THE USE OF SELECTED PLANT GROWTH REGULATORS FOR THE PRODUCTION OF SMALL WHOLE SEED POTATOES (SOLANUM TUBEROSUM L.)

by

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DEDICATION

To my parents, grandparents, and all relatives whose prayers remain priceless.

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ABSTRACT

Shongwe, Victor Dumisani Vikizitha. M.Sc., The University of Manitoba, December, 1988. The Use of Plant Growth Regulators for the Production of Small Whole Seed Potatoes (*Solanum tuberosum* L.). Major Professor: Dr M.K. Pritchard

Five plant growth regulators, gibberellic acid (GA), chlormequat (CCC), daminozide, ethephon, and ancymidol were evaluated in field trials for their potential to increase the number of seedsize tubers of Russet Burbank and Norchip potatoes. GA was applied at 90% emergence followed two weeks after by an application of one of the other growth regulators. Growth room studies were conducted to evaluate the effects of the individual growth regulators on plant and tuber development. On Norchip potatoes, GA seemed to promote a higher proportion of smallsize tubers four weeks after application compared with the control in field studies. In 1985, GA+daminozide and GA+CCC also increased the number of small tubers two weeks after application of the growth regulators in field studies. Four weeks after application of growth regulators, GA+CCC and GA+daminozide indicated a potential of promoting seedsize tubers on Norchip whilst GA+ethephon resulted in a higher number of tubers in general compared to other treatments. Final yield results showed that GA+daminozide and GA+ethephon were the most effective treatments in increasing the proportion of seedsize tubers although results were not statistically

significant. On Russet Burbank, GA+CCC as well as GA+ancymidol resulted in the highest yield of tubers in the seedsize range at the final harvest.

In 1986 field studies GA significantly reduced the proportion of largesize (>5cm diameter) tubers whilst indicating a potential of increasing seedsize tubers at the final harvest on Russet Burbank. The GA+CCC treatment was most effective in promoting a higher proportion of seedsize tubers (3-5cm diameter) in Russet Burbank. GA+ancymidol seemed to appreciably reduce tuber size as seen by its promotion of undersized tubers (<3cm diameter) on Russet Burbank. On Norchip, GA+ethephon and GA+CCC increased the proportion of seedsize tubers compared with the control or GA applied alone. In addition, these treatments also seemed to reduce the proportion of oversized tubers.

In the growth room studies, GA effectively increased plant height, stolon number and stolon length compared with the control and growth retardant treatments. On the other hand, the growth regulators reduced plant height and stolon elongation. Ethephon resulted in the greatest reduction of both stem and stolon elongation. All the treatments seemed to promote stolon tips. CCC was the best promoter of tubers (>6mm diameter) at days 28 and 35 of sampling. CCC application rate of 0.28g ai/l was the best in increasing small tubers. Ethephon was the next best treatment with a significant promotion of tubers at 28 and 35 days after treatment. GA alone initially resulted in no increase in tubers at the 21 and 28 day sampling, however at day 35 the treatment significantly increased small tubers compared with the control. Daminozide was the fourth most effective treatment with a significant increase in tubers compared with the control. There was no increase in the number of tubers resulting from ancymidol application in the growth room. At the time of final sampling there were still an appreciable number of stolon tips with tuber-bearing potential however not large enough to be designated as tubers. Hence CCC, ethephon, and GA were the best treatments in both growth room and field trials. Daminozide was good only in field trials in 1985 whilst ancymidol was only effective in the field trials.

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FOREWORD

This thesis is presented in the form of two manuscripts intended for publication either in the American Potato Journal or Potato Research.

INTRODUCTION

The potato is the fourth most widely grown food crop after rice, wheat and maize and it is fairly adaptable in a wide range of environmental conditions (Horton and Sawyer, 1985). At least one third of the total vegetable land area across Canada is occupied by potatoes. In Manitoba, at least 18,000 hectares are devoted to the crop and in excess of 80% of the total produce is used in the processing industry. Manitoba produces potatoes of reputably good processing qualities thus leading to the success of the chip, french-fry, and flaking industry in the province. The major french-fry processing cultivar grown is Russet Burbank, a high-yielding, late season, medium sized, oblong-shaped potato with shallow eyes. Norchip, a high yielding early maturing, white, shallow-eyed, upright cultivar has excellent chipping qualities.

Van der Zaag and Horton (1983) stated that the single most important factor in potato yields is the use of quality seed tubers. Horton and Sawyer (1985) further indicated that in South/Central America, Asia, and Tropical Africa, seed tubers could account for 30 to 50% of the total variable costs of production. The Atlantic provinces of Canada, New Brunswick and Prince Edward Island are the major seed production regions of the country. Quality standards in terms of health and grade are set by Agriculture Canada for the export market. Most North American growers have also established that the best seed is that produced in northern areas like Manitoba. Hence there is an increasing concern about the production of quality seed in terms of viability, health, appearance, and grade.

The conventional method of cutting seed potatoes before planting is still widely practised in Canada and most of North America. However such a method has several problems. The cutting procedure if done by hand is laborious and time consuming, whilst machine cutting is obviously more efficient, size and uniformity of the seed may be variable, and there may even be the total destruction of some eyes (buds) on the pieces. All this may affect the growth and final yield of the crop. Futhermore, the cutting procedures may allow disease transmission either through the blades themselves or in the soil once the protective skin has been severed.

Early experiments (Stuart et al.,1924) suggested the superiority in the yielding ability of plants from whole as opposed to cut seed. Other workers have stated that even though there might not be any direct yield advantage from whole seed plants, the gains from reduction of disease, handling, and storage of cut material may far outweigh whatever yield loss occurs. More recently, Andrew and Silva (1981) have shown that the yield variability due to stem number may be moderated by the use of whole seed. Andrew and Silva (1982) and Andrew et al., (1983) further indicated that the cutting of seed tubers might damage the eyes resulting in variable yields. They even reported increasing variability (CVs) with the increase in intensity of cutting.

Several approaches towards obtaining whole seed material have been known, for example increasing plant population although this may require certain adjustments in the seeding and other cultural practices. Grading out and using small seed tubers has also been attempted. Whilst in North America the use of cut seed is still widely practised, the use of various growth regulators for the production of whole seed is gaining popularity.

Local results by LaCroix and Adam (1983) have provided a basis for this study by suggesting an increase in the proportion of seedsize tubers as a result of applying GA and ethephon on Norland potatoes. On Russet Burbank potatoes, ethephon did not have desirable results hence a search for another chemical to be used on this cultivar was a further objective of this study. In addition, another cultivar, Norchip was used for the first time and several other growth regulators tested on both cultivars.

Field studies were conducted during the summers of 1985 and 1986 using Russet Burbank and Norchip. The treatments in the field consisted of GA alone or preceding selected growth retardant. A variety of growth components had to be evaluated to investigate some trends that might have a bearing on the final tuber yields. Growth room studies on Norchip were undertaken to investigate the exclusive effects of the growth regulators on general growth, and tuberization of potatoes under controlled environment with a view to help select the treatments which give the highest proportion of tubers.

LITERATURE REVIEW

WHOLE VS CUT SEED POTATOES

The productivity of a seed piece tends to decline with an increase in the number of cut surfaces (Andrew and Silva, 1982; Andrew et al., 1983). Hence one of the advantages of using whole over cut seed would be a gain in yields (Andrew et al., 1983). Using whole seed should eliminate diseases transmitted through the cutting procedures and reduce disease incidence due contact with soil pathogens on planting. Andrew et al. (1983) attributed the lower tuber yields obtained from multiple cuts to a high frequency of missing hills, delayed emergence (which could also be caused by disease), fewer mainstems per hill and a higher incidence of mechanical damage during cutting and planting operations.

Experiments by Roberts (1885) which compared the yield of plants from whole seed, medium-size cut, and single-eye seed cut from apical and basal ends, showed that whole seed plants had superior yield. Sanborn (1880) had also compared the relative merits of 1-eye, 2-eye, and 3-eye seed pieces, apical-end and basal-end pieces, as well as small and large whole seed tubers. Apical-end seed pieces had the highest yielding plants followed by stem-end pieces. Whole small seed ranked third, 3-eye pieces fourth, large whole seed fifth, and 2-eye seed sixth. Emery (1890, 1891) reported a significant increase in yield as a result of using whole seed as opposed to cut seed.

Contrasting results were obtained by Johnson (1892) who reported that large cut seed was superior to whole seed in terms of marketable product. Goff (1890) reported a larger yield of marketable tubers from 2-eye seed than from whole or halved tubers, but the total yield was highest from whole seed. Stubbs et al. (1890) found no difference in net yield between seed pieces of two or more eyes and large whole tubers. Moorkerji (1903) reported that when the same weights of cut seed and of whole seed were planted on a given area, the cut seed plants resulted in a higher overall yield. On the other hand, Smith (1909) reported an average 12% yield increase in favour of whole seed in a four-year trial of cut and whole seed productivity.

A summary of results by Aicher (1917) indicated that, total yield from whole tubers was 15.4% more than from cut seed. Cut tubers yielded 18% more marketable potatoes per acre than whole. Larger seed pieces also tended to produce more smallersize tubers. Welch (1917) reported that whole seed resulted in smaller-sized potatoes than when tubers were halved or quartered. Salaman (1922) stated that there is an inverse ratio between the size of the seed piece and the percentage of largesize tubers in the resultant crop. Steward (1922) concluded that uncut seed may be superior to cut seed of equal weight.

Stuart et al. (1924) concluded that the number of stems, which is determined by seed size, could be an important yield determinant. They also indicated that seed size determines the number of stems and subsequently the number of tubers. Conlon et al. (1985) also reported that uncut seed results in a greater number of smaller size tubers than cut seed.

Relationship between stem number and tuber yield

Bremner and Taha (1966), Gifford and Moorby (1967), and Sale (1974) all concluded that carbohydrate assimilation was dependent upon the number of developing tubers which provide a sink. Collins (1977) established that the variation in tuber yields of the potato cultivar Kennebec was due to varying stem numbers per hill. This confirms earlier findings by Reestman and de Wit (1959) and Bleasdale (1965) who also reported a direct relationship between stem number and tuber yield. Bleasdale (1965) concluded that both total yield and proportions of the yield in size grades were a function of the number of main stems per unit area. Using two cultivars, Irish Cobbler and Green Mountain, Stuart at al. (1924) reported that whole tubers produced more stems and tubers than halved seed tubers.

Smith (1909) stated that with an increase in seed piece weight, plants develop more vigorously resulting in an increase in the number of stems per hill, and the number of stolons and tubers per stem. Further, the larger the number of stems the greater the assimilation area per plant and the higher the yield. Hammes (1985) studied the effect of plant population on tuber yield using single-stem seed pieces. He found that with an increase in stem population, the percentage of small tubers increased, however at very high stem populations, the total number of tubers decreased.

Cho and Iritani (1983) reported that the correlation coefficient of stem and tuber number showed a decline from $r=0.92$ for the early planted potatoes to $r=0.46$ for the late planted crop. They attributed this decline to the reabsorption of small tubers when nutrients and other environmental factors become limiting. They also reported that increasing stem number from 2.5 to 4.5 resulted in a decrease in yield of oversized tubers and an increase in smaller size tubers.

Entz and LaCroix (1984) studied the effect of in-row spacing on tuber yield and quality and reported that at wider spacing, whole seed or large seed produced more main stems and branches thus compensating for any gaps during planting. LaCroix and Adam (1983) reported that increases in the number of small tubers after application of GA and ethephon, an ethylene precursor, were associated with an increase in the number of stems. The correlation coefficient was found to be r=0.77 for the cultivar Norland. Andrew and Silva (1981) observed that the greatest variations in tuber yield were associated with a corresponding variation in mainstem number and the number of tubers per hill among other factors. They concluded that a higher tuber yield and a lower hill to hill variation could be achieved by planting whole seed or by using apical and distal portions from the cut seed mix. Productivity of a seed piece has been shown to decline as the number of cut surfaces increases (Andrew and Silva, 1982; Andrew et al., 1983).

Wurr (1974) and Sharpe and Dent (1968) pointed out that the number of mainstems is a major limiting factor in tuber yield. The main stem has been defined by Krijthe (1955) as a stem arising directly from the seed tubers. Large seed is known to contain numerous eyes which because of apical dominance fail to grow thus reducing the number of stems per unit seed weight. Cutting helps break apical dominance although possible damage to the eyes might cause erratic emergence and even affect yield (Allen, 1979). Allen (1979) then concluded that it would be economical to establish an optimum stem density from minimum seed weight. The use of GA to enhance the number of mainstems was reported as successful by Timm et al. (1962). Toosey (1958) suggested that treatments which cause a large number of stems per hill will result in a large number of tubers and a greater proportion of small-size grades. This was confirmed by Timm et al. (1962). However, although GA treatment did result in increased stem number and small tubers, yields were not significantly affected.

Smeltzer and MacKay (1963), dipped Keswitch seed in GA solutions and reported a highly significant reduction in tuber size occured as a result of an increase in the number of stems. Holmes et al. (1970) treated Majestic tubers with GA solutions at 5, 50, and 100 ug/ml and found that the higher rate greatly increased the number of growing apices, the length of sprouts, and the number of stolons on the sprouts. The percentage of sprouts growing into mainstems was also increased. Although differences in tuber yield were not significant, the GA treatments at 5, 50, and 100 ug/ml increased tuber number by 25, 58, and 88%, respectively. There was also a high proportion of seedsize tubers (25-125g).

Al-Rawi (1981) treated Vanessa seed with GA solutions at 50 ug/ml and reported an acceleration in breaking of dormancy, increased sprout growth and an increase in the number of mainstems. Subsequently, the number of stolons and seed-size tubers (32-51mm diameter) were increased. Other growth regulators such as kinetin and indoleacetic acid have been shown to promote multiple shoots in culture (Novak et al., 1980).

FACTORS AFFECTING GROWTH AND TUBER DEVELOPMENT

Environmental factors

Like many other crops, the growth of the potato is under the influence of environmental and endogenous regulatory factors (Steward et al.,1981). The development of the potato may be divided into root, shoot, and stolon growth, which is followed by tuber initiation and subsequent tuber bulking. Each of these stages is important in the final performance of the crop.

The potato seed tuber bears a number of eyes (buds) from which sprouts develop (Moorby, 1978). Like any other stem, a sprout grows by the production and expansion of a succession of internodes (Morris, 1966). Root and stolon primordia start to develop at the nodes to a limited extent before planting (Moorby, 1978). Light, moisture, and nutrients seem to be the factors required for the early development, although a possible supply of growth substances from the root primordia have been implicated (Hall, 1973; Jones, 1973). Moorby (1968) proved that each of the sprouts that grow as stems compete for available nutrients particularly nitrogen. Light is another important factor since sprouts grown in the dark have longer internodes and smaller leaves than those grown in light (Morris, 1966). After planting, the lateral shoots from the primary stems developing beneath the soil either grow vertically as leafy shoots or diageotropically as stolons. Morris (1967) showed that stolon growth depends on intersprout competition i.e. there was a greater stolon growth at lower temperature which limits shoot growth. The first stolons are initiated at the lower nodes and progressively develop acropetally, at a rate that depends on the time of initiation (Lovell and Booth, 1969).

Plant hormones and growth regulators

Since the supply of nutrients could not fully explain the competition between shoot and stolon growth, Kumar and Wareing (1972) suggested that roots were acting as a source of cytokinins favouring the production of stolons when the lateral buds were subjected to apical dominance. They added that the apical dominance resulting in stolon development resulted from higher cytokinin levels in the mainstem than in the axillary shoots. Accumulation of cytokinins in stolon tips has since been reported (Woolley and Wareing, 1972) using ^{14}C-labelled benzyl amino purine (BAP) on decapitated plants. In the absence of gibberellic acid or of gibberellic acid and auxin (IAA), stolons would be transformed by the cytokinins into leafy shoots (Booth, 1963).

Tuber initiation and tuberization as affected by hormones

Tuber initiation occurs at the stolon tips. Slater (1968) suggested tuber initiation was due to an accumulation of nutrients at the stolon apices, whereas Madec (1963) favoured the involvement of some specific tuber-forming substance. Environmental factors interact with the endogenous plant hormones to influence tuber initiation and tuberization (Melis and van Staden, 1984). As well, plant hormones interact amongst themselves thus influencing certain growth processes like tuber initiation and tuberization (Dimalla et al., 1977). Obata-Sasamoto and Suzuki (1979) reported that exogenously applied cytokinins increase auxin levels in stolon tips which contain low levels of gibberellin, auxin, and cytokinins, thus resulting in starch deposition and tuberization.

Cytokinins

Cytokinins promote cell division (Skoog and Miller, 1957) and cell expansion (Scott and Liverman, 1956). Cytokinins have been suggested as the hormone responsible for tuber initiation. Palmer and Smith (1970), Mingo-Castel et al. (1976), and Mauk and Langille (1978) all reported an induction of tuber formation following cytokinin application onto isolated potato stolons. Cytokinin levels have also been shown to increase sharply before (Forsline and Langille, 1975) or after (Obata-Sasamoto and Suzuki, 1979) tuber initiation. Sattelmacher and Marschner (1978) also reported increased cytokinin activity in stolons and tubers of potatoes during the period of tuberization. They further reported that nitrogen withdrawal induces tuberization due to a sharp increase in cytokinin activity in roots creating new attraction sites for assimilates in tubers. Kumar and Wareing (1972) reported that cytokinin application may convert stolons into leafy shoots. Van Staden and Dimalla (1977) found high levels of cytokinins in actively growing tubers and suggested that they could be responsible for mediating the assimilate supply between the shoot and the tuber sink. Cytokinin-mediated assimilate translocation has been suggested by Palmer and Smith (1970), van Staden and Dimalla (1977), and Gersani and Kende (1982).

Dwelle and Hurley (1984) applied 'Cytex', a seaweed containing natural cytokinins onto Lemhi potatoes at the time of tuber initiation and reported a 10% tuber yield increase thus indicating some role of cytokinins in enhancing tuber yields.

