers was produced following vine cutting at four WAE (Fig. 1C). No large tubers were produced by plants after vine cutting at 6 WAE in both years. Total number of tubers produced varied from intermediate at four WAE to similar to control at six WAE (Table 2). Highest number of small tubers and least number of main stems were produced after vine cutting at this stage (Fig. 2). No large tubers

(Table 2) or main stems (Fig. 3) were produced following vine cutting at 6 WAE. Shoot dry weight increased to 58.4 and 64.0 g/plant at 6 WAE in 1992 and 1993, respectively (Fig. 4).

Discussion

Vine cutting of newly emerged plants (1 WAE) resulted in decreased rate of leaf senescence and increased yield of US No. 1 and large tubers. Delayed senescence extended the period of tuber bulking, leading to increased tuber yields. Other researchers have shown that plants remained greener (longer leaf area duration) after the tops were cut (Carmi and Koller, 1979; Colbert and Beever, 1981). Decreased yield of US No. 1 tubers after vine cutting at two WAE in 1993 compared to 1992 was possibly as a result of higher mean air temperature (23.3C) experienced during the month of July in 1993 compared to 21.6C in 1992.

Cutting vines between the fourth and sixth WAE resulted in decreased yield of US No. 1 tubers. The greatest decrease in yield of US No. 1 tubers occurred following vine cutting at 4 WAE while the least decrease was observed after vines were cut at two WEA. Similar results were reported following partial defoliation of 'Red La Soda' (Wellik et al., 1981) and 'Russet Burbank' (Wille and Kleinkopf, 1992).

Regrowth of shoots after vines were cut at 2 WAE in 1992 and 1993 resulted in partial resumption of photosynthates flow to the developing tubers, leading to the least reduction in yields of US No. 1 tubers compared to control plants. Several researchers have also shown that the developing tubers were less sensitive to water and nutrient stresses at this stage of growth compared to the later stages (Ojala et al., 1990; Van Loon, 1981). Partial defoliation of 'Red la Soda' (Wellik et al., 1981) and 'Russet Burbank' (Wille and Kleinkopf (1992) at 2 WAE produced similar results, suggesting that the leaves that remained on the canopy were able to compensate for some lost photosynthates from the missing leaves.

Yield of US No. 1 tubers was most sensitive to vine cutting at four WAE. Similar results were obtained by Wellik et al. (1981) and Wille and Kleinkopf (1992) after partial defoliation of 'Russet Burbank' and 'Red La Soda'and by Kandeel et al. (1991) after killing potato vines by hand defoliation and using 1, 1-dimethyl-4, 4-bipridinium (paraquat) and ametryne: 2-ethylamino-4-(iso-propylamino)-6-(methylthio)-S-triazine (gesapax). At this stage (4 WAE) the average size per tuber was between 2.5 and 4.8 cm in diameter, which corresponded to the phase of linear tuber growth in potato (Jefferries and Lawson, 1991; Ojala et al, 1990; Van Loon, 1981). Decreased yield of US No. 1 tubers after vines were cut at this stage was accompanied by the greatest increase in yield of small tubers (2.5-4.8 cm dia), indicating that removal of the canopy at 4 WAE reduced tuber bulking. Growth rate of potato tubers during bulking is limited mainly by the supply of photosynthates from the shoot (Engels and Marschner, 1986). Cutting vines at 4 WAE and the large reduction in shoot regrowth that followed apparently deprived developing tubers of photosynthates, leading to increased yield of small tubers.

Decreased yield of US No. 1 and absence of large tubers that followed vine-cutting at 6 WAE was also probably due to lack of photosynthates to the tubers as a result of absence of vine regrowth at this stage. Research conducted on potato vine-killing using chemicals (gesapax and paraquat) or mechanical (cutting and mowing) methods reported decreased tuber yield of equivalent magnitude after vines were killed immediately after flowering stage (Barry 1994; Singh and Arora, 1984; Kandeel et al., 1991; Ogilvy, 1992; Songin et al., 1980a). Songhin et al. (1980b) reported that normal vine regrowth occurred in several potato cultivars following vine cutting during and immediately after flowering. In our study using 'Yukon Gold', however, vine regrowth started to decline at 2 WAE and little regrowth occurred when plants were cut during flowering (4-6 WAE). Songhin et al. (1980b) possibly grew indeterminate potato cultivars with longer period of vine growth than the determinate cultivar,'Yukon Gold'.

In addition to its effects on tuber yield, the stage at which vine cutting occurred affected the number of tubers produced. Total number of tubers produced per hectare was most sensitive to vine cutting early in the season and the greatest reduction in total tubers was observed at 1-2 WAE, indicating that presence of shoots at this stage was critical for tuber initiation. These results agreed with observation made by Allen and Scott (1992) that, for a given cultivar, tuber initiation begins at a fixed time after emergence and lasts no more than 2-3 weeks during which the number of tuber initials rises to a peak. Terminal buds and young expanding leaves of potato are the source of stimulus required for tuber initiation (Cutter, 1992; Koda et al., 1991; Jackson and

Willmitzer, 1994; Pelacho and Mingo-Castel, 1991). Therefore, cutting vines early in the season might have deprived the plants of this stimulus, leading to reduction in numbers of total tubers produced.

Approximately 75% of the total number of tubers had been produced at two WAE, suggesting that the stage of tuber initiation for 'Yukon Gold' plants began soon after plant emergence. Tuber initiation in 'Yukon Gold' appears to be approximately 2-3 weeks earlier than that reported for 'Russet Burbank' (Ojala et al., 1990; Wille and Kleinkopf, 1992). Tubers of 'Yukon Gold' exhibit a relatively short dormancy period (Johnston and Rowberry, 1981; McKeown, 1990a,b). Therefore, at the time of planting seed tubers were probably physiologically old and were capable of producing tubers (Allen et al., 1992; Beukema and Van Der Zaag, 1990). Cutting vines at six WAE had no effect on the total number of tubers produced, indicating that tuber initiation for 'Yukon Gold' had been completed prior to 6 WAE. Similar results were reported by Songin et al. (1980a) after cutting vines of five potato cultivars immediately after flowering (6-7 WAE).

Stage of vine-cutting also affected size distribution of tubers. Number of small tubers decreased after vine cutting at 1-2 WAE then increased at 4-6 WAE. On the contrary, number of large tubers increased following vine cutting at 1 WAE and then decreased at 2-6 WAE. Rapid shoot regrowth and delayed shoot senescence that resulted after vines were cut at 1 WAE led to prompt resumption and extended flow of photosynthates to the developing tubers while reduction or absence of vine regrowth at

2-6 WAE deprived the tubers of photosynthates, resulting in decreased yield of large and increased yield of small tubers.

Increased yields of large tubers, and decreased tuber set during 1992 compared to 1993 might have been due to a combination of moderate temperatures during growth and well distributed rainfall, which resulted in a longer growing season (151 days) in 1992 compared to 133 days in 1993. It has been shown that potato plants produce low tuber yields and less number of tubers (Jefferies and MacKerron, 1993; Malik et al.; 1992; Struik et al.; 1989) when air and soil temperatures during tuber initiation and tuber bulking are above 20C. Potato plants also accumulate dry matter in the shoot when growth temperatures are high (Gawronska et al; 1992; Malik et al; 1992; Manrique, 1989; Wolf et al.; 1990). Therefore, higher temperatures during growth period in 1993 compared to 1992 might have led to higher shoot dry weight for most stages in 1993.

Table 1. Summary of analysis of variance indicating source effects on yields of US No. 1, small, and large tubers, and number of total, small, and large tubers, and shoot dry weight of 'Yukon Gold'.

		P-value							
		Tuber yield/ha				Numbers/ha			
Source	df	US No. 1	Small	Large	Shoot dwt	Total tubers	Small tubers	Large tubers	Main stems
Year (Y)	1	0.0603	0.0005	0.0511	0.0010	0.0005	0.0143	0.8597	0.1399
Error a	3								
Stage (S)	4	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Y x S	4	0.0001	0.0005	0.0001	0.067	0.0001	0.0002	0.6099	0.0013
Block	3								
Error b	24								
Total	39								

Table 2. Number of large tubers and main stems/ha of 'Yukon Gold' as influenced by year and stage of vine cutting.

Year	Number of large[z] tubers/ha x 1000	Stage (weeks)	Number of large tubers/ha x 100
1992	15.8a[y]	0	18.0b
1993	14.1a	1	34.2a
		2	18.5b
		4	3.2c
		6	0.0c

[y]Means separation within column for each main effect by Tukey's HSD test at P = 0.05. Year x stage interaction was not significant. [z]Large tubers, ≥6.4 cm diameter.

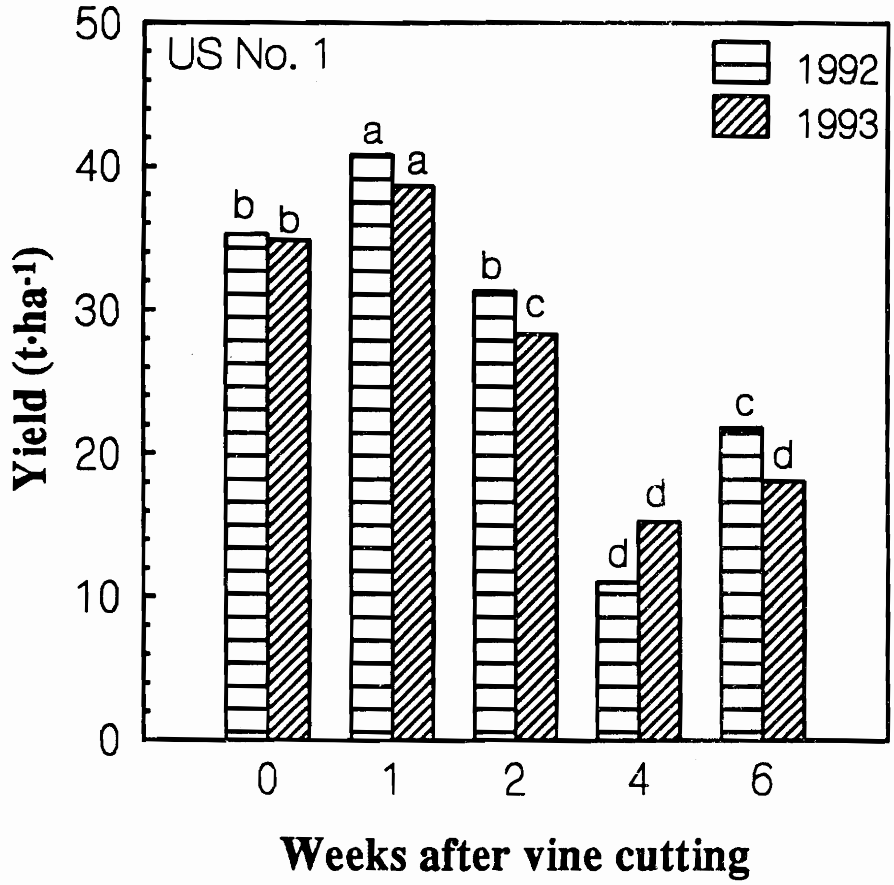

Fig. 1A. Yield of US No. 1 tubers (≥4.8 cm dia) of control plants and after vine cutting between 1 and 6 weeks after emergence, 1992 and 1993. Tubers were harvested at 22 and 19 weeks after planting in 1992 and 1993, respectively. For each year, letters above the bars represent mean separation by Tukey's HSD test ($P \leq 0.05$).

