AN ABSTRACT OF THE THESIS OF

Mahlon Malcolm Schallig Hile for the degree of Doctor of Philosophy in Agronomic Crop Science presented on April 15, 1976

Title: PHYSIOLOGY, QUALITY, AND AGRONOMIC PERFORMANCE OF SNAP BEANS (Phaseolus vulgaris L.) AND SPRING WHEAT (Triticum aestivum L.) AS AFFECTED BY ENVIRONMENT AND SEVERAL PLANT GROWTH REGULATORS

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Abstract approved: Dr. D. O. Chilcote

Experiments were conducted to determine the effect of environment and several plant growth regulators on the physiology, quality, and agronomic performance of snap beans (Phaseolus vulgaris L.) and spring wheat (Triticum aestivum L.). The potassium salts of naphthenic acid and cyclohexanecarboxylic acid, received particular attention.

Application of potassium naphthenate solutions to the foliage of 14-day-old wheat seedlings caused significant reductions in height for the first 4 weeks after treatment. Reductions were observed in water-soluble sugars in the shoots and roots. Accompanying increases in water-soluble protein and free amino acids were measured in the shoots. No significant effect on amino acid levels was

noted in the roots but increases were observed in soluble protein. The reductions in sugars and increases in proteins and amino acids indicate a shunting of carbon skeletons from carbohydrate to nitrogen metabolism.

Under field conditions, 2-chloroethylphosphonic acid (ethephon) and(2-chloroethyl) trimethylammonium chloride (chlormequat) regardless of rate or time of application produced significant reductions in wheat plant height. Ethephon was more effective in height reduction than chlormequat. Potassium cyclohexanecarboxylate and potassium naphthenate in many cases significantly increased the length of the uppermost internodes.

Differential wheat cultivar response to growth regulator application was evident with the exception of plant height and associated measurements which were similar between cultivars with a given regulator. Changes in grain nutritional quality components exemplify these differential responses. Vitamin content was generally lowered by potassium naphthenate, and potassium naphthenate and potassium cyclohexanecarboxylate lowered the mineral content of the grain. Individual quality components appeared to be affected independently.

No significant increase in snap bean yield resulted from regulator treatments in the field. Protein content was significantly increased in spring-planted snap bean pods by at least one rate of all

the regulators studied with the exception of potassium cyclohexan-carboxylate which lowered protein. Several growth regulators produced significant increases of B-carotene content in summer-planted snap beans whereas, ascorbic acid was significantly reduced by all applications in the spring but not in the summer planting.

Controlled environment experiments where high temperature and low relative humidity were imposed had little effect on pod protein and B-carotene content. In contrast, ascorbic acid content was drastically reduced the first day after exposure to stress conditions. Though plants tended to adjust to their new growing conditions, after 5 days they had not reached levels of ascorbic acid found in unstressed control plants. Treatment with potassium naphthenate tended to lower levels more and retard adjustment to the higher temperatures.

Nutritional quality in snap bean pods appeared to be affected more by the prevailing environmental conditions near harvest even though yield varied greatly between cultivars and to a lesser extent between dates of planting. Ascorbic acid content appears to be more sensitive to seasonal fluctuation in environment than B-carotene or protein content, as large variations in ascorbic acid content between planting dates were evident.

Subjection of cultivars to growth at 80 and 50% relative humidity resulted in differences in growth habit though no differences

were observed in yield or nutrient content. The relative ranking of yield of cultivars in controlled environments differed from that observed in the field though differences in B-carotene and ascorbic acid contents were similar.

A comprehensive review of the literature pertaining to the effects of naphthenates on plants is discussed in detail. In addition, an exhaustive summarized review of the effects of naphthenates on biological systems (plants, microorganisms, warm and cold-blooded animals) illustrates the wide range of biological actions of this series of naturally occurring petroleum acids.

# Physiology, Quality, and Agronomic Performance of Snap Beans (*Phaseolus vulgaris* L.) and Spring Wheat (*Triticum aestivum* L.) as Affected by Environment and Several Plant Growth Regulators

by

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# PHYSIOLOGY, QUALITY, AND AGRONOMIC PERFORMANCE OF SNAP BEANS (Phaseolus vulgaris L.) AND SPRING WHEAT (Triticum aestivum L.) AS AFFECTED BY SEVERAL PLANT GROWTH REGULATORS

## GENERAL INTRODUCTION

Spring wheat (Triticum aestivum L.) and bush snap beans (Phaseolus vulgaris L.) are both economically and nutritionally important in Oregon. Increasing importance is being placed on both yield and nutritional quality, yet relatively few reports are available on the effects of environment and plant growth regulators on these crops.

The objective of this research is to gain a fuller understanding of the effects of plant growth regulators and environment on the physiology, quality, and agronomic performance of these crops. Particular attention was given the naphthenic acids as it has been reported that these plant growth regulators have the potential for not only increasing yield (Aslanov, 1970; Bulavas and Rimkevicius, 1970; Fattah, 1972; Gasanov, 1970; Volkov, 1970; Wort and Patel, 1970a) but also nutritional quality (Aliev, 1963; Fattah, 1972; Volkov, 1970) and storage (Chu, 1969; Fattah, 1972).

This dissertation is presented in four sections to maintain the continuity of the subject covered. Each article with the exception of the common bibliography is written in a manner which is suitable

for direct submission to a professional journal. It is hoped that the continuity and brevity of presentation will enable a greater number of individuals to gain access to the principles and data presented.

A comprehensive review of the literature on naphthenic acids is presented in the Appendix. Published material, from the Western Hemisphere, pertaining to the action of these acids on plants, is discussed in detail. The effect of naphthenic acids on plants, animals, and microorganisms is presented in summarized form, cross-referenced to the organism tested. Though the naphthenic acids are referred to in this dissertation as plant growth regulators, the effects presented in the review suggest a more general metabolic stimulant.

# CLARIFICATION OF NOMENCLATURE

Naphthenic acids (petroleum acids) are monocarboxylic acids of the naphthene (alicyclic) series of hydrocarbons. They are natural components of crude oil and are normally extracted using caustic alkali. $R(CH_2)_nCOOH$, may serve as a general formula, where R is a cyclic nucleus composed of one or more rings. These rings may be alkylated and are predominantly cyclopentane (five membered) but cyclohexane rings are present in varying amounts. The plant growth regulators obtained from this petroleum fraction have been named and abbreviated primarily by Eastern European investigators. The nomenclature used is very ambiguous and appears to have been designed to designate source and action. This makes mechanical retrieval of information nearly impossible unless one is aware of all possible names.

This investigator, in an attempt to standardize, will refer to the saponification products as <u>naphthenates</u>.

Other generic listings for the naphthenate fraction are as follows:

Naphtha growth matter

Stimulator of naphtha origin

Naphtha substances

Naphthenic growth substance (NGS)

Oil growth substance (OGS)

Oil growth matter

Oil hormone substance (OHS)

Petroleum nutrient

Petroleum growth factor

Petroleum growth stimulant

Petroleum growth substance

Petroleum growth-promoting substance

Petroleum growth regulator (PGR)

Petrochemical growth compounds

Petrochemical growth substance (PGS)

Sintovit (an oxidized petroleum product)

Sh-8 (a substituted cyclohexylbutanol)

Or the additional abbreviations:

(PRV)

(NRB)

(NRV) from Neft Rostovogo Veshchestva

(KhTI) Bulgarian equivalent of NRV

# GROWTH AND METABOLIC RESPONSES OF WHEAT SEEDLINGS TO NAPHTHENATE APPLICATION

## ABSTRACT

Potassium naphthenate (KNap) has significant effects on early wheat (Triticum aestivum L.) seedling development. Though numerous accounts show favorable agronomic responses on wheat, little physiological information is available. This study evaluated the effect of foliarly applied naphthenate on seedling growth, $CO_2$ exchange, and the levels of water-soluble sugars, proteins, and amino acids.

Application of KNap solutions to the foliage of 14-day-old wheat seedlings caused reductions in water-soluble sugars in the shoots and roots 4 weeks after treatment. Increases in water-soluble protein of 17.5 to 30% were measured in the shoots accompanied by increases of 21 to 44.5% in free amino acids (4 weeks after spraying). No significant effect on amino acid levels was noted in the roots but up to a 39% increase in soluble protein was observed with 750 ppm KNap (at 4 weeks). The reductions in sugars and increases in protein and amino acids indicate a shunting of carbon skeletons from carbohydrate to nitrogen metabolism. Trends in net photosynthesis, dark respiration, and gross photosynthesis although not significant statistically, may have biological significance.

Significant reductions in height at all times and rates of application were observed. Though this collaborates recent work on corn, it is in contrast with results published on bush beans and peas. GA-antagonised or IAA-promoted responses resulting from KNap application may be dependent on the relative levels of endogenous regulators.

## INTRODUCTION

Naphthenic acids (petroleum acids) are monocarboxylic acids of the naphthene (alicyclic) series of hydrocarbons. It has been reported (Huseinov, 1960; Wort and Patel, 1970a; Wort and Patel, 1970b) that these acids and their sodium and potassium salts (Wort, 1969) have growth stimulating activity. They are natural components of crude oil and are normally extracted using caustic alkalies. $R(CH_2)_nCOOH$, may serve as a general formula, where R is a cyclic nucleus composed of one or more rings. These rings may be alkylated and are predominantly cyclopentane (five membered) but cyclohexane rings are present in varying amounts (Jolly, 1967). The first report of increased metabolic activity was by Neuberg and Sandberg (1921) when they observed an enhancement of the alcoholic-splitting activity of yeast. Agronomic experimentation began in Russia in the late 1940's. Soil application (Aslanov, 1970), seed treatments (Bulavas and Rimkevicius, 1970) and seed soaking

(Volkov, 1970) have produced increases in yield and protein content in wheat. Gasanov (1970) reported foliar application of 0.05% of solution increased winter wheat yields 19-37%. Volkov (1970) noted that spraying at tillering and flowering increased the yield and protein content of spring wheat, barley, oats, and millet.

Though numerous accounts show favorable agronomic responses on wheat, little physiological information is available. This paper presents the effect of foliarly applied naphthenates on seedling growth, $CO_2$ exchange, and the levels of water-soluble sugars, proteins, and amino acids.

## MATERIALS AND METHODS

Twenty seeds of spring wheat 'Twin' were planted in 15-cm plastic pots containing 20-mesh white quartz sand. Plants were watered on alternate days with half-strength nutrient solution throughout the experiments. Ten days after planting, the seedlings were thinned to ten per pot. After thinning, pots for each sampling date were placed in a latin square design, in a controlled environment room equipped with cool white fluorescent and 60-w incandescent lamps providing 21.5 klux (425ue $m^{-2}$ $s^{-1}$) at plant height. The photoperiod was 12-hour, with day/night temperatures of 21/10$\pm$1C and relative humidities 55/60$\pm$5%. Two weeks after planting, plants were sprayed to drip with the appropriate concentration of potassium

naphthenate (KNap). The spray solutions were prepared by the neutralization of naphthenic acid, average molecular weight 230, (Eastman Organic Chemicals, Rochester, NY) with KOH. The spray solution also contained 0.4% X-77 and was adjusted to pH 10 with HCl.

At weekly intervals pots were covered with a plexiglass assimilation chamber in which $CO_2$ exchange was measured by an infrared gas analyzer. Carbon dioxide fixation (net photosynthesis) and dark respiration were monitored and recorded for 1 minute after peak readings were attained (10 min). Plants were removed and another pot with plants was placed in the chamber for measurement until all measurements were completed. Net photosynthesis and dark respiration were summed and recorded as gross photosynthesis.

Plants from the experiment using the infrared gas analyzer were harvested the subsequent midnight. Samples from the four replicates were analyzed for water-soluble sugars, proteins and amino acids using colorimetric procedures. One gram of leaf blades or roots were immediately ground after harvest in a mortar and pestle and then homogenized with a Servall homogenizer at high speed for 2 minutes in a 0.1 M $PO_4$ buffer pH 7.2 at 2 C. The homogenate was centrifuged at 25,000 x g for 5 minutes at 2 C and the residue was re-extracted twice in buffer then discarded. A

2 ml aliquot of the combined supernatant was treated with 0.22 ml 100% trichloroacetic acid (TCA). The protein was reprecipitated with 10% TCA. The precipitated proteins were centrifuged at 10,000 x g. Aliquots of the supernatant were analyzed for sugars by the anthrone method (Yemm and Willis, 1954), and amino acids by the ninhydrin method (Yemm and Cocking, 1955), with the acetate modification of Moore and Stein (1954). Fructose and leucine were used as standards, respectively. The precipitated protein residues were extracted with ethanol, ether, chloroform (2:2:1) and centrifuged at 10,000 x g for 10 minutes. This step was repeated twice. Protein was solubilized with 2 ml 1N NaOH and allowed to stand overnight. Aliquots of the above were used for the determination of protein using the methods of Lowry et al. (1951) (at 500 nm) using bovine serum albumin as the standard. Four samples were analyzed per treatment.