Abscisic acid

Abscisic acid (ABA), a natural growth inhibitor (Cathey, 1964) has been reported to promote tuberization as evidenced by increased tuber growth after leaf application of the hormone (El-Antably et al., 1967; Menzel, 1980). Melis and van Staden (1984) suggested an indirect effect of ABA whereby tuber growth is promoted as a result of suppression of shoot growth. On the other hand Smith and Rappaport (1969), and Palmer and Smith (1969) reported that ABA inhibits cytokinin (kinetin)-induced tuber initiation of in vitro cultured potato stolons. Krauss and Marschner (1976) reported that ABA promotes tuber initiation under non-inducing conditions. Wareing and Jennings (1980) suggested an inhibition of stolon growth (apical meristem) by ABA thus indirectly promoting tuber initiation. Krauss (1978) also stated that ABA promotion of tuberization depends on its interaction with endogenous GAs and environmental factors. Okazawa (1967) and Krauss (1978) also suggested that high levels of inhibitors (ABA) in stolons do not directly promote cell division but their main effect is to counter gibberellins which promote stolon elongation and thus delay tuber initiation. Krauss and Marschner (1976) reported that an interruption of nitrogen nutrition increases ABA export from roots whilst that of cytokinins decreases, and GAs decrease in shoots and stolons resulting in tuberization.

Auxins

Auxins are known to be involved in the process of cell enlargement, and the interaction of cytokinin and auxin guarantees tuber growth (Melis and van Staden, 1984). Obata-Sasamoto and Suzuki (1979) reported high levels of auxin activity before tuber initiation in stolon tips. Williams (1974) suggested that auxin (indoleacetic acid, IAA) might be transported from shoots under inductive short days to underground sites where it promotes cell differentiation, leading to the formation of parenchymatous xylem cells for carbohydrate storage. Kumar and Wareing (1973) suggested a role for auxin in stolon development to be related to apical dominance in which case application of IAA onto shoots suppresses upper axillary shoots and stimulates basal nodes to grow out as stolons. However they later observed that the inhibition of the axillary buds was due to low cytokinin levels and high gibberellins under dark conditions. Palmer and Barker (1972) reported an increase in auxin degrading enzyme (peroxidase) activity under inducing conditions. They further reported that low IAA oxidase in GA-treated stolons was related to increased stolon elongation and delayed tuber initiation. They suggested that the auxin-degradation products may be important sources of endogenous inhibitors essential for tuber initiation.

Ethylene

Garcia-Torres and Gomes-Campo (1973) reported a stimulation of tuberization by ethephon (which releases ethylene) of potato sprouts cultured in vitro. Mingo-Castel et al. (1976) reported an inhibition by ethephon of both in vitro cultured stolons and sprouts. Ethylene has also been reported to promote the tuber initiation process whilst inhibiting the latter stages of tuber bulking (Catchpole and Hillman 1969). Palmer and Barker (1972) suggested that ethylene might have a greater effect on stolon growth than on tuberization. Dimalla and van Staden (1977) reported that ethylene inhibits cell division of subapical meristems by inhibiting the action of cytokinins. They later reported an accumulation of cytokinin glycosides (inactive forms of cytokinins) as a result of ethylene treatment. Dimalla and van Staden (1977) then suggested that the promotion of lateral cell expansion and inhibition of cell division might be an indirect effect of ethylene rather than a direct promotion of tuber initiation since it was not accompanied by any starch deposition. Moorby (1978) stated that the cessation of stolon elongation and swelling of the sub-apical internodes as well as starch accumulation would be fair indicators of tuber initiation.

Gibberellins

Gibberellins are known to promote the breaking of dormancy and cell elongation as well as promote shoot and stolon elongation thus delaying tuber initiation (Lippert et al., 1958; Rappaport et al., 1957; Lovell and Booth, 1967; Menzel, 1980; Tizio, 1971). Smith and

Rappaport (1969) reported high GA levels in stolon tips which decreased shortly before tuber initiation. High levels of GA tend to occur under conditions of high temperatures, long days and high levels of nitrogen nutrition (Menzel, 1980; Steward et al., 1981). On the other hand, low gibberellic acid levels promote tuber initiation due to the deposition of starch on the stolon tips (Moorby, 1968). Lovell and Booth (1967) suggested that perhaps high gibberellins were inhibiting starch deposition hence factors antagonistic to gibberellins such as growth retardants, would hasten tuber initiation (Dyson, 1965; Gunasena and Harris, 1969, 1971). However, Smith and Rappaport (1969) found no effect of ABA on tuber initiation. It was also suggested that since the site of gibberellin synthesis is in the leaves, daylength could be an important factor (Chapman, 1958; Okazawa and Chapman, 1962). Whilst short days favour tuber initiation, long days inhibit it due to high gibberellins promoting shoot growth (Okazawa and Chapman, 1962).

The influence of the mother tuber

The mother tuber probably has an effect on tuber initiation. Although Bodlaender and Marinus (1969) reported that the mother tuber was not essential for tuberization, Bottini et al. (1981) stated that the mother tuber might be a source of gibberellins or their precursors, which could be used and/or interconverted into other endogenous gibberellins by the leaves. Plants originating from tubers have been shown to contain a greater activity of gibberellins than those originating from cuttings (Bottini et al., 1981). Racca and

Tizio (1969) and Pont-Lezica (1970) showed that the potato plant synthesizes different kinds of gibberellin-like substances which may be involved in tuber initiation. Tizio and Tizio (1981) stated that the mother tuber does not seem to favour tuber initiation of the Bintje cultivar. They also observed that plants with their own mother tubers grown under inductive conditions, had delayed tuber initiation compared with excised pieces of buds or those plants grown under non-inductive conditions with their mother tubers. From this, Tizio and Tizio (1981) then decided that perhaps under all photoperiodic conditions, the leaves synthesize some 'light factor' that would antagonize the delaying effect exerted by the mother tubers on growing buds when they become leafy shoots.

Earlier, Gregory (1956) had observed that under inducing conditions, potato plants exhibited a definite pattern of tuberization. This was supported by experiments with sprout sections (Mingo-Castel, 1976), stem cuttings (Chapman, 1958), and intact plants (Plaisted, 1957; Lovell and Booth, 1969). Gregory (1956), Chapman (1958) and Forsline and Langille (1975) stated that tuberization was greater on stolons closer to the mother tuber at the stem base, implying a basipetal movement of a tuberization stimulus. Okazawa (1967) also noted that apical tips of sprouts would not tuberize *in vitro* while basal parts of such sprouts tuberized readily. Forsline and Langille (1975) indicated that tuberization was greater on younger nodes of stem cuttings. However experiments by Kahn and Ewing (1983) have ruled out the mother tuber and the age of underground buds as factors in tuberization thus further compounding the controversies regarding the subject.

PLANT GROWTH RETARDANTS

Cathey (1964) referred to growth retardants as all the chemicals that slow cell division and/or cell elongation causing a height reduction on plants but with no formative effects.

Mode of action of growth retardants

The mode of action of growth retardants is still a subject of research. Growth retardants are generally known to inhibit gibberellin biosynthesis by interfering with the levels of their precursors: transgeraniol, kaurene-19-ol, and kaurene-19-al, and also by inhibiting sterol biosynthesis which is important in membrane integrity (Cathey, 1964). The antagonism of growth retardants and gibberellins has also been proven in microorganisms where GA biosynthesis was inhibited due to chlormequat (CCC), a growth retardant in *Fusarium moniliforme.*

Dicks (1976) outlined the possible modes of action of growth retardants as either: (i) an inhibition of gibberellin biosynthesis which is only active against endogenous GAs, and thus reversible with exogenous GAs, or (ii) a promotion of the destruction of gibberellin. Dicks (1976) then decided that since growth retardants do not exhibit competitive inhibition (possessing a structure to allow competition for binding sites) or prevent the product from entering the reactions leading to the biological response (not reversible by GA), then neither of the two possibilities would represent the mode of action of growth retardants. On the other hand, most of the recent evidence suggests that retardants inhibit the biosynthesis of gibberellin precursors (Lang, 1970). However such evidence has also been supplemented with a few other suggestions. Daminozide has been reported to stimulate peroxidase and IAA-oxidase activity (Halevy, 1963), inhibit tryptamine oxidation to indoleacetaldehyde (Reed et al., 1965), inhibit respiration (Halevy et al., 1966), is involved in the uncoupling of oxidative phosphorylation (Heatherbell et al., 1966), increase membrane permeability due to the effects on sterol biosynthesis (Undurrago and Ryugo, 1969), inhibit protein turnover (Knypl, 1969), inhibit ent -kaurene synthesis (Wylie et al., 1970), and stimulate apparent photosynthesis (Dicks, 1976).

General effects of retardants on plants

Cathey (1964) reported that retardants might be effective specifically on subapical meristems causing a reduction of stem growth, a rosette form of growth, but no adverse effect on leaf initiation and the flowering ability of the plants.

Chlormequat (2-chloroethyl trimethylammonium chloride, CCC) and daminozide (N-dimethylamino succinic acid) have been widely used for the reduction of plant height and lodging prevention in cereals because of their ability to shorten internodes (Cathey, 1964; Larter, 1967). However some reports on growth retardants have been controversial. Cathey (1964) reported that low levels of daminozide might stimulate vegetative growth and promote flowering due to some effect on cambial activity of pine shoots.

Radwan et al. (1971) reported that stem retardation due to CCC on potatoes was proportional to the dosage applied. They indicated an increase in tuber dry weight in proportion to the rate of application, with an optimum at 1000g/ha. The timing of application was also shown to be crucial since too early an application resulted in severe stem retardation.

Bottini et al. (1981) proved that CCC and daminozide were antagonistic to GA (which promotes stem elongation) biosynthesis by blocking kaurene synthesis, a precursor of gibberellins.

Dyson (1965) treated plants with both GA and CCC and found that CCC exerted faster stem retardation on non-GA treated than on GA-treated plants. CCC was shown to slow down stem and stolon elongation and leaf expansion such that a larger proportion of assimilates was redirected for earlier tuber formation. The opposite was observed in the case of GA. Although GA did not promote net assimilation rate (NAR) however it was found to result in faster emergence, increase in the number of sprouts per tuber, increase in the number of stems per plant, and an increase in the number of small tubers per plant. Holmes et al. (1970) reported an increase in the number of seedsize tubers due to GA application.

Dimalla et al. (1977) examined the levels of hormones in potato sprouts and stolons in relation to cell division. They reported that high GA and low inhibitor levels in sprouts favoured cell elongation whilst limiting cell division. On the other hand, a low GA and high inhibitor levels in stolons seemed to favour cell division. The deduction from this was that since cell division was not inhibited by high inhibitor levels in stolons, then the primary effect of the growth retardants must be directed specifically at countering the GAs.

Ancymidol (α-cyclopropyl-α (4-methoxyphenyl)-5-pyrimidine methanol), as a growth retardant is most widely used on floricultural and ornamental crops (Cathey, 1964). Miranda and Carlson (1980) reported a significant stem retardation and an enhancement of flowering after ancymidol application on ornamentals. Ancymidol has exhibited desirable dwarfing effects without interference with flowering on *Euphorbia*, *Lilium*, and *Petunia*, and like other growth retardants in common use, it has been reported to enhance flowering in *Azalea* (Cathey, 1964). On *Pyracantha forteana*, ancymidol treatment was reported to promote more uniform flowering whilst untreated plants could not flower (Cathey, 1964). Like other growth retardants, timing and form of application are crucial with ancymidol (Cathey, 1964). *Lilium* plants were reported to be 50 to 60% shorter when treated three months prior to Easter. On the other hand height control was not as effective when ancymidol was applied two months prior to Easter. Satisfactory results were also obtained when the growth retardant was applied as a 6mg/l spray eleven and nine weeks prior to Easter, or as a 0.25mg per pot drench applied at the same time.

THEORIES ON THE MODE OF ACTION OF GROWTH REGULATORS

Hormonal regulation of assimilate transport

Although this subject remains a matter of controversy, several schools of thought have been advanced (Marre, 1982): (a) substances produced by the growing areas (meristematic apices, fertilized ovaries and developing reproductive organs) are actively diverting nutrient fluxes not only towards these growing regions, but also towards the neighbouring sites, and that (b) hormone-containing preparations can very efficiently substitute for the growing centres in this action. Patrick and Wareing (1976) observed a marked early enhancement of the translocation of ^{14}C-metabolites towards the point of application of an auxin-lanolin paste. Similarly, cytokinins, gibberellins and abscisic acid (ABA) have been shown to activate the capacity for H^+ secretion and to inhibit the capacity for K^+ uptake in germinating seeds (Lado et al., 1975; Ballarin-Denti and Cocucci, 1979).

Contrary to the same belief that hormones mobilise nutrients around the source regions, Luttge and Higinbotham (1979) have now shown that the hormones determine the duration of nutrient fluxes by regulating at cell level, the capacity of the various tissues to absorb or extrude nutrients, thus controlling the exchanges with the vascular system.

Effects of hormones at the cell level

The rates of fluxes in the symplast and apoplast determine the loading and unloading of the vascular system and the accumulation or the release of solutes in the various plant parts (Marre, 1982). Marre (1979) suggested that the site of hormonal action may be the plasmalemma. Spanswick (1981) and Mercier and Poole (1980) provided evidence suggesting that the energy-dependent electrogenic pump is influenced by hormones, including the fungal toxin, fusicoccin. Auxins have been shown to stimulate proton secretion in stem and coleoptile segments where they also increase cell enlargement (Cleland, 1973; Rayle, 1973). On the other hand, ABA was found to inhibit the development of electrogenic proton secretion and K^+ uptake in germinating seeds (Ballarin-Denti and Cocucci, 1979). Marre (1982) noted that the apparent effect of ABA on the H^+ pump seems in some way opposite to that of IAA: Auxin stimulates while ABA inhibits electrogenic H^+ secretion in shoot tissues, while the opposite situation is true in roots. Lado et al. (1975) have reported that gibberellins could also act by promoting electrogenic H^+ extrusion in germinating seeds. However since the results were non-reproducible, Ballarin-Denti and Cocucci (1979) suggested that they may be affecting phospholipid metabolism in membranes.

Effects at the source-end

Most of the evidence of hormonal control of assimilate distribution at the source-end of the phloem pathway centres around photosynthesis and phloem loading (Patrick, 1982). Wareing et al. (1968) found that GA_3 and kinetin could stimulate photosynthetic activity. Sturgis and Rubery (1982) further stated that in contrast to sink uptake, auxin action on phloem loading did not appear to be mediated through changes in net proton extrusion.

In view of the preceding evidences, several hypotheses of assimilate distribution have been suggested (Patrick, 1982): (a) Sink hypothesis: where the control mechanism is thought to be exclusively across the sink boundary. Hence consequent changes in assimilate pool sizes would act as signals to coordinate assimilate supply to the sink. Milthorpe and Moorby (1969) stated that in this hypothesis, leaf growth would appear to be limited by the size of its sugar pool, resulting in a drop in sucrose levels to mediate feed-back control of membrane transfer. This would inevitably result in an under-exploitation of any increase in growth potential. However Kemp (1981) pointed out that as the leaf enlarges, sugar concentrations increase to levels that may be in excess of the growth requirement thus providing conditions in which the sink hypothesis could be inadequate as an effective regulatory mechanism for sugar transport. (b)Supply/sink hypothesis: whereby sink-produced hormones might act to integrate assimilate utilization with supply by directly controlling both processes. In this case, the sink's own hormonal supply would have to be transported to target sites.

The supply/sink hypothesis

Such an integrated mechanism would definitely alleviate any problems where the pool size of sucrose limits growth (Patrick, 1982). Wareing et al. (1968) stated that the photosynthate demand by root apices would be signalled by the levels of root-produced cytokinins reaching the leaves in the transpiration stream and regulating photosynthetic activity. Hence the root would depend on the partitioning pattern of the leaf. On the other hand, the shoot apex may have the potential to control some active component of phloem translocation by basipetally moving IAA (Patrick, 1982). Evidence for this has been found from studies where basipetal auxin movement, impaired by inhibitors of polar auxin transport prevented assimilate flow to the shoot apices (Croxdale, 1977).

Patrick and Wareing (1976) stated that carbohydrates were preferentially translocated to the plant parts with the highest hormone levels. Sattelmacher and Marschner (1978) used nitrogen withdrawal methods to promote tuberization and found increased levels of cytokinins in meristematic tissue. Van Staden and Dimalla (1977) pointed out that since cytokinins were present in relatively high levels in actively growing tubers and xylem sap, they could possibly be regulating the influence of the tuber sink on the shoot of the plant.

Palmer and Smith (1969) earlier suggested that cytokinins in the tubers could act by establishing a metabolic storage sink which attracts metabolites to the organ.

Mingo-Castel et al. (1976) found enhanced phosphorylase and ADP-glucose pyrophosphorylase activities during kinetin induced tuberization of in vitro grown potato sprouts. This promotion of starch deposition and tuberization by cytokinins was also reported by Obata-Sasamoto and Suzuki (1979). Melis and van Staden (1984) concluded that through regulation of enzyme activities, hormones could regulate tuberization not only at the site of the process but also affect all phases of assimilate translocation and distribution, from sink growth, phloem loading and unloading, phloem transport, as well as assimilation and carbohydrate synthesis in the leaves.

Effect of hormones on enzyme activity

Obata-Sasamoto and Suzuki (1979) suggested that the biochemical role of phytohormones might be in the regulation of enzyme activity. Mingo-Castel et al. (1976), reported that during kinetin-induced tuberization of potato sprout sections, activities of phosphorylase and ADP-glucose pyrophosphorylase were enhanced significantly. On the other hand, soluble starch synthetase activities remained low. Activities of both phosphorylase and bound synthetase increased in proportion to the starch content. The activity of the phosphorylase was found to be five times higher during tuber development. However, towards the latter stages of tuberization, the activities of soluble synthetase and phosphorylase were reported to decline (Obata-Sasamoto and Suzuki, 1979). Phosphorylase might be involved in the synthesis of ß-glucans which are structural components of the cell wall.