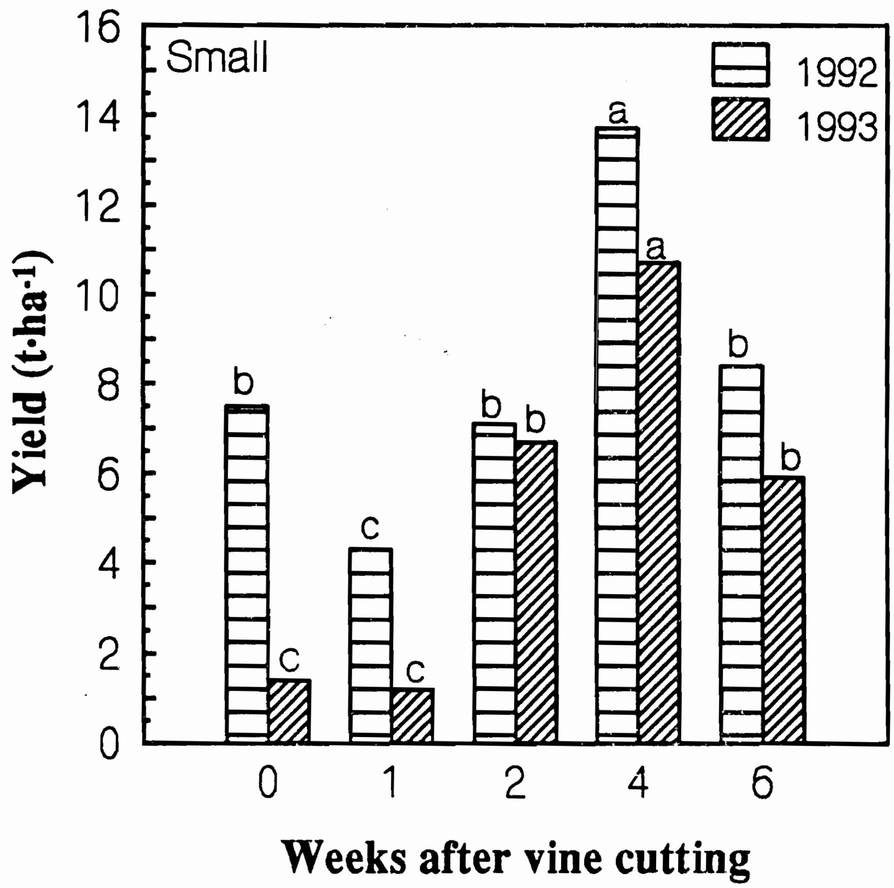

Fig. 1B. Yield of small tubers (2.5-4.8 cm dia) of control plants and after vine cutting between 1 and 6 weeks after emergence, 1992 and 1993. Tubers were harvested at 22 and 19 weeks after planting in 1992 and 1993, respectively. For each year, letters above the bars represent mean separation by Tukey's HSD test ($P \leq 0.05$).

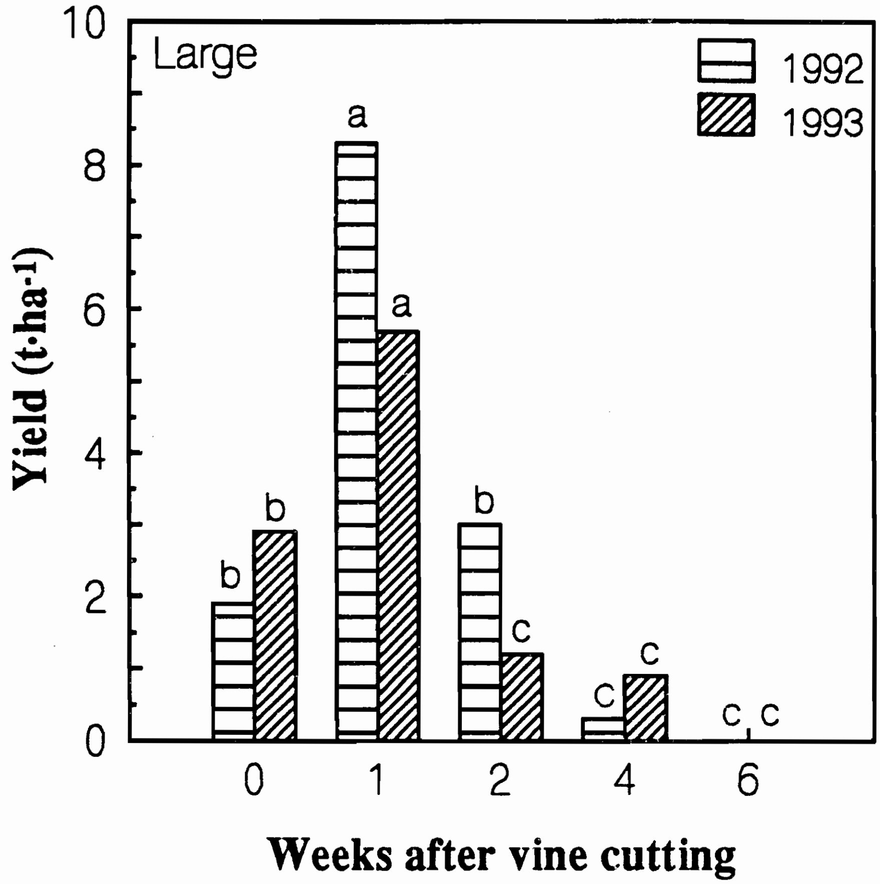

Fig. 1C. Yield of large tubers (≥6.4 cm dia) of control plants and after vine cutting between 1 and 6 weeks after emergence, 1992 and 1993. Tubers were harvested at 22 and 19 weeks after planting in 1992 and 1993, respectively. For each year, letters above the bars represent mean separation by Tukey's HSD test ($P \leq 0.05$).

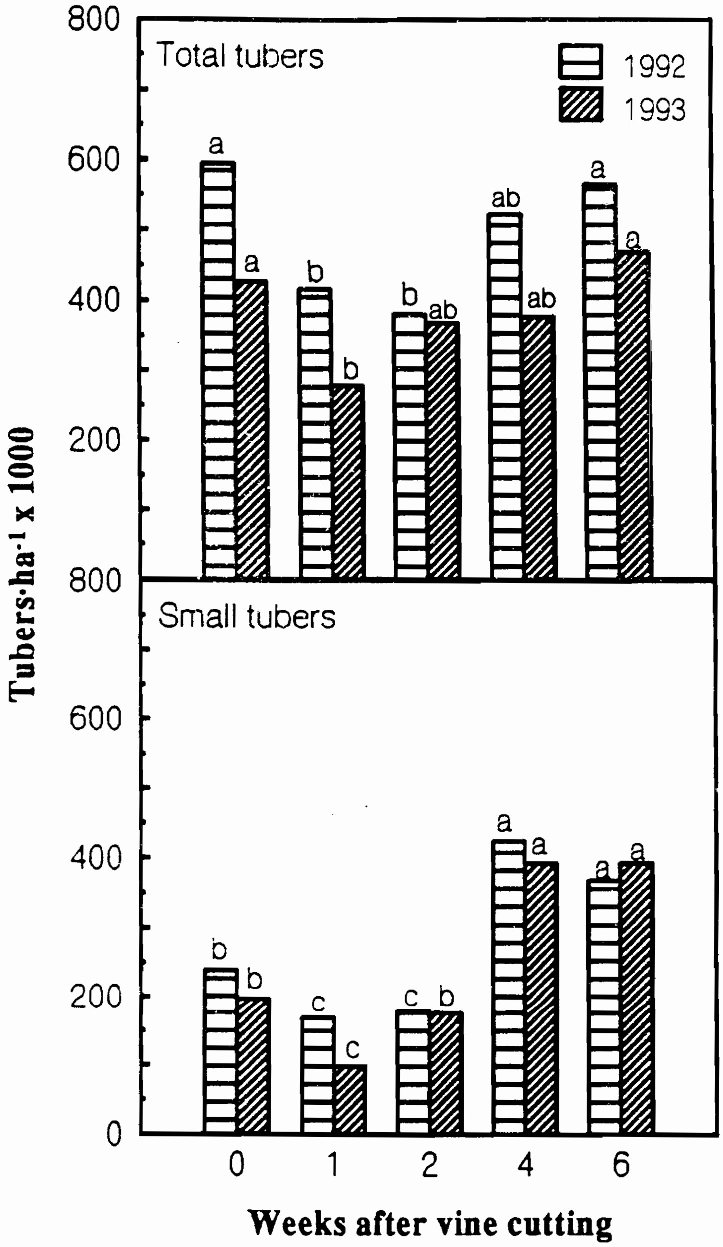

Fig. 2. Total number of tubers (≥2.5 cm dia) and number of small tubers (2.5-4.8 cm dia) for control plants and after vine cutting between 1 and 6 weeks after emergence, 1992 and 1993. Tubers were harvested at 22 and 19 weeks after planting in 1992 and 1993, respectively. For each year, letters above the bars represent mean separation by Tukey's HSD test ($P \leq 0.05$).

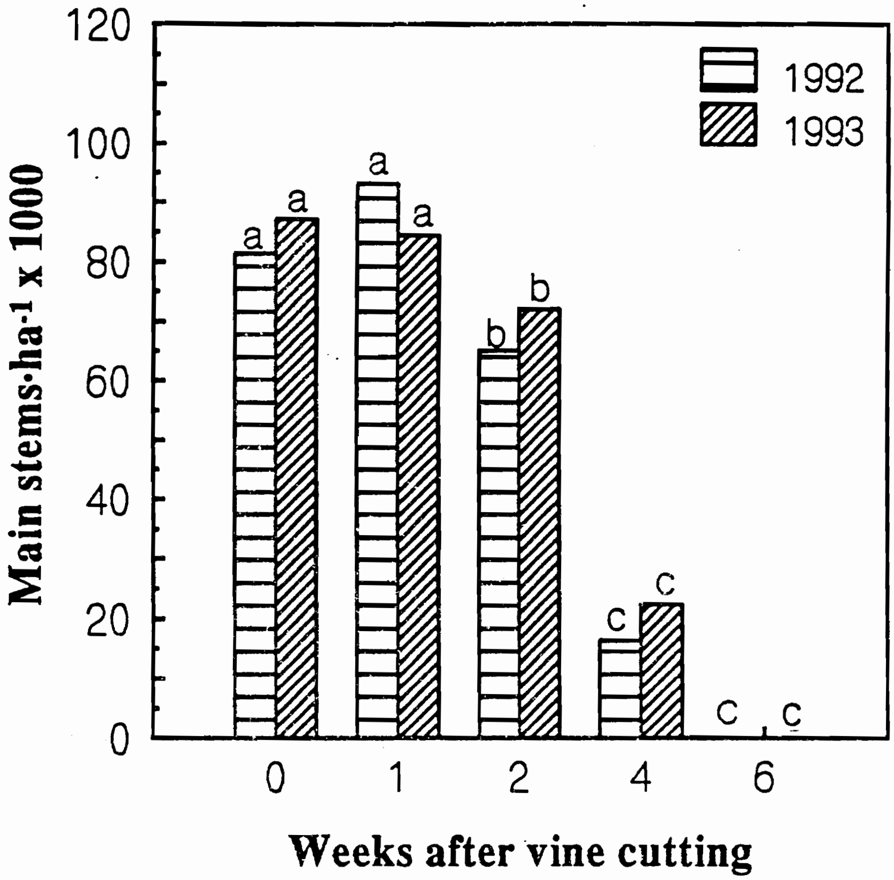

Fig. 3. Number of main stems of control plants and after vine cutting between 1 and 6 weeks after emergence, 1992 and 1993. Stems were counted at 10 weeks after planting. For each year, letters above the bars represent mean separation by Tukey's HSD test ($P \leq 0.05$).