## RESULTS AND DISCUSSION

The effect of KNap concentrations on net photosynthesis, dark respiration, and gross photosynthesis at weekly intervals after treatment is shown in Table 1. Though no statistically significant differences (5% level) were apparent, several trends are worthy of note. The above three factors tended to be depressed for the first two weeks after application. Immediate increases in diffusive

Table 1. The effect of potassium naphthenate on net photosynthesis, dark respiration, and gross photosynthesis 1, 2, 3, and 4 weeks after treatment.

| Concentration (ppm) | Net photosynthesis mg $CO_2$/plant/hr | | | |
|---|---|---|---|---|
| | 1 week | 2 weeks | 3 weeks | 4 weeks |
| 0 | 2.19 | 3.04 | 3.06 | 3.99 |
| 250 | 2.02 | 2.88 | 3.42 | 4.07 |
| 500 | 1.91 | 2.82 | 2.97 | 4.22 |
| 750 | 1.94 | 2.61 | 3.12 | 4.65 |

| Concentration (ppm) | Dark respiration mg $CO_2$/plant/hr | | | |
|---|---|---|---|---|
| | 1 week | 2 weeks | 3 weeks | 4 weeks |
| 0 | 1.11 | 1.90 | 2.06 | 2.41 |
| 250 | 1.03 | 1.80 | 2.00 | 2.57 |
| 500 | 0.92 | 1.87 | 2.06 | 2.60 |
| 750 | 0.97 | 1.67 | 2.05 | 2.81 |

| Concentration (ppm) | Gross photosynthesis mg $CO_2$/plant/hr | | | |
|---|---|---|---|---|
| | 1 week | 2 weeks | 3 weeks | 4 weeks |
| 0 | 3.30 | 4.94 | 5.12 | 6.40 |
| 250 | 3.05 | 4.68 | 5.42 | 6.64 |
| 500 | 2.83 | 4.69 | 5,03 | 6.82 |
| 750 | 2.91 | 4.28 | 5.17 | 7.46 |

resistance after treatment on bush beans and wheat have been noted (Hile and Chilcote, 1975). From the work here it is not possible to explain whether this is a direct effect on guard cells or an indirect one through metabolic activity. It also appears that subsequent newly formed leaves have a reduced diffusive resistance (Hile and Chilcote, 1975). Four weeks after application all naphthenate treatments exceeded the control in net photosynthesis, dark respiration, and gross photosynthesis with the 750 ppm treatment exceeding the control by 16.5% in these three measurements. Responses in bush beans reported by Fattah and Wort (1970) are similar, although no prolonged repression was seen. They showed that both apparent photosynthetic and dark respiratory levels were significantly elevated by KNap applications.

Alterations in water-soluble sugars, proteins, and amino acids appear to be generally concentration related (Table 2). Soluble sugars in the shoots and roots show the same basic pattern, with an initial increase the first week and decreases at the remaining three weekly measurements after treatment. Protein levels in the shoots for the first 2 weeks after treatment were not greatly affected. Protein increases began to be apparent the third week and at 4 weeks all naphthenate treatments exhibited higher levels of soluble protein, with 750 ppm showing a 36% higher level of protein. The roots exhibited an overall increase in protein content after

Table 2. The effects of potassium naphthenate on water-soluble sugars, proteins, and amino acids, 1, 2, 3, and 4 weeks after treatment.

| Concentration (ppm) | Soluble sugars (mg/g fr. wt.) | | | |
|---|---|---|---|---|
| | 1 week | 2 week | 3 weeks | 4 weeks |
| A. SHOOTS | | | | |
| 0 | 27.0 | 21.5 | 39.1 | 41.8 |
| 250 | 31.3 | 16.5** | 24.5** | 30.2** |
| 500 | 30.2 | 16.5** | 26.0** | 33.1** |
| 750 | 28.6 | 24.7** | 36.7 | 38.1 |
| B. ROOTS | | | | |
| 0 | 7.3 | 9.7 | 14.5 | 17.6 |
| 250 | 9.8 | 8.0 | 8.6** | 10.4** |
| 500 | 11.0 | 8.7 | 10.0** | 13.2** |
| 750 | 12.0 | 10.5 | 9.1** | 13.4** |

| | Soluble proteins (mg/g fr. wt.) | | | |
|---|---|---|---|---|
| | 1 week | 2 weeks | 3 weeks | 4 weeks |
| A. SHOOTS | | | | |
| 0 | 18.8 | 19.8 | 10.7 | 13.7 |
| 250 | 20.4 | 20.0 | 11.4 | 16.1** |
| 500 | 16.0 | 19.3 | 11.7 | 16.9** |
| 750 | 19.0 | 19.3 | 12.5 | 17.9** |
| B. ROOTS | | | | |
| 0 | 2.7 | 1.5 | 0.8 | 0.9 |
| 250 | 3.1 | 1.5 | 0.8 | 1.1 |
| 500 | 3.6** | 1.7 | 1.2 | 1.1* |
| 750 | 3.9** | 1.9 | 0.9 | 1.3** |

| | Soluble amino acids (μ/g fr. wt.) | | | |
|---|---|---|---|---|
| | 1 week | 2 weeks | 3 weeks | 4 weeks |
| A. SHOOTS | | | | |
| 0 | 1747 | 1233 | 1279 | 1202 |
| 250 | 1758 | 1031** | 1494 | 1462* |
| 500 | 1766 | 1089** | 1558 | 1768** |
| 750 | 1860 | 999** | 1652 | 1737** |
| B. ROOTS | | | | |
| 0 | 1535 | 1662 | 1320 | 1289 |
| 250 | 1895 | 1244 | 1100 | 1081 |
| 500 | 1720 | 1296 | 1269 | 1154 |
| 750 | 1618 | 1624 | 1140 | 1189 |

*, ** = Value differs significantly from control value at the 5 and 1% levels, respectively.

treatment with the first and fourth weeks being statistically greater than the controls. This may indicate a greater anabolic enzyme activity (Wort et al., 1973) as a result of KNap treatment. Huseinov (1970), in a series of studies, showed greater root growth as a result of treatment with KNap.

Soluble amino acids present a less discernable pattern. In the shoots during the second week, amino acid content decreased as sugars decreased, with the 750 ppm rate being a glaring exception. The general decrease could be partially explained by two factors. First, the unavailability of carbons skeletons (low sugars) could cause low amino acid levels. Secondly, during this period of time tillers were rapidly growing and increasing in size, using available sugars for growth. Tillers per plant (Table 3) appeared to be increased as a result of treatment. Amino acids were significantly increased the fourth week as were proteins with sugars being repressed. No significant effects on amino acids were noted in the roots, although the patterns were similar to that of sugars.

The trend toward significant increases in soluble protein and amino acids, plus the significant decrease in soluble sugars, indicate that more photosynthate is being channeled to the synthesis of nitrogenous compounds. This relationship coupled with greater soluble protein adds support to the suggestion of Wort et al. (1973) that these compounds cause greater anabolic enzyme activity related

Table 3. The effect of potassium naphthenate on plant height at weekly intervals after treatment and tillers/plant on termination.

| Concentration (ppm) | Plant height (cm) | | | | Tillers/plant |
|---|---|---|---|---|---|
| | 1 week | 2 weeks | 3 weeks | 4 weeks | % of check |
| 0 | 31.6 | 34.5 | 38.1 | 42.3 | 100.0 |
| 250 | 28.0** | 31.2** | 35.5** | 39.0** | 111.5 |
| 500 | 27.2** | 29.0** | 33.7** | 37.6** | 105.8 |
| 750 | 26.5** | 28.5** | 33.7** | 36.7** | 106.2 |

** = Value differs significantly from control value at the 1% level.

to nitrogen metabolism.

Reductions in plant height (Table 3) were significant at all concentrations and times of measurements. The degree of reduction appears to be directly related to concentration, with the higher concentrations reducing height to a greater extent. Marcus and Goldthwaite (1973) have reported that cyclopentanecarboxylic (CPCA) had activity antagonistic to gibberellin (GA). They noted antagonism for $d_5$ dwarf maize growth, Rumex leaf disc senescence, and amylase production in barley half-seeds. They also showed that the inhibitory effect on dwarf maize could be overcome by simultaneous application of saturating doses of $GA_3$ or $GA_7$. This suggests activity may be dependent on the relative levels of endogenous regulators. The lack of activity in their studies of zeatin-inhibited senescence in the Rumex system and auxin promoted growth of oat coleoptiles adds some specificity for GA-induced effects. Previous field experimentation (Hile and Chilcote, 1975) has shown that the uppermost nodes of treated spring wheat were significantly longer than their corresponding controls. However, no reduction in overall height or number of nodes was noted. This corresponds with the reduction noted here on early seedling growth. Under the conditions of this experiment height reductions were transient and were no longer apparent at booting.

Loh (1974) suggests that KNap has at least two properties of

auxin. He observed significant stimulation of adventitious rooting in Phaseolus vulgaris L. stems and increases in the straight growth test of dark grown Alaska pea stem segments, though less effective than IAA. Additionally, Loh (1973) observed an increase (140.5%) in the content of IAA in KNap-treated bush beans, suggesting an augmentation of IAA biosynthesis. Increases in plant height have been reported in Phaseolus vulgaris L. (Fattah and Wort, 1970).

As noted earlier, KNap contains both cyclopentane and cyclohexanecarboxylic acids. Padmanabhan (1972) and Severson (1972) feel that the glucose or aspartate conjugates of cyclohexanecarboxylic acids are responsible for growth and metabolic stimulations they have noted. A perplexing point now arises in the literature as the response of two monocotyledons (corn and wheat in this study) may be attributed to GA antagonism but the two dicotyledons (beans and peas) are believed to be auxinic responses. Appropriate studies (considering we are probably dealing with a weak antagonist of GA and a weak promoter of IAA in this KNap mixture) using CPCA and CHCA to solve this apparent dichotomy (differential height reduction) are suggested.

# INFLUENCE OF SEVERAL PLANT GROWTH REGULATORS ON AGRONOMIC AND QUALITY FACTORS IN SPRING WHEAT

## ABSTRACT

The effect of several plant growth regulators applied to the cultivars Twin and Anza spring wheat (Triticum aestivum L.) were studied under field conditions. Agronomic characteristics evaluated included grain yield components, plant height, internode lengths, and flag leaf placement. Grain quality factors of protein, vitamin, and mineral content were also evaluated.

2-chloroethylphosphonic acid (ethephon) and (2-chloroethyl) trimethylammonium chloride (chlormequat) regardless of rate or time of application produced significant reductions in plant height. Ethephon was more effective in height reduction than chlormequat. Potassium cyclohexanecarboxylate (KCHC) and potassium naphthenate (KNap) in many cases significantly increased the length of the uppermost internodes.

Differential cultivar responses to growth regulator application were evident with the exception of plant height and associated measurements which were similar between cultivars with a given regulator. Grain quality components exemplify these differential responses. Vitamin content was generally lowered by KNap, and KNap and KCHC lowered the mineral content of the grain. The

cultivar Twin was generally more responsive in component alteration than Anza. Individual quality components appeared to be affected independently.

## INTRODUCTION

Wheat may be described as a pillar of human nutrition, both in the U.S. and worldwide. Senti and Rizik (1974) point out that the U.S. national average per capita (protein, thiamine, riboflavin, pyridoxine, and niacin) availability provided by wheat is 14.2, 9.7, 4.6, 11.3, 10.3%, respectively. It also provides major contributions of several minerals, particularly Ca and Mg.

Certain plant growth regulators have not only shown promise for manipulating plant height and controlling lodging, but also may increase yield and may affect quality. Prominent among these are (2-chloroethyl) trimethylammonium chloride (chlormequat), 2-chloroethylphosphonic acid (ethephon), potassium naphthenate (KNap) and the individual naphthenic acid salt potassium cyclohexanecarboxylate (KCHC) which were chosen for study because of significant reported effects on yield and yield components. Little is known of quality effects particularly on vitamin and mineral content.

Yield increases from chlormequat application have often been attributed to the prevention of lodging. Yet even in the absence of lodging, applications have produced increases in yield. Working

with spring wheat, Humphries et al. (1965) found that although untreated plants did not lodge, chlormequat increased mean grain yield by 5% by increasing the number of ears and number of grains per ear. Larter et al. (1965) showed varietal differences in response on barley. No yield differences under restricted water conditions were noted although chlormequat reduced water consumption. Goodin et al. (1966) also observed less water use in chlormequat-treated wheat. He felt that seed production depends more on seeds per head than the number of seed heads or an increased seed weight. Bokhari and Younger (1971) using the uniculm barley mutant, which under normal conditions produces no tillers, found tillering with increasing chlormequat concentration. Greater grain yield in their study resulted directly from the larger number of tillers.

Brown and Early (1973) reported that ethephon effectively reduced plant height and lodging in wheat and oats (Avena sativa L.). They noted that higher yields in ethephon-treated plots were generally associated with heavier seeds. Rowland (1973) working with both chlormequat and ethephon felt that chlormequat was suitable for controlling lodging but that it was not practical to use ethephon for this purpose. This is probably due to the high rates of application (1.5 and 3.0 kg/ha ai) since he observed a 13.2% reduction in the number of fertile spikelets per ear. But large increases in

fertile tillers were seen with all ethephon application rates or times.

The potassium salt of naphthenic acids (Pract.), [members of the naphthene(alicylic) series of hydrocarbons] have been shown to have profound effects on early wheat seedling growth (Hile and Chilcote, 1975). Increases have been reported in both yield and protein content of spring wheat, barley, oats, and millet when sprayed at tillering and flowering (Volkov, 1970). Gasanov (1970) reported foliar application of 0.5% of solution increased winter wheat yields 19-37%. Wort and Patel (1970) in pot studies have shown increases in the yield of spring wheat. Goryaev et al. (1967) have shown both increases and decreases in growth depending on the fraction obtained.

Specific regulators may allow management of plant growth and development, to facilitate harvest and crop recovery. But little information is available on the effects of these regulators, especially ethephon and the naphthenates, on wheat yield and quality. Information on quality is particularly significant, as wheat provides such a large source of vitamins and minerals in the human diet. The purpose of this study is to further elucidate the effects of growth regulators on quality and evaluate height alteration under prevailing environmental conditions.

# MATERIALS AND METHODS

Two cultivars of spring wheat ('Twin' and 'Anza') were selected for this study because of their diverse genetic background and contrasting morphological characteristics. Two sets of field experiments were conducted in 1974. In both experiments wheat was seeded in 30-cm rows at approximately 100 kg/ha. Eighty kg/ha of nitrogen was supplied as ammonium nitrate, preplant. Treatments are described in Table 1. Growth stages were described after the scale of Zadoks et al. (1974). Using this scale growth stages are placed on a 2 digit code and the stages on which treatments were made are given in Table 1.