Sowokinos (1976) reported a high ADP-glucose pyrophosphorylase activity at the phase of procambial cell division. Similar results were reported by Reeve et al. (1969). Palmer and Barker (1972) reported an indirect relationship between starch deposition and invertase activity whilst investigating the effect of ethylene upon tuberization of isolated stolons. Other reports have confirmed high specific activities of invertase in sink tissues and the hydrolysis of sucrose by invertase as an early step in the metabolism of imported carbohydrate (Walker et el., 1978). By regulating tissue levels of sucrose, invertase might be acting to maintain sucrose import into sinks (Walker et al., 1978). Hawker and Walker (1978) added that the reported high levels of invertase in tissues undergoing cell expansion could be associated with reduced levels of sucrose and elevated hexoses.

El-Fouly and Garas (1968), investigated the effect of CCC on amylase and invertase activity in cotton leaves. They reported an increase in amylase activity after foliar application of CCC. An increase in invertase activity only occurred in the first sampling (15 days after spraying). They concluded that the increase in activities of the enzymes might not be due to the stem retardation effect of CCC but rather a change in nucleic acid levels.

Obata-Sasamoto and Suzuki (1978) summarised their results indicating that: (i) tuber initiation could be stimulated under conditions such as preceding the disappearance of gibberellins, and the presence of cytokinins on the stolon tips, and (ii) that the subsequent decrease in auxin level could be enhancing the activities of starch-synthesizing enzymes to support continuing starch deposition.

EFFECT OF SELECTED PLANT GROWTH REGULATORS ON THE PRODUCTION OF SEEDSIZE TUBERS OF NORCHIP AND RUSSET BURBANK POTATOES (SOLANUM TUBEROSUM L.)

ABSTRACT

Five growth regulators were evaluated for increasing the number of seedsize tubers (30-60g) on two potato cultivars Russet Burbank and Norchip at Carman in 1985 and Bagot in 1986. Treatments on Norchip included gibberellic acid (GA) applied at 90% emergence alone or followed by chlormequat (2-chloroethyl trimethylammonium chloride), daminozide (N-dimethylamino succinic acid), or ethephon (2-chloroethyl phosphonic acid) two weeks later. On Russet Burbank, ancymidol (α-cyclopropyl-α (4-methoxyphenyl) -5-pyrimidine methanol) was applied in place of ethephon. GA increased shoot and stolon elongation soon after application. GA also seemed to increase stolon number although results were not significant. Growth retardants generally decreased internode and stolon elongation. On Norchip, GA increased plant height, stolon length, and the number of tubers >2cm diameter in 1985. There was no significant increase in seedsize tubers compared with the control. In 1986, the treatment increased stolon number and tips and the proportion of seedsize tubers at the final harvest. GA also reduced the proportion of large tubers. GA+daminozide did not increase the number of stems but seemed to increase the number of stolons and tubers 42 days after planting. Hence daminozide offered the best results when applied after GA on Norchip in 1985. The next best treatment on Norchip was GA+ethephon with a tendency to increase the number of stems, stolons, stolon tips, and the number of tubers >2cm although results were not statistically significant. This trend

seemed to persist with a potential to increase seedsize tubers in both years whilst reducing that of largesize tubers. The correlation coefficients were highly significant for stem and tuber number (r=0.96) as well as that of stem and stolon number (r=0.67), indicating that the treatment increased tuber number via the promotion of stems and stolons. GA+chlormequat (CCC) treatment increased stolons and the number of tubers >2cm diameter 28 and 42 days after planting in 1985. In 1986 the treatment resulted in an increase in stems, stolons, and seedsize tubers whilst reducing the proportion of larger and smaller-sized tubers. The correlation coefficients were highly significant for stem and stolon number (r=0.94), stem and tuber number (r=0.96), as well as stolon and tuber number (r=0.92).

On Russet Burbank, GA resulted in an increase in stems, stolons, but did not affect tuber number in 1985. In 1986, there was an increase in tubers both > and < 2cm diameter 42 days after planting, though not significant. GA showed a potential of increasing the number of seedsize and small tubers whilst reducing the proportion of large tubers compared with the control in 1986. GA+CCC was the best treatment on Russet Burbank, indicating a potential to increase the proportion of seedsize tubers (3-5cm diameter) whilst reducing the proportion of largersized tubers. GA+ancymidol was the next best treatment in increasing seedsize tubers compared with the control. GA+daminozide resulted in the least increment of seedsize tubers over the control on Russet Burbank. Hence on Russet Burbank, the treatments with an indication of increasing seedsize yield were GA+CCC, GA+ancymidol, and GA alone, in order of effectiveness.

INTRODUCTION

Cutting seed tubers before planting is still a conventional practice in most of North America although there is increasing interest in using whole seed tubers. Whole seed would eliminate the need for labour where handcutting is used, reduce problems with non-uniform seed pieces due to mechanical cutters which causes yield variability, and reduce disease problems.

Evidence supporting the relative yielding advantage of plants from whole as opposed to cut seed has been largely controversial. Reports by Roberts (1885), Emery (1890, 1891), Smith (1909), and Aicher (1917, 1920) have favoured whole seed. On the other hand, Stubbs et al. (1890) reported no difference in yielding ability whilst Moorkerji (1903), and Conlon et al. (1985) favoured cut seed over whole seed. Recently, Andrew and Silva (1981, 1982), and Andrew et al. (1983) have suggested that whole seed plants outyield those from cut seed. Conlon et al. (1985) stated that whole seed tubers result in a higher proportion of smaller-size tubers compared to cut seed.

Stuart et al. (1924) concluded that even though whole seed did not significantly increase yields, there was a benefit from reduction of disease. The cutting procedure transmits disease through the cutting blades and predisposes the cut tuber surface to soil diseases.

The use of growth regulators as a means to increase the set of seedsize tubers has shown promise in the potato cultivars Norland and Russet Burbank according to LaCroix and Adam (1983). They reported a promotion of seedsize tubers by GA applied at 90% emergence followed by ethephon applied two weeks after GA on Norland. Ethephon had some deleterious side effects on Russet Burbank though, hence the search for a substitute treatment on Russet Burbank. Al-Rawi (1981) also reported a promotion of stem number and stolon number, as well as tubers between 3.2 and 5.1 cm diameter by GA. GA has also been reported to delay tuber initiation by prolonging or favouring shoot and stolon elongation (Lovell and Booth, 1967; Okazawa and Chapman, 1962). Since some growth retardants are anti-gibberellins (Cathey, 1964), they would be expected to terminate stolon elongation and cause swelling of stolon tips and increase the number of tubers (Dyson, 1965; Gunasena and Harris, 1969, 1971).

In this study, the growth regulators chlormequat (CCC), daminozide, ancymidol, or ethephon were applied two weeks after GA to Norchip and Russet Burbank potatoes during the period of tuber initiation. Their effects on general growth and development of shoots, roots, stolons and tubers were evaluated at three mid-season harvest periods. At the final harvest, the treatments showing the best potential to promote a high proportion of seedsize tubers were considered the most effective.

MATERIALS AND METHODS

Two potato cultivars, Russet Burbank and Norchip, were planted in a randomised complete block design (RCBD) consisting of six replicates. An application of sethoxydin (2.5 kg ai/ha) was done for weed control on July 3, 1985. Seeding was done on May 5, 1985 at Carman Manitoba on a fine sandy loam soil previously fertilised with a broadcast mixture consisting of NPK (45-20-10) at 224kg/ha. In 1986, seeding was done on June 2 at Bagot, Manitoba on a loamy fine sand fertilized with a NPKS (19-13-18-6) mixture at 341kg/ha. Certified seed tubers >5 cm were handcut to about 30 to 50g size using blades dipped in a disinfectant. Some tubers were planted whole in rows of 15 metre length. In 1986, the apical portion of a seed piece was used for the treatments as an attempt to minimize the variability that might be due to non-uniform planting material. The remaining seed portions were planted in the guard rows. Ridges of about 45 cm in height were also constructed on the rows after plant growth. Spacing was 1 metre between rows, 40cm within rows for Russet Burbank and 20cm within rows for Norchip. There was a guard row on each side of the treatment row. Plots were cultivated as necessary during the growing season.

The treatments in Russet Burbank in 1985 were GA at 0.04 kg ai/ha applied at 90% emergence (July 3) alone or in combination with CCC at 0.5 kg ai/ha, daminozide at 2.0 kg ai/ha, or ancymidol at 0.0028 kg ai/ha applied after two weeks. On Norchip the treatments were similar to those of Russet Burbank with ethephon (0.5 kg ai/ha) replacing ancymidol.

In 1986, the daminozide treatment was excluded from both cultivars leaving four treatments for each cultivar. All treatments were applied with a CO_2 sprayer with volume output of 120 l/ha at a pressure of 150kPa. In 1985 the three mid-season samples were taken on July 3 (first harvest), 17 (second harvest), and 31 (third harvest) whilst in 1986 they were taken on July 14 (first harvest), 28 (second harvest), and August 11 (third harvest) on both cultivars. They were taken by hand digging two plants per treatment randomly selected in each treated row of each cultivar.

Plant stand counts were taken periodically throughout the sampling period. Parameters measured at and after each sampling were number of stems, average plant heights (cm), number of stolons, length of 3 longest stolons (cm), number and diameter (cm) of tubers greater than 2 cm, fresh and dry weights of shoots ,roots, stolons and tubers, and tuber yields. Stem number refers to those stems arising directly from the seed tubers excluding the branches. Plant height was measured between the stem apex and the stem base at the beginning of the root zone. Top fresh weight refers to the weight after harvest, of the stems, branches, and leaves before oven drying. With the use of a garden fork, plants were uprooted individually ensuring maximum recovery of roots, stolons, and tubers. The plant parts were then washed in a sink and weighed before and after drying to determine the fresh and dry weights. Whilst roots were weighed with stolons in 1985, they were weighed separately in 1986. The root weight measurement would serve to provide more information on dry matter distribution between roots and stolons. Stolons or stolon branches were counted if they measured 5mm or more in length. The average length of the main stolons was determined in 1985 and not in 1986. Instead, in 1986 the number of stolon tips were considered a more important parameter. The stolon apices that seemed to have a potential to develop into tubers were recorded as stolon tips. Stolons were also weighed before and after oven drying to give the fresh and dry weight values. The number of tubers between 0.6mm and 3cm and between 3 and 5cm in diameter was determined. Their fresh and dry weights were also recorded. Nine metres of the 15m treatment row was harvested on September 18 in 1985 and on September 25 in 1986. The tubers were graded into three categories: largesize (>5cm diameter), seedsize (4-5cm in 1985 and 3-5cm in 1986), small (<4cm in 1985 and <3cm in 1986) at the time of final harvesting.

RESULTS AND DISCUSSION

NORCHIP

Effects of GA

There was a significant reduction in the combined dry weight of roots and stolons as a result of GA but no change in other parameters during the first sampling (3/7/85) (Table 1). At the second sampling (17/7/85), GA resulted in a significant increase in stolon length without much effect on the other parameters. There was an indication of some potential to promote tubers > 2 cm in diameter but this was not statistically significant. At the third sampling (31/7/85), GA had little effect on the parameters measured.

In 1986, GA had no significant effect on any of the parameters at the first sampling (14/7/85) however at the second sampling (28/8/86), there was a slight but not significant decrease in shoot fresh weight compared to the control (Table 1). At the third sampling (11/8/86) GA caused a slight though not significant reduction in plant height and root fresh weight without much effect on the other parameters.

Stolon number and tuber number had a high correlation (r=0.94), implying that promotion of tubers due to GA might be due to a promotion of stolon number.

Table 1 Effect of growth regulators on stems, stolons, roots and tubers of field grown Norchip potatoes at three harvest dates in 1985 and 1986.

Treatment #	Stems		Stolons		Stolons+Roots	Tubers >2cm		Tubers < 2cm
	No.	Ht.(cm)	No.	Lgth.(cm)	DWt.(g)	No./plant	Ave. Diam.(cm)	No.
First harvest 3/7/85								
Control	2.8a*+	21.8a	14.7a	13.8a	0.39a	0	-	0
GA	2.8a	20.2a	16.7a	16.2a	0.18b	0	-	0
Second harvest 17/7/85								
Control	2.5a	31.6ab	11.0a	12.3a	1.87a	8.0a	3.2a	5.5a
GA	2.5a	34.6ab	10.5a	15.8b	1.80a	11.8a	3.1a	5.5a
GA+ethephon	2.0a	29.6b	11.8a	17.4b	2.53a	9.2a	3.4a	5.7a
GA+CCC	2.7a	36.0a	12.7a	16.5b	2.13a	10.2a	3.5a	5.5a
GA+daminozide	2.0a	31.9ab	20.1b	10.5a	2.13a	8.7a	3.4a	4.7a
Third harvest 31/7/85								
Control	2.7a	47.4a	12.8a	11.9a	7.03a	9.5a	5.0a	7.3a
GA	2.3a	47.2a	11.3a	11.0a	6.26a	9.7a	5.1a	5.8a
GA+ethephon	2.2a	46.7a	12.7a	11.7a	6.93a	11.5a	5.4a	6.3a
GA+CCC	2.3a	49.3a	12.2a	13.1a	6.23a	11.2a	4.9a	7.5a
GA+daminozide	2.2a	47.5a	13.8a	11.5a	6.90a	11.7a	5.1a	7.2a

Treatment	Stems				Roots		Stolons				Tubers 2-5cm diam.		
	No.	Ht.(cm)	FWt.(g)	DWt.(cm)	FWt.(g)	DWt.(g)	No.	Tip No.	FWt.(g)	DWt.(g)	No.	FWt.(g)	DWt.(g)
First harvest 14/7/86													
Control	2.8a	23.4a	157.5a	20.8a	11.8a	1.9a	9.8a	10.7a	25.2a	1.6a	0	-	-
GA	3.0a	25.4a	211.8a	24.7a	14.0a	2.6a	10.5a	12.7a	23.2a	1.8a	0	-	-
Second harvest 28/7/86													
Control	2.5a	23.0a	176.9ab	31.9a	13.2a	2.8a	8.0a	15.0a	4.0a	0.33a	10.5a	175.9a	36.1a
GA	3.3a	23.7a	163.5b	33.8a	15.9a	2.6a	7.7a	16.5a	3.0a	0.33a	8.7a	128.8a	32.5a
GA+ethephon	3.3a	26.3a	192.7ab	36.2a	19.7a	3.1a	11.2a	17.5a	4.1a	0.34a	11.0a	115.4a	28.8a
GA+CCC	3.5a	26.9a	244.9a	45.8a	19.8a	3.5a	10.3a	18.5a	2.1a	0.49a	11.0a	162.0a	34.0a
Third harvest 11/8/86													
Control	1.8a	30.3a	175.2a	25.8a	7.5ab	2.4a	5.7a	9.7a	6.0a	0.63a	6.2a	204.5a	52.2a
GA	2.0a	24.9ab	131.6a	24.4a	5.8b	1.9a	4.5a	6.8a	5.6a	0.51a	5.5a	153.9a	37.2a
GA+ethephon	2.2a	23.7ab	145.1a	24.7a	9.4a	2.5a	7.3a	7.7a	8.8a	1.37a	11.5a	147.4a	29.7a
GA+CCC	2.0a	22.6b	116.9a	18.5a	6.5ab	2.0a	5.5a	9.3a	6.6a	0.63a	6.5a	161.8a	33.2a

*Means within a column for each harvest date with the same letter are not significantly different (LSD 5%).
#Treatments and rates used were:
GA = gibberellic acid (0.04 kg ai/ha)
daminozide (2.0 kg ai/ha)
CCC (0.5 kg ai/ha)
ethephon (0.5 kg ai/ha)
+all data are the per plant average for 2 plants per replicate

Effects of GA+ethephon

The treatment resulted in a significant increase in stolon length at the second sampling (17/7/85) without any change in the other parameters (Table 1). As a growth retardant, ethephon would be expected to decrease stolon elongation. At the third sampling (31/7/85) the treatment had no significant effect on any of the parameters although there was an indication of an increase in the number of tubers > 2cm diameter, though not significant. In 1986, the treatment caused no significant changes in the parameters in the second harvest however there was some indication of an increase in stolon number and tubers (2-5cm) though not significant. Similarly at the third sampling (11/8/86) the treatment resulted in slight increases in stolon and tuber number though not significant. There was also a slight reduction, though not significant in shoot fresh weight which might suggest a reduction in shoot growth by the growth retardant possibly in favour of root growth. There is an indication from the results that the addition of ethephon after GA might increase stolon and tuber numbers on Norchip potatoes.

Effects of GA+CCC

The treatment caused a significant increase in stolon length in the second sampling (17/7/85) and some increase though not significant in the number of tubers >2cm compared with the control (Table 1). At the third sampling (31/7/85), the treatment had no significant effect on the parameters however there was an indication of an increase in the number of tubers >2cm diameter. GA+CCC had no significant effect on any of the parameters in the second sampling (28/7/86) although there were marginal increases in shoot fresh weight, root fresh weight, stolon number and tips. At the third sampling (11/8/86) GA+CCC plants treated with GA+CCC were significantly shorter than the controls. This is an expected effect of a growth retardant such as CCC. The correlation coefficients (Appendix Table 2) were significant for stem and stolon number (r=0.94), stem and tuber number (r=0.96), as well as stolon and tuber number (r=0.92).

Effects of GA+daminozide

The GA+daminozide treatment significantly increased stolon number at the second sampling (17/7/85) (Table 1). This increase in stolons by the treatment might potentially increase the number of tubers later on in growth. However this difference was not evident by the third sampling.

In summary, the best treatment on Norchip was GA+ethephon which seemed to increase stem number, stolon number, and tuber number in both years. GA+CCC was the next best, resulting in an overall increase in the number of tubers. Although there was a tendency to increase the number of stolons, tips, and stolon length, there was no change in the number of tubers by GA.

Tuber Yields

Large tubers (>5cm diameter)

The GA treatment did not result in any significant change in the number of large tubers compared with the control in 1985 (Fig. 1).

The GA+daminozide treatment resulted in a significant reduction in the proportion of largesize tubers compared with GA in 1985. White et el. (1985) reported a reduction in the proportion of large tubers after daminozide application. The GA+CCC treatment was not significantly different in tuber numbers from the control in 1985 or 1986 (Fig. 2). The GA+ethephon treatment seemed to increase though not significantly, the number of large tubers in 1985 whereas in 1986 there was a significant reduction in the number of large tubers. A reduction in the largesize tubers might be beneficial if a large part of the final yield is represented by tubers that may be used as seed whereas an increase in large tubers may be unfavourable if it occurs at the expense of seedsize tubers.