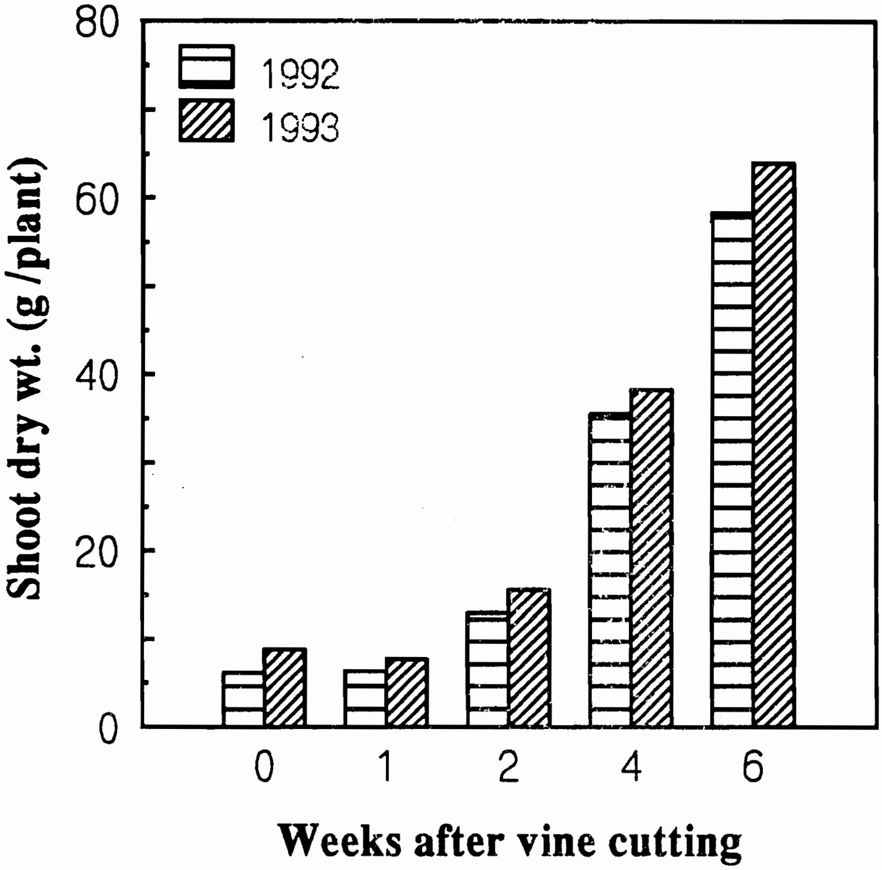

Fig. 4. Shoot dry weight of control plants and after vine cutting at 1, 2, 4, and 6 weeks after emergence, 1992 and 1993. Shoots were dried in oven at 75C for 3-5 days.

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Chapter two.

Effects of Topping on Canopy Growth and Tuber Yield of Potato (*Solanum tuberosum* L.)

Abstract

Seed tubers of 'Yukon Gold' (*Solanum tuberosum* L.) exhibit strong apical dominance, resulting in relatively low stem emergence (low stem density). Cutting seed tubers to overcome apical dominance in 'Yukon Gold' results in irregular, uneven stem emergence. Therefore, experiments were established in 1992, 1993, and 1994, to evaluate the effects of topping on canopy growth and tuber yield of 'Yukon Gold'. Two separate experiments were conducted in 1994 to evaluate the effect of topping on canopy growth and tuber yields of 'Kennebec', 'Superior', and 'Yukon Gold'. Topping during the first week of emergence produced uniform plant stands and increased yields of US No. 1 tubers by 20, 16, and 15% and large tubers ($\geq$6.4 cm diameter) by 340, 64, and 83% in 1992, 1993, and 1994, respectively, compared to control plants. Yield of US No. 1 tubers in $t \cdot ha^{-1}$ were 42.3 and 35.2 in 1992; 40.4 and 34.8 in 1993; and 33.7 and 29.3 in 1994 for topped and control plants, respectively. Results obtained in 1994 showed that the benefits derived from topping were not restricted to 'Yukon Gold', as average yields of US No. 1 tubers for 'Kennebec', 'Superior' and 'Yukon Gold' increased by approximately 10% following topping. Weekly measurements of leaf area index (LAI) and tuber yield of 'Yukon Gold' in 1994 showed that increased tuber yields

from topping were positively correlated with number of branches and leaves per plant, and leaf area duration (LAD). Topped plants appeared greener and flowered later than control plants.

Introduction

Potato (*Solanum tuberosum* L.) is the fourth most important crop in the world after rice, wheat, and maize (Beukema and Van der Zaag, 1990; Hawkes, 1992; Spooner and Bamberg, 1994). Allen and Scott (1992) reported that potential yield of potato tubers is between 100 and 120 metric ton per hectare. Results obtained under experimental conditions in the United States have shown that the average yields of US No. 1 tubers vary from 15 (McKeown, 1990b) to 63 $t \cdot ha^{-1}$ (Rykbost and Maxwell, 1994).

It has been shown that under adequate water, mineral nutrition, and pest control, potato tuber yield under temperate climates is limited mainly by efficiency of radiation interception by the canopy (Allen and Scott, 1992; Bouman et al., 1992; Haverkort et al., 1991). Despite the importance of canopy in determining tuber yields in potato, little research has been conducted to improve tuber yield through change in canopy distribution and form. Research conducted to improve tuber yield in potato has focused mainly on improvement of cultural practices and breeding for suitable cultivars (Beukema and Van der Zaag, 1990; Harris, 1992).

Seed tubers of some of the recently introduced yellow-flesh cultivars such as 'Yukon Gold' exhibit strong apical dominance (Chase et al., 1989; McKeown, 1990a,b).

After emergence, the terminal buds reimpose apical dominance on the rest of the canopy leading to erect stem growth habit and production of relatively few secondary branches (Johnston and Rowberry, 1981). Chase et al. (1989) and McKeown (1990b) have suggested that suppressed canopy growth may contribute to reduced tuber yields of 'Yukon Gold'.

Topping of terminal buds soon after emergence would break apical dominance and may promote earlier branching and lead to increased photosynthetic efficiency of the canopy and greater tuber yields. The objectives of this study were to investigate (a) the effects of topping (cutting 2-3 cm of apical buds of each stem) at five weeks after planting (approximately 80% plant emergence) on canopy growth, tuber bulking rate and yield of 'Yukon Gold'and (b) the effects of topping on canopy growth and tuber yields of 'Kennebec', 'Superior', and 'Yukon Gold'.

Materials and Methods

Field studies were conducted in 1992, 1993, and in 1994 at the Virginia Polytechnic Institute and State University Kentland Farm, Blacksburg. Soil type was a Hyter loam (fine-loamy, mixed, mesic ultic, Hapludalf) with 2.7% slope and pH values of 7.1, 7.2, 6.8 in 1992, 1993, and 1994, respectively.

Propagation materials consisted of a mixture of whole and fresh-cut seed pieces of 'Yukon Gold' each weighing between 70 and 80 g in 1992, 1993, 1994. Whole seed pieces of 'Yukon Gold' weighing 80 and 100 g and whole seed pieces of 'Kennebec', 'Superior', and 'Yukon Gold' weighing between 90 and 110 g were planted in the second and third experiments in 1994. Seed pieces of 'Superior' and 'Yukon Gold' were obtained from Canada (Agriculture Canada, Montreal) and seed pieces of 'Kennebec' were supplied by Green Ridge Farms Inc. (Fort Fairfield, Maine).

Each year, the experimental design was a randomized complete block with four replications. Treatments during each year were untopped (control) and topped. Equal portions of each plot were either left intact (control) or topped by excising 2 to 3 cm of the terminal shoots. Because stem emergence in potato is not uniform, normally occurring over a 2 to 3 week period, topping was done on two dates- the majority (approximately 80%) of emerged stems were topped at 5 weeks after planting (WAP) and the remaining later-emerged stems were topped at 6 WAP.

Seed pieces were treated with manganese ethylene bisdithiocarbamate (maneb) at the rate of 0.08 kg a.i/100 kg seed and stored at room temperature for 2 days in 1992 and 1993 or for 4 days in 1994 before planting. Spacing of 91 cm between rows and 20 cm within the row was used in all experiments. Experiments were planted on 18 April in 1992 and on 20 April in 1993 and 1994. Three-row plots measuring 5 m long were used in 1992, 1993, and 1994 for the experiments involving cultivars in 1994. Three rows each measuring 6.1 m long were used for the second experiment of 'Yukon Gold' in 1994 due to periodic sampling of plants. Granular fertilizer consisting of 101N-43P-84K in 1992 and 1993 and 101N-86P-168K $kg \cdot ha^{-1}$ in 1994 was incorporated in the furrow bottoms prior to planting. Weed control was done by pre-emergence application of a mixture of 2-chloro-N-(2-ethyl-6-methylphenyl) acetamide (metolachlor) at 1.96 kg a.i·ha^{-1} and 3-(3,4-dichlorophenyl)-1-methoxy-1-methylurea (linuron) at 0.84 kg a.i·ha^{-1}. Diseases and insect control and other cultural practices were performed as recommended for white potato cultivation in Virginia (Baldwin et al., 1992).

In 1994, four plants from each replication were selected at random and harvested weekly beginning from the date of topping (5 WAP) and continued for twelve weeks (17 WAP). Total leaf area (cm^2) and number and weight of tubers were determined at each harvest. Leaves were collected in paper bags and taken to the laboratory then sprinkled with cold water and kept in the refrigerator to prevent them from drying. Leaf area was determined by LI-300 portable area meter (LI-COR, Lincoln, NE). Leaf area index (LAI) was calculated by dividing total leaf surface area by the surface area occupied by plants (Gardner et al., 1985; Hay and Walker 1989). Leaf area duration (LAD) was calculated by multiplying average LAI by total number of days taken from emergence to the time of vine death (Allan and Scott, 1992).

Number of main stems per plant, number of plants in flower, number of branches, and number of leaves per plant were counted each year from plants harvested after 6 weeks from the initial date of topping (10 WAP). Stems that originated directly from each seed piece were counted as main stems (Allen and Wurr, 1992; Kleinhenz and Bennett, 1992).

Tubers from ten plants per replication were harvested after 151, 133, and 127 days from the date of planting in 1992, 1993, and 1994, respectively, graded according to United States Department of Agriculture (USDA) Standards (USDA, 1991), counted, and weighed. Ten large tubers from each replication were cut with a knife and assessed for the presence of hollow heart (Nelson and Thoreson, 1986).

For each factor measured, data were analyzed across years by analysis of variance (ANOVA) (Gomez and Gomez, 1984; SAS, 1988). The two experiments conducted in 1994 were analyzed separately by analysis of variance (ANOVA) (SAS, 1988). The relationships between number of leaves per plant, number of branches per plant, and leaf area duration (LAD) with yield of US No. 1 tubers were determined by Pearson Correlation Coefficients (PROC CORR) (SAS, 1988). Means from each treatment were separated by Tukey's HSD test ($P \leq 0.05$) according to (SAS, 1988). Graphs were drawn by CoPlot and CoDraw (CoHort Software, Minneapolis, MN).

Results

Except for yield of large tubers (Table 3), there were no year x topping interactions and thus the rest of the data wil be presented as main effects.

Year effects. Number of main stems·ha^{-1} was not significantly influenced by year (Table 4). Percent plant emergence was greater in 1992 and 1993 than in 1994 (Table 4). Highest number of total tubers were produced in 1992 followed by 1994 and least number of tubers were produced in 1993 (Table 4). Yield of US No. 1 and average weight per tuber were higher in 1992 and 1993 than in 1994 (Table 4).

Topping effects. Percent plant emergence and number of main stems per plant were similar for control and topped plants (Table 4). Total number of tubers ($\geq$ 2.5 cm diam) was greater for control plants (Table 4).

Topping increased yield of US No. 1 and average weight of marketable tubers each by 16% (Table 4). Yields of large tubers ($\geq$ 6.4 cm diam) increased by 340, 64, and 83% after plants were topped in 1992, 1993, and 1994, respectively (Fig. 5). In 1994, topped plants produced more branches and leaves than control plants (Table 5). Leaf area duration (LAD) was longer for topped than control plants (Table 5). Pearson Correlation Coefficients for the relationships between yield of US No. 1 and numbers of branches and leaves per plant, and leaf area duration (LAD) were 0.90, 0.86, and 0.95, respectively (Table 5). Thirty percent of control plants had flowered after 6 weeks from the initial date of topping (10 WAP) in 1994 compared to 10% for topped plants (Table 5). Percent hollow heart in large tubers was similar for topped and control plants (Table 5).

The average leaf area index (LAI) for control and topped plants taken weekly for a period of 12 weeks after the date of topping are shown in Fig. 6. At the time of topping control and topped plants had average LAI values of 0.5 and 0.6, respectively. LAI for control plants increased at an average rate of 1.2 per week within the next five weeks reaching a maximum value of 5.8 by the end of fifth week (Fig. 6). LAI for topped plants increased at the rate of 1.4 per week during the six weeks following topping and reached a maximum value of 6.2 at the end of the sixth week (Fig. 6). Average LAI for control plants declined rapidly beyond the fifth week following the date of topping and by the end of eighth week, control and topped plants had LAI values of 1.8 and 3.9, respectively (Fig. 6). At the end of the twelfth week topped plants were still maintaining a LAI value of approximately 0.4 while control plants had senesced (Fig. 6).