Potassium naphthenate (KNap) spray solutions were prepared by the neutralization of naphthenic acids, average molecular weight 230, (Eastman Organic Chemicals, Rochester, NY) with KOH and adjusted to pH 10 with HCl. Potassium cyclohexanecarboxylate (KCHC) was prepared by the neutralization of cyclohexanecarboxylic acid with KOH. Aqueous sprays of KNap, KCHC, chlormequat and ethephon contained 0.4% X-77 as a surfactant.

In the first experiment separate randomized complete block designs with six replications were used for each cultivar. Foliar applications were made using a hand sprayer and adjacent plots were shielded from drift. The plots were trimmed to 1.2 meter by 4.6

Table 1. Description of treatments in Experiments 1 and 2 including chemical, rates, and stages of application.

| Treatment | Chemical | Rate (ppm) | Growth stage[2] Number | Description |
|---|---|---|---|---|
| Experiment 1[1] | | | | |
| 1 | Control | -- | -- | -- |
| 2 | KNap | 1000 | 12 | 2 leaves unfolded |
| 3 | KNap | 5000 | 12 | 2 leaves unfolded |
| 4 | KCHC | 1670 | 12 | 2 leaves unfolded |
| 5 | Ethephon | 520 | 32 | 2nd node just detectable |
| 6 | Ethephon | 1040 | 32 | 2nd node just detectable |
| 7 | Ethephon | 520 | 45 | boots swollen, flag leaf opening not apparent |
| 8 | Ethephon | 1040 | 45 | boots swollen, flag leaf opening not apparent |
| Experiment 2[3] | | | | |
| 1 | Control | -- | -- | -- |
| 2 | KNap | 250 | 12 | 2 leaves unfolded |
| 3 | KNap | 500 | 12 | 2 leaves unfolded |
| 4 | KNap | 750 | 12 | 2 leaves unfolded |
| 5 | KCHC | 334 | 12 | 2 leaves unfolded |
| 6 | KCHC | 835 | 12 | 2 leaves unfolded |
| 7 | Chlormequat | 1852 | 22 | main shoot and 2 tillers visible |
| 8 | Chlormequat | 4630 | 22 | main shoot and 2 tillers visible |
| 9 | Chlormequat | 9260 | 22 | main shoot and 2 tillers visible |
| 10 | Chlormequat | 1852 | 32 | 2nd node just detectable |
| 11 | Chlormequat | 4630 | 32 | 2nd node just detectable |
| 12 | Chlormequat | 9260 | 32 | 2nd node just detectable |

[1] 540 liters/ha spray volume.

[2] Stages and descriptions after Zadoks et al. (1974).

[3] Sprayed to drip.

meter and the entire area harvested for yield and quality determinations. The agronomic traits of plant height, spikes per meter of row, seeds per spike, seed weight, and yield were determined. Internode lengths and flag leaf measurements were made on eight plants per replication 2 weeks prior to harvest. Two samples were taken from the harvested material of each replication and analyzed for percent protein (% N x 5.7) by the method of Nelson and Sommers (1973). A bulk sample was prepared for each treatment by sampling each replication. The amount of material taken from each replication was based on the percentage of total treatment yield provided by that replication. The bulk sample from each treatment was taken and analyzed commercially for mineral content (Atomic Emission Spectrophotometry) and vitamins $B_1$, $B_2$, $B_6$ and niacin using AOC 39.024-.029, 39.040-.042, 39.142-.147 and 29.080-.081, respectively.

In the second experiment sufficient plants were selected at random in the large border area, so that 50 plants per treatment could be collected for measurement and analysis. Plants were sprayed to drip with a hand atomizer. The individual plants were harvested and plant height and yield components were measured. The grain, five sets of ten plants each, was analyzed for percent protein (% N x 5.7) as previously noted.

# RESULTS

## Experiment 1

Plant height and associated measurements were significantly altered due to treatment (Table 2). Ethephon regardless of stage or rate of application produced significant reductions in height, decreased the distance between the upper internodes which resulted in the flag leaf being closer to the spike (1% level). Responses due to KNap or the individual naphthenic acid salt KCHC were not as visually apparent as the ethephon treatments. Significant but minor reductions in height were noted in Twin but not with Anza at the higher KNap application. Both varieties exhibited significant increases in length of the first internode and distance from the flag leaf to the collar of the spike at the lower rate of KNap. This was accompanied by a trend (although statistically non-significant) toward increased plant height. KCHC increased both internode lengths as well as flag leaf distance in Twin but no statistical changes were noted with Anza.

Tillers per meter of row were slightly but not significantly altered by any treatment.

Seeds per spike were statistically reduced by the earliest ethephon applications on both cultivars (Table 2). KCHC and the higher rate of KNap also decreased the number of seeds per spike.

Table 2. Effects of several plant growth regulators on agronomic characteristics of two cultivars of spring wheat in Experiment 1.

| Cultivar | Treatment | Height (cm) | Internode length[2] (cm) No. 1 | Internode length[2] (cm) No. 2 | Flag leaf[3] Distance (cm) | Spikes/ meter row | Seeds/ spike | Seed wt. mg/seed | Yield kg/ha |
|---|---|---|---|---|---|---|---|---|---|
| Twin | 1[1] | 84.4[4] | 33.6 | 20.8 | 16.6 | 155 | 45.0 | 38.4 | 5634 |
| | 2 | 84.9 | 35.3* | 21.1 | 18.0* | 155 | 45.8 | 38.7 | 5729 |
| | 3 | 83.0** | 35.5* | 20.5 | 16.4 | 166 | 43.4 | 39.0 | 5559 |
| | 4 | 84.8 | 35.8** | 21.7** | 18.2* | 171 | 45.9 | 39.3* | 6197* |
| | 5 | 68.3** | 28.8** | 15.3** | 13.1** | 169 | 40.4** | 38.4 | 5108** |
| | 6 | 65.1** | 27.7** | 15.3** | 12.1** | 168 | 39.9** | 38.9 | 4835** |
| | 7 | 69.6** | 26.1** | 15.7** | 8.9** | 163 | 45.2 | 38.3 | 4974** |
| | 8 | 66.7** | 24.4** | 15.7** | 7.5** | 156 | 43.8 | 37.8 | 4666** |
| LSD .05= | | 0.9 | 1.4 | 0.7 | 1.3 | NS | 1.8 | 0.7 | 473 |
| LSD .01= | | 1.1 | 1.8 | 0.9 | 1.6 | NS | 2.4 | 0.9 | 636 |
| CV = | | 3.0% | 8.1% | 6.6% | 15.8% | 19.9% | 7.3% | 3.2% | 7.6% |
| Anza | 1 | 70.4 | 33.8 | 13.7 | 18.3 | 164 | 43.0 | 43.5 | 5257 |
| | 2 | 70.9 | 35.0* | 13.7 | 19.3* | 158 | 41.9 | 42.5 | 4904 |
| | 3 | 70.4 | 34.3 | 13.8 | 19.0 | 166 | 40.1** | 42.8 | 5102 |
| | 4 | 70.4 | 34.2 | 13.3 | 19.0 | 167 | 39.3** | 42.6 | 4922 |
| | 5 | 60.0** | 27.8** | 11.1** | 13.2** | 172 | 39.1** | 41.0** | 4964 |
| | 6 | 57.8** | 26.5** | 11.2** | 11.7** | 175 | 39.8** | 40.4** | 4797 |
| | 7 | 62.6** | 27.9** | 11.9** | 12.6** | 166 | 41.4 | 40.4** | 4856 |
| | 8 | 60.7** | 26.1** | 11.9** | 11.4** | 164 | 41.3 | 40.2** | 4845 |
| LSD .05= | | 0.7 | 1.0 | 0.5 | 0.9 | NS | 2.2 | 1.1 | NS |
| LSD .01= | | 0.9 | 1.3 | 0.7 | 1.2 | NS | 2.8 | 1.4 | NS |
| CV = | | 1.9% | 5.7% | 7.0% | 10.3% | 15.2% | 9.3% | 4.6% | 9.7% |

*, ** = Value differs significantly from control value at the 5 and 1% levels, respectively.

[1] Described in Table 1.

[2] Internode No. 1 is the peduncle or uppermost internode, No. 2 is the internode just below the peduncle.

[3] 4, 8, 8, 8, 4, 12, 4, and 1 observations per replication, respectively.

Seed weight of Anza was significantly lowered by all ethephon treatments but little effect was noted on Twin (Table 2). A significant increase in seed weight from KCHC application was noted but only on the variety Twin.

The yield of Twin was significantly lowered by all ethephon treatments while Anza was not affected. A significant increase of 10% in yield of Twin was observed with KCHC application.

The effects of growth regulator treatments upon protein content in the grain are presented in Table 3. Protein content was little affected by any of the naphthenate treatments. The variety Twin exhibited small but significant increases in protein with all ethephon treatments. However Anza was not statistically affected although a trend is apparent which is opposite to the response of Twin.

Results of analyses of vitamin content are presented in Table 3. Though bulk samples are not conducive to statistical analysis several trends are worthy of notation. Niacin tended to be increased by all treatments with the ethephon treatments appearing to have the greatest enhancing effect. Pyridoxine (vitamin $B_6$) content seemed to be unaffected in Twin, whereas in Anza it appeared to be reduced by all treatments with the naphthenates giving the greatest reduction. Riboflavin (vitamin $B_2$) content in Twin appeared to be enhanced slightly by ethephon application at both stages of development, but

Table 3. Effect of several plant growth regulators on protein and vitamin content in the grain of two cultivars of spring wheat in Experiment 1.

| Cultivar | Treatment | % Protein | mg/100g | | | |
|---|---|---|---|---|---|---|
| | | | $B_1$ | $B_2$ | $B_6$ | Niacin |
| Twin | 1 | 8.98 | .45 | .12 | .37 | 5.3 |
| | 2 | 8.93 | .49 | .12 | .37 | 5.5 |
| | 3 | 8.94 | .46 | .12 | .36 | 5.5 |
| | 4 | 9.43 | .39 | .12 | .37 | 5.7 |
| | 5 | 10.10** | .39 | .13 | .36 | 6.0 |
| | 6 | 10.33** | .42 | .13 | .36 | 6.1 |
| | 7 | 9.92* | .46 | .13 | .37 | 5.8 |
| | 8 | 11.04** | .49 | .13 | .37 | 6.2 |
| Anza | 1 | 10.42 | .41 | .12 | .37 | 4.5 |
| | 2 | 9.94 | .41 | .12 | .33 | 4.7 |
| | 3 | 10.02 | .38 | .12 | .33 | 4.7 |
| | 4 | 9.46 | .39 | .12 | .30 | 4.9 |
| | 5 | 10.16 | .41 | .12 | .36 | 5.0 |
| | 6 | 9.86 | .38 | .12 | .35 | 5.1 |
| | 7 | 10.50 | .45 | .13 | .33 | 5.0 |
| | 8 | 10.30 | .42 | .13 | .31 | 4.9 |

All data expressed on a dry wt. basis.

*, ** = Value differs significantly from control value at the 5 and 1% levels, respectively.

only in the later stage for Anza. Ethephon applied at the later date seemed to enhance thiamine (vitamin $B_1$) content as compared to the control or earlier application. Doubling the rate of ethephon on Twin tended to increase the content of $B_1$ whereas in Anza the reverse seemed apparent. Increasing the rate of KNap seemed to result in decreased $B_1$ content and KCHC seemed to reduce $B_1$ content in both cultivars.

The effects of the growth regulators on mineral composition in the grain of the two cultivars of spring wheat is listed in Table 4. Of the eight minerals studied only four (Ca, Mn, Fe, and Zn) exhibited trends related to treatment which may have nutritional importance. It must be noted that these responses were, with the exception of Fe, only notable with the variety Twin as Anza was only slightly altered in many instances and obviously was noticeably less affected by treatment. Calcium content appeared to be lowered by all chemical treatments, with the ethephon treatments resulting in the lowest content particularly at the late application. Treated material was also generally lower in Mn with the naphthenates producing the greatest reductions. Naphthenate treatment also appeared to lower Zn content.

Iron content appeared to be both lowered and elevated by naphthenate treatment depending on cultivar. All of the naphthenate treatments lowered grain Fe content in Twin, whereas the opposite

Table 4. Effect of several plant growth regulators on mineral composition in the grain of two cultivars of spring wheat in Experiment 1.

| Cultivar | Treatment | % Dry wt. | | | | ppm Dry wt. | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | K | P | Ca | Mg | Mn | Fe | Cu | Zn |
| Twin | 1 | .43 | .40 | .031 | .13 | .36 | 49 | 9 | 54 |
| | 2 | .49 | .40 | .028 | .12 | .27 | 41 | 5 | 44 |
| | 3 | .46 | .38 | .023 | .11 | .25 | 31 | 6 | 44 |
| | 4 | .45 | .38 | .027 | .12 | .26 | 39 | 7 | 47 |
| | 5 | .44 | .46 | .027 | .13 | .31 | 61 | 7 | 53 |
| | 6 | .45 | .44 | .024 | .13 | .31 | 52 | 7 | 54 |
| | 7 | .44 | .43 | .024 | .12 | .30 | 56 | 7 | 56 |
| | 8 | .46 | .43 | .023 | .12 | .31 | 46 | 7 | 54 |
| Anza | 1 | .38 | .46 | .040 | .13 | .30 | 46 | 5 | 47 |
| | 2 | .41 | .44 | .040 | .12 | .28 | 44 | 5 | 45 |
| | 3 | .39 | .42 | .027 | .12 | .29 | 53 | 7 | 42 |
| | 4 | .40 | .44 | .039 | .12 | .31 | 51 | 5 | 44 |
| | 5 | .39 | .46 | .036 | .12 | .30 | 54 | 7 | 46 |
| | 6 | .38 | .47 | .037 | .13 | .31 | 65 | 7 | 44 |
| | 7 | .38 | .43 | .036 | .12 | .28 | 55 | 5 | 46 |
| | 8 | .42 | .45 | .035 | .11 | .30 | 56 | 6 | 49 |

All data expressed on a dry wt. basis.

trend was present in Anza. Ethephon treatment appeared to result in higher Fe content in both cultivars.