Figure 1: Effect of growth regulators on large, seed, and small-size tubers of Norchip potatoes on September 18, 1985

LEGEND:

GA = gibberellic acid (0.04 kg ai/ha)

ethephon (0.5 kg ai/ha)

CCC = chlormequat (0.5 kg ai/ha)

daminozide (2.0 kg ai/ha)

*Values with the same letter for each tuber size are not significantly different (LSD=5%).

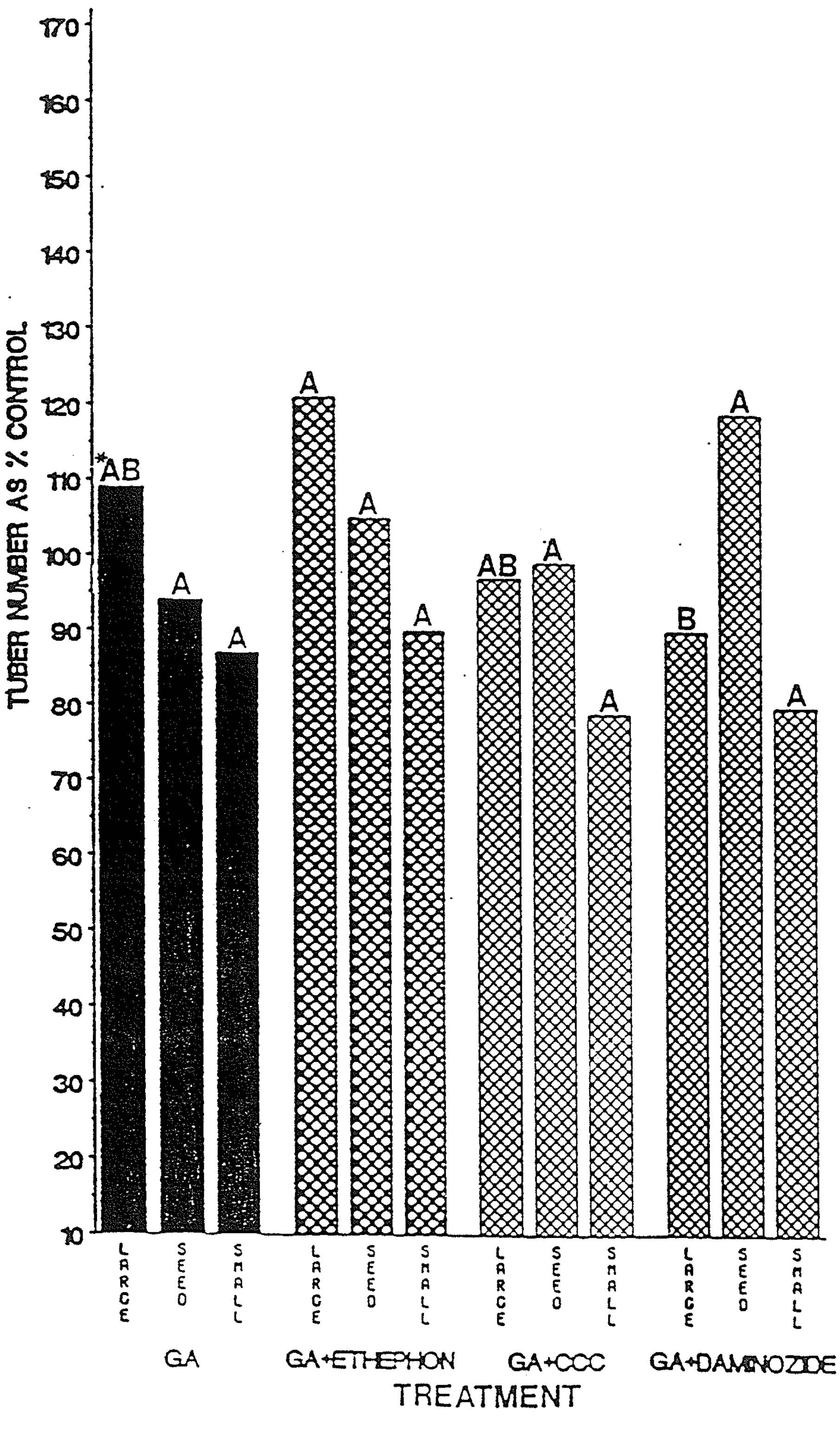

TUBER NUMBER AS % CONTROL
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
*AB
A
A
A
A
A
AB
A
A
B
A
A
LARGE
SEED
SMALL
LARGE
SEED
SMALL
LARGE
SEED
SMALL
LARGE
SEED
SMALL
GA
GA+ETHEPHON
GA+CCC
GA+DAMINOZIDE
TREATMENT

Figure 2: Effect of growth regulators on large, seed, and small-size tubers of Norchip potatoes on September 25, 1986

LEGEND:

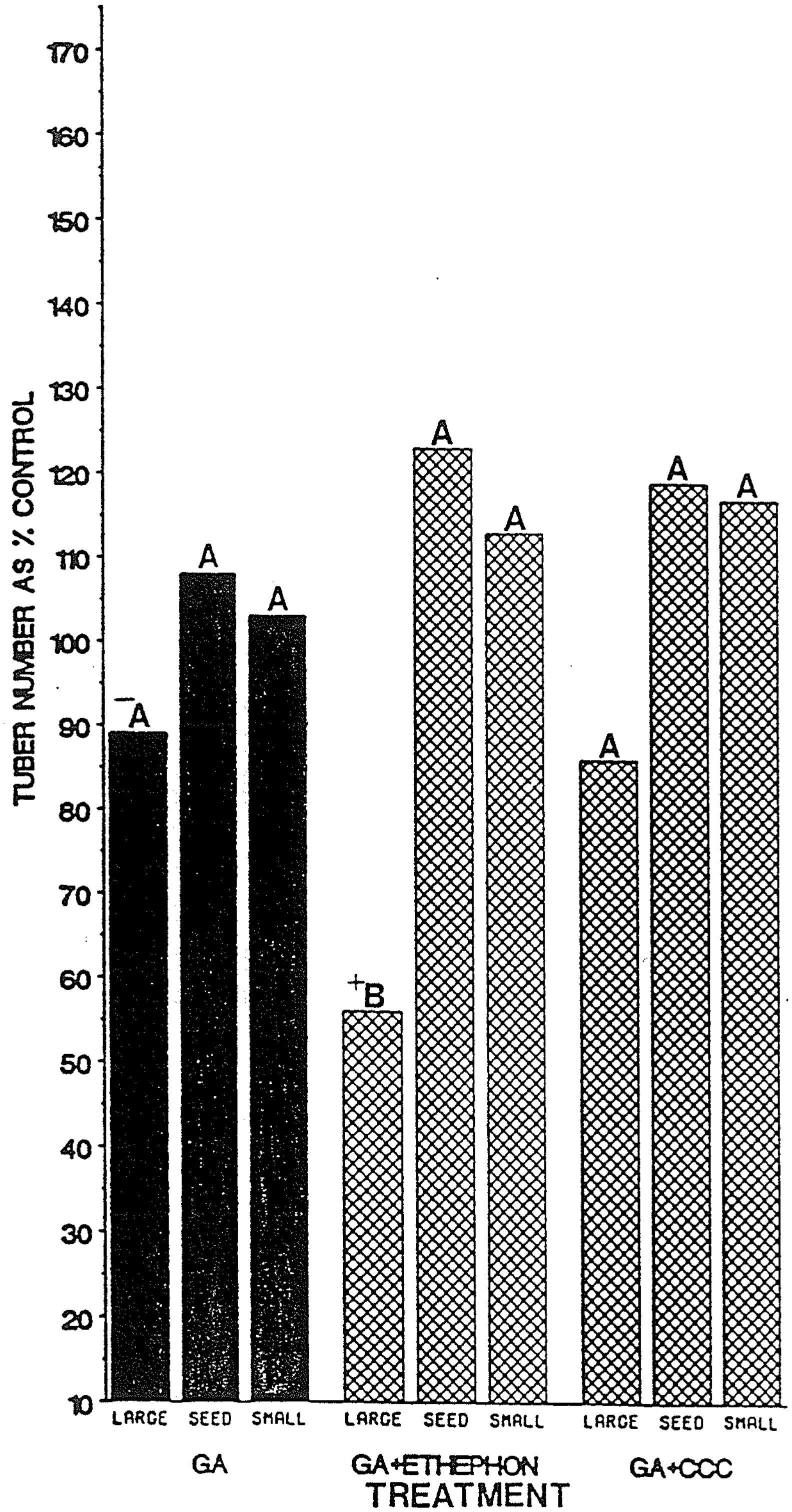
GA = gibberellic acid (0.04 kg ai/ha)

ethephon (0.5 kg ai/ha)

CCC = chlormequat (0.5 kg ai/ha)

-Values with the same letter for each tuber size are not significantly different (LSD=5%).

+Values significantly different from the control (LSD=5%)



170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
TUBER NUMBER AS % CONTROL
⁻A
A
A
⁺B
A
A
A
A
A
LARGE SEED SMALL
LARGE SEED SMALL
LARGE SEED SMALL
GA
GA+ETHEPHON
GA+CCC
TREATMENT

Seedsize Tubers (4-5cm in 1985 and 3-5cm in 1986)

Although the results were not statistically significant, there was a general increase in the proportion of seedsize tubers due to GA+daminozide and GA+ethephon treatments in 1985 (Fig. 1). In 1986, GA+ethephon was the best treatment in increasing the proportion of seedsize tubers (Fig. 2). There was also some increment in the number of seed tubers resulting from GA+CCC, though not significant. Hence GA+ethephon was the best treatment on Norchip in 1986 with GA+CCC also showing some potential to increase the number of seed tubers.

Small Tubers (<4cm in 1985 and <3cm in 1986)

None of the treatments resulted in a significant change in the proportion of small tubers although there was a general decrease in the proportion of small tubers by all the treatments in 1985 (Fig. 1). In 1986 the treatments resulted in a higher proportion of small tubers, though not statistically significant (Fig. 2). An increase in the number of small tubers may not be considered valuable if they are too small for use as whole seed.

RUSSET BURBANK

Effects of GA

GA resulted in a slight increase in the number of stolons though not significant at the first sampling (3/7/85) (Table 2). The treatment resulted in a significant reduction in the weight of roots compared to the controls at the first sampling (14/7/86) probably due to an alteration in source/sink relationships i.e. a promotion of topgrowth at the expense of root growth. GA is known to promote shoot growth

Table 2 Effect of growth regulators on stems, stolons, roots and tubers of field grown Russet Burbank potatoes at three harvest dates, 1985 and 1986.

Treatment #	Stems		Stolons		Roots+Stolons	Tubers >2cm		Tubers < 2cm
	No.	Ht.(cm)	No.	Lgth.(cm)	DWt.(g)	No./plant	Ave. Diam.(cm)	No.
First harvest 3/7/85								
Control	2.3a*+	23.0a	12.5a	37.7a	0.15a	0	-	0
GA	2.5a	25.7a	14.1a	36.4a	0.17a	0	-	0
Second harvest 17/7/85								
Control	3.3a	52.4a	17.5a	40.4a	2.21a	6.8a	3.1a	5.2a
GA	2.7a	48.8a	17.0a	39.0a	1.72a	5.5a	2.7a	4.5a
GA+CCC	2.7a	51.4a	17.1a	17.2b	1.59a	6.2a	2.7a	5.2a
GA+daminozide	3.2a	49.0a	20.3a	31.7a	1.87a	7.5a	2.9a	5.7a
GA+ancymidol	2.8a	51.3a	17.0a	40.4a	2.00a	6.3a	3.0a	5.5a
Third harvest 31/7/85								
Control	2.2a	55.7a	21.2a	30.9a	6.61a	7.2a	4.4a	5.0a
GA	2.3a	59.1a	23.0a	55.4a	5.64a	7.2a	4.2a	4.7a
GA+CCC	3.0a	58.8a	25.8a	33.4a	8.16a	10.2a	4.5a	8.2a
GA+daminozide	2.7a	56.5a	23.2a	36.1a	6.34a	8.7a	4.4a	8.7a
GA+ancymidol	3.2a	59.0a	24.8a	42.2a	7.09a	7.8a	4.6a	6.0a

	Stems				Roots		Stolons				Tubers 2-5cm diam.		
	No.	Ht.(cm)	FWt.(g)	DWt.(g)	FWt.(g)	DWt.(g)	No.	Tip No.	FWt.(g)	DWt.(g)	No.	FWt.(g)	DWt.(g)
First harvest 14/7/86													
Control	3.8a	28.1a	159.3a	33.7a	24.9a	2.8a	20.5a	24.8a	6.8a	0.14a	0	-	-
GA	3.3a	28.7a	149.3a	32.8a	11.3b	2.4a	17.3a	24.4a	5.2a	0.21a	0	-	-
Second harvest 28/7/86													
Control	4.0ab	28.1a	153.3a	24.4a	13.4a	4.5a	14.8a	30.2a	6.4a	0.33a	14.5a	32.0a	17.2ab
GA	4.2a	29.6a	159.8a	26.0a	13.6a	3.6a	12.3a	26.0a	6.3a	0.43a	15.2a	33.9a	14.4a
GA+CCC	3.2ab	29.2a	136.2a	19.1a	13.8a	3.7a	13.3a	23.5a	6.1a	0.38a	12.3a	25.6a	16.4b
GA+ancymidol	2.8b	28.9a	136.7a	22.5a	11.9a	3.6a	9.0a	16.8a	4.2a	0.49a	12.8a	33.0a	16.2ab
Third harvest 11/8/86													
Control	3.3a	37.1a	215.8a	31.5a	15.8ab	4.2a	8.3a	15.2a	9.3a	0.79a	10.3a	84.1a	14.7a
GA	3.8a	35.7a	236.0a	35.3a	19.4a	3.5a	8.7a	13.7a	9.0a	0.53a	13.8a	94.8a	14.9a
GA+CCC	4.0a	36.4a	234.7a	29.0a	16.8ab	3.5a	9.7a	15.3a	9.1a	0.85a	14.4a	100.1a	18.6a
GA+ancymidol	3.0a	36.6a	209.1a	32.1a	15.1b	3.4a	6.5a	12.3a	5.1a	0.52a	11.4a	70.5a	12.1a

*Means within a column for each harvest date with the same letters are not significantly different (LSD 5%).
#Treatments and rates used were:
GA = gibberellic acid (0.04kg ai/ha)
CCC (0.5 kg ai/ha)
ancymidol (0.0028 kg ai/ha)
daminozide (2.0 kg ai/ha)
+all data are the per plant average for 2 plants per replicate

(Cathey, 1964). There were slight but not significant increases in plant height, shoot fresh weight and tuber number as a result of GA at the second sampling (28/7/86). The treatment also seemed to increase though not significantly, shoot fresh weight, root fresh weight, and tuber number at the third sampling (11/8/86).

Effects of GA+CCC

The treatment significantly reduced stolon length at the second sampling (17/7/85) (Table 2) probably due to a reduction in cell division and/or elongation of the stolons by CCC. At the third sampling (31/7/85) GA+CCC resulted in slight increments of all parameters which however were not significant. At the second harvest (28/7/86) GA+CCC resulted in some reduction, though not significant in shoot fresh weight without any effect on any of the other parameters and at the third harvest (11/8/86) the treatment resulted in some increase in stolons and tubers though not significantly. Hence in 1985 GA+CCC appeared to increase, though not significantly, stems, stolons, and tubers at the third sampling. In 1986, although results were not significant the treatment seemed to promote tubers compared with the control at the third sampling. The correlation coefficients were indicative of a generally positive effect of the treatment on stolons and tubers. Stolon and tuber number correlation increased from r=0.48 at the second sampling to r=0.96 at the third sampling in 1986 indicating that an increase in stolons might be a significant factor in the promotion of tuber numbers.

Effects of GA+daminozide

GA+daminozide resulted in no change in any of the parameters however there were was an indication of an increase in stolon number and tuber number at the second sampling (17/7/85), although this was not statistically significant (Table 2). Similarly at the third sampling there were marginal increases in stems, stolons, and tubers which however were not significant. The decision was made to drop this treatment from further testing.

Effects of GA+ancymidol

No significant effect resulted from the treatment in 1985 although there was a marginal increase in stolon number, stolon length, weight of roots and stolons, and tuber number at the third sampling (31/7/85) (Table 2). The marginal promotion of tubers at the third sampling in 1986 might be a result of an increase in stolons since the correlation coefficient of stolon number and tuber number increased from r=0.39 in the second sampling date to a significant r=0.94 at the third sampling date. It is logical to assume that an increase in stolons will likely result in an increase in tubers. Although the data were not statistically significant the correlation coefficients give an indication as to the strength of association amongst parameters as affected by the respective treatments. The correlation of stolon number and stolon tips was a high r=0.98 at the second period but in the third it declined to r=0.11 which might be indicative of the crop growth stage when more assimilates go towards tuber growth rather than formation of more stolon tips. The treatment was of little benefit in 1986, resulting in less tubers than GA alone.

Tuber Yields

Large tubers (>5cm diameter)

The treatments GA and GA+ancymidol resulted in a higher proportion of large tubers in 1985 although this was not significant (Fig. 3). GA+CCC resulted in a lower proportion of large tubers in 1985. In 1986 all the treatments resulted in a lower proportion of large tubers relative to the control (Fig. 4).

Seedsize tubers (4-5cm in 1985 and 3-5cm in 1986)

In 1985, GA+CCC and GA+ancymidol resulted in high but not significant increases in tuber number (Fig. 3). In 1986, GA+ancymidol and GA alone also resulted in high but not significant increases in seedsize tubers (Fig. 4).

Small tubers (<4cm in 1985 and <3cm in 1986)

In 1985, all the treatments increased tuber number compared with the control although results were not significant (Fig. 3). In 1986, all the treatments except GA+CCC resulted in an increase in the number of smallsize tubers over the control, although not significantly. GA+ancymidol significantly increased the number of small tubers compared with the other treatments (Fig. 4).