Between the first and the second week following topping the average tuber bulking rate for control plants was 1.5 $t \cdot ha^{-1} \cdot wk$ while that of topped treatments was 1.2 $t \cdot ha^{-1} \cdot wk$ (Fig. 7). Between the third and sixth week after topping, however, tuber bulking rate of topped plants increased to 4.8 compared to 5.8 for control plants. Tuber bulking rate of control plants declined from 3.7 to 0.1 between the seventh and the eleventh week after the date of topping compared to 4.9 to 0.6 for topped plants. By the end of the twelfth week after the date of topping, the tuber bulking rates for control and topped plants had declined to 0 and 0.3, respectively (Fig. 7).

Cultivar x topping effects, 1994. Results obtained after six weeks from the date of initial topping in 1994 showed that 'Kennebec', 'Superior', and 'Yukon Gold' had produced similar numbers of branches and similar numbers of tubers per plant (Table 6). At that stage, however, 'Kennebec' had greater number of leaves per plant and had produced greater leaf area index (LAI) than 'Superior' or 'Yukon Gold' (Table 6).

The average tuber yields per plant at 6 weeks after topping (WAT) were highest for 'Superior' followed by 'Yukon Gold', and least for 'Kennebec'. 'Superior' and 'Kennebec' produced greater percentage of plants in flower than 'Yukon Gold' (Table 6). Seventy-four percent of plants from control treatments were in flower at this time compared to 7% from topped treatments (Table 6). Total tuber yield per plant for control plants were 76% higher than topped plants (Table 6).

Data obtained at the time of final harvest showed that cultivar did not influence yield of US No. 1 tubers (Table 7). Yields of US No.1 were 34.6, 31.3 and 32.6 $t \cdot ha^{-1}$ for 'Kennebec', 'Superior', and 'Yukon Gold', respectively. Average weight per tuber was greater for 'Kennebec' than for 'Superior' and 'Yukon Gold' (Table 7).

'Kennebec and 'Superior' produced greater number of total tubers and greater number of main stems per hectare than 'Yukon Gold' (Table 7). Greater percentage of plant emergence was recorded for 'Superior' than for 'Yukon Gold' or 'Kennebec'. 'Yukon Gold' produced 40 and 6 fold greater percentage of large tubers (208-254 g) with hollow heart than 'Superior' or 'Kennebec', respectively (Table 7).

Averaged over cultivars, yield of US No. 1 tubers was 10% higher and tuber weight was 15% higher in topped than in control plants (Table 7). Topping did not influence number of main stems and number of total $tubers \cdot ha^{-1}$, percentage of large tubers with hollow heart, or percent plant emergence. Interaction effects between topping and cultivar were not significant for all variables tested (table 6 and 7).

Discussion

In this study, yield of US No. 1 tubers, number of branches and leaves per plant of the three cultivars and leaf area duration (LAD) of 'Yukon Gold' increased after topping. There were strong positive correlations between yield of US No. 1 tubers and number of branches (r=0.90***), number of leaves (r=0.86***), and leaf area duration (LAD) (r=0.95***) for 'Yukon Gold' suggesting that increase in canopy size and longevity after topping contributed to increased tuber yields. Hossain and Rashid (1992) and Dhingra et al. (1980) reported increased tuber yields and increased canopy size following topping as was recorded in this study. Increase in canopy size following damage of terminal buds has been reported in other crop plants (Maschinski and Whitham, 1989; Trumble et al., 1993).

Removal of apical dominance by topping increased branching, resulting in enhanced rate of canopy development (Fig. 6). Although rate of canopy closure was not measured in our studies, visual observations indicated that topping resulted in earlier and more uniform spatial distribution (ground cover) of potato leaf canopy, which in turn reduced the intensity of shading. Shaded leaves reduce plant growth potential and crop yield because the photosynthates they produce is only sufficient for their maintenance (Gardner et al., 1985; Olensinski et al., 1989; Perumal et al., 1989; Trumble et al., 1993). By delaying and reducing the intensity of shading, topping improved solar radiation utilization possibly leading to increased net assimilation rate (NAR). Other researchers have shown increased NAR with several different plant species when practices like topping, disbudding, or partial defoliation were used (Mayoral et al., 1991; Martinez-Carrasco et al., 1991; Yamashita and Fujino, 1986).

Topped Plants were noticeably greener and senescenced later than untopped plants, perhaps resulting from less number of shaded leaves and enhanced NAR. Research conducted in several plant species has shown that chlorophyll content, integrity of chloroplasts (Yamashita and Fujino, 1986; Mayoral eta al., 1991), and amount of photosynthesis (Carmi and Koller, 1979; Mayoral et al., 1991; Yamashita and Fujino, 1986) increased after topping. Apparently, during early tuber bulking (5 to 10 weeks after topping) (WAT), more photosynthates were invested to stimulate plant growth and maintain the integrity of potato leaves in topped plants than were used in control plants. This mid-season energy investment resulted in increased LAD and yield of US No. 1 tubers for topped plants. From 4 to 12 WAT, the tuber bulking rate ($t \cdot ha^{-1} \cdot wk$) was highest in topped plants (Fig. 7). At the end of 12 WAT the tuber bulking rate of topped plants was 0.3 $t \cdot ha^{-1} \cdot wk$ compared to 0 t·ha-1·wk for control plants, indicating that the period (duration) of tuber bulking was longer in topped plants. Leaf area duration (LAD), as measured by maintenance of LAI (Fig. 6), and LAI days (Table 5) was highest also in topped plants. Apparently, in topped plants, the combination of enhanced leaf photosynthetic efficiency (increased NAR) from increased branching and reduced leaf shading and improved LAD resulted in increased tuber bulking rate and duration, leading to increased yields of US No. 1 and large tubers.

Old leaves export the greatest amount of photosynthates to storage organs, like potato tubers (Sonnewald and Willmitzer, 1992). Therefore, increased LAD as a result of topping possibly contributed to greater tuber yields through increase in average leaf age of the canopy. Other researchers have reported decreased rate of leaf senescence after plants were topped (Carmi and Koller, 1979; Colbert and Beever, 1981) and increase in potato tuber yields as a result of increase in LAD (Allen and Scott, 1992; Nobel, 1992; Wolf, 1993; Zrust and Cepl, 1991). Topping delayed time of flowering and this might have contributed to increased LAD, since it has been shown that plants maintain leaves for a longer period when flowering was prevented or postponed (Crafts-Brandner and Egli, 1987; Thomas and Stoddart, 1980). Several researchers have shown that cytokinin increase in various plant species after topping (Colbert and Beever, 1981; Venkatarayappa et al., 1984), resulting in decreased rate of senescence (increased LAD) (Venkatarayappa et al., 1984; Smart 1994). Possibly, increased LAD after topping in this study might have resulted from increased cytokinins content in the shoots. Topping increased tuber yields of 'Kennebec' and 'Superior' in addition to 'Yukon Gold', suggesting that it can be used by growers as a cultural practice to improve tuber yields of potato cultivars with different growth habits.

Total number of tubers decreased following topping in this study. However, Dhingra et al. (1980) reported that topping increased number of tubers in four cultivars. Hossain and Rashid (1992) also showed increased tuber set from topping. Topping removed terminal buds and young expanding leaves, which are the source of stimulus required for tuber initiation (Cutter, 1992; Ewing and Struik, 1992; Koda et al., 1991), and this might have contributed to decrease in total number of tubers produced. Physiological age of seed tubers affects the stage and period over which tuber initiation occurs (Ewing and Struik, 1992, Firman et al., 1991a,b). In our studies, the seed tubers were physiologically "old" at planting, resulting in an early and abbreviated tuber initiation period (Fig. 7). Physiologically "young" tubers might have been used by Dhingra et al. (1980) and Hossain and Rashid (1992), since their studies were conducted in tropical climates, which typically use short-term storage and therefore physiologically young seed tubers for planting. Topping under those conditions apparently enhanced and/or extended tuber initiation, resulting in increased total tuber set. Possibly, our yield increases from topping would have been greater if physiologically younger seed tubers were used and/or topping would have been delayed until after full tuber set had occurred.

Greatest increase in yield of US No. 1 and large tuber yields observed after topping in 1992 compared to 1993 and 1994 might have been due to a combination of moderate temperatures and well distributed rainfall, which resulted in a longer growing season (151 days) in 1992 compared to 133 and 127 days in 1993 and 1994, respectively. Allen and Scott (1992) reported that early planting of potatoes and longer growing season increased tuber yield. Therefore, higher yield of US No. 1 tubers and average weight per tuber in 1992 and 1993 compared to 1994 was possibly due to early plant emergence and longer growing season.

Increase in yield of US No. 1 tubers by between 10 and 20% after topping resulted from a combination of increased leaf area duration and tuber bulking period. These results were in agreement with the suggestion made by Allen and Scott (1992), that most agronomic treatments fail to increase potato tuber yield because they fail to delay senescence, even though they may increase canopy size.

Table 3. Summary of analysis of variance indicating source effects on plant emergence, number of main stems, total tubers, US No. 1, large tubers, and average weight per tuber of 'Yukon Gold', 1992-1994.

Source	df	P-value					
			Number·ha^{-1}		Tuber yield·ha^{-1}		
		Emergence	Main stems	Total tubers	US No. 1	Large	Average wt /tuber (g)
Year (Y)	2	0.0057	0.1949	0.0001	0.0012	0.0003	0.0008
Error a	6						
Topping(T)	2	0.0942	0.6635	0.0001	0.0001	0.0001	0.0001
Y x T	2	0.8431	0.5107	0.0514	0.2159	0.0001	0.2206
Error b	9						
Block	3						
Total	23						

Table 4. Percent plant emergence, number of main stems and total tubers/ha, yield of US No. 1 and average weight per tuber of 'Yukon Gold' as influenced by year and topping.

Treatment	Emergence (%)	Main stems $\cdot ha^{-1}$ x 1000	Total tubers[z] $\cdot ha^{-1}$ x 1000	Marketable yield: US No.1[z] ($t \cdot ha^{-1}$)	Marketable yield: Average wt (g)
Year					
1992	92a[y]	91.4a	511.4a	39.6a	178.6a
1993	91a	86.0a	298.6c	36.7a	188.5a
1994	83b	97.1a	361.1b	32.0b	136.8b
Topping					
Control	87a	90.5a	473.3a	33.5b	154.7b
Topped	91a	92.4a	345.0b	38.8a	179.8a

[y]Mean separation within columns for each main effect by Tukey's HSD test, $P \leq 0.05$. Year x topping interactions were not significant.
[z]Tuber sizes: total, $\geq$ 2.5 cm; US No. 1, $\geq$4.8 cm diameter.

Table 5. Number of branches and leaves/plant, leaf area duration, and number of plants in flower at six weeks after the date of topping, number of large tubers with hollow heart, and Pearson Correlation Coefficients for 'Yukon Gold', 1994.

Variable	Control	Topped	Pearson Correlation Coefficient (r)	Treatment effect
Branches/plant	4.9	11.0	0.90	***
leaves/plant	68.4	195.2	0.86	***
leaf area duration (LAI x days)	384.0	525.3	0.95	***
Plants in flower (out of 40)	12.0	4.0	-	***
Tubers with hollow heart (out of 40)	21.2	19.2	-	NS

NS, ***, nonsignificant or significant at $P \leq 0.001$, respectively.

Table 6. Total number of branches, leaves, and tubers per plant and percentage of plants in flower at 6 weeks after topping as influenced by cultivar and topping, 1994.

Treatment	Number/plant			Leaf area index (LAI)	Tuber yield (g/plant)	Plants in flower (out of 40)
	Branches	Leaves	Tubers			
Cultivar						
Kennebec	8a[z]	123a	14a	3.8a	63c	12.8a
Superior	9a	108b	18a	3.2b	171a	16.0a
Yukon Gold	8a	104b	16a	3.6b	124b	8.8b
Topping						
Control	5b	109b	18a	4.4a	218a	29.6a
Topped	13a	135a	15a	3.9b	124b	2.8b

[z]Mean separation within columns for each main effect by Tukey's HSD test at $P \leq 0.05$. Cultivar x topping interactions were not significant.