Experiment 2

Treatment effects on plant height in Experiment 2 are presented in Table 5. Reductions in plant height from chlormequat treatment were significant at all concentrations and times. Though most of the naphthenate treatments were taller than their respective controls only the 500 ppm KNap treatment on Twin was significantly effected (5%).

Tillers per plant were significantly increased on both cultivars with 500 ppm KNap and 835 ppm KCHC. Applications of 250 ppm KNap and 9260 ppm chlormequat (Stage 22) also produced statistically greater numbers of tillers on Anza. Additionally all KNap, KCHC, and early applications of chlormequat tended to increase tillering.

Significant changes in seed weight were only apparent on Twin. Increases were noted with both KCHC treatments and KNap at 250 and 500 ppm. A significant reduction in seed weight was observed following application of chlormequat (4630 ppm) at Stage 22. No statistical changes in seeds per spike were observed.

Yield was significantly altered by several treatments. KNap (500 ppm) and KCHC (835 ppm) significantly increased yield in both cultivars. Twin additionally responded to KNap (250 ppm) and

Table 5. Effects of several plant growth regulators on agronomic characteristics and % protein of two cultivars of spring wheat in Experiment 2.

| Cultivar | Treatment | Height (cm) | Tillers/ plant | Seeds/ spike | Seed wt. mg/seed | Grain/ plant (g) | Protein % |
|---|---|---|---|---|---|---|---|
| Twin | 1 | 84.7 | 5.25 | 35.6 | 35.4 | 6.54 | 9.21 |
| | 2 | 85.6 | 5.48 | 35.4 | 36.6** | 7.06* | 9.58 |
| | 3 | 85.8* | 5.66** | 35.6 | 36.6** | 7.31** | 9.64 |
| | 4 | 85.1 | 5.38 | 35.7 | 35.6 | 6.71 | 9.49 |
| | 5 | 85.1 | 5.49 | 35.9 | 36.7** | 7.11* | 9.63 |
| | 6 | 84.9 | 5.63* | 36.1 | 36.6** | 7.43** | 9.72 |
| | 7 | 79.1** | 5.46 | 35.7 | 35.0 | 6.76 | 9.44 |
| | 8 | 76.3** | 5.53 | 35.4 | 34.4* | 6.71 | 9.61 |
| | 9 | 74.2** | 5.49 | 34.9 | 34.7 | 6.54 | 9.19 |
| | 10 | 81.7** | 5.17 | 35.4 | 35.5 | 6.47 | 9.34 |
| | 11 | 79.6** | 5.08 | 35.5 | 35.1 | 6.31 | 9.18 |
| | 12 | 78.9** | 4.97 | 35.1 | 35.2 | 6.11* | 9.13 |
| LSD .05= | | 0.9 | 0.29 | 2.1 | 0.8 | 0.43 | 0.77 |
| .01= | | 1.2 | 0.39 | 2.7 | 1.0 | 0.58 | 1.33 |
| CV = | | 2.8% | 13.7% | 14.7% | 5.6% | 16.3% | 6.4% |
| Anza | 1 | 70.9 | 5.34 | 34.1 | 38.4 | 6.92 | 10.61 |
| | 2 | 71.4 | 5.65* | 34.5 | 38.1 | 7.37 | 10.15 |
| | 3 | 71.7 | 5.81** | 34.2 | 38.7 | 7.54* | 10.89 |
| | 4 | 71.3 | 5.44 | 34.0 | 37.7 | 7.03 | 10.18 |
| | 5 | 71.3 | 5.56 | 34.2 | 38.9 | 7.29 | 10.54 |
| | 6 | 70.5 | 5.87** | 33.6 | 39.3 | 7.58* | 10.31 |
| | 7 | 67.6** | 5.63 | 33.4 | 38.7 | 7.37 | 10.77 |
| | 8 | 64.7** | 5.62 | 33.3 | 37.6 | 7.07 | 10.81 |
| | 9 | 62.6** | 5.72* | 32.9 | 38.7 | 7.21 | 10.43 |
| | 10 | 68.5** | 5.39 | 33.4 | 37.9 | 6.78 | 10.59 |
| | 11 | 67.1** | 5.27 | 34.1 | 37.3 | 6.74 | 10.94 |
| | 12 | 66.7** | 5.47 | 33.2 | 37.4 | 6.86 | 10.79 |
| LSD .05= | | 0.8 | 0.31 | 2.0 | 1.3 | 0.51 | 0.77 |
| .01= | | 1.1 | 0.41 | 2.7 | 1.7 | 0.67 | 1.03 |
| CV = | | 3.1% | 14.1% | 15.2% | 8.7% | 17.9% | 5.7% |

*, ** = Value differs significantly from control value at the 5 and 1% levels, respectively.

KCHC (418 ppm) applications. A yield reduction was noted at the highest rate and the latest stage of application of chlormequat.

Protein content was not significantly altered on either cultivar although Twin appeared to have elevated grain protein levels after treatment with the naphthenates.

## DISCUSSION

Cultivar differences in yield were noted in this study of responses to growth regulator application. KCHC produced significant increases in yield at all rates tested on the cultivar Twin. But in Anza only the (835 ppm) rate in Experiment 2 caused an increase in yield. This is not uncommon as Larter et al. (1965) has shown that two cultivars of barley responded differentially to chlormequat application. Appleby et al. (1966) has reported similar findings with winter wheat.

The significant decrease in yield when chlormequat was applied at 9260 ppm, when the second node was just detectable, and the general trend towards lower yields from chlormequat at this stage of development may be the result of leaf scorching. This has been previously reported (Humphries et al., 1965) and may also account for the relative lower number of tillers at the late application. Survival of late formed tillers may not be favored due to the temporary but significant reduction in effective leaf area.

Though ethephon at both rates and stages produced significant increases in protein with Twin, these increases were associated with appreciable decreases in yield, however protein yield per acre remained relatively constant. Of particular interest is the general elevation of protein content with all of the naphthenates applied in Experiment 2, as these were also associated with elevated yields, thus protein yield per acre would be greater. The results from Experiment 1 do not show this trend. Rates in Experiment 1 may have been too high or the spray coverage was not sufficient for responses in protein content. It has been suggested by Wort et al. (1973) that increases in protein content in Phaseolus vulgaris L. from naphthenate application is related to greater anabolic enzyme activity related to nitrogen metabolism. It also has been shown that a shunting of carbon skeletons from carbohydrate to nitrogen metabolism appears to exist after naphthenate treatment on wheat seedlings (Hile and Chilcote, 1975). It would appear that a potential exists to advantageously manipulate protein content and yield in specific cultivars.

The results of the vitamin and mineral analyses may serve as an indication of possible effect; though bulk samples, no matter how well composited or analyzed, do not allow statistical interpretation of inherent biological variability. Even so, it appears that niacin content may be beneficially elevated as all regulators in

Experiment 1 showed trends to increase on both cultivars. KCHC in general adversely affected vitamin content, and KCHC and KNap lowered mineral content. Of interest is the sizeable increase in Fe content in both varieties from ethephon application. This has not been previously reported. Oplinger et al. (1975) noted increases in groat Fe content in oats but as the result of RH-551 application which is similar in action to ethephon.

It is apparent that the rates of KNap used in Experiment 1 were not in the correct range or the coverage was not sufficient as the lower rates employed with the individual plants produced significant effects on yield. The particular rate which should be used appears to be governed by the effect of environmental preconditioning effects on endogenous regulators. Whereas chlormequat and ethephon give fairly consistent visual effects, height reduction and increased tillering, the naphthenates are highly unpredictable.

What appears certain from both visual and statistical analysis under this set of environmental conditions is that ethephon is far more effective than chlormequat in reducing plant height. In the cultivar Twin it is not uncommon to observe some very tall plants. But within ethephon-treated plots they were not apparent. This contrasts with additional observational areas sprayed with chlormequat, in which tall plants present were reduced to varying degrees. The seed heads in ethephon-treated plots were thus placed in a more

narrow plane, resulting in fields which would be more uniform and easily combined.

# YIELD AND NUTRITIONAL QUALITY RESPONSES OF SNAP BEANS TO PLANT GROWTH REGULATORS

## ABSTRACT

The effects of plant growth regulators on yield and nutritional quality of snap beans (Phaseolus vulgaris L.) were studied under field and controlled environment conditions.

No significant increase in yield, marketable or total pods per plant resulted from regulator treatments in the field. Protein content was significantly (5%) increased in the spring planting by at least one rate of all the regulators with the exception of potassium cyclohexanecarboxylate (KCHC) which lowered protein content. B-carotene content tended to be lowered by all regulator treatments in the spring planting but several significant increases were observed from application in the summer planting. Ascorbic acid content was significantly decreased by all regulator treatments in the spring planting but not in the summer planting.

Controlled environment studies using high temperature (39, 35 C) and low relative humidity (20, 30%) following preconditioning (26 C, 80 and 45% RH) appeared to little effect protein and B-carotene contents. But ascorbic acid content was drastically reduced the first day after exposure. Though plants tended to adjust

they did not reach the levels of ascorbic acid of unexposed, preconditioned plants. Treatment with potassium naphthenate (KNap) tended to lower levels more and retard adjustment to the higher temperatures.

## INTRODUCTION

Bush beans are of major economic importance for processing in Oregon. They are an important source of ascorbic acid and vitamin A in the diet. Numerous workers have reported increased yield and nutritional quality in snap beans from growth regulator application. Murneek et al. (1944) reported that under hot and dry weather conditions yields were increased 59 to 72% by treatment with naphthaleneacetic and naphthoxyacetic acids. Wittwer and Murneek (1946) noted that these compounds were not consistently effective in increasing yields.

Tompkins et al. (1971) using 5 chloro, 2-thenyl, tri-n-butyl-phosphoniumchloride (CTBP) found increased pod set and yields of two cultivars planted in late summer and two of four planted in the late spring. They also noted that Ca, Mg, P, and K levels were not influenced by CTBP treatment. Weigle et al. (1973) working with CTBP and other compounds also found increased pod set in beans. However this initial increase in pod set was not retained through harvest. Campbell and Greig (1974) attributed increased yield,

from CTBP and TIBA, to greater pod set. They also found no difference in P, K Ca, Mg, Fe, or Zn levels in treated foliage samples.

Rathore and Wort (1971) observed that 2, 4-D-micronutrient sprays increased yield and ascorbic acid content of green pods. The same effect has been shown more dramatically by Wort and associates using potassium naphthenate. Fattah (1972) has shown that potassium naphthenate can significantly increase the yield and ascorbic acid content of green pods under greenhouse conditions. It was also noted that during storage there was less ascorbic acid loss in pods from naphthenate-treated plants as compared to untreated plants.

This investigation was conducted to determine effects on yield and nutritional quality of snap beans by growth regulator applications under differing field and controlled environments.

## MATERIALS AND METHODS

Oregon 1604, a bush blue lake snap bean cultivar, was used in all experiments. The spring planting was planted May 8 on a Chehalis silty loam and the summer planting was planted July 11 on a Woodburn clay loam soil. A randomized block design with eight replications was used in both locations. Stands were established at about 31 plants per meter in .91 meter rows. Because of previous crop history the spring planting received 50, 66, 40 and the summer

planting received 110, 26, 50 kg/ha of N, P, K, respectively. Single row plots were 8 and 3.5 meters in length in the spring and summer plantings, respectively, with 4 and 2.5 meters harvested, respectively.

Growth regulators and rates of application are listed in Table 1. Plots treated with potassium naphthenate (KNap) and potassium cyclohexanecarboxylate (KCHC) were sprayed 2 weeks after planting. Applied at first bloom were: 2, 3, 5-triidobenzoic acid (TIBA), 5 chloro, 2-thenyl, tri-n-butyl-phosphoniumchloride (CTBP) and XE326-S (Chevron proprietary). Applications were made with a handsprayer at a spray volume of 540 liters/ha with 0.4% X-77 added as a surfactant.

Plants were pulled by hand and all pods were removed to simulate a once-over mechanical harvest. Individual plots were weighed and two replications were combined by treatment and mechanically graded into sieve sizes and weighed. Immediately, after sizing and weighing, pod samples of sieve size 4 were blanched, canned, frozen, and stored at -40 C for later analyses. Marketable (over four cm in length) and total pods were determined three days prior to harvest, from samples of 10 plants per replication.