Figure 3: Effect of growth regulators on yield of large, seed, and small tubers of Russet Burbank on September 18, 1985

LEGEND:

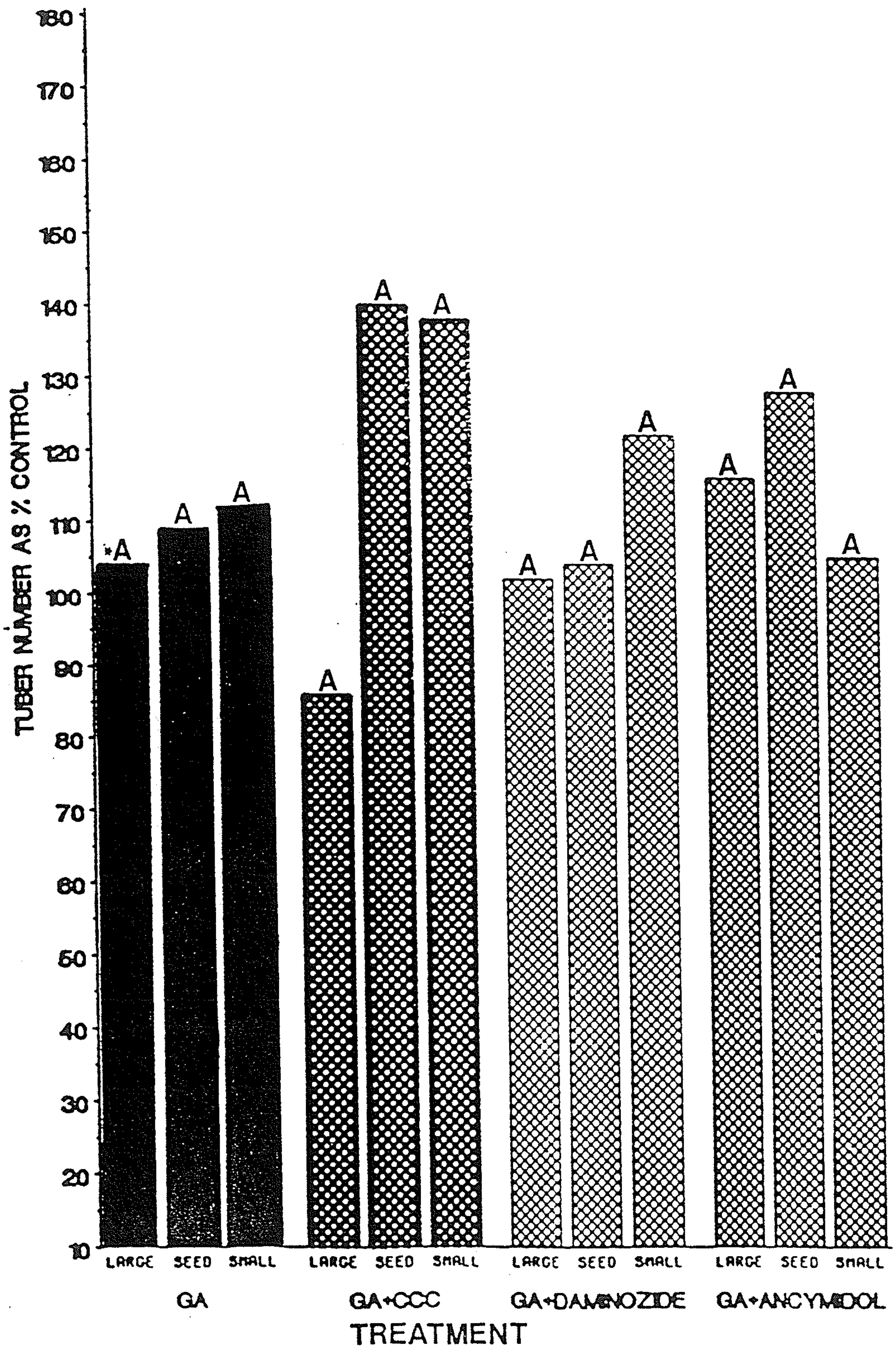
GA = gibberellic acid (0.04 kg ai/ha)

ancymidol (0.0028 kg ai/ha)

CCC = chlormequat (0.5 kg ai/ha)

daminozide (2.0 kg ai/ha)

*Values with the same letter for each tuber size are not significantly different (LSD=5%).



TUBER NUMBER AS % CONTROL
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
*A
A
LARGE SEED SMALL
LARGE SEED SMALL
LARGE SEED SMALL
LARGE SEED SMALL
GA
GA+CCC
GA+DAMINOZIDE
GA+ANCYMIDOL
TREATMENT

Figure 4: Effect of growth regulators on yield of large, seed, and small tubers of Russet Burbank on September 25, 1986

LEGEND:

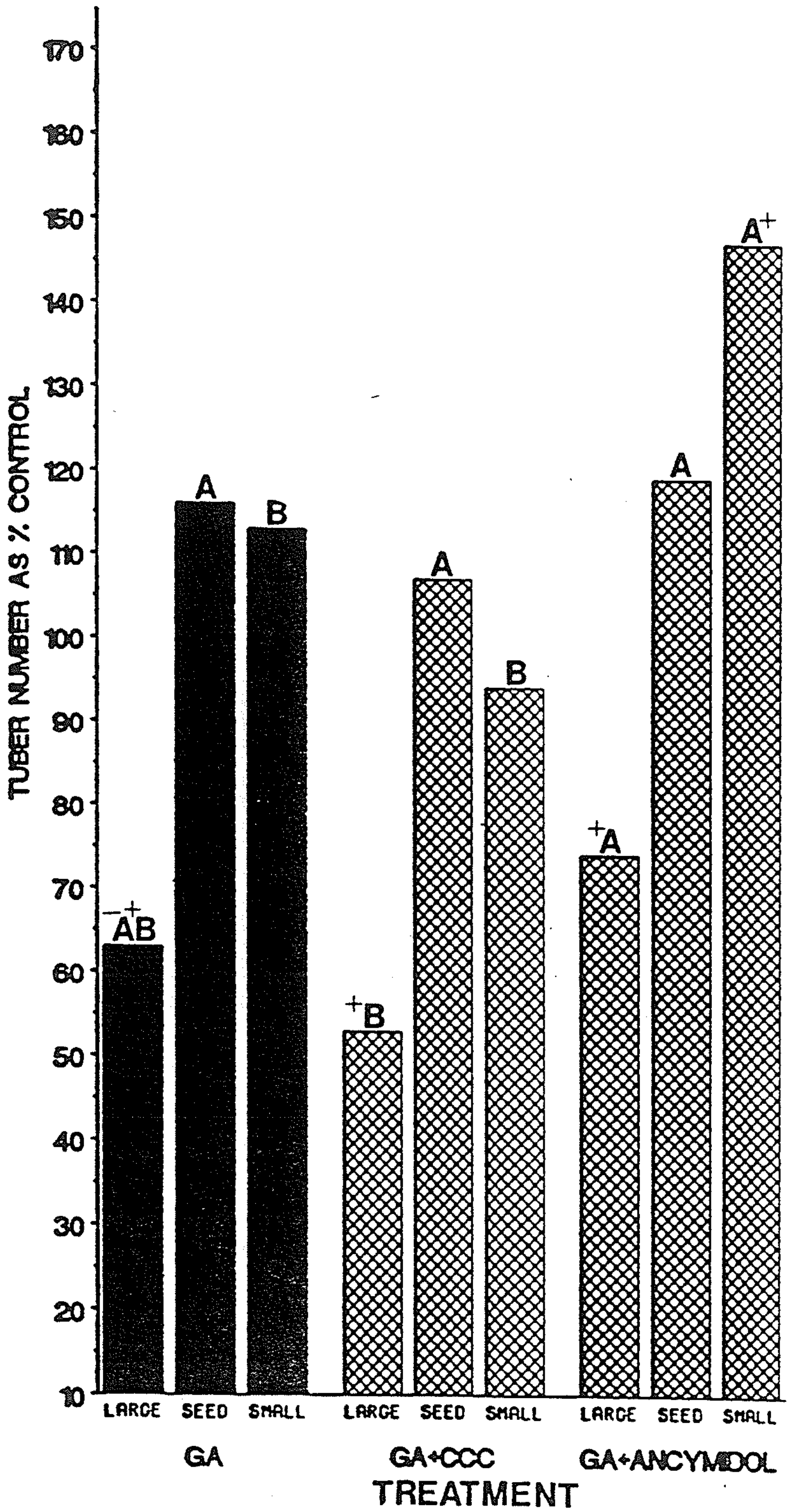
GA = gibberellic acid (0.04 kg ai/ha)

ancymidol (0.0028 kg ai/ha)

CCC = chlormequat (0.5 kg ai/ha)

-Values with the same letter for each tuber size are not significantly different (LSD=5%).

+Values significantly different from the control (LSD=5%).


TUBER NUMBER AS % CONTROL
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
AB
A
B
B
A
B
A
A
A
LARGE
SEED
SMALL
LARGE
SEED
SMALL
LARGE
SEED
SMALL
GA
GA+CCC
GA+ANCYMIDOL
TREATMENT

CONCLUSION

On Norchip, the most effective treatment for modification of tuber development appeared to be GA+daminozide in 1985, which reduced the proportion of oversized tubers whilst increasing seedsize tubers although results were not significant. GA+ethephon although resulting in more large tubers, also showed some promotion, though not significant, of seedsize tubers over the control. GA alone seemed to increase larger tubers in general. Although the GA+CCC treatment caused no remarkable increase in seedsize tubers in 1985, there was a reduction in weight (g) per tuber of oversized tubers as well as undersized tubers. In 1986, GA+ethephon and GA+CCC increased seedsize tubers and also reduced the proportion of larger tubers.

On Russet Burbank, in 1985, although none of the treatments significantly increased seedsize tubers, GA+CCC and GA+ancymidol showed slight increases of seed tubers over the control. In 1986, although there were no significant effects of the treatments on seedsize tubers, GA+ancymidol and GA alone appeared to result in a higher proportion of seedsize tubers. In addition, all the treatments significantly reduced the proportion of large tubers. Hence on Norchip the good treatments were GA+ethephon, GA+CCC and GA+daminozide whilst on Russet Burbank, GA+ancymidol and GA+CCC had positive results. Hence benefits from growth regulators might be an increase in the proportion of seedsize and a decrease in the proportion of largesize tubers.

EFFECT OF SELECTED PLANT GROWTH REGULATORS ON THE PRODUCTION OF SEEDSIZE TUBERS OF NORCHIP AND RUSSET BURBANK POTATOES (*SOLANUM TUBEROSUM* L.)

ABSTRACT

Effects of the growth regulators gibberellic acid (GA), ancymidol, ethephon, chlormequat (CCC), and daminozide on growth and development of Norchip potatoes were evaluated in growth room studies. All the growth retardants resulted in some general height reduction. Ethephon caused malformation of top growth and caused the most severe height retardation. Some retardant-treated plants had an enhanced green colouring of leaves. GA increased stem elongation and resulted in somewhat light-green coloured plants in general. All the treatments seemed to increase both the stolon number and tips per stolon. Whereas GA increased stolon length, the growth retardants had the opposite effect. All the treatments with the exception of ancymidol resulted in a higher mean tuber number than untreated plants.

The best treatments were found to be CCC and ethephon with a consistent promotion of small tubers (>6mm diameter) throughout the sampling period. GA and daminozide were effective in significantly increasing small tubers at the last sampling. Although ancymidol promoted stolons and tips, it did not effectively enhance tuber number compared with either the control or the other treatments. Hence CCC and ethephon were the best treatments overall. The application rate for CCC which was found most effective in increasing the number of tubers was 0.28g ai/l.

INTRODUCTION

Growth room studies provide controlled environment conditions thus eliminating most of the variability which is common under field conditions. In addition, the use of single stem cuttings from a few mother potato plants would further help limit the wide variability characteristic of field studies.

It is known that high concentrations of GA promote internode and stolon elongation (Lovell and Booth, 1967) which might delay tuber initiation (Dyson and Humphries, 1966). Application of growth retardants might be expected to advance tuber initiation (Dyson, 1965; Dyson and Humphries, 1966). There have also been reports that GA enhances stolon growth and branching, which might indicate a higher potential for tuber formation (LaCroix and Adam, 1983). GA and ethephon have been shown to enhance the yield of small tubers on Norland potatoes (LaCroix and Adam, 1983).

Chlormequat has been reported to reduce plant height (Cathey, 1964), promote tuber growth (Radwan et al., 1971), and advance tuber initiation on GA-treated plants (Dyson, 1965). Similarly, daminozide has been reported to promote the yield of seedsize tubers whilst reducing the proportion of oversized tubers (Laycock, 1971; White et al., 1985). Ethephon, an ethylene liberator, has been reported to promote tuber initiation (Catchpole and Hillman, 1969; Garcia-Torres and Gomez-Campo, 1973). Palmer and Barker (1973) indicated that ethylene inhibits cell division. Ancymidol, another growth retardant (Cathey, 1964) has been reported to shorten stems and enhance flowering of seed geraniums (Miranda and Carlson, 1980).

The major aim of the growth room studies was to evaluate the effects of all the chemicals on the growth and development of Norchip potatoes under controlled environment. This would also help explain some of the trends observed in the field research.

MATERIALS AND METHODS

Mother plants were grown in clay pots of 30 cm diameter filled with a 2:1:1 (sand: soil:perlite) soil mixture and fertilized with a ful strength 20:20:20 (N:P:K) nutrient solution. Stem cuttings of approximately 10 cm in height were selected and dipped in naphthalene butyric acid powder (rooting compound) and placed in a misting chamber in vermiculite till rooting and watered with a 20:20:20 (N:P:K) nutrient solution. After rooting, the cuttings were transplanted into flats containing vermiculite and placed in a growth room under conditions of 23 C day, 17 C night temperature and 12 hr day. The vermiculite was watered with a nutrient solution (Appendix Table 6) twice a week. Plants were treated with CCC at 0.14g ai/l, ancymidol at 13.3g ai/l, GA at 0.112g ai/l, daminozide at 2.9g ai/l, and ethephon at 0.65g ai/l after a week and five plants were assessed beginning 7 days after treatment and continued on for 35 days at weekly intervals. The application rates, comparable with reports in the literature were higher than the field rates in order to exploit the full potential of each chemical. The chemicals were foliar applied using a laboratory sprayer. Complete wetness was attained on each plant. The flats each containing five plants, were placed in the growth room in a completely randomised design with six treatments and six replicates. Parameters assessed included plant height (cm), measured from the shoot apex to the start of the root system, stem branching, number of stolons per plant, stolon branching, nodes and tips, stolon length (cm), as well as the number and diameter of tubers obtained. Visual observations on leaf colour and form were made. Once the stolon tip was developed beyond 6mm it was considered a tuber and no longer counted as a tip whilst that stolon was included in the stolon number.

Another experiment was carried out to evaluate the most effective rate of application of chlormequat. Four rates of CCC were used: 0.07g ai/l, 0.14g ai/l, 0.28g ai/l, and 0.56g ai/l. A final harvest was done at the end to compare the effects of the treatments on tuber set of Norchip.

RESULTS AND DISCUSSION

EFFECTS OF GA

GA significantly increased plant height at 14, 28, and 35 days after treatment (Appendix Table 5). Lang (1970) and Cathey (1964) also reported internode elongation by GA. The leaves showed some pale colouration compared with either the control or retardant-treated plants. No significant effects on branching and flowering were observed as a result of GA treatment.

GA significantly increased the number of stolons throughout the sampling period (Fig. 5). This seems to concur with reports by Lovell and Booth (1967). GA has been reported to delay tuber initiation (Dyson and Humphries, 1966). The stolons in GA treated plants were significantly longer than the controls at most sampling dates except at 14 days (Fig. 6). Some of the longer stolons had but a few branches and all showed a general increase in the nodes or tip number (Fig. 7).

Although there have been reports that GA retards tuberization (Timm et al., 1962), there was no evidence of such in this case (Fig. 8-10). Instead the results seem to concur with observations that GA might promote seedsize tubers (LaCroix and Adam, 1983).

Figure 5: Effects of GA, daminozide, ancymidol, ethephon, and CCC on stolon number per plant of Norchip at five sampling dates

LEGEND:

GA = gibberellic acid (0.112g ai/l)

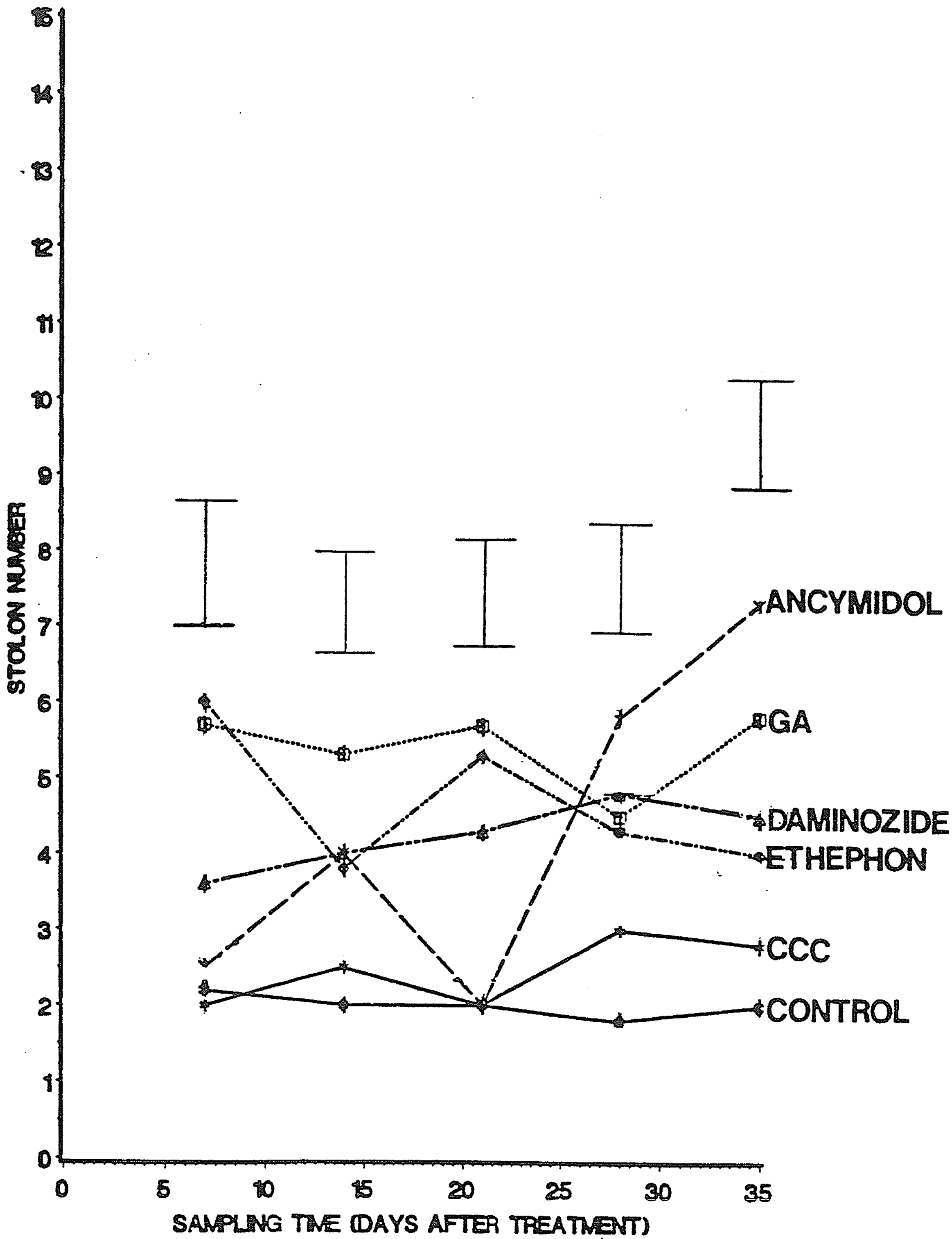
ethephon (0.65g ai/l)

ancymidol (13.3g ai/l)

CCC = chlormequat (0.14g ai/l)

daminozide (2.9g ai/l)

Bars represent LSD=5% for each sampling date.