Table 7. Total number of tubers, yield of US No. 1 tubers, average weight per tuber, main stems/ha, percent emergence, and percentage of large tubers with hollow heart as influenced by cultivar and topping, 1994.

Treatment	Total tubers[z] $\cdot ha^{-1}$ x 1000	Marketable: US No.1[z] ($t \cdot ha^{-1}$)	Marketable: Average wt (g /tuber)	Main stems $\cdot ha^{-1}$ x 1000	Emergence (%)	Hollow heart (%)
Cultivar						
Kennebec	338a[y]	34.6a	233a	252a	84b	7b
Superior	316a	31.3a	186b	264a	97a	1b
Yukon Gold	260b	32.7a	201b	180b	87b	40a
Topping						
Control	348a	31.2b	190b	252a	91a	15a
Topped	318a	34.2a	218a	204a	88a	17a

[y]Mean separation within columns for each main effect by Tukey's HSD test at $P \leq 0.05$. Cultivar x topping interactions were not significant.
[z]Tuber sizes: Total, $\geq$ 2.5 cm ; US No. 1, $\geq$4.8 cm diameter.

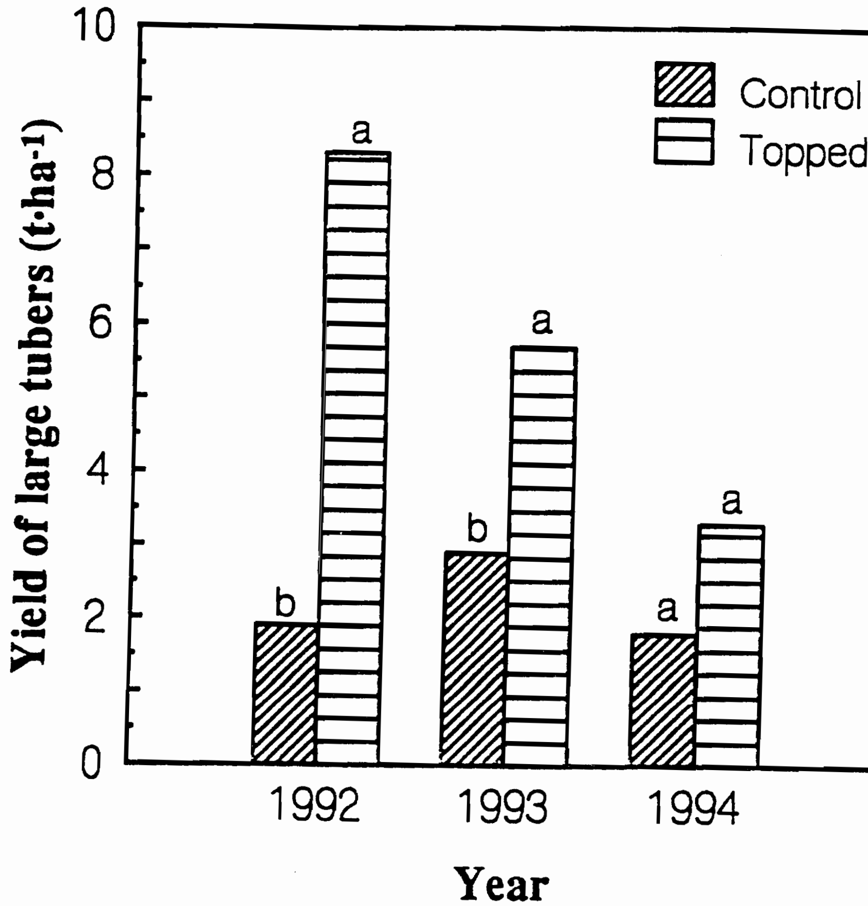

Fig. 5. Yield of large tubers of control and topped plants of 'Yukon Gold' in 1992, 1993, and 1994. Tubers were harvested at 22, 19, and 18 weeks after planting in 1992, 1993, and 1994, respectively. For each year, letters above the bars represent mean separation by Tukey's HSD test ($P \leq 0.05$).

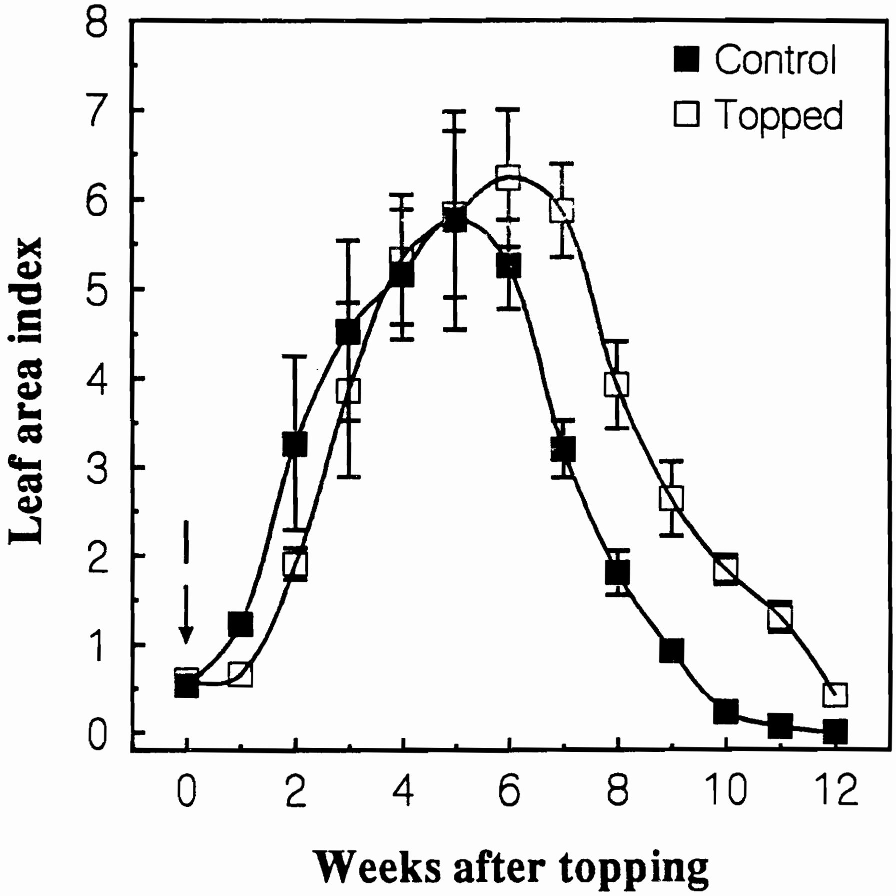

Fig. 6. Leaf area index of control and topped plants of 'Yukon Gold' between the date of topping and after 12 weeks later. Plants were topped at 5 weeks planting (arrow). Each value is an average of 8 plants. Vertical bars represent ± SE of the mean.

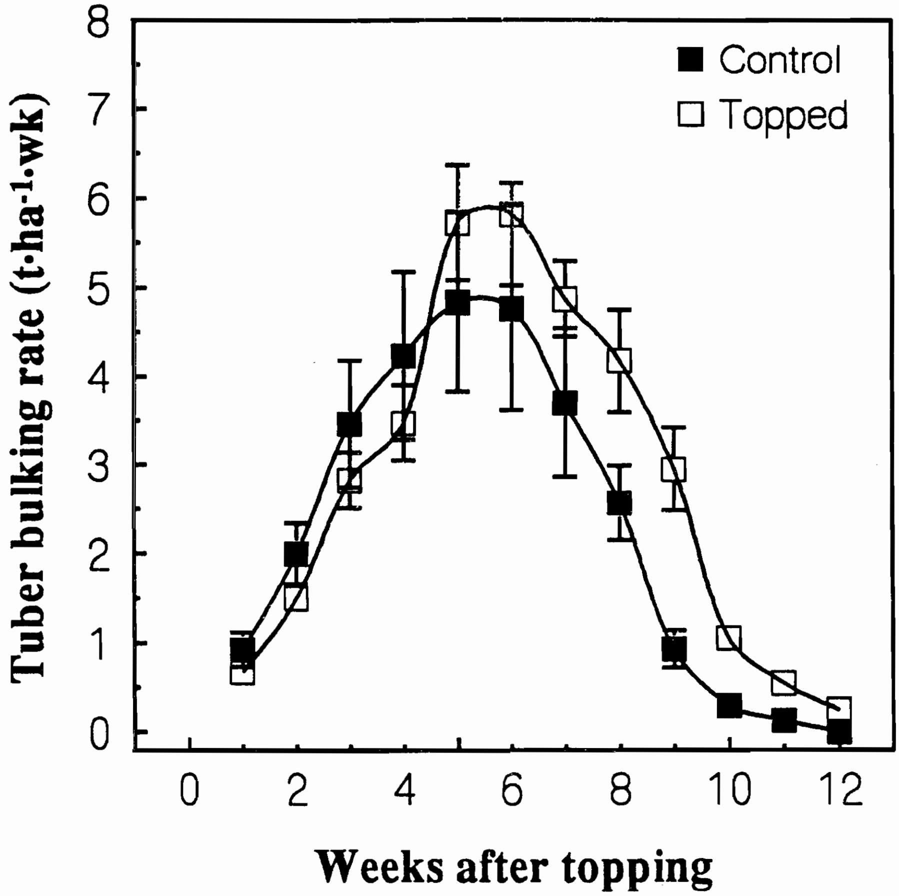

Fig. 7. Tuber bulking rate of control and topped plants of 'Yukon Gold' between 1 and 12 weeks after topping, 1994. Plants were topped at 5 weeks planting (arrow). Each value is an average of 8 plants. Vertical bars represent $\pm$ SE of the mean.

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Chapter three.

Effects of Topping and Stem Density on Canopy Growth and Tuber Yield of 'Yukon Gold'

Abstract

Seed tubers of 'Yukon Gold' potato (*Solanum tuberosum* L.) exhibit strong apical dominance, resulting in relatively poor stand establishment. After emergence, terminal buds reimpose apical dominance on developing shoots, leading to production of upright stems with few branches per plant. In 1993 an experiment was conducted to evaluate the effects of number of main stems per seed piece and in-row spacing on canopy growth and tuber yield of 'Yukon Gold'. Two experiments were conducted in 1994 to evaluate the effects of in-row spacing and topping on canopy growth, tuber yield, and tuber bulking rates of 'Yukon Gold'. Results obtained in 1993 showed that the interaction effects between in-row spacing and main stems per plant were not significant for tuber yields and canopy growth factors tested. Yield of US No. 1 tubers were significantly greater at 20, 25, and 30 cm than at 15 cm in-row spacing. Three main stems produced the highest yield of US No.1 tubers. Topping x in-row spacing interaction effects were significant in 1994 - at 15 cm, untopped plants produced the highest yield of US No. 1 tubers, while topped plants produced the highest yield at 20, 25, and 30 cm at both sites. Interaction effects might have been due to variations in tuber bulking rates since results obtained from one site showed that topped plants produced greater average tuber bulking

rates than control plants at 20, 25, and 30 cm but control plants had greater tuber bulking rate than topped plants at 15 cm in-row spacing.

Introduction

Research conducted in temperate climates has shown that under adequate water, mineral nutrition, and pest management, potato tuber yield is limited mainly by the amount of radiation intercepted by the canopy (Allen and Scott, 1992; Bouman et al., 1992; Haverkort et al., 1991).

Seed tubers of 'Yukon Gold', one of the recently introduced yellow-fleshed cultivar in United States and Canada (Johnston and Rowberry, 1981) exhibit strong apical dominance that results in uneven plant emergence (Chase et al., 1989; McKeown, 1990a,b). After emergence, the terminal buds reimpose apical dominance on the rest of the canopy leading to erect stem growth habit and production of relatively few secondary branches (Johnston and Rowberry,1981). Chase et al. (1989) and McKeown (1990a,b) suggested that suppressed canopy growth may contribute to reduced tuber yields for 'Yukon Gold'.

Topping of terminal buds soon after plant emergence can break apical dominance and promote early branching and greater photosynthetic efficiency of the canopy leading to increased tuber yields (Chapter two). Canopy size and leaf distribution could also be altered by different combinations of main stems per seed piece and in row spacings. No research has been conducted to evaluate the effects of in row spacing and number of main stems on canopy size and tuber yields of 'Yukon Gold'.