Table 1. Effect of several plant growth regulators on yield, sieve sizes, marketable, and total pods per plant of Oregon 1604 snap bean grown under two sets of field conditions.

| Spring planting Vegetable Res. Farm | Growth regulator | Treatment rate ppm | Yield tons/acre | % Total yield ≤ 5 sieve sizes | Marketable pods/ plant | Total pods/ plant |
|---|---|---|---|---|---|---|
| | Control | 0 | 8.51 | 62 | 14.8 | 21.8 |
| | KNap | 2500 | 8.23 | 65 | 15.6 | 22.6 |
| | KNap | 5000 | 9.64 | 65 | 18.1 | 24.5 |
| | KCHC | 1670 | 8.71 | 66 | 16.6 | 23.7 |
| | KCHC | 3340 | 9.40 | 67 | 17.8 | 25.4 |
| | XE326-S | 229 | 9.20 | 65 | 17.4 | 24.0 |
| | XE326-S | 367 | 8.49 | 68 | 16.5 | 24.6 |
| | TIBA | 11.5 | 9.11 | 68 | 16.8 | 23.9 |
| | TIBA | 29.9 | 7.86 | 65 | 15.7 | 22.3 |
| | TIBA | 45.9 | 9.30 | 66 | 17.4 | 25.6 |
| | $LSD_{.05}$ = | | 1.14 | NS | NS | NS |
| | CV= | | 13.4% | 4.1% | 18.3% | 21.9% |
| Summer planting Hyslop Farm | | | | | | |
| | Control | 0 | 5.99 | 50 | 11.5 | 20.9 |
| | KNap | 5000 | 5.83 | 52 | 12.3 | 22.9 |
| | KCHC | 3340 | 5.87 | 53 | 12.4 | 22.7 |
| | XE326-S | 183 | 5.53 | 49 | 11.7 | 22.5 |
| | XE326-S | 367 | 5.84 | 51 | 11.9 | 23.8 |
| | TIBA | 11.5 | 5.40 | 47 | 11.4 | 23.2 |
| | TIBA | 22.9 | 5.13 | 44 | 10.6 | 25.3 |
| | CTBP | 12.5 | 5.61 | 51 | 10.9 | 20.0 |
| | CTBP | 25.0 | 5.37 | 52 | 10.4 | 22.9 |
| | $LSD_{.05}$= | | NS | NS | NS | NS |
| | CV= | | 11.0% | 5.3% | 15.5% | 21.3% |

Greenhouse experiments

Eight seeds were planted in 15-cm plastic pots containing vermiculite. Visual uniformity of plants was obtained by thinning to one plant per pot 3 days after emergence. Plants were placed after sowing in two controlled environment rooms differing only in relative humidity. Cool white fluorescent and 60-w incandescent lamps provided 25.8 klux at plant height. The photoperiod in both rooms was 14 hour with day/night temperatures of 26/21±1 C. Relative humidities (day/night) in controlled environments rooms were 80/85±5 and 45/50±5%, respectively. Plants were watered on alternate days with half-strength nutrient solution. Later as temperatures were elevated all treatments were watered twice daily.

Fourteen days after planting, primary leaves were fully expanded and the first trifoliate leaf was in the bud, the foliage of half of the 90 plants contained in each chamber was thoroughly sprayed with a 5000 ppm solution of KNap.

Ten days after flowering, groups (15 control and 15 treated) from each preconditioning treatment were placed in chambers with 39/21 C-20/30% RH and 35/21 C-30/40% RH. An attempt was made to balance light intensity and photoperiod between the chambers. At noon on the date of transfer the original chambers were sampled. Sampling consisted of picking at least 20 pods (approximately sieve

size 4) per treatment. These were immediately cut into 1-cm pieces, blanched, canned, frozen, and stored at -40 C for later analyses. Pods from all chambers were sampled at noon, 1, 3, and 5 days after exposure to high temperature and low relative humidities and compared to samples taken from plants in the original chambers.

Frozen, blanched samples were analyzed without thawing for B-carotene using AOAC 39.015-39.017 and ascorbic acid by the method of Pearson (1970). Samples were also dried to constant weight for % moisture. Dried material was ground to 40-mesh and analyzed for total N (Nelson and Sommers, 1973) and reported as % protein (%N x 6.25). All tabulated data are reported on a 90% moisture basis.

## RESULTS AND DISCUSSION

No growth regulator treatment at either planting time resulted in significant (5%) increases in yield, marketable, or total pods per plant (Table 1). Six of 9 regulator treatments produced greater yield than the control in the early planting but all were lower in yield in the late planting.

Protein, B-carotene and ascorbic acid contents of pods (Table 2) from treated plants were altered in many cases significantly even though the growth regulators failed to effect yield. Protein content

Table 2. Effect of several plant growth regulators on protein, B-carotene, and ascorbic acid content of Oregon 1604 snap bean grown under two sets of field conditions.

| Spring planting Vegetable Res. farm | Growth regulator | Treatment rate (ppm) | Protein % Fresh wt.[1/] | B-carotene µg/100g Fresh wt. | Ascorbic acid mg/100g Fresh wt. |
|---|---|---|---|---|---|
| | Control | 0 | 1.52 | 249 | 13.8 |
| | KNap | 2500 | 1.52 | 207 | 12.6** |
| | KNap | 5000 | 1.59** | 208 | 11.5** |
| | KCHC | 1670 | 1.45** | 185 | 11.5** |
| | KCHC | 3340 | 1.43** | 219 | 10.4** |
| | XE326-S | 229 | 1.62** | 178 | 11.3** |
| | XE326-S | 367 | 1.46** | 198 | 12.9** |
| | TIBA | 11.5 | 1.58** | 193 | 11.5** |
| | TIBA | 29.9 | 1.61** | 178 | 10.8** |
| | TIBA | 45.9 | 1.61** | 180 | 11.1** |
| | $LSD_{.01}$= | | .034 | NS | .74 |
| | CV= | | 4.0% | 19.9% | 2.7% |
| Summer planting Hyslop Farm | | | | | |
| | Control | 0 | 2.01 | 287 | 16.4 |
| | KNap | 5000 | 1.82 | 293 | 18.5 |
| | KCHC | 3340 | 1.83 | 330 | 17.9 |
| | XE326-S | 183 | 1.94 | 347* | 15.7 |
| | XE326-S | 367 | 2.03 | 300 | 15.1 |
| | TIBA | 11.5 | 1.90 | 367** | 17.1 |
| | TIBA | 22.9 | 1.74 | 347* | 17.7 |
| | CTBP | 12.5 | 1.85 | 310 | 16.7 |
| | CTBP | 25.0 | 1.97 | 343* | 15.9 |
| | $LSD_{.05}$= | | NS | 48 | NS |
| | .01= | | NS | 66 | NS |
| | CV= | | 9.7% | 8.5% | 8.7% |

[1/] Fresh weights based on pods corrected to 90% moisture content.

*, ** = Value differs from the control value at the 5 and 1% levels, respectively.

was increased (5% level) at the early planting by at least one rate of all the regulators with the exception of KCHC which lowered protein content. No significant alterations of protein content resulting from treatment was observed in the late planting.

B-carotene content tended to be lowered by all chemical treatments in the spring planting. In contrast, B-carotene content in the summer planting appeared to be raised by growth regulator application: XE326-S (183 ppm), CTBP (25 ppm) and both rates of TIBA (11.5, 22.9 ppm) produced significant increases in B-carotene.

Ascorbic acid content of pods was significantly lowered by all growth regulator applications in the spring planting but they had no significant effects in the summer planting. KNap and KCHC appeared to elevate ascorbic acid though not significantly. Fattah (1972) has shown significant increases in ascorbic acid content in green pods grown in the greenhouse. The differential response in ascorbic acid content between the times of planting, particularly in respect to KNap application appears conflicting. Aliev (1965) has reported an increase in ascorbic acid content in fruits of KNap treated tomato plants; Chu (1969) reported a decrease.

The failure of bush beans to respond similarly in yield or nutritional quality at the two dates of planting may be due to different prevailing environmental conditions after treatment. The spring-planted bush beans were harvested under conditions of high

temperature and low relative humidity, whereas the summer planting experienced overcast skies with lower temperature and light intensity.

Hume et al. (1972) have reported positive yield responses to TIBA only in years when precipitation was above normal. Vetter et al. (1970) suggested moisture deficiency may have restricted favorable response of flax to TIBA application. Increases in soybean pod number using TIBA in greenhouse and growth chamber studies have been observed by Ohki and McBride (1972). They have also found that the imposition of low soil moisture conditions sometimes produced negative responses to TIBA. Stutte et al. (1974) feel that growth regulator application to increase seed yield must be accompanied by adequate water during flowering and pod-filling stages of soybean development. Stutte (1974) suggests that high temperature during pod development may contribute more to yield loss than water stress.

Epinasty of the upper leaves and interveinal puckering made TIBA-treated rows visually apparent 4 days after treatment. This response was transient since 9 days after treatment no visual symptoms could be observed.

Spring-planted snap beans experienced conditions of lower temperature and higher % relative humidity than did the summer planting. Visual wilting in the field at harvest was observed in the

spring-planted snap beans but not in the summer planting. It is conceivable that plant moisture stress is possible even when adequate soil moisture is available, particularly if plants are preconditioned to high moisture conditions.

The effect of temperature and relative humidity levels on protein, B-carotene, and ascorbic acid contents grown in controlled environments are presented in Tables 3, 4, and 5, respectively. Protein and B-carotene levels appeared to be little affected by elevated temperature or low relative humidity levels. KNap application appeared to effect protein content more under preconditioning with high relative humidity and treated plants seemed to tolerate higher temperatures.

Pods were selected of the same sieve size over a 6-day period. The maturity of pods would increase with time even though they are all about sieve size 4. The general increase in protein content and decrease in B-carotene content with increasing maturity corresponds well with the work of Flynn et al. (1946).

Ascorbic acid content (Table 5) was drastically lowered the first day after exposure to high temperature and low relative humidity. Stressed plants tended to adjust to their new growing conditions but after 5 days had not reached levels comparable to those without stress. KNap tended to reduce ascorbic acid contents under stress more than the untreated control. In addition, treated plants did not

Table 3. Effect of temperature and relative humidity levels on protein content of preconditioned snap beans (Oregon 1604), treated with KNap.

Preconditioning treatment 1.

26/21 C, 80/85% RH

| Treatment | Temperature | RH | % Protein | | | |
|---|---|---|---|---|---|---|
| | Day/Night | Day/Night | Days after exposure | | | |
| | C | % | 0 | 1 | 3 | 5 |
| | 39/21 | 20/30 | - | 2.00 | 2.27 | 2.24 |
| Untreated | 35/21 | 30/40 | - | 2.07 | 1.99 | 2.19 |
| | 26/21 | 80/85 | 1.95 | 1.94 | 2.07 | 2.22 |
| | 29/21 | 20/30 | - | 2.11 | 2.27 | 2.42 |
| 5000 ppm | 35/21 | 30/40 | - | 2.22 | 2.32 | 2.34 |
| KNap | 26/21 | 80/85 | 2.02 | 2.24 | 2.39 | 2.41 |

Preconditioning treatment 2.

26/21 C, 45/50% RH

| Treatment | Temperature | RH | % Protein | | | |
|---|---|---|---|---|---|---|
| | Day/Night | Day/Night | Days after exposure | | | |
| | C | % | 0 | 1 | 3 | 5 |
| | 39/21 | 20/30 | - | 2.05 | 2.04 | 2.28 |
| Untreated | 35/21 | 30/40 | - | 2.00 | 2.18 | 2.30 |
| | 26/21 | 45/50 | 1.89 | 2.04 | 2.04 | 2.34 |
| | 39/21 | 20/30 | - | 2.02 | 2.24 | 2.33 |
| 5000 ppm KNap | 35/21 | 30/40 | - | 2.05 | 2.29 | 2.38 |
| | 26/21 | 45/50 | 1.97 | 1.99 | 2.21 | 2.37 |

All data based on pods corrected to 90% moisture content.

Table 4. Effect of temperature and relative humidity levels on B-carotene content of preconditioned snap beans (Oregon 1604), treated with KNap.

Preconditioning treatment 1.

26/21 C, 80/85% RH

| Treatment | Temperature | RH | mg B-carotene/100g | | | |
|---|---|---|---|---|---|---|
| | Day/Night | Day/Night | Days after exposure | | | |
| | C | % | 0 | 1 | 3 | 5 |
| Untreated | 39/21 | 20/30 | - | 356 | 341 | 337 |
| | 35/21 | 30/40 | - | 379 | 393 | 329 |
| | 26/21 | 80/85 | 397 | 427 | 371 | 343 |
| 5000 ppm KNap | 39/21 | 20/30 | - | 373 | 356 | 322 |
| | 35/21 | 30/40 | - | 389 | 378 | 344 |
| | 26/21 | 80/85 | 401 | 373 | 398 | 355 |

Preconditioning treatment 2.

26/21 C, 45/50% RH

| Treatment | Temperature | RH | mg B-carotene/100g | | | |
|---|---|---|---|---|---|---|
| | Day/Night | Day/Night | Days after exposure | | | |
| | C | % | 0 | 1 | 3 | 5 |
| Untreated | 39/21 | 20/30 | - | 348 | 356 | 317 |
| | 35/21 | 30/40 | - | 354 | 329 | 308 |
| | 26/21 | 45/50 | 364 | 400 | 353 | 317 |
| 5000 ppm KNap | 39/21 | 20/30 | - | 341 | 343 | 317 |
| | 35/21 | 30/40 | - | 354 | 379 | 291 |
| | 26/21 | 45/50 | 351 | 372 | 368 | 335 |

All data based on pods corrected to 90% moisture content.

Table 5. Effect of temperature and relative humidity levels on ascorbic acid content of preconditioned snap beans (Oregon 1604), treated with KNap.

Preconditioning treatment 1.

26/21 C, 80/85% RH

| Treatment | Temperature | RH | mg ascorbic acid/100g | | | |
|---|---|---|---|---|---|---|
| | Day/Night | Day/Night | Days after exposure | | | |
| | C | % | 0 | 1 | 3 | 5 |
| Untreated | 39/21 | 20/30 | - | 8.5 | 10.8 | 12.7 |
| | 35/21 | 30/40 | - | 9.3 | 11.4 | 13.3 |
| | 26/21 | 80/85 | 11.4 | 12.7 | 13.5 | 14.9 |
| 5000 ppm KNap | 39/21 | 20/30 | - | 7.6 | 9.4 | 10.3 |
| | 35/21 | 30/40 | - | 8.9 | 10.2 | 11.8 |
| | 26/21 | 80/85 | 12.5 | 12.4 | 13.7 | 15.3 |

Preconditioning treatment 2.