STOLON NUMBER
SAMPLING TIME (DAYS AFTER TREATMENT)
ANCYMIDOL
GA
DAMINOZIDE
ETHEPHON
CCC
CONTROL
0
5
10
15
20
25
30
35
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

Figure 6: Effects of GA, daminozide, ancymidol, ethephon, and CCC on average stolon length per plant of Norchip at five sampling dates

LEGEND:

GA = gibberellic acid (0.112g ai/l)

ethephon (0.65g ai/l)

ancymidol (13.3g ai/l)

CCC = chlormequat (0.14g ai/l)

daminozide (2.9g ai/l)

Bars represent LSD=5% for each sampling date.

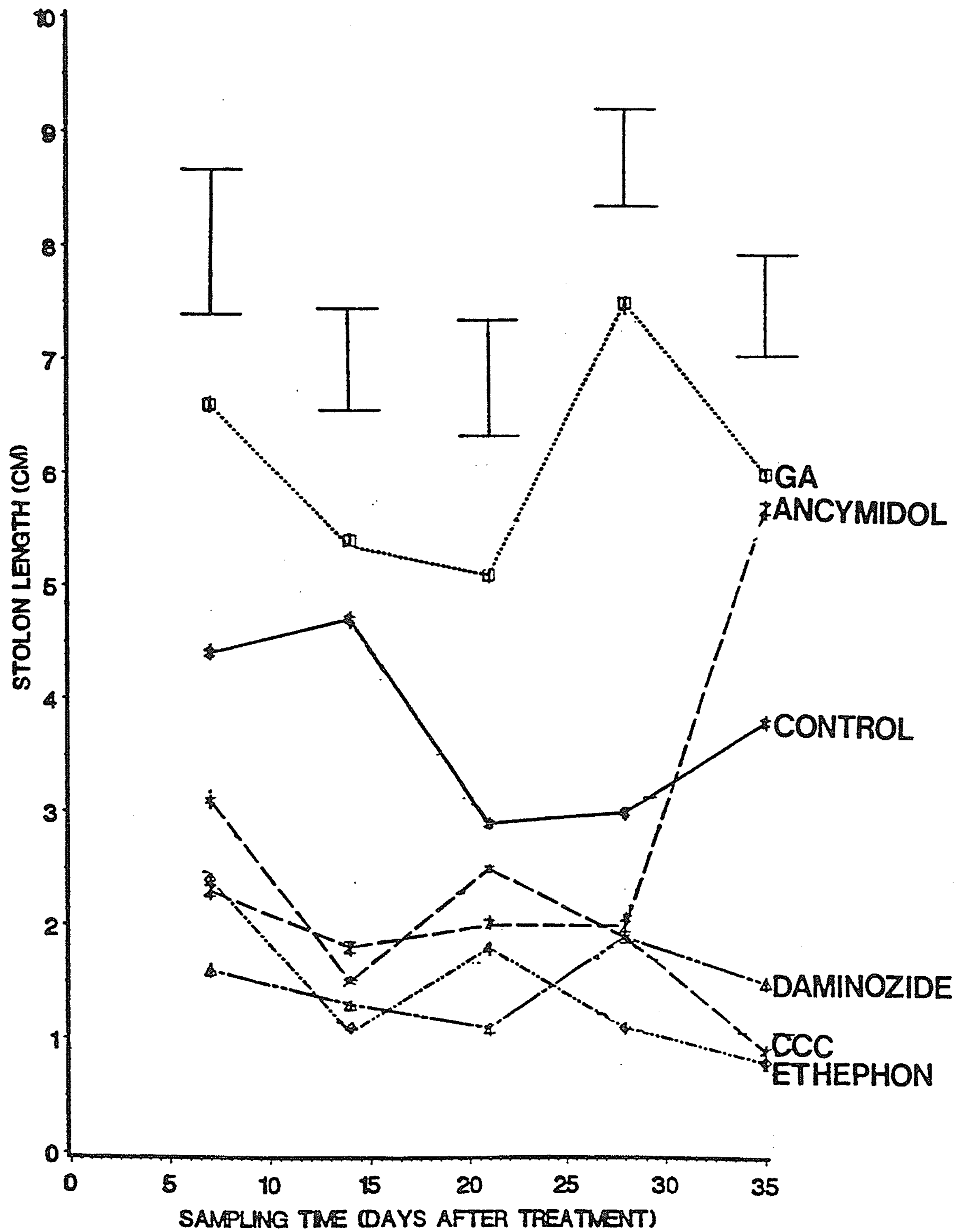

STOLON LENGTH (CM)
SAMPLING TIME (DAYS AFTER TREATMENT)
0
5
10
15
20
25
30
35
1
2
3
4
5
6
7
8
9
10
GA
ANCYMIDOL
CONTROL
DAMINOZIDE
CCC
ETHEPHON

Figure 7: Effects of GA, daminozide, ancymidol, ethephon, and CCC on stolon tips per plant of Norchip at five sampling dates

LEGEND:

GA = gibberellic acid (0.112g ai/l)

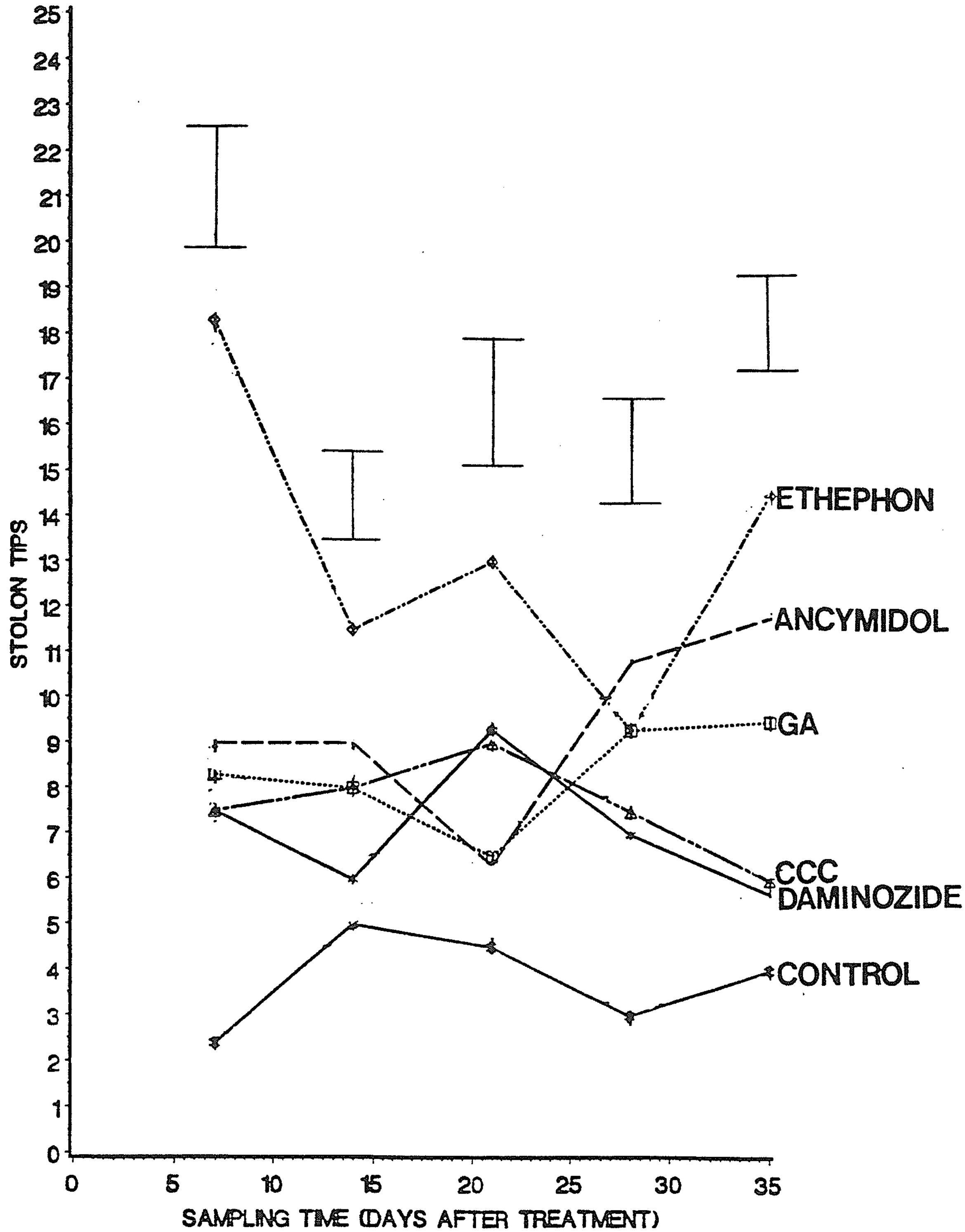
ethephon (0.65g ai/l)

ancymidol (13.3g ai/l)

CCC = chlormequat (0.14g ai/l)

daminozide (2.9g ai/l)

Bars represent LSD=5% for each sampling date.



STOLON TIPS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
ETHEPHON
ANCYMIDOL
GA
CCC
DAMINOZIDE
CONTROL
0
5
10
15
20
25
30
35
SAMPLING TIME (DAYS AFTER TREATMENT)

Figure 8: Tuber number per plant for Norchip potatoes as influenced by growth regulators 21 days after treatment

LEGEND:

GA = gibberellic acid (0.112g ai/l)

ethephon (0.65g ai/l)

ancymidol (13.3g ai/l)

CCC = chlormequat (0.14g ai/l)

daminozide (2.9g ai/l)

*Values with the same letter are not significantly different (LSD=5%)

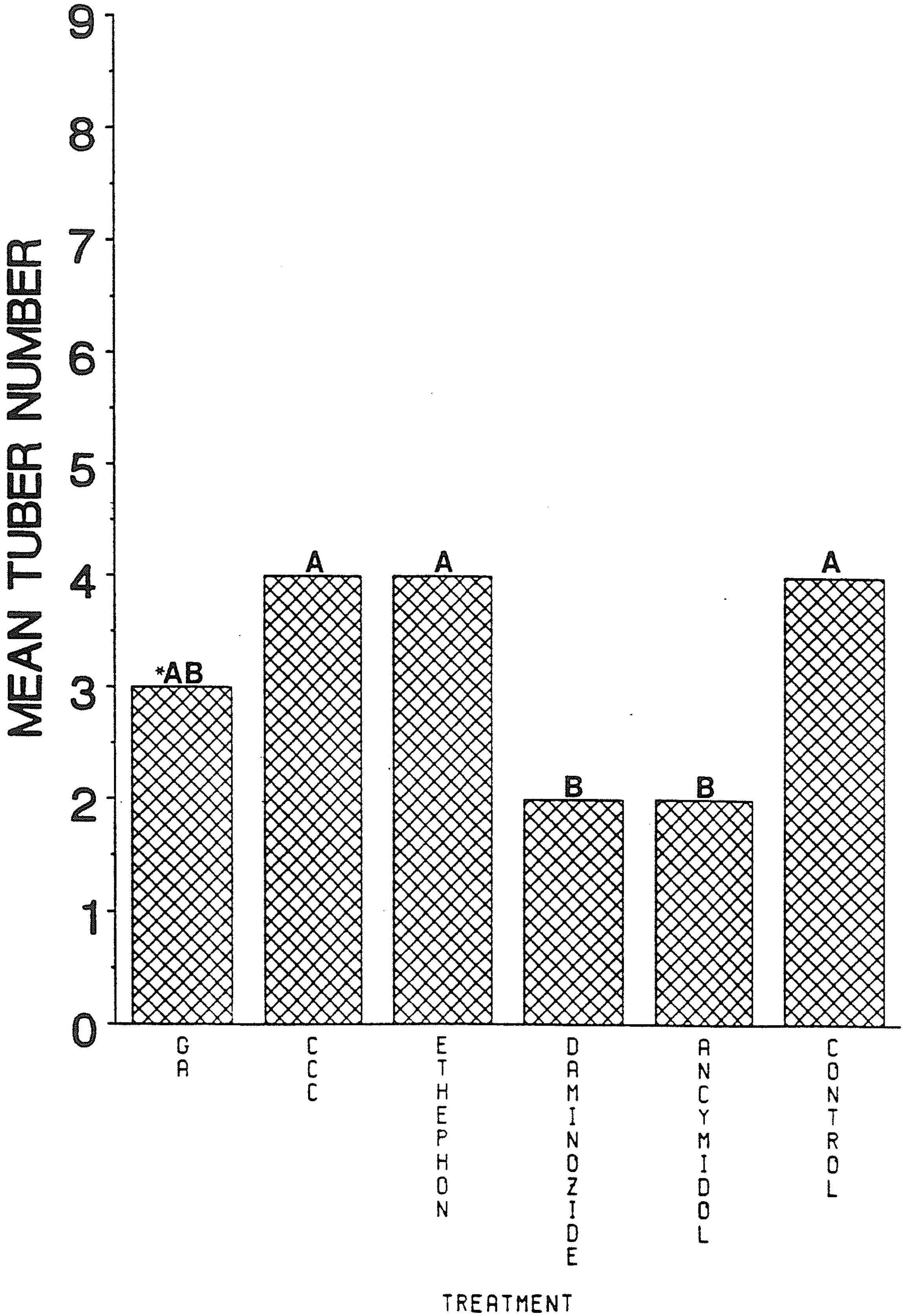

MEAN TUBER NUMBER
9
8
7
6
5
4
3
2
1
0
*AB
A
A
B
B
A
GA
CCC
ETHEPHON
DAMINOZIDE
ANCYMIDOL
CONTROL
TREATMENT

Figure 9: Tuber number per plant for Norchip potatoes as influenced by growth regulators 28 days after treatment

LEGEND:

GA = gibberellic acid (0.112g ai/l)

ethephon (0.65g ai/l)

ancymidol (13.3g ai/l)

CCC = chlormequat (0.14g ai/l)

daminozide (2.9g ai/l)

*Values with the same letter are not significantly different (LSD=5%)

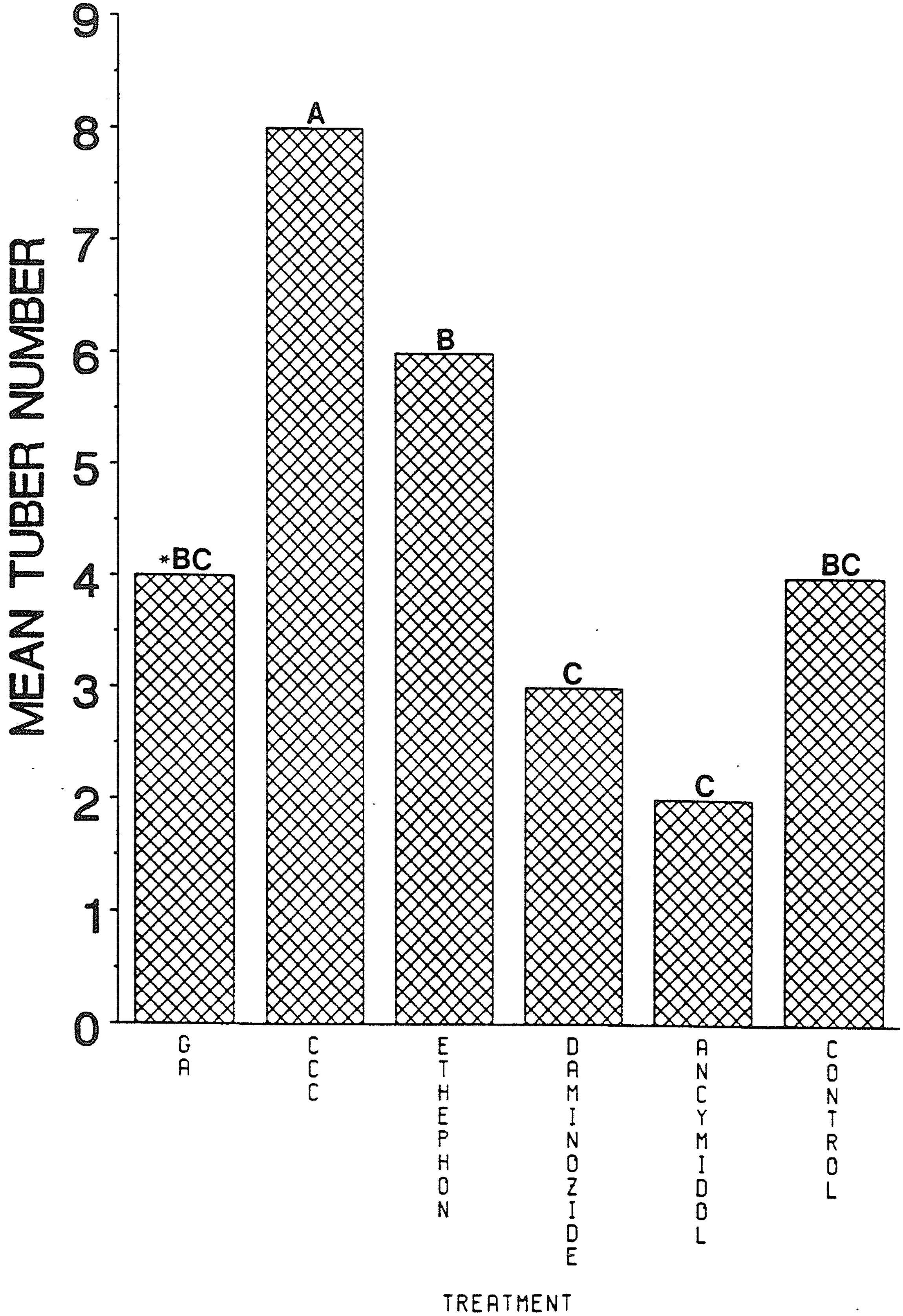

MEAN TUBER NUMBER
9
8
7
6
5
4
3
2
1
0
*BC
A
B
C
C
BC
GA
CCC
ETHEPHON
DAMINOZIDE
ANCYMIDOL
CONTROL
TREATMENT

Figure 10: Tuber number per plant for Norchip potatoes as influenced by growth regulators 35 days after treatment