The objectives of this study were to investigate the main effects and interactions of: (a) in-row spacing and number of main stems per seed piece on canopy growth and tuber yields of 'Yukon Gold' and (b) in-row spacing and topping (cutting 2 to 3 cm of apical shoots of each stem) at one WAE (after approximately 80% plant emergence) on canopy growth, tuber bulking rate and yield of 'Yukon Gold'.

Materials and Methods

Experiments were established in 1993 and 1994 at the Virginia Polytechnic Institute and State University Kentland Farm, Blacksburg. Soil type was Hyter loam (fine loamy, mixed, mesic, ultic, Hapludalf) with 2.7% slope and pH values of 6.7 in 1993 and 6.8 in 1994. One experiment was conducted in 1993 while two experiments (Expt.I and Expt. II) were conducted in 1994. The first experiment in 1994 was also duplicated at two sites (IA and IB).

Certified seed of 'Yukon Gold' planted in both years were purchased from Canada (Canada Department of Agriculture, Montreal). Whole seed pieces weighing between 70 and 80 g were planted in 1993 and for Expt. IA and Expt. IB in 1994. Seed pieces weighing between 90 and 110 g were planted in Expt. II in 1994. Seed pieces were treated with manganese ethylene bisdithiocarbamate (maneb) at the rate of 0.08 kg a.i /100 kg seed and stored at room temperature for two days in 1993 and for four days in 1994 before planting.

Plot sizes consisting of three rows, each measuring 3.5 m long, were used in 1993 and for Expt. IA and Expt. IB in 1994. Three rows each measuring 6.10 m long were used for Expt. II in 1994 to allow for periodic sampling of plants. Granular fertilizer at the rate of 101N-43P-84K and 101N-86P-168K $kg \cdot ha^{-1}$ in 1993 and 1994, respectively was incorporated in the furrow bottoms prior to planting based on recommendation from the results of soil analysis test.

Weed control was done by pre-emergence application of a mixture of 2-chloro-N-(2-ethyl-6-methyl phenyl) acetamide (metolachlor) at 1.96 kg $a.i \cdot ha^{-1}$ and 3-(3,4-dichloro phenyl)-1-methoxy-1-methyl urea (linuron) at 0.84 kg $a.i \cdot ha^{-1}$. Pest control and other cultural practices were performed as recommended for white potato cultivation in Virginia (Baldwin et al., 1992).

Spacing of 91 cm between the rows by 15, 20, 25, and 30 cm within the row were used in 1993 and in 1994. Percent plant emergence was determined after 28 days from the date of planting (DAP).

1993. The experimental design was a randomized complete block with three replications. Treatments were factorial combinations of in-row spacing (15, 20, 25, and 30 cm) and number of main stems (1, 2, and 3) per plant. Before planting the seed pieces were desprouted by hand to one, two, or three sprouts (main stems) each. Plots were inspected weekly to ensure that no extra stems grew from the desprouted seed pieces.

Plants were harvested from 0.91 x 3.05 m^2 sections of the plots in each replication 133 DAP. Thererafter the tubers were graded according to the United States Department of Agriculture (USDA) standards (USDA, 1991), counted and weighed.

1994 (Expt. IA and IB). The experimental design was a split plot with four replications. Main plots were in-row spacing (15, 20, 25, and 30 cm) and sub plots consisted of untopped (control) verses topped. Equal portions of each plot were either left intact (control) or topped by excising 2 to 3 cm of the terminal shoots. Because stem emergence in potato is not uniform, normally occurring over a 3-4 week period, topping was done on two dates -the majority (approximately 80%) of emerged plants was topped at five weeks after planting (WAP) and the remaining later-emerged stems were topped at six WAP.

Plants were harvested from 0.91 x 3.05 m^2 sections in each plot 127 DAP. The tubers were graded and weighed as described for the 1993 plots. In 1994 (Expt. IA only), ten large tubers from each replication were cut open with a knife and assessed for the presence of hollow heart (Nelson and Thoreson, 1986).

1994 (Expt. II). In 1994 Expt. II was a randomized complete block design with four replications. Treatments were factorial combinations of in-row spacing (15, 20, 25, and 30 cm) and topping (untopped verses topped) at five WAP as previously described in Expt. I.

Beginning from the initial date of topping (five weeks after planting), four plants from each replication were selected at random and harvested weekly until the end of twelve weeks (16 WAP). Number and weight of tubers were determined at each harvest.

Number of branches, leaves, main stems per seed piece, and total leaf area were recorded from plants after harvesting at six WAE (10 WAP). Leaf area index (LAI) was calculated by dividing leaf area by the area occupied by plants as recommended by Gardner et al., (1985) and Hay and Walker, (1989). Stems that originated directly from the seed piece were counted as main stems based on recommendations of Firman et al. (1991) and Wurr et al. (1993).

Data analysis. Data obtained in 1993 and from Expt. II in 1994 were analyzed separately by analysis of variance (SAS, 1988). Data from Expt. I were analyzed across sites (IA and IB) by analysis of variance (Gomez and Gomez, 1984; SAS, 1988). Treatment means were separated by Tukey's HSD test ($P \leq 0.05$) according to SAS (SAS, 1988).

Results

In row spacing and main stems/plant effects, 1993. Yields of US No.1 ($t \cdot ha^{-1}$) were 25.4, 35.2, 38.3, and 35.1 for plants spaced at 15, 20, 25, and 30 cm within the row, respectively. Yield of small tubers (2.5-4.8 cm diam)$\cdot$/ha^{-1} was highest for plants spaced at 15 cm followed by plants spaced at 20 and 25 cm and least for plants spaced at 30 cm (Table 8). Plants spaced at 30, 25, and 20 cm produced higher yield of large tubers than plants spaced at 15 cm (Table 8).

Highest total number of tubers ($\geq$2.5 cm diam)$\cdot ha^{-1}$ was produced at 15 cm followed by 20 and 25 cm, and least total tubers were produced at 30 cm in-row spacing

(Table 8). In-row spacings of 30 and 25 cm produced higher number of branches/m^2 than plants spaced at 20 and 15 cm (Table 8).

Seed pieces with three main stems each produced higher yield of US No. 1 and small tubers than those with two or one main stem(s) each (Table 8). Yield of US No. 1 (t·ha^{-1}) was 41.1, 36.1, and 39.4 for plants with three and two main stems and one main stem, respectively (Table 8).

Plants with two main stems produced higher yield of large tubers than plants with one or three main stems (Table 8). Highest number of total tubers was produced by seed pieces with three main stems followed by plants with two main stems and least number of total tubers were produced by plants with one main stem (Table 8). Seed pieces with one and two main stem(s) produced more branches /m^2 than seed pieces with 3 main stems (Table 8). Interaction effects between in-row spacing and stems/plant were not significant for all variables tested (Table 8). Thirty, 25, and 20 cm in-row spacing produced higher yield of US No. 1 tubers/ha than 15 cm in-row spacing (Table 8).

In-row spacing and topping effects, 1994. Site and topping affected all the variables tested (Table 9). Yields of large and small tubers/ha was significantly affected by in-row spacing. In-row spacing, however, did not affect yield of US No. 1 and total number of tubers produced (Table 9). Interactions between site and spacing and between site, spacing, and topping were significant for total number of tubers and yield of large tubers but not for yields of US No. 1 and small tubers (Table 9).

During the initial five weeks after topping (WAT), tuber bulking (t·ha^{-1}·week) for control and topped plants spaced at 15 cm increased at the rates of 3.5 and 3.7, respectively to peak values of 5.0 for control and 4.5 for topped treatments (Fig. 8A). Within the next six WAT the tuber bulking rate for control and topped plants decreased rapidly reaching values of 1 and 0.3 at the end of the twelfth WAT (Fig. 8A).

Tuber bulking of control and topped plants spaced at 20 cm increased at the rates of 3.2 and 3.6 $t \cdot ha^{-1} \cdot week$ for the first five and six WAT respectively, reaching peak value of 5.3 for control and 6.2 for topped plants (Fig. 8B). Thereafter, tuber bulking rates for control plants declined more rapidly than for topped plants and by the end of the twelfth WAT had decreased to 0 compared to 0.4 for topped plants (Fig. 8B).

At 25 cm in-row spacing, the tuber bulking of control and topped plants increased at the rate of 3.6 and 3.9 $t \cdot ha^{-1} \cdot week^{-1}$ to maximum values of 5.3 and 6.2 at the end of five and six WAT, respectively (Fig. 8C). Tuber bulking rates for both treatments declined slowly within the period that followed and by the end of the twelfth WAT were 0.2 and 0.4 for control and topped plants, respectively (Fig. 8C).

At 30 cm in-row spacing, however, tuber bulking of control plants increased at the rate of 3.0 $t \cdot ha^{-1} \cdot week^{-1}$ compared to 3.3 $t \cdot ha\text{-}1 \cdot week^{-1}$ for topped plants to peak values of 5.1 and 5.3 after five and six WAT, respectively (Fig. 8D). Tuber bulking rates of both treatments declined slowly in the next period and by the end of the twelfth WAT were still averaging 0.4 and 0.8 for control and topped plants, respectively (Fig. 8D). Control plants spaced at 15 cm produced higher yield of US No. 1 tubers than topped plants in the first site in 1994 (Fig. 9). At the second site, however, yield of US

No. 1 tubers for control and topped plants spaced at 15 cm were not significantly different. At 20, 25, and 30 cm, yield of US No. 1 was higher for topped than for control treatments at both sites (Fig. 9).

Control plants spaced at 15 cm produced higher yield of large tubers ($\geq$6.4 cm in diam) than topped plants in both sites (Fig. 10). At 20 and 25 cm in-row spacings, yield of large tubers was similar for topped and control treatments at the two sites (Fig. 10). Topped plants spaced at 30 cm in-row produced higher yield of large tubers than control plants at the second site but yield of large tubers for control and topped plants was similar at the first site (Fig. 10).

Yield of small tubers ($t \cdot ha^{-1}$) was higher at the second than at the first site (Table 10). In- row spacings of 15 and 20 cm produced higher yield of small tubers than 25 and 30 cm (Table 10). Yield of small tubers was higher for control than topped plants (Table 10). Control plants spaced at 15 cm in-row produced higher total number of tubers/ha than topped plants at both sites (Fig. 11). At 20 cm in-row spacing, however, control plants had higher total number of tubers than topped plants at the first site but the total number of tubers for both treatments was significantly similar at the second site (Fig. 11). Total number of tubers for control and topped plants spaced at 25 and 30 cm in-row was similar at both sites (Fig. 11).

Results obtained from Expt. IA in 1994 showed that percent hollow heart for large tubers (234-271 g) was not affected by in-row spacing or topping (Table 11). Number of branches/m^2 were similar at the four in-row spacings (Table 12). Plants spaced at 15 cm produced the highest number of leaves/m^2 and greatest leaf area index (LAI) at the time of flowering followed by plants spaced at 20 and 25 cm and the least number of leaves/m^2 and least LAI were produced by plants spaced at 30 cm within the row (Table 12). At this stage, topped plants had produced higher number of branches and leaves/m^2 and LAI than control (Table 12). Interaction effects between in-row spacing and topping were not significant for all variable tested at this stage (Table 12).

Discussion

Control plants produced higher yields of US No. 1 and large tubers than topped plants at 15 cm in-row spacing. This yield trend was, however, reversed when plants were spaced at wider in-row spacings; topped plants produced higher tuber yield than control plants at 20, 25, and 30 cm. Control plants produced higher tuber bulking rate (3.5 $t \cdot ha^{-1} \cdot wk$) during the first five WAT compared to 2.7 $t \cdot ha^{-1} \cdot$week for topped plants (Fig. 8A), indicating that the differences in yields of US No.1 and large tubers for the two treatments were due to higher tuber bulking rate for control than for topped plants at 15 cm in-row spacing.