26/21 C, 45/50% RH

| Treatment | Temperature | RH | mg ascorbic acid/100g | | | |
|---|---|---|---|---|---|---|
| | Day/Night | Day/Night | Days after exposure | | | |
| | C | % | 0 | 1 | 3 | 5 |
| Untreated | 39/21 | 20/30 | - | 9.6 | 12.1 | 12.7 |
| | 35/21 | 30/40 | - | 10.1 | 13.3 | 13.1 |
| | 26/21 | 45/50 | 12.3 | 13.3 | 13.6 | 14.3 |
| 5000 ppm KNap | 39/21 | 20/30 | - | 9.1 | 11.5 | 12.7 |
| | 35/21 | 30/40 | - | 11.7 | 12.9 | 13.9 |
| | 26/21 | 45/50 | 12.1 | 12.8 | 14.1 | 14.7 |

All data based on pods corrected to 90% moisture content.

adjust to the new stress situation as rapidly as untreated. The reduction in ascorbic acid content in KNap-treated plants over that of untreated controls may partially explain the large significant reduction observed in the spring planting. The content of untreated plants in the spring planting though low was further significantly reduced with all the regulators applied.

The metabolism of ascorbic acid has been shown to be affected by external factors, such as light and temperature, by Isherwood and Mapson (1962). But they could not establish any definite relationship between temperature and ascorbic acid synthesis. It is suggested here that preconditioning and subsequent stress (high temperature and low relative humidity) can lower ascorbic levels where those conditions without preconditioning would have less effect. But the specific mechanism by which growth regulators produced significant reductions in ascorbic acid under stress remains unresolved. At this time, it is apparent that the predictability of specific responses to growth regulators is limited by an incomplete understanding of mechanisms of action and their environmental interactions.

# SEASONAL VARIATION IN YIELD AND NUTRITIONAL QUALITY IN SNAP BEANS

## ABSTRACT

The seasonal variation of yield, protein, B-carotene, and ascorbic acid contents was observed in four snap bean cultivars (Phaseolus vulgaris L.) in the field and under controlled environment.

The yield and maturity of individual cultivars varied with planting date. Variation in mean protein content between planting dates and cultivars was slight, with more variation observed between cultivars within a planting date. B-carotene content varied between and within cultivars at different planting dates. The maximum variation for planting date and cultivar was 18 and 30%, respectively. Cultivars varied within a planting date from a slight difference to 72%. Large variations in ascorbic acid content between planting dates were evident.

Nutritional quality appeared to be affected more by the prevailing environmental conditions near harvest even though yield varied greatly between cultivars and to a lesser extent between dates of planting. Ascorbic acid content appears to be more sensitive to seasonal fluctuation in environment than B-carotene or protein content.

Subjection of cultivars to 80 and 50% relative humidity resulted in differences in growth habit though no differences were observed in yield or nutrient content. The relative ranking of yield of cultivars in controlled environments differed from that observed in the field though differences in B-carotene and ascorbic acid contents were similar.

## INTRODUCTION

The relative concentrations of various nutritional quality components in green snap beans have been shown to be highly variable (Flynn, et al., 1946; Mack et al., 1939; Zscheile et al., 1943). Investigators have shown that this variability in composition of snap bean pods is due chiefly to differences in stage of maturity. Zscheile et al. (1943) have reported that carotene in the whole pods of shorter beans was lower than that of longer, older ones. Wade and Kanapaux (1943) have found no significant differences in ascorbic acid content of small, medium, or larger pods within a cultivar. Flynn et al. (1946) have reported that ascorbic acid and protein content gradually increase with increasing maturity. They also noted lower ascorbic acid content in the fall as compared to the summer whereas carotene content was higher, unfortunately these plantings were not in the same season although in the same location.

The influence of seasonal patterns on nutritional quality in

snap beans is an important practical concern. The interaction of environmental factors within a season may make it difficult for food processors to produce a product with a uniform nutritional value, or the home gardener to harvest a product at a peak in nutrition for canning. Younkin (1974) also points out that the interaction of environmental factors on the composition of food crops raises important questions relative to testing procedures necessary to develop data needed for GRAS classification of a new cultivar.

Bush snap beans are of major commercial importance in Oregon. Bush beans are also an important source of ascorbic acid and vitamin A. Little is known of the interaction of environmental factors within a season on the nutritional quality of snap beans. This study was conducted to determine the seasonal variation of yield and nutritional value in snap beans. The variation of yield, protein, B-carotene (Provitamin A), and ascorbic acid (Vitamin C) content was observed in four commercial bush snap bean cultivars under commercial conditions in the field and under selected controlled environments.

## MATERIALS AND METHODS

Four cultivars of bush snap beans, 'Asgrow 290', 'Gallatin 50', 'Oregon 58', 'Oregon 1604', were planted on six different dates. Dates of planting and harvest (which varied due to differential

ripening) are presented in Table 1. A randomized block design was used for each date. Single row plots were 6.1 meter long and the middle 4.6 meter were harvested. Stands were established at about 26-30 plants per meter in 0.91 meter rows. Plots were fertilized with 50, 66, 40 kg/ha of N, P, K respectively, by sidedressing at time of planting. Plantings were irrigated by sprinkler at 7-10 day intervals, to maintain a good moisture status.

Table 1. 1974 Field Trial, Cultivar, planting and harvest dates of four snap bean cultivars.

| | Planting date | | | | | |
|---|---|---|---|---|---|---|
| | 4/25 | 5/08 | 5/28 | 6/07 | 6/18 | 7/15 |
| Cultivar | Harvest date | | | | | |
| Asgrow 290 | 7/24 | 7/28 | 8/09 | 8/16 | 8/20 | 9/24 |
| Gallatin 50 | 7/18 | 7/26 | 8/05 | 8/12 | 8/23 | 9/19 |
| Oregon 58 | 7/18 | 7/24 | 8/05 | 8/09 | 8/21 | 9/16 |
| Oregon 1604 | 7/18 | 7/24 | 8/05 | 8/12 | 8/21 | 9/18 |

Planting and harvest dates of the four snap bean cultivars are given in Table 1. Though all four cultivars were planted at each respective planting date, harvest dates varied due to differential ripening. Brendler (1969) has noted that though the yield of pod sizes 1 through 4, expressed in terms of percentage of total yield, can be used as a practical measure for some cultivars, different standards may be necessary for different cultivars. Farkas (1967)

suggests that seed size measurements should be continuously compared with pod diameter distributions to maintain quality in the processed product.

Cultivars were harvested when they were judged to be at acceptable yield and maturity using both sieve size distribution and seed size as criteria. Plants were pulled by hand and all pods were removed to simulate a once-over mechanical harvest. Green pods from each plot were weighed, combined by cultivar and mechanically graded into sieve sizes and then reweighed for sieve size distribution. A 3-5 kg sample of sieve size 4 pods was immediately taken to the laboratory, cut into 2-cm pieces, blanched, canned, frozen, and stored at -40 C for later analyses.

One hundred grams of frozen, blanched samples from the field were quickly cut into 5-mm pieces and mixed well, reduced to a 20 gram sample and without thawing analyzed for B-carotene using AOAC 39.015-.017. Samples were treated similarly but reduced to 50 grams for ascorbic acid analysis by the method of Pearson (1970). Samples were also dried to constant weight for % moisture. Dried material was ground to 40-mesh and analyzed for total N (Nelson and Sommers, 1973) and reported as % protein (%N x 6.25). All tabulated nutritional data are reported on a 90% moisture basis.

Controlled environment studies

Snap beans were grown under controlled environment conditions to determine: 1) The effect of relative humidity on yield and nutritional quality; 2) if the relative ranking of the cultivars, in terms of yield and nutritional quality, differed from that in the field.

Six seeds were planted in 15-cm plastic pots containing vermiculite. Uniformity of plants was obtained by thinning to one plant per pot 3 days after emergence. Plants were placed after sowing in two controlled environment rooms differing only in relative humidity. Cool white fluorescent and 60-w incandescent lamps provided 29.1 klux at plant height. The photoperiod in both rooms was 14 hour with day/night temperatures of 26 1/21±1 C. Relative humidities (day/night) in controlled environment rooms were 80/85 and 45/50±5%, respectively. Plants were watered on alternate days with half-strength nutrient solution. After flowering plants were watered daily.

Plants were harvested when both yield and quality were maximum. Marketable pods (4 cm or longer) were weighed. Samples of sieve size 4 pods were taken from each replication and immediately cut in 2-cm pieces, blanched, canned frozen, and stored at -40 C for later analyses. Analyses were conducted as previously described for the field samples except only 25% as much material was used.

# RESULTS AND DISCUSSION

Yield of individual cultivars varied with planting date (Table 2). This variation in yield between planting dates has been previously described by Haun et al. (1972), in several cultivars at several locations. The 5/28 planting date, with subsequent midseason harvest dates, resulted in the highest mean yield of cultivars. Oregon 1604 produced the highest average yield exceeding all other cultivars in 4 out of 6 dates of planting; sieve size distribution also varied with planting date (Table 3). Both Oregon 1604 and Oregon 58 produced larger pods than Asgrow 290 before quality was affected.

Seed length (Table 4) was observed in sieve size 4 pod samples. No pods contained seed smaller than 4 mm or longer than 12 mm. With the exception of the 7/15 planting of Asgrow 290, seed length in sieve size 4 pods varied from 4-8 mm. The differences of seed length and sieve size distribution in these cultivars illustrates the value of both these parameters to describe maturity for optimum yield and quality.

Protein content of snap beans was recorded though not of major nutritional importance in the diet. Protein levels varied between cultivar and planting dates (Table 5). The variation between means of planting dates and cultivars was slight, with more variation observed between cultivars within a planting date (Figure 1).

Table 2. 1974 Field Trial. Effect of planting date on yield (Tons/A) of four snap bean cultivars.

| | Planting date | | | | | | |
|---|---|---|---|---|---|---|---|
| Cultivar | 4/25 | 5/08 | 5/28 | 6/07 | 6/18 | 7/15 | Mean |
| Asgrow 290 | 5.9 | 7.0 | 7.1 | 6.3 | 7.3 | 7.7 | 6.9 |
| Gallatin 50 | 5.2 | 4.0 | 5.6 | 5.5 | 4.4 | 4.7 | 4.9 |
| Oregon 58 | 7.5 | 6.3 | 7.9 | 5.8 | 6.7 | 6.4 | 6.8 |
| Oregon 1604 | 8.0 | 7.5 | 8.5 | 8.6 | 6.6 | 7.4 | 7.8 |
| Mean | 6.7 | 6.2 | 7.3 | 6.6 | 6.3 | 6.6 | 6.6 |

Table 3. 1974 Field Trial. Effect of planting date on sieve sizes (% $\geq$ 4) in four snap bean cultivars at harvest.

| | Planting date | | | | | | |
|---|---|---|---|---|---|---|---|
| Cultivar | 4/25 | 5/08 | 5/28 | 6/07 | 6/18 | 7/15 | Mean |
| Asgrow 290 | 61.4 | 77.2 | 86.8 | 92.3 | 64.3 | 58.7 | 73.5 |
| Gallatin 50 | 44.1 | 30.0 | 57.5 | 84.3 | 51.9 | 63.4 | 55.2 |
| Oregon 58 | 25.3 | 44.1 | 27.8 | 56.3 | 38.0 | 29.2 | 36.8 |
| Oregon 1604 | 31.3 | 26.3 | 37.9 | 56.7 | 49.9 | 20.9 | 37.2 |
| Mean | 40.5 | 44.4 | 52.5 | 72.4 | 51.0 | 43.1 | 50.7 |

Table 4. 1974 Field Trial. Effect of planting date on seed length (cm) in sieve size 4 pods at harvest.

| | Planting date | | | | | | |
|---|---|---|---|---|---|---|---|
| Cultivar | 4/25 | 5/08 | 5/28 | 6/07 | 6/18 | 7/15 | Mean |
| Asgrow 290 | 8.9[1/] | 8.1 | 7.3 | 7.9 | 7.2 | 9.8 | 8.2 |
| Gallatin 50 | 6.2 | 5.1 | 5.8 | 6.4 | 5.3 | 6.2 | 5.8 |
| Oregon 58 | 7.9 | 7.3 | 6.8 | 7.3 | 7.0 | 7.1 | 7.2 |
| Oregon 1604 | 6.8 | 6.3 | 6.6 | 6.0 | 7.1 | 7.5 | 7.0 |
| Mean | 7.5 | 6.7 | 6.6 | 6.9 | 6.7 | 7.7 | 7.0 |

[1/] Mean of 5 samples of the seed lengths of the single (largest) seed, end to end, in cm, from each of 10 sieve size 4 pods.

Table 5. Field Trial. Effect of planting date on protein (g/100g) content in four snap bean cultivars.

| | Planting date | | | | | | |
|---|---|---|---|---|---|---|---|
| Cultivar | 4/25 | 5/08 | 5/28 | 6/07 | 6/18 | 7/15 | Mean |
| Asgrow 290 | 1.68[1/] | 1.80 | 1.84 | 1.70 | 1.79 | 1.90 | 1.79 |
| Gallatin 50 | 1.77 | 1.61 | 1.56 | 1.49 | 1.61 | 1.57 | 1.60 |
| Oregon 58 | 1.82 | 1.70 | 1.97 | 1.81 | 1.78 | 1.72 | 1.80 |
| Oregon 1604 | 1.75 | 1.59 | 1.75 | 1.38 | 1.69 | 1.67 | 1.64 |
| Mean | 1.76 | 1.68 | 1.78 | 1.60 | 1.72 | 1.72 | 1.71 |

[1/] Based on pods corrected to 90% moisture content.