LEGEND:

GA = gibberellic acid (0.112g ai/l)

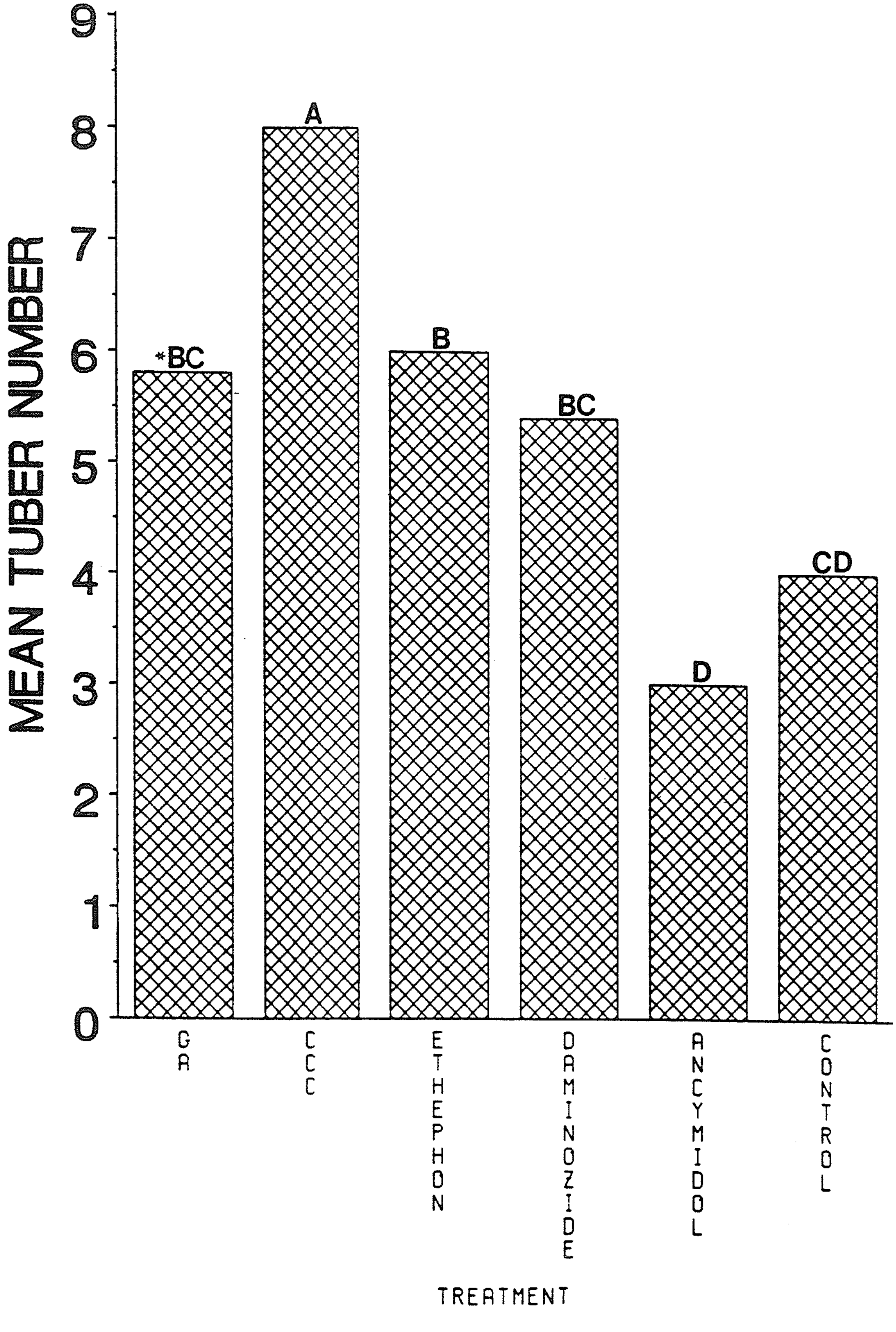
ethephon (0.65g ai/l)

ancymidol (13.3g ai/l)

CCC = chlormequat (0.14g ai/l)

daminozide (2.9g ai/l)

*Values with the same letter are not significantly different (LSD=5%)



MEAN TUBER NUMBER
0
1
2
3
4
5
6
7
8
9
*BC
A
B
BC
D
CD
GA
CCC
ETHEPHON
DAMINOZIDE
ANCYMIDOL
CONTROL
TREATMENT

Correlations

TABLE 3

Correlation coefficients of parameters of Norchip as influenced by GA at three sampling dates

Sampling date	Stolon number & stolon tips	Stolon number & tuber number	Stolon tips & tuber number
21 days	0.29	0.70*	0.50
28 days	0.39	0.93**	0.10
35 days	0.02	0.34	0.22

*, ** = significant at 5% and 1% levels respectively

The correlation of stolon number and tubers was significant (r=0.70) on plants harvested 21 days after treatment (Table 3). and it was highly significant (r=0.93), 28 days after treatment. The later decline in the relationship could be indicative of either a diluted effect of GA with time or rather a switch in the growth pattern of the plants, i.e. less production of stolons. The correlation of stolon number and stolon tips was rather low and not significant. Similarly that of stolon tips and tubers was low indicating perhaps that either GA does not significantly promote stolon tips or else stolon tips might not be an important factor in enhancing tuber numbers. However such deductions require further elucidation.

EFFECTS OF CCC

The results show that CCC effectively reduced the height of treated plants. The greatest reduction in plant height was at 7 days whilst the effect was less at 35 days (Appendix Table 5) This could indicate that the effect of CCC is diluted with time in which case a split application of the chemical perhaps could be recommended or rather a higher rate of application might be required. These height reduction results concur with reports by Radwan et al.(1971) and Dyson (1965). No colour changes or malformations were evident on CCC-treated leaves.

The effect of CCC on stolon number was variable. CCC-treated plants were not significantly different n stolon number from the control however by day 35 CCC resulted in a lower mean value compared to the other growth regulators (Fig. 5). The stolons were shorter (Fig. 6) and occurred more frequently on the nodes. CCC generally resulted in more stolon tips than the control (Fig. 7). Perhaps the retardation of internode elongation by CCC is compensated by an increased number of stolons set at the nodes. This seems to relate well with the observation by Woolley and Wareing (1972) that a high gibberellin concentration below-ground favours stolon elongation hence growth retardants would oppose such an effect.

CCC significantly increased tuber numbers compared with ancymidol, or daminozide, but was not significantly different from the control, GA, or the ethephon treatment 21 days after treatment (Fig. 8). At the 28 and 35 sampling dates, CCC was the most superior treatment with a significant increase in small tubers over all the other treatments and the control (Figs. 9&10). This promotion of tuber number by CCC was also reported by Gunasena and Harris (1969) and Menzel (1980).

Correlations

TABLE 4

Correlation coefficients of parameters of Norchip potatoes as influenced by CCC at three sampling dates

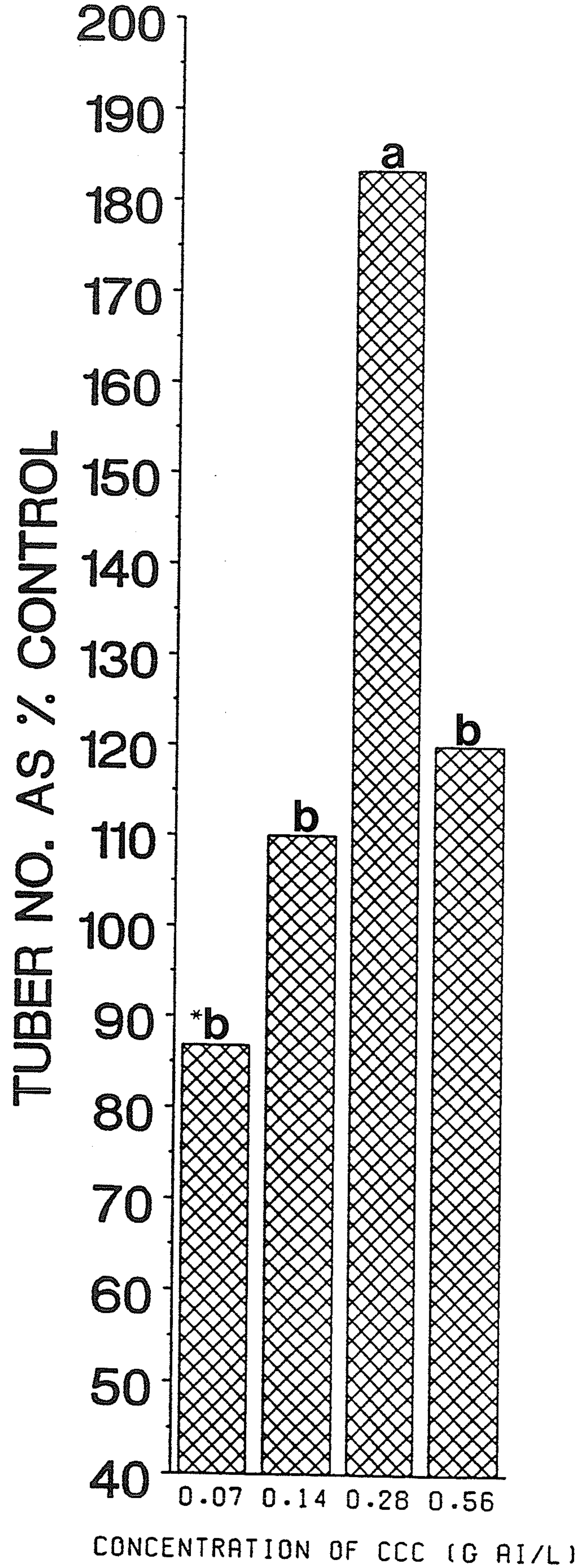
Sampling date	Stolon number & stolon tips	Stolon number & tuber number	Stolon tips & tuber number
21 days	0.44	0.20	0.45
28 days	0.54	0.37	0.46
35 days	0.26	0.39	0.36

The correlations of stolon and tuber number though not significant also showed an increasing trend with time. Hence we might conclude that CCC generally favours the relationship of stolons and tuber numbers rather than stolon tips.

The most effective concentration of CCC was 0.28g ai/l in this study (Figure 11). Hence the rate used in the initial study was underestimated for optimal promotion of tubers.

Figure 11: Effect of various concentrations of CCC on tuber number per plant for Norchip potatoes in the growth room

*Values with the same letter are not significantly different (LSD=5%)



TUBER NO. AS % CONTROL
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
*b
b
a
b
0.07
0.14
0.28
0.56
CONCENTRATION OF CCC (G AI/L)

EFFECTS OF ANCYMIDOL

Ancymidol reduced plant height greatly between 14 and 21 days of sampling, the effect then decreased with time, however in the end, the treatment resulted in a significant height reduction compared with the control (Appendix Table 5). Cathey (1964) and Miranda and Carlson (1980) reported stem retardation by ancymidol.

The treatment resulted in a significant increase in the number of stolons over the control at days 14, 28, and 35 (Fig. 5) and caused a significant increase in the number of stolon tips at sampling days 7, 14, 28, and 35 (Fig. 7) At the first two sampling dates, the treatment resulted in a significant reduction in stolon length compared with the control however by the last sampling date, there was a significant increase in stolon length (Fig. 6). The treatment did not result in a significant increase in tubers compared with the control (Figs. 8-10). This means that whatever promotion of stolons was realised earlier, was of no benefit in the final tuber counts. It was observed that at the final harvest date, there were still substantial numbers of stolons for tuber bearing potential later. Perhaps the low concentration used in these studies could not permit substantial effects on underground parts. On the other hand the rate might have been too high thus limiting tuber development.

Correlations

TABLE 5

Correlation coefficients of parameters of Norchip potatoes as influenced by ancymidol at three sampling dates.

Sampling date	Stolon number & stolon tips	Stolon number & tuber number	Stolon tips & tuber number
21 days	0.88**	0.02	0.26
28 days	0.55	0.15	0.53
35 days	0.26	0.70*	0.95**

*, ** = significant at 5% and 1% levels respectively

Ancymidol significantly promoted the number of stolon tips early in growth as the correlation (r=0.88) suggests (Table 5). This relationship showed a decline with time. On the other hand, stolon and tuber number showed an increasing relationship with time. An even stronger trend was that of stolon tips and tubers. We might conclude that the treatment does promote stolons and tips which might synergistically contribute to whatever tuber number increase may occur later in growth.

EFFECTS OF ETHEPHON

Ethephon resulted in the greatest plant height reduction compared with the control or any of the other treatments throughout the sampling period (Appendix Table 5). This was accompanied by leaf and petiole distortion and discolouration typical of ethylene effects. LaCroix and Adam (1983) reported some deformation of foliage and tubers after ethephon application to Russet Burbank potatoes.

Ethephon significantly increased stolon number (Fig 5), and stolon tips (Fig. 7), and reduced stolon length compared with the control (Fig. 6). The treatment also significantly increased tuber number over ancymidol and daminozide treatments, 21 days after treatment (Fig. 8). At the 28 and 35 sampling times, ethephon was the second best treatment to CCC in terms of significantly increasing tuber number (Fig. 9 & 10). An enhancement in yields of seed-size tubers after ethephon application two weeks after GA on Norland potatoes was indicated by LaCroix and Adam (1983). Hence it appears as though such encouraging results may be reproducible with Norchip.

Correlations

TABLE 6

Correlation coefficients of parameters of Norchip potatoes as influenced by ethephon at three sampling dates

Sampling date	Stolon number & stolon tips	Stolon number & tuber number	Stolon tips & tuber number
21 days	0.06	0.68*	0.96**
28 days	0.31	0.30	0.14
35 days	0.08	0.73*	0.94**

*, ** = significant at 5% and 1% levels respectively

The correlation of stolon number and tips was relatively low at the early stages of growth whilst that of stolon number and tuber number was fairly high (Table 6). The strongest relationship was that of stolon tips and tubers. This means that the treatment might be beneficial in increasing tubers as a result of enhancing stolon tips as well as stolons to varying extents. It seems ethephon favours more stolon tips per stolon which promote tuber numbers later.

EFFECTS OF DAMINOZIDE

Daminozide significantly reduced plant height compared with the control, throughout the sampling period (Appendix Table 5). The greatest effect was on the main stem rather than lateral growth. There was a slight reduction in leaf size but no deformation. Similar results were obtained by Dyson (1965)

The treatment did not significantly increase stolon number over the control at the first sampling day (Fig. 5), but significantly increased the number of stolon tips (Fig. 7) and reduced stolon length (Fig. 6). At 14 days, daminozide significantly increased stolon number compared with the control. The treatment also significantly decreased stolon length throughout the sampling period compared with the control. Although not statistically significant, daminozide increased tuber number compared with the control (Fig. 10).

This promotion of small tubers by daminozide has been reported by White et al. (1985), who stated that there are benefits in the promotion of small tubers at the expense of larger ones even if the overall yields are not enhanced. Hence these results indicate some positive benefits from the application of the individual growth regulators. However the magnitude of the benefits will depend on sufficient information pertaining to their application rates, timing with respect to the growth stage of the plant, and frequency of application amongst other factors.

Correlations

TABLE 7

Correlation coefficients of parameters of Norchip potatoes as influenced by daminozide at three sampling dates

Sampling date	Stolon number & stolon tips	Stolon number & tuber number	Stolon tips & tuber number
21 days	0.51	0.59	0.46
28 days	0.87**	0.13	0.37
35 days	0.41	0.87**	0.04

*, ** = significant at 5% and 1% levels respectively

The correlation of stolons and tubers was significantly enhanced from r=0.59 at the initial stages of growth to a significant r=0.87. Hence the treatment seems to be beneficial in increasing tubers as a result of promoting the number of stolons.

GENERAL DISCUSSION

GA generally increased stems, plant height,stolon number, stolon tips, and stolon length in 1985 and 1986 on both cultivars, Norchip and Russet Burbank. This treatment also increased the proportion of seedsize tubers whilst reducing the proportion of largesize tubers. Likewise, in the growth room studies, GA significantly increased plant height for most of the sampling period. There was also a significant promotion of stolons and stolon tips throughout the sampling period. The stolons from GA-treated plants were significantly longer. This confirms reports that GA promotes stem and stolon elongation (Cathey, 1964; Lang, 1970; Lovell and Booth, 1969). A potential for increasing the number of seedsize tubers using GA, has been suggested by the 1985 and 1986 field studies on both Norchip and Russet Burbank potatoes as well as the growth room screening trials using Norchip. We might deduce that perhaps the elongated stolons and stems have a much greater capability to form nodes on which other stolons and stolon apices may develop thus potentially increasing the number of tubers per plant. Hence GA has a definite promoting effect on stolons and if the prolonged stolonization occurs at the expense of tuberization, then the addition of growth retardants might be required.