During the stage of linear tuber growth, rate of tuber bulking is limited mainly by the supply of photosynthates to the developing tubers (Allen and Wurr, 1992; Engels and Marschner, 1986b). In this study topped plants spaced at 15 cm in-row lodged and started to senesce earlier than control plants. This probably resulted from excessive inter-plant competition due to excessive shading within topped plants as a result of increased canopy size (higher number of branches and leaves/plant and higher LAI) compared to control plants (Table 6). Excessive rate of inter-plant competition at 15 cm for topped plants might have decreased photosynthate supply to the tubers leading to decreased tuber bulking rate and duration and decreased yield. Several researchers have shown that plants grown at closer stem densities senesced earlier than less crowded plants (Allen and Scott, 1992; Allen and Wurr, 1992; Almekinders, 1993).

Low inter-plant competition at wider in-row spacings might have contributed to decreased rate of plant senescence (higher LAI) at 20, 25, and 30 cm in-row spacings (Fig. 9). This, in turn possibly increased photosynthate supply to the tubers, resulting in higher yield of US No. 1 and large tubers for topped than control plants. Highest tuber yield (Fig. 9 and 10) and greater tuber bulking rates (Fig. 8C) obtained at 25 cm might have been due to more ideal inter-plant competition at 25 cm in contrast with shading at 20 cm and insufficient ground cover at 30 cm.

Researchers have shown that topping resulted in increased concentration of cytokinin in the xylem sap of plants (Colbert and Beever, 1981; Engels and Marschner, 1986a; Smart, 1994). Increased supply of cytokinin to potato plants resulted in increased rate of tuber bulking (Ahmed and Sagar, 1981; Engels and Marschner, 1986b; Koda, 1982). Therefore, the decrease in canopy senescence for topped plants spaced at wider in-row spacings contributed to increased tuber bulking rate possibly through improved supply of cytokinin to the leaves and tubers. Increased rate of plant senescence at 15 cm in-row spacing were possibly due to greater inter-plant competition for nutrients, cytokinin and light as Thomas and Stoddart (1980) reported that plants senesced early if they are grown under conditions that encouraged competition for light, nutrients, and growth regulators.

Topping removed terminal buds and young expanding leaves which are the source of stimulus required for tuber initiation in potato (Cutter, 1992; Ewing and Struik, 1992; Koda et al., 1991) and this might have contributed to decreased total number of tubers produced by topped plants at most in-row spacings.

Large tubers were tested for hollow heart in this study because they have been shown to be most susceptible to this physiological disorder (Nelson and Thoreson, 1986). Neither in-row spacing nor topping increased percent hollow heart in tubers. Researchers have shown that in-row spacing did not increase the incidence of hollow heart (Rex, 1990; Rex et al., 1989).

Significant interaction effects did not occur between in-row spacing and number of main stems per seed piece in 1993. These results disagreed with those of Siddique et al. (1987), who reported that increasing in-row spacing reduced tuber yields of 'Cardinal' potato when seed pieces contained one or three stems but had no effect when there were two stems. Increasing main stems per seed piece decreased number of branches/m^2 but increased yields of US NO. 1 and large tubers/ha, indicating that increased number of main stems per seed piece more than compensated for the reduced number of branches.

Highest yield of US No. 1 tubers were obtained from seed pieces containing three stems each. Similar results were obtained from research conducted in several potato cultivars by Allen and Wurr (1992) and Lemaga and Caesar (1990). Vecchio et al. (1991) and O'Brien and Allen (1992a) however, showed that tuber yields of potato plants were not affected by increase in stem density. Results obtained in this study indicated that the low average number of main stems (2.2 stems) produced by seed pieces of 'Yukon Gold' resulted in decreased tuber yield.

In addition to its effects on yield of US No. 1 tubers, variation in number of main stems per seed piece affected size distribution of tubers. Seed pieces containing two main stems produced higher yield of large tubers ($\geq$ 6.4 cm diam) than seed pieces containing three main stems or one main stem. These results suggested that profuse branching and higher LAI of single-stemmed plants did not result in increased yield of large tubers, while increased inter-plant competition at increased stem density (three main stems/plant) possibly reduced yield of large tubers. Yield of small tubers increased with increase in number of main stems per seed piece, possibly as a result of greater competition for photosynthates from increased tuber set per hectare.

Yield of US No. 1 tubers increased with increased in-row spacing in 1993. Several researchers reported similar results for other potato cultivars (Krishnappa, 1991; Rex et al., 1989; Rykbost and Maxwell, 1993; Sawicka and Skalski, 1992). Decrease in yield of US No. 1 tubers reported for other cultivars (Rykbost and Maxwell, 1993; Vecchio et al., 1991), however, were not observed in this study. Higher tuber yields at wider in-row spacings were mainly due to increase in tuber size since greatest number of tubers were produced by plants spaced 15 cm within the row. Research conducted with other potato cultivars showed that number of tubers$\cdot$ha^{-1} increased as plant density was increased (O'Brien and Allen 1992b).

In 1993, plants spaced at 30 and 25 cm produced greater number of branches/m^2 than plants spaced at 20 and 15 in-row. Several researchers have shown that the number of branches/plant for potato increased with increased in-row spacing mainly as a result of decreased inter-plant competition (Allen and Scott, 1992; Van Der Zaag et al., 1990). Plants spaced at 20, 25, and 30 cm within the row produced the same yield of US No. 1 tubers, indicating that increased amount of branching at 25 and 30 cm in-row spacing did compensate for fewer number of plants per m^2.

Results in this study showed that increasing the number of main stems per seed piece resulted in increased yields of US No. 1 and large tubers, suggesting that the low number of main stems produced by 'Yukon Gold' contributed to decreased tuber yield. Topping increased number of branches/m^2 but did not affect the number of main stems/ha, suggesting that topping removed apical dominance from shoots but failed to remove apical dominance from seed pieces. The study showed that topping increased yield of marketable tubers as a result of increase in leaf area duration and increase in tuber bulking period. Finally, the results showed that topped plants of 'Yukon Gold' should be spaced at 25 cm in-row in order to achieve maximum tuber yield per hectare.

Table 8. Yield of US No.1 and small tubers, total number of tubers, and number of branches of 'Yukon Gold' as influenced by in-row spacing and number of stems/seed piece, 1993.

Treatment	Yield ($t \cdot ha^{-1}$) US No.1[y]	Small	Large	Total tubers $\cdot ha^{-1}$ x 100	Branches/m^2
In-row spacing (cm)					
15	25.4b[z]	5.4a	2.6b	403a	26b
20	35.2a	3.7ab	4.7a	316b	29b
25	38.3a	2.5ab	5.6a	290b	33a
30	35.1a	1.4b	6.4a	253c	36a
Main stems/ plant					
1	39.4b	2.2b	2.8b	177c	38a
2	36.1b	2.6ab	6.1a	263b	35a
3	41.1a	4.6a	3.8b	343a	30b

[y]Mean separation within columns for each main effect by Tukey's HSD test at $P \leq 0.05$. Spacing x main stems interactions were not significant. [z]Tuber sizes: US No.1, $\geq$4.8 cm; small, 2.5-4.8 cm; large, $\geq$6.4 cm; total, $\geq$2.5 cm diameter.

Table 9. Summary of analysis of variance indicating source effects on total number of tubers and yields of US No. 1, large, and small tubers of 'Yukon Gold' (Expt. IA and Expt. IB), 1994.

		P-value			
		Total tubers $\cdot ha^{-1}$	Tuber yield		
Source	df		US No. 1	Large	Small
Site (ST)	1	0.0001	0.0001	0.0003	0.0001
Error a	3				
Spacing (SP)	3	0.5841	0.4651	0.0001	0.0001
ST x SP	3	0.0001	0.0001	0.0056	0.1305
Error b	9				
Topping (T)	1	0.0001	0.0001	0.0001	0.0001
ST x T	1	0.0001	0.8286	0.0235	0.9058
SP x T	3	0.0006	0.0001	0.0001	0.5830
ST x SP x T	3	0.0001	0.0661	0.0214	0.8594
Block	3				
Error c	33				
Total	63				

Table 10. Yield of small tubers of 'Yukon Gold' as influenced by site, in-row spacing, and topping (Expt. IA and Expt. IB), 1994.

Treatment	Yield of small tubers[z] ($t \cdot ha^{-1}$)
Site	
1	8.7b[y]
2	13.4a
In-row spacing (cm)	
15	13.3a
20	12.2a
25	9.6b
30	9.0b
Topping	
Control	12.0a
Topped	10.1b

[y]Means separation within column for each main effect by Tukey's HSD test at $P \leq 0.05$). There were no significant interactions among treatments. [z]Small tubers, 2.5-4.8 cm diameter.

Table 11. Number of tubers with hollow heart for 'Yukon Gold' (Expt. IA), 1994.

Treatment	Tubers with hollow heart (out of 40)
In-row spacing (cm)	
15	16.2a[z]
20	20.3a
25	20.8a
30	20.6a
Topping	
Control	21.2a
Topped	17.2a

[z]Mean separation within column for each main effect by Tukey's HSD test at $P \leq 0.05$. Topping x in-row spacing was not significant.

Table 12. Number of main stems, branches, and leaves per m^2, and leaf area index (LAI) of 'Yukon Gold' at 6 weeks after the date of plant emergence in the first site (Expt. II), 1994.

	Number/m^2		
Treatment	Branches	Leaves	Leaf area index (LAI)
In-row spacing (cm)			
15	35.2a[z]	1062a	5.8a
20	37.4a	995b	5.5b
25	41.3a	928b	5.4b
30	38.8a	839c	5.1c
Topping			
Control	27.2b	924b	5.2b
Topped	61.1a	1073a	5.9a

[z]Means within columns for each main effect by Tukey's HSD test at $P \leq 0.05$. Spacing x topping interactions were not significant.

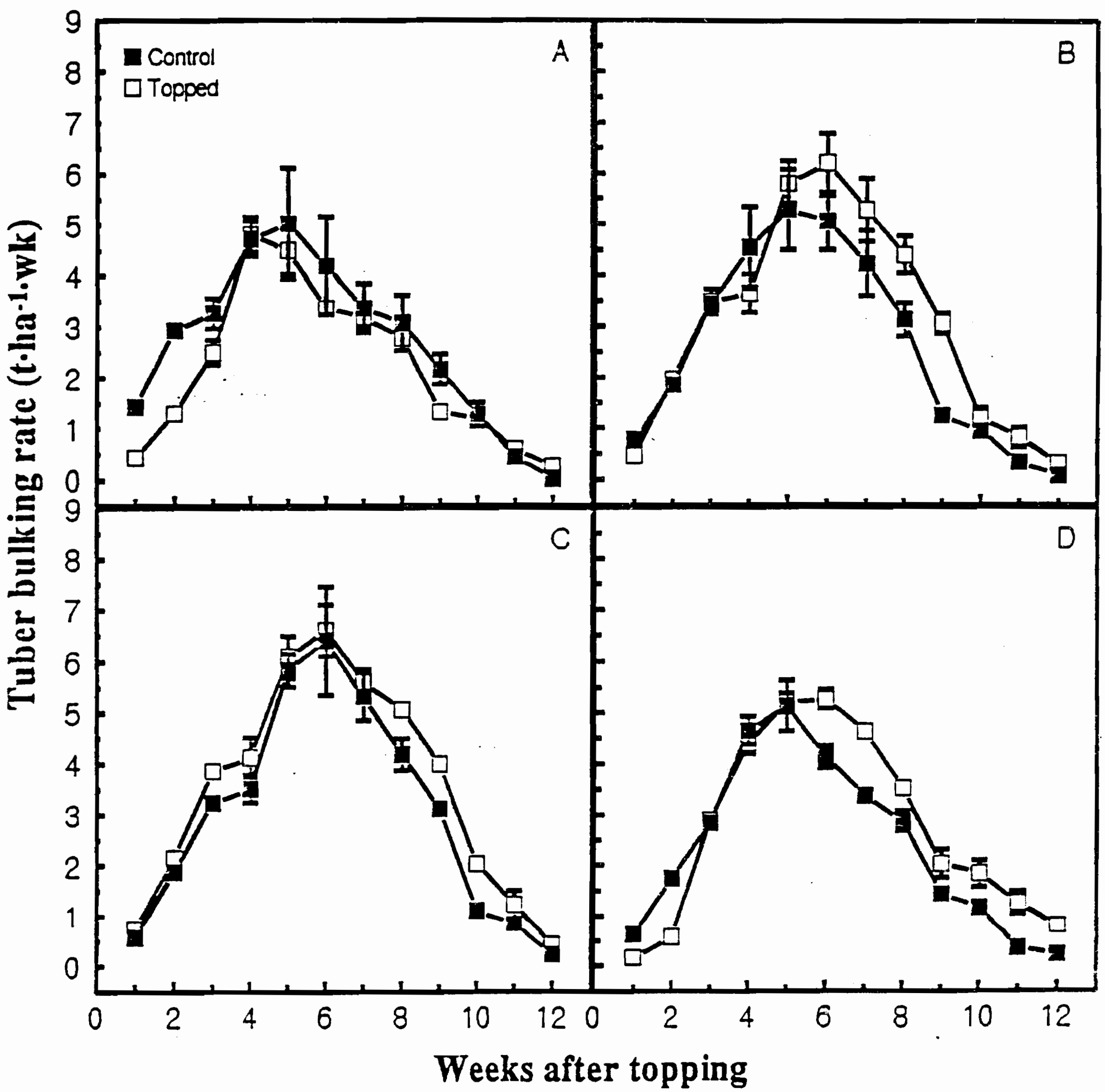

Fig. 8. Tuber bulking rate of control and topped plants of 'Yukon Gold' spaced at 15 (A), 20 (B), 25 (C), and 30 (D) cm within the row (Expt. I)B, 1994. Each value is an average of 8 plants. Plants were topped at 5 and harvested at 18 weeks after planting. Vertical bars for each point represent ± SE of the mean.

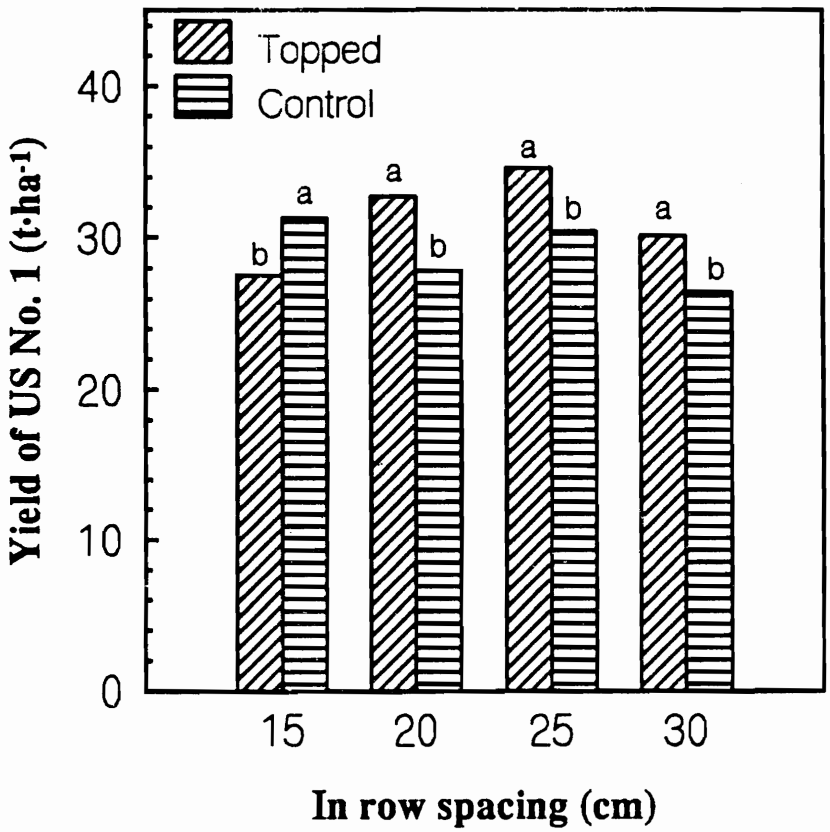

Fig. 9. Yield of US No. 1 tubers ($\geq$4.8 cm dia) of control and topped plants of 'Yukon Gold' spaced at 15, 20, 25, and 30 cm in-row (Expt. I), 1994. Letters above the bars represent mean separation by Tukey's HSD test at $P \leq 0.05$. Site x spacing interaction was not significant. Tubers were harvested at 18 weeks after planting. For each spacing, data are means of Expt. IA and Expt. IB.

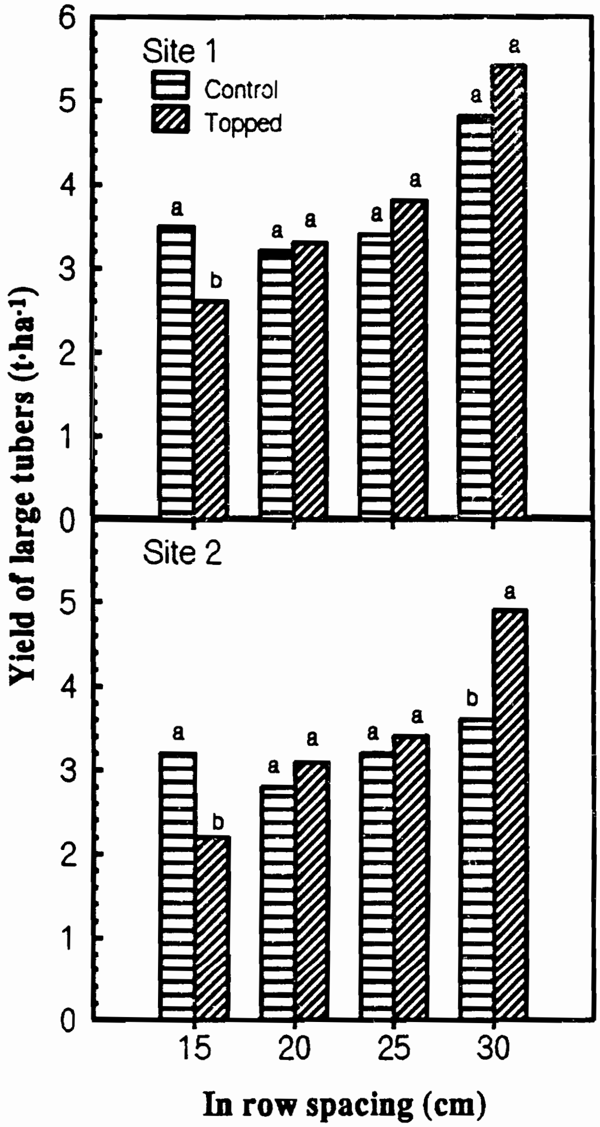

Fig. 10. Yield of large tubers (≥6.4 cm dia) of control and topped plants of 'Yukon Gold' spaced at 15, 20, 25, and 30 cm within the row at 2 sites, 1994. Tubers were harvested at 18 weeks after planting. For each site, letters above the bars represent mean separation by Tukey's HSD test at $P \leq 0.05$.

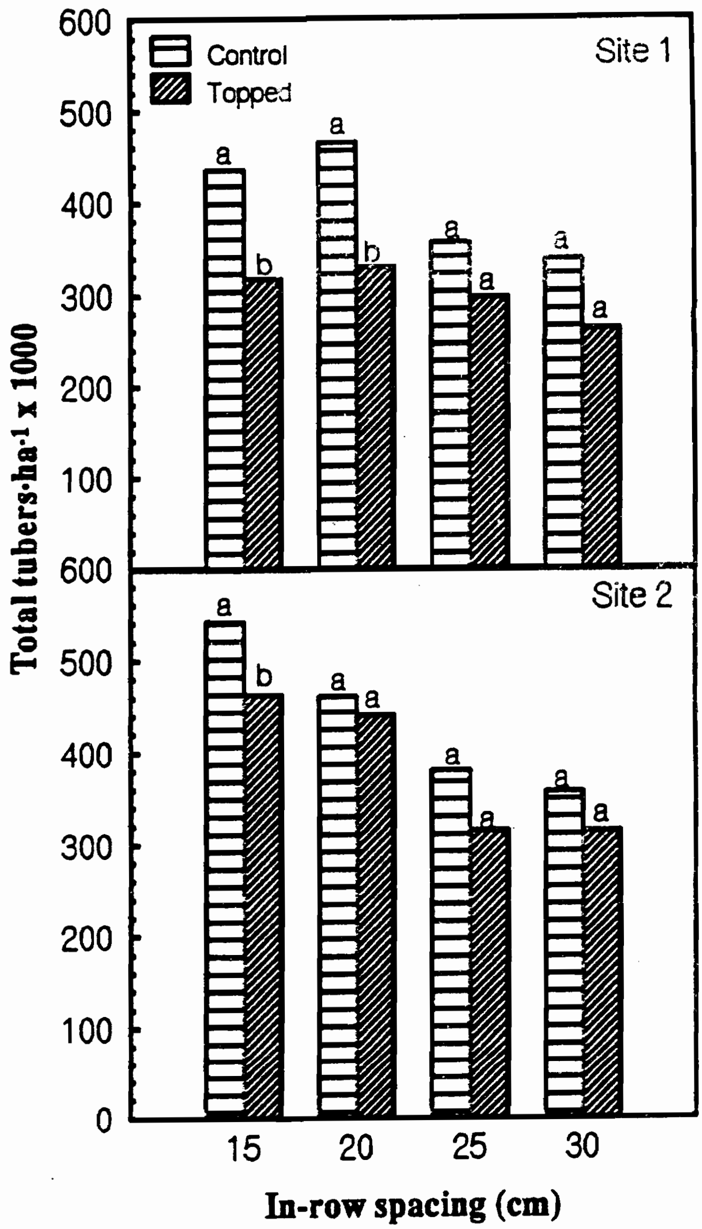

Fig. 11. Total number of tubers ($\geq$2.5 cm dia) of control and topped plants of 'Yukon Gold' spaced at 15, 20, 25, and 30 cm in-row at two sites, 1994. Tubers were harvested at 18 weeks after planting. For each site, letters above the bars represent mean separation by Tukey's HSD test at $P \leq 0.05$.

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Conclusions and Recommendations

Results from this study support the original hypothesis that the small, erect-growing canopy of 'Yukon Gold' limits tuber yield. Multiple experiments with 'Yukon Gold' showed that yield of US No. 1 and yield of large tubers were increased by topping, mainly due to stimulation of earlier, more extensive development, and longer duration of secondary branches, which in turn probably led to improved efficiency and duration of radiation interception by the canopy. Supportive single-year experiments using late-maturing cultivar with spreading canopy structure, such as 'Kennebec', and early-maturing cultivar with medium-size canopy, such as 'Superior' and 'Yukon Gold' showed that marketable tuber yields of all three cultivars were increased following topping.

These results showed that topping can be used to enhance tuber yields of potato cultivars with different growth habits. In depth studies will be required to elucidate the physiological factors responsible for tuber enhancement from topping, to explore possibility of using chemicals for topping, and to identify appropriate pre-planting tuber conditioning techniques that will delay physiological aging of seed tubers. Finally, research is also needed to determine the optimal planting dates and optimal growth stage for topping potato plants in order to achieve maximum tuber yield.

VITA

Okeyo James Ajuoga was born on August 21, 1953 on Rusinga Island, Homa Bay district, Kenya. He received his primary education at Kamasengere in Rusinga from 1964 to 1970. He then proceeded for secondary education in Mbita from 1971 to 1974.

He attended Egerton College, Njoro, Kenya from 1975 to 1978 and graduated with a Diploma in Horticulture (with Distinction). Thereafter, he joined the Ministry of Agriculture in April, 1978 and worked at the National Horticultural Research Station, Thika, and the National Pyrethrum and Horticultural Research Station, Molo, up until July, 1981.

He joined Egerton College and worked as a demonstrator from August, 1981 to September, 1985. From here, he continued his education at the University of Nairobi, Kenya in 1985 from where he received a B.S. degree in Agriculture in 1988. He joined Egerton University and worked as an Assistant lecturer in Horticulture from July, 1988 to December, 1989. In January, 1990 he entered graduate school at Virginia Polytechnic Institute and State University. He earned a Master of Science in Horticulture in August, 1992 and Ph.D. in September 1995. He is married to Ruphina Nyawade. They have four children; Ogaya, Nyawade, Bunge, and Obiero.

James Ajuoga Okeyo