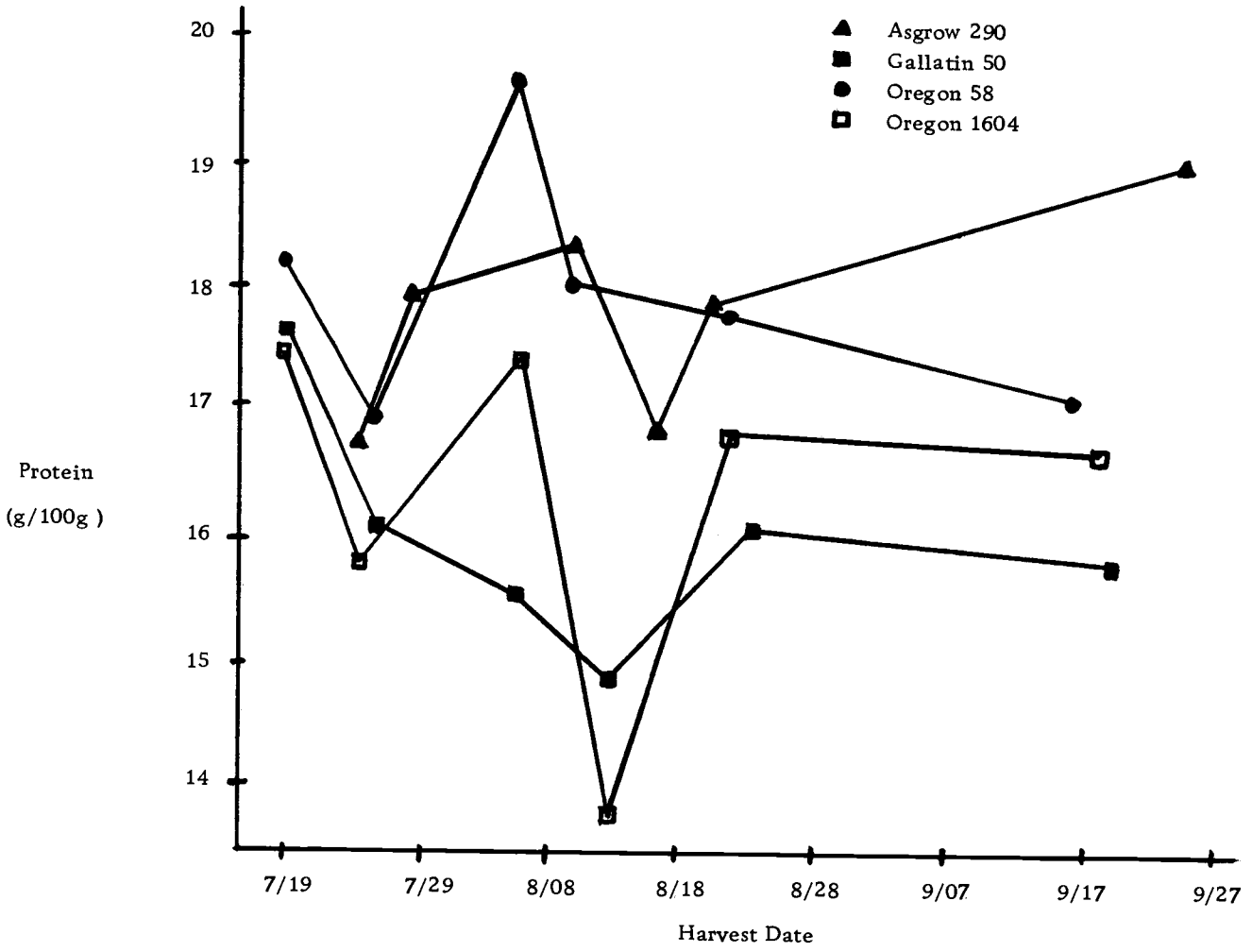


Figure 1. Protein content (g/100g) of four snap bean cultivars as affected by harvest date.

B-carotene content exhibited appreciable variation between and within cultivars at different planting dates (Table 6, Figure 2). The maximum variation in B-carotene means of planting date and cultivars was 18 and 30%, respectively. The 5/28 and 7/15 planting dates produced the lowest mean levels of the four cultivars. Pods of Oregon 58 (Figure 2) contained the highest B-carotene content at all the dates of planting. It must be noted that though the B-carotene content of Oregon 58 was greater than the other cultivars the magnitude of this difference was not consistent. At the 7/15 planting date the difference between Oregon 58 and Gallatin 50 was slight but at the 5/28 planting date this difference was 72%.

Ascorbic acid content was highest in Oregon 1604, which was the lowest in B-carotene content. Large variations between planting dates in ascorbic acid content are evident. The pods from the third planting date contained lowest levels of ascorbic acid. This response was similar for all of the cultivars. The harvest of cultivars from this planting date was during a period of high temperature and low relative humidity accompanied by slight winds. Wilting of plants was visually apparent even though soil moisture was adequate.

Light and temperature have been shown to have considerable effect on the metabolism of ascorbic acid by Isherwood and Mapson (1962), though they could establish no definite relationship between

Table 6. 1974 Field Trial. Effect of planting date on B-carotene (μg/100g) content in four snap bean cultivars.

| | Planting date | | | | | | |
|---|---|---|---|---|---|---|---|
| Cultivar | 4/25 | 5/08 | 5/28 | 6/07 | 6/18 | 7/15 | Mean |
| Asgrow 290 | 326[1/] | 300 | 244 | 296 | 308 | 256 | 288 |
| Gallatin 50 | 292 | 280 | 204 | 288 | 276 | 272 | 269 |
| Oregon 58 | 346 | 370 | 352 | 308 | 364 | 283 | 337 |
| Oregon 1604 | 248 | 306 | 264 | 228 | 264 | 240 | 258 |
| Mean | 303 | 314 | 266 | 280 | 303 | 263 | 288 |

1/ Based on pods corrected to 90% moisture content.

Table 7. 1974 Field Trial. Effect of planting date on ascorbic acid (mg/100g) content in four snap bean cultivars.

| | Planting date | | | | | | |
|---|---|---|---|---|---|---|---|
| Cultivar | 4/25 | 5/08 | 5/28 | 6/07 | 6/18 | 7/15 | Mean |
| Asgrow 290 | 16.4[1/] | 15.8 | 10.7 | 14.1 | 13.5 | 17.5 | 14.7 |
| Gallatin 50 | 15.9 | 16.8 | 9.6 | 17.5 | 14.4 | 15.4 | 14.9 |
| Oregon 58 | 14.3 | 17.2 | 10.6 | 18.6 | 15.7 | 14.9 | 15.2 |
| Oregon 1604 | 15.3 | 18.1 | 12.3 | 15.0 | 17.2 | 15.1 | 15.5 |
| Mean | 15.5 | 17.0 | 10.8 | 16.3 | 15.2 | 15.7 | 15.1 |

1/ Based on pods corrected to 90% moisture content.

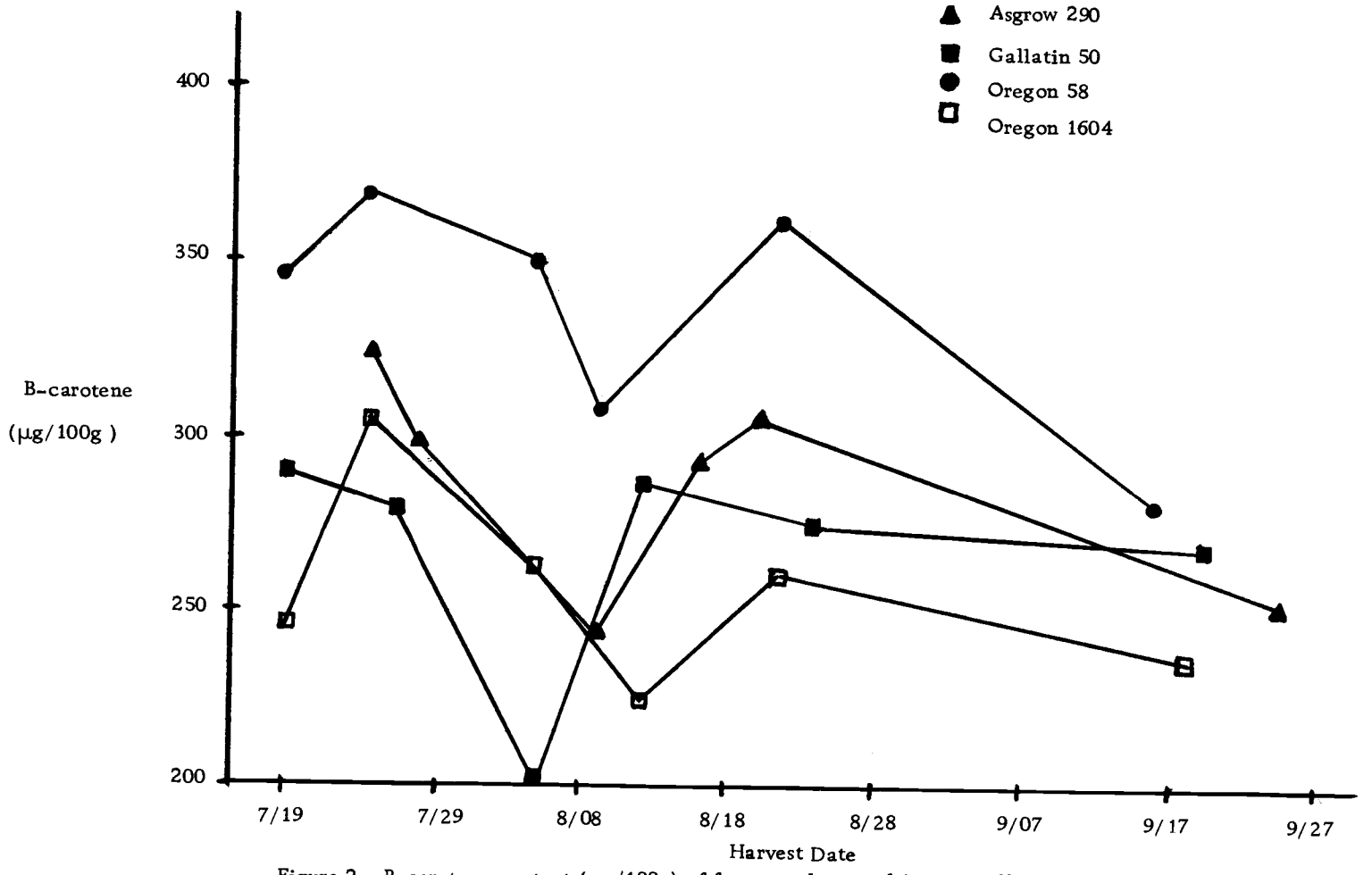


Figure 2. B-carotene content (µg/100g) of four snap bean cultivars as affected by harvest date.

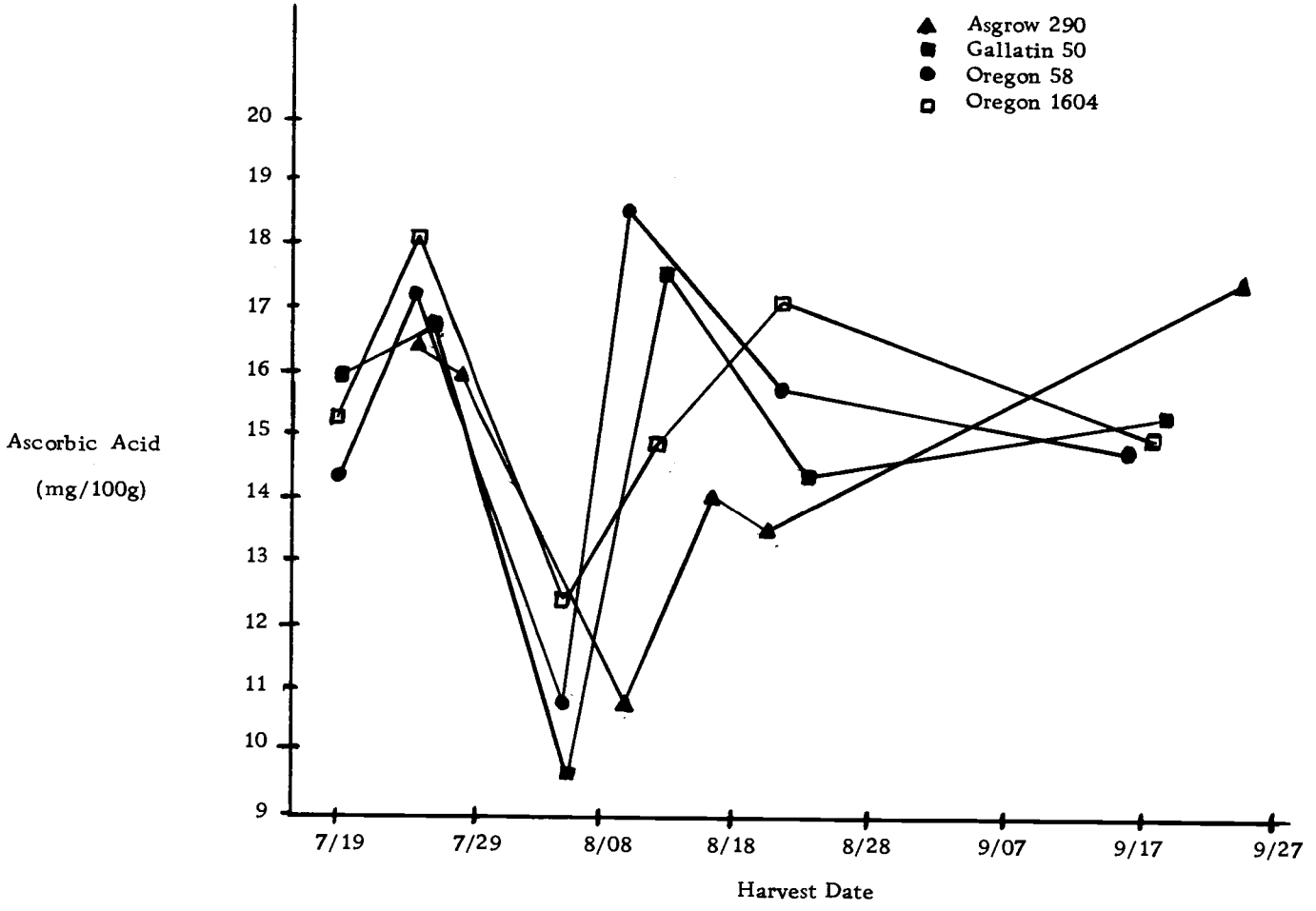


Figure 3. Ascorbic acid content (mg/100g) of four snap bean cultivars as affected by harvest date.

temperature and ascorbic acid synthesis. The observed wilting was probably accompanied by a reduction in photosynthesis. The decrease in available photosynthetic substrates and an acceleration in growth at the higher temperature coupled with utilization at a rate more rapid than synthesis, could account for the lower pod ascorbic acid content in the third planting.

The relative yielding potential of the four cultivars grown in both controlled environments (Table 8) differed from that of the field plantings (Table 2). Gallatin 50 which produced the lowest yield at all the dates of planting did not differ significantly (5%) from Asgrow 290 in either controlled environment. Oregon 58 and Oregon 1604 produced statistically greater yields than Asgrow 290 and Gallatin 50. Plants grown at 50% relative humidity appeared to produce higher yields than when grown at 80% relative humidity though not statistically. Visual differences in development were noted. Cultivars grown under the higher relative humidity grew more rapidly, had larger leaves, longer internodes, and lodged earlier compared to the lower relative humidity.

No significant differences in protein content (Table 8) were noted between cultivars or environments, though the pods from plants growing in higher relative humidity generally were higher in protein content.

Table 8. Yield, protein, B-carotene, and ascorbic acid contents in four snap bean cultivars grown in controlled environments at 26/21 C with differing relative humidities.

80% Relative Humidity

| Cultivar | Yield grams/plant | Protein % | B-carotene µg/100 grams | Ascorbic acid mg/100 grams |
|---|---|---|---|---|
| Asgrow 290 | 33.38 a | 2.08[1/] | 412 a | 13.2 |
| Gallatin 50 | 33.48 a | 2.16 | 424 a | 13.0 |
| Oregon 58 | 43.57 b | 2.19 | 518 b | 13.2 |
| Oregon 1604 | 46.04 | 2.17 | 427 a | 13.4 |
| CV= | 24.3% | 6.4% | 6.1% | 4.3% |

50% Relative Humidity

| Cultivar | Yield grams/plant | Protein % | B-carotene µg/100 grams | Ascorbic acid mg/100 grams |
|---|---|---|---|---|
| Asgrow 290 | 38.10 a | 2.00 | 407 a | 13.3 |
| Gallatin 50 | 44.57 a | 1.95 | 411 a | 13.2 |
| Oregon 58 | 52.82 b | 2.06 | 496 b | 13.3 |
| Oregon 1604 | 46.72 a | 1.94 | 400 a | 13.6 |
| CV= | 19.3% | 4.8% | 4.8% | 6.5% |

[1/] Protein, B-carotene, and ascorbic acid contents based on pods corrected to 90% moisture.

Means having a letter in common are not significantly different at the 5% level (Newman-Keuls').

Oregon 58, which had the highest B-carotene in the field, contained statistically more B-carotene than the other cultivars which did not differ significantly from one another. The higher relative humidity appeared to favor higher levels of B-carotene than the lower humidity. B-carotene content was higher in the controlled environment rooms than in the field. Ellis and Hamner (1943) reported tomatoes produced in the greenhouse under natural or artificial light were always lower in carotene content than those grown in the field. They also noted that the carotene content varied in fruit grown in soil receiving different fertilizer treatments. Plants in both controlled environments received about 29.1 klux at plant height and a complete-nutrient solution which was replaced every 2 days. The light intensity and availability of essential nutrients coupled with less photooxidation, may partially explain the higher levels attained in the controlled environments.

Ascorbic acid content of pods was not statistically affected by cultivars or environment, although ascorbic acid appeared to be slightly higher at the lower relative humidity. Oregon 1604 which had the highest seasonal ascorbic acid content in the field also had the highest content in both controlled environments.

Though yield varied greatly between cultivars and to a less extent between dates of planting, nutritional quality appeared to be affected more by the prevailing environmental conditions near

harvest. Ascorbic acid content appears to be more sensitive to seasonal fluctuations in environment than B-carotene or protein content.

Even if care is taken to keep stage of maturity relatively constant, environmental factors can greatly affect nutritive value. This does not take into consideration locational differences which have been shown to be large in tomatoes (Ellis and Hamner, 1943; Hamner et al., 1945). Of particular concern is the variability in the magnitude of differences between varieties. This variability is probably due to differential cultivar response to prevailing environmental conditions within a season.

Our results suggest that cultivar variability as well as seasonal fluctuations are important in assessing nutritional composition of snap beans. These factors, as well as others, should be considered in characterization of nutritional content as proposed by the GRAS regulations.

# SUMMARY AND GENERAL CONCLUSIONS

Potassium naphthenate (KNap) had significant effects on early wheat seedling development. Analysis of plant tissue 1, 2, 3, and 4 weeks after foliar application of KNap to 14-day-old wheat seedlings indicated a shunting of carbon skeletons from carbohydrate to nitrogen metabolism. This corresponds with the previously reported increases in anabolic enzymes of nitrogen metabolism (Wort et al., 1973). Fattah and Wort (1970) have reported significant increases in net photosynthesis and dark respiration resulting from KNap application in bush beans. Observed increases, herein with wheat seedings, in net photosynthesis, dark respiration, and gross photosynthesis, 4 weeks after KNap application, were not statistically significant.

Obvious visual differences were noted between KNap-treated and untreated wheat seedlings. Significant reductions in height were observed 1, 2, 3, and 4 weeks after foliar applications of 250, 500, and 750 ppm KNap. This reduction was also observed in the field following KNap application, but was transient as the later internodes were in many cases significantly longer than the untreated plants resulting in no significant alterations in overall plant height at harvest. No significant reductions in plant height were observed in bush beans following KNap application.

It has been suggested that cyclopentanecarboxylic acid is a GA-antagonist (Marcus and Goldthwaite, 1973) and that cyclohexane-carboxylic acid is an IAA-promoter (Loh, 1974a; Loh, 1974b; Wort and Patel, 1970b; Wort et al., 1970). Work with KNap which contains both (predominantly cyclopentanecarboxylic acids) on peas has shown IAA-promoting activity. It is interesting to note that the suggested apparent GA-antagonism was on two monocotyledons (corn and wheat) and the possession of IAA-promoting activity was on two dicotyledons (peas and beans). This relationship may be of biological significance. But as height reduction responses observed on wheat are transient and the responses on corn could be prevented with simultaneous application of saturating doses of GA (Marcus and Goldthwaite, 1973), the effect on height may be more dependent on the relative levels of endogenous regulators than on inherent differences between monocots and dicots.

Field experiments were conducted to ascertain the influence of growth regulators on agronomic and quality components in spring wheat. Two cultivars were selected because of their diverse genetic background and contrasting morphological characteristics.

2-chloroethylphosphonic acid (ethephon) and (2-chloroethyltrimethylammonium chloride (chlormequat), regardless of rate or time of application, produced significant reductions in plant height. Ethephon was more effective in height reduction than chlormequat.

Potassium cyclohexanecarboxylate (KCHC) and KNap in many cases significantly increased the length of the uppermost internodes without influencing overall height. Whereas chlormequat and ethephon gave fairly uniform visual effects, height reduction and increased tillering, the naphthenates often are highly unpredictable. This predictability may be governed by the activity of naphthenate having a greater susceptibility to interaction with endogenous regulators which are being affected by microenvironmental differences.

Cultivar differences in yield were noted in response to growth regulator application. KCHC produced significant increases in yield at all rates tested on the variety Twin. Anza was noticeably less responsive. KNap appeared to be more effective at lower concentrations. Lower yields resulted from late foliar application of chlormequat. Chlormequat at this stage of development produced leaf scorching which was more pronounced at the higher rates of application. Survival of late formed tillers and the general plant vigor may not be favored due to the temporary but significant reduction in effective leaf area due to scorching. Ethephon application either early or late resulted in large significant reductions in the grain yield of the cultivar Twin. The yield of Anza was also reduced but not as markedly.

Ethephon produced significant increases in protein content in the cultivar Twin. However these increases were associated with

appreciable decreases in yield, resulting in protein yield remaining relatively constant on a unit area basis. Of particular interest is the general elevation of protein content following applications of the lower naphthenate concentrations, as these were also associated with elevated yields. It would appear that a potential exists to advantageously manipulate protein content and yield in specific cultivars.

Vitamin analyses of grain from plants treated in the field showed various trends which may be worthy of further study. Niacin content appeared to be increased by all growth regulator treatments. Vitamin $B_2$ (riboflavin was either not affected or slightly elevated by ethephon applications. Vitamin $B_6$ (pyridoxine) was not appreciably affected on the cultivar Twin but was lowered by nearly all of the regulators on Anza, especially by the naphthenates and the late applications of ethephon. KCHC lowered vitamin $B_1$ (thiamine) on both cultivars and $B_1$ content appeared to decrease with increasing KNap concentration but only in the case of Anza was it lower than the control. The effect on $B_1$ content from ethephon application appeared to be concentration dependent but the two cultivars were exactly opposite in response to concentration. It did appear that the earliest ethephon application (2nd node just detectable) adversely affected $B_1$ content especially in the grain of Twin.

Mineral content of grain appeared altered as a result of growth regulator application. KCHC and KNap lowered Zn content in the grain of both cultivars. Manganese content was decreased by all regulators on the cultivar Twin, but no large decreases were observed on Anza. Magnesium concentration was not greatly affected by growth regulator application on either cultivar. Calcium content was lowered by all regulators on Twin and with the exception of KNap, Anza responded similarly though not as markedly. With Anza a very large reduction in the grain Ca content was observed resulting from the application of 5000 ppm KNap. Potassium and P contents in the grain of Twin was raised by all the regulators, less effect was noted on Anza. Of particular interest is the alteration of Fe content due to regulator application. Iron content in the grain from Twin was markedly reduced by all naphthenate applications. Ethephon appreciably raised Fe content in both cultivars and this has been previously reported with RH-531 in oat groats (Oplinger et al., 1975). Both ethephon and RH-531 are effective dwarfing agents.

The effects of growth regulators and environment on yield and nutritional quality of bush snap beans were studied under field and controlled environment conditions.

No significant increase in yield, marketable, or total pods per plant resulted from regulator treatments in the field. The effects

of growth regulator application on pod protein content appears to be highly variable. Protein content was significantly increased in spring-planted snap beans by at least one rate of all the regulators with the exception of KCHC which lowered protein content. But significant increases in protein content in bush bean pods have resulted from KCHC application (Hile and Chilcote, 1975). B-carotene was significantly increased by several regulators in summer-planted snap beans but a general trend towards lower content resulted from application in the spring planting.

Ascorbic acid content in bush bean pods appears to be quite sensitive to environmental changes near harvest. Controlled environment studies using high temperatures (39, 35 C) and low relative humidity (20, 30%) following preconditioning (26 C, 80 and 45% RH) appeared to affect protein and B-carotene contents little while ascorbic acid was markedly reduced the first day after exposure. Though plants tended to adjust they did not reach the levels of ascorbic acid of unexposed preconditioned plants. Treatment with KNap tended to lower levels more and retard adjustment to the higher temperatures. This effect was also observed in the field where ascorbic acid content was significantly decreased by KNap application during a period of high temperature and low relative humidity.

Ascorbic acid content was significantly decreased by all the regulator treatments including KNap in the spring planting. Analyzed pods were harvested during a period of high temperature and low relative humidity. This period of harvest was also the period in which several cultivars observed over the season for variation in nutritional quality and yield contained their lowest levels of ascorbic acid. Spring plantings normally develop under cooler temperatures and higher relative humidity than later plantings in that season. The imposition of stress conditions appears to be the reason for the lower ascorbic acid levels during this period.

Isherwood and Mapson (1962) have pointed out that the influence of light upon the accumulation of ascorbic acid in the leaf was similar to the effect of light on photosynthesis. The stress conditions in the field or employed in the laboratory on preconditioned plants would result in partial closure of stomata, reducing photosynthesis and the availability of hexose sugars for ascorbic acid synthesis. Stutte (1974) has also shown that growth regulators resulted in partial closure of stomata. This additional partial closure of stomata could result in an even lower photosynthetic rate thereby intensifying the reduction of ascorbic acid observed in all of the regulator treatments in the spring planting.

The yield and maturity of individual cultivars varied with planting date. Variation in mean protein content between planting

dates and cultivars was slight, with more variation observed between cultivars within a planting date. B-carotene content varied between and within cultivars at different planting dates. The maximum variation for planting date and cultivar was 18 and 30%, respectively. Cultivars varied within a planting date from a slight difference to 72%. Large variations in ascorbic acid content between planting dates were evident.

Nutritional quality appeared to be affected more by the prevailing environmental conditions near harvest even though yield varied greatly between cultivars and to a lesser extent between dates of planting. Ascorbic acid content appears to be more sensitive to seasonal fluctuation in environment than B-carotene or protein content.

Subjecting cultivars to 80 and 50% relative humidity resulted in differences in growth habit though no differences were observed in yield or nutrient content. The relative ranking of yield of cultivars in controlled environments differed from that observed in the field though differences in B-carotene and ascorbic acid contents were similar.

It is apparent that environment and plant growth regulators can affect nutritional quality and yield. It is also important to note that this effect is highly variable. Morphological characteristics are easier to modify than nutritional components with

existing regulators. This is most likely the result of extensive screening of compounds under many differing environments. It appears possible that nutritional quality could be enhanced through the application of exogenous compounds. At this point, it is not possible to predict with certainty the effect of growth regulators on nutritional quality and yield enhancement.

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# APPENDICES

# APPENDIX I

## THE EFFECTS OF NAPHTHENATES ON BIOLOGICAL SYSTEMS: A REVIEW

FOREWORD:

The following review is provided to the reader for the express purpose of dissemination of information pertaining to not only the naphthenate compounds but their effect on biological systems, no matter how diverse.

Metabolic regulators obtained from the naphthenic acid fraction have been named and abbreviated