GA+CCC proved to be the best treatment on Russet Burbank, increasing though not significantly, the number of stems, stolons, stolon tips, and seedsize tubers, and reducing the proportion of oversized tubers during the two sampling periods as well as the final harvest. The greatest effect of the treatment seems to have been on limiting stem and stolon elongation thus promoting the initiation of tubers. The correlation coefficients for stem and stolon number showed an increase from r=0.48 at the second sampling to r=0.96 at the third sampling. On Norchip, the treatment also increased the number of tips per stolon. The correlations of stem and stolon number, stem number and tuber number, and stolon number and tuber number were r=0.94, r=0.96, and r=0.92, respectively at the second sampling in 1986. CCC applied alone in the growth room screening studies reduced stem and stolon elongation, and increased stolon number and tips as well as the number of tubers per plant, thus confirming the effectiveness shown in the field trials. Similar results were reported by Gunasena and Harris (1969) and Menzel (1980). Radwan et al (1971) also reported a role for CCC in tuber development. The most effective rate of application of CCC in the growth room was shown to be 0.28g ai/l. This shows that the original rate used (0.14g ai/l) might have offered less optimal promotion of tubers. Hence CCC was the best growth retardant to enhance tuber number on its own as well as in combination with GA.

The GA+ethephon treatment increased the number of tubers >2cm diameter at both the second and third sampling periods in 1985, via a promotion of stolons in Norchip. Similarly in 1986 the treatment resulted in high correlations of stem and tuber number (r=0.96) and stem and stolon number (r=0.67). Toosey (1958) suggested that any treatment causing a large number of stems per hill might likely result in a large number of tubers. Using Norland cultivar, LaCroix and Adam (1983) reported a high correlation of stem number and tuber number (r=0.77). Hence it seems as though similar results may be obtained using Norchip. The final yield results suggested that GA+ethephon had a potential of being an effective promoter of seedsize tubers. As well, ethephon applied alone in the growth room, significantly reduced stem and stolon elongation whilst promoting stolon number and tips consistently throughout the sampling period. In the end the treatment had more smaller tubers that the control. Hence after CCC, ethephon proved to be the next best growth retardant which may be combined with GA to increase seedsize tubers on Norchip potatoes. LaCroix and Adam (1983) reported a promotion of small tubers due to ethephon application after GA on Norland potatoes. Similar results though not significant, were obtained in the present study using Norchip. According to LaCroix and Adam (1983), there was foliage and tuber deformation as a result of ethephon application on Russet Burbank potatoes. In our studies, the Norchip potatoes recovered from foliage and stolon abnormalities such that not much deformation was detected on the tubers. At the rate used in the growth room, there was no evidence of tuber deformation from ethephon although abnormalities on foliage and stolons were observed. The plants seemed to recover with time.

The GA+daminozide treatment was also effective in promoting seedsize tubers at the second and third sampling periods as well as the final harvest in 1985 on Norchip. The treatment reduced plant height, did not promote the number of stems but increased the number of stolons. Hence the promotion of tubers by GA+daminozide seems to have been through an increase in the number of stolons. The promotion of tubers by daminozide has been reported by Laycock (1971) and White et al. (1985). White et al. (1985) added that there was a reduction in the proportion of large tubers due to daminozide application. Although results were not statistically significant, there was an indication of a reduction in the proportion of large tubers by GA+daminozide on Norchip in 1985. In the growth room studies, daminozide reduced plant height and stolon length and promoted more stolons and tips. The treatment did not increase the number of small tubers at sampling days 21 and 28 however at day 35, there were more small tubers compared with the control. This might indicate that the retardant exerts most of its effect at the latter stages of growth. On the other hand this might have a bearing on the translocation, absorption, distribution, and metabolism of the chemical within the plant. It would thus be interesting to monitor the translocation rate of the chemical and its accumulation in relation to the commencement of tuber initiation in the plant.

The GA+ancymidol treatment increased stems, stolons, and tubers at the third sampling on Russet Burbank in 1985. There was also an increase in seed and undersized tubers in 1985 and 1986 on Russet Burbank. The growth room studies indicated a significant reduction in plant height, an increase in stolon number and tips, and reduced stolon length. Miranda and Carlson (1980) reported stem height reduction due to ancymidol. The treatment however did not increase tuber number over the control in the growth room screening studies.

It was observed that at the time of the last sampling, there were still an appreciable number of stolon apices with a tuber-bearing potential.

Previous work by LaCroix and Adam (1983) has suggested a potential for GA applied soon after emergence to promote stolon set and branching which when followed by a growth retardant to induce tuber set could increase the number of small potato tubers for use as whole seed. Holmes et al. (1970), also reported an increase in the number of stems and stolons after GA application. In our studies, GA did seem to increase the number of stolons and the number of stolon tips and length but did not significantly increase the number of tubers. Ancymidol gave a similar response whereas ethephon not only increased stolon and tip number but also increased tuber number over the control. CCC on the other hand had little effect on stolon development but increased the number of tubers which developed. El-Fouly and Garas (1968) also stated that CCC might be promoting tuber development in potatoes. Combinations of GA+ethephon, GA+CCC, ancymidol+CCC, ancymidol+ethephon, or ancymidol+CCC are suggested from this work as potential treatments to increase tuber number. This study also provided information on the relationships among the parameters. The correlation coefficients were significantly high for stolon and tuber number for both cultivars suggesting that the growth regulators increase tuber number through the promotion of stolons. The correlation of stem number and tuber number was high at the early stages of growth and decreased later, suggesting that an increase in stems later in growth would not be beneficial in increasing tuber number. On Russet Burbank which is a late cultivar and characterised by vigorous vegetative growth, the correlation of stem and tuber number was fairly high.

Several factors might have to be considered when interpreting the results obtained in these studies. Environmental influences were minimized in the growth room studies since light, daylength, nutrition, moisture, temperature, and wind were fairly standard. The laboratory sprayer also offered a more reliable medium for chemical application whereas wind and rain showers might have affected interception, absorption, and the eventual translocation of each chemical in the field studies. Some possible dilution of the chemicals is more likely under field conditions than in the growth room. In addition, the application rates were lower in the field than in the growth room. As well, complete wetting of the plant was attained in the growth room whereas the volume output was the standard in the field.

The source of planting material was likely another variable. Whilst a mixture of whole and cut seed of various sizes was used in 1985, in 1986 only the apical portion was used as an attempt to limit plant to plant variation in the field. In the growth room, stem cuttings were used instead of seed tubers. Bodlaender and Marinus (1969) reported that the mother tuber might contain some factors inhibitory to tuber initiation. Bottini et al. (1981) then showed that plants originating from tubers contain large amounts of gibberellin-like substances, the supplies of which decrease at the beginning of tuber initiation. This means that tuber initiation would generally be delayed in plants originating from tubers compared to those grown from stem cuttings even with due regard to prevailing enviromental factors and different application rates of the individual chemicals. Hence it is worthwhile to consider these factors when interpreting the present results.

SUGGESTIONS FOR FURTHER RESEARCH

It would be worthwhile to test the chemicals individually for a longer period of time at various rates of application in the growth room in order to correlate the trends of the other parameters with final tuber yields. The rates currently used could serve as a baseline from which to start. The method of application (foliar) may be convenient for field studies however some chemicals best perform when soil-applied hence some more growth room studies relating to the method of application might be helpful in establishing the optimum potential of some of the chemicals. At the initial stages of these studies, we encountered problems with the growing medium. We found that although peat moss allows earlier and more prolific rooting in the misting chamber, it also helps transmit disease problems hence vermiculite seems to be the best medium for stem cuttings.

Autoradiography studies should be conducted for each chemical in order to establish the accumulation of each chemical in stolon apices in relation to the beginning of tuber initiation. This would help explain if the trends observed in the present study were due to the chemical effects or rather a manifestation of the environment or both.

From this work we would recommend GA and ancymidol as stolon promoters preceding ethephon and CCC as tuber initiation growth retardants to increase tuber set. Some follow-up experiments relating to the residual effects of the chemicals on the first year seed crop were done although not reported in the present text. Such studies would help determine if any of the chemicals do have adverse effects on the succeeding crop. None of the growth regulators seemed to affect the sprouting of the seed in storage. However more information on emergence, general plant vigour and yielding ability is necessary.

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Appendix

Appendix Table 1 Effect of growth regulators on tuber yield and weight per tuber of Norchip potatoes

September 18, 1985

Treatment	Large tubers (>5cm) Wt./plot (kg)	Large tubers (>5cm) Wt.as% control	Large tubers (>5cm) Wt.per tuber(g)	Seedsize (4-5cm) Wt./plot (kg)	Seedsize (4-5cm) Wt.as% control	Seedsize (4-5cm) Wt.per tuber(g)	Small (<4cm) Wt./plot (kg)	Small (<4cm) Wt.as% control	Small (<4cm) Wt.per tuber(g)
Control	16.8a	100.0a	168.3a	7.1a	100.0	71.9a	1.6a	100.0	36.1a
GA	16.6a	98.8a	153.3a	5.9a	83.1	63.2a	1.7a	106.3	43.8a
GA+ethephon	16.6a	98.8a	137.2a	5.7a	80.3	55.1a	2.0a	125.0	50.0a
GA+CCC	15.2a	90.5a	156.7a	6.1a	85.9	62.2a	1.7a	106.3	48.6a
GA+daminozide	15.2a	90.5a	168.9a	6.9a	97.2	58.7a	1.3a	81.3	36.6a

September 25, 1986.

Treatment	Large tubers (>5cm) Wt./plot (kg)	Large tubers (>5cm) Wt. as % control	Large tubers (>5cm) Wt. per tuber(g)	Seedsize (3-5cm) Wt./plot (kg)	Seedsize (3-5cm) Wt. as % control	Seedsize (3-5cm) Wt. per tuber(g)	Small (<3cm) Wt./plot (kg)	Small (<3cm) Wt. as% control	Small (<3cm) Wt. per tuber(g)
Control	12.1a	100.0a	165.8ab	6.3a	100.0	63.0a	1.4a	100.0	46.7a
GA	11.1a	91.7a	170.8a	7.1a	112.7	65.7a	0.9ab	64.3	29.0b
GA+ethephon	5.9b	48.8b	143.9a	7.4a	117.5	60.2a	0.6b	42.9	17.7c
GA+CCC	10.5a	86.8a	116.7c	7.1a	112.7	59.7a	0.8ab	57.1	22.9bc

*Means within a column with the same letter are not significantly different (LSD 5%)
Treatment and rate:
GA = gibberellic acid (0.04 kg/ha)
daminozide (2.0 kg/ha)
ethephon (0.5 kg/ha)
CCC (0.5 kg/ha)

Appendix Table 2 'Correlation coefficients of parameters of Norchip potatoes at two sampling dates in 1986'

28/7/86	stem & stolon number	stem & tuber number	stolon & tuber number	stolon number & stolon tips
GA	0.04	0.17	0.94**	0.04
GA+CCC	0.94**	0.96**	0.92**	0.44
GA+Ethephon	0.23	-0.02	0.96**	-0.50
11/8/86				
GA	0.60	0.96	0.62	0.81
GA+CCC	0.75*	0.65*	0.43	0.65
GA+ethephon	-0.19	-0.58	0.94**	0.94**

*, ** = significant at 5% and 1% levels respectively

Appendix Table 3 'Correlation coefficients of parameters of Russet Burbank potatoes at two sampling dates in 1986'

28/7/86	stem & stolon number	stem & tuber number	stolon & tuber number	stolon number & stolon tips
GA	-0.34	0.13	0.80**	0.67*
GA+CCC	0.63	0.66*	0.48	0.64*
GA+A-Rest	0.49	0.45	0.39	0.98**
11/8/86				
GA	0.60	0.66*	0.60	0.77**
GA+CCC	-0.22	0.85**	0.96**	0.82**
GA+A-Rest	0.57	0.56	0.94**	0.11

*, ** = significant at 5% and 1% levels respectively

Appendix Table 4 Effect of growth regulators on tuber yield and weight per tuber of Russet Burbank potatoes

September 18, 1985

Treatment	Large tubers(>5cm)			Seedsize (4-5cm)			Smallsize (<4cm)		
	Wt./plot (kg)	Wt.as % control	Wt.per tuber(g)	Wt./plot (kg)	Wt.as % control	Wt.per tuber(g)	Wt./plot (kg)	Wt.as % control	Wt.per tuber(g)
Control	*21.5a	100.0a	216.1a	4.7a	100.0	96.4a	2.4a	100.0	65.8a
GA	21.6a	100.5a	209.7a	4.9a	104.3	92.5a	2.7a	112.5	65.9a
GA+CCC	18.4a	85.6a	214.0a	6.7a	142.6	98.8a	3.2a	133.3	55.4a
GA+daminozide	20.6a	95.8a	204.0a	4.5a	95.7	89.5a	2.8a	116.7	62.9a
GA+ancymidol	19.8a	92.1a	171.4a	4.7a	100.0	75.4a	1.3a	54.2	33.8a

September 25, 1986

Treatment	Large tubers (>5cm)			Seedsize tubers (3-5cm)			Smallsize tubers (<3cm)		
	Wt./plot (kg)	Wt.As% control	Wt.per tuber(g)	Wt./plot (kg)	Wt. As % control	Wt. per tuber(g)	Wt./plot (kg)	Wt. As % control	Wt. per tuber(g)
Control	19.2a	100.0a	178.9a	8.6a	100.0	71.1a	0.8a	100.0	25.0a
GA	13.2b	68.8b	183.3a	9.6a	112.0	68.6a	1.2a	150.0	33.3a
GA+CCC	14.8b	77.1b	180.0a	8.3a	97.0	63.8a	0.8a	100.0	26.7a
GA+ancymidol	14.4b	75.0b	171.4a	9.2a	107.0	63.9a	1.1a	138.0	23.4a

*Means within a column for each tuber size with the same letters are not significantly different (LSD 5%)
Treatment and rate:
GA = gibberellic acid (0.04 kg/ha)
chlormequat (0.5 kg/ha)
daminozide (2.0 kg/ha)
ancymidol (0.0028 kg/ha)

Appendix Table 5 'Growth regulator screening studies using Norchip potatoes at five sampling dates in the growth room in 1986'

Treatment (rate)	Plant Height (cm)	Stolon No.	Stolon Tip No.	Stolon Length (cm)	Tubers >6mm
	7 Days after treatment				
Control	*27.5a	2.2b	2.4d	4.4b	0
GA (0.112g ai/l)	31.1a	5.7a	8.3b	6.6a	0
CCC (0.14g ai/l)	15.6c	2.0b	7.5bc	3.1bc	0
Ancymidol (13.3g ai/l)	23.4b	2.5b	9.0b	2.3cd	0
Ethephon (0.65g ai/l)	11.0d	6.0a	18.3a	2.4cd	0
Daminozide (2.9g ai/l)	16.6c	3.6b	7.5bc	1.6d	0
	14 Days after treatment				
Control	23.1b	2.0c	5.0d	4.7a	0
GA (0.112g ai/l)	41.9a	5.3a	8.0bc	5.4a	0
CCC (0.14g ai/l)	13.3d	2.5c	6.0cd	1.5b	0
Ancymidol (13.3g ai/l)	14.6cd	4.0b	9.0b	1.8b	0
Ethephon (0.65g ai/l)	14.1cd	3.8b	11.5a	1.1b	0
Daminozide (2.9g ai/l)	16.7c	4.0b	8.0bc	1.3b	0
	21 Days after treatment				
Control	24.6a	2.0c	4.5c	2.9b	4a
GA (0.112g ai/l)	21.8a	5.7a	6.5bc	5.1a	3ab
CCC (0.14g ai/l)	14.3bc	2.0c	9.3b	2.5bc	4a
Ancymidol (13.3g ai/l)	14.7bc	2.0c	6.3c	2.0bcd	2b
Ethephon (0.65g ai/l)	13.4c	5.3ab	13.0a	1.8cd	4a
Daminozide (2.9g ai/l)	16.8b	4.3b	9.0b	1.1d	2b
	28 Days after treatment				
Control	22.5b	1.8d	3.0d	3.0b	4bc
GA (0.112g ai/l)	38.9a	4.5ab	9.3ab	7.5a	4bc
CCC (0.14g ai/l)	15.0c	3.0cd	7.0c	1.9cd	8a
Ancymidol (13.3g ai/l)	16.5c	5.8a	10.8a	2.0c	2c
Ethephon (0.65g ai/l)	11.4d	4.3bc	9.3ab	1.1de	6b
Daminozide (2.9g ai/l)	16.2c	4.8ab	7.5bc	1.9cd	3c
	35 Days after treatment				
Control	25.0b	2.0d	4.0de	3.8b	4cd
GA (0.112g ai/l)	34.3a	5.8b	9.5c	6.0a	5.8bc
CCC (0.14g ai/l)	16.5c	2.8d	6.0d	0.9c	8a
Ancymidol (13.3g ai/l)	18.6c	7.3a	11.8b	5.7a	3d
Ethephon (0.65g ai/l)	12.3d	4.0c	14.5a	0.8c	6b
Daminozide (2.9g ai/l)	15.4d	4.5bc	6.0d	1.5c	5.4bc

*Means in a column with the same letter are not significantly different (LSD 5%)

Appendix Table 6 Potato Nutrient Solution

$Ca(NO_3)_2 4H_2O$ - 82g/l

KNO_3 -50g/l

KH_2PO_4 - 14g/l

$MgSO_4 7H_2O$ - 49gl

H_3BO_3 - 286mg/l

$ZnSO_4 7H_2O$ - 22mg/l

$CuSO_4 5H_2O$ - 8mg/l

H_2MoO_4 - 9mg/l

$MnSO_4 H_2O$ - 13.8mg/l

KCl - 3.7g/l

$FeSO_4 7H_2O$ - 1ml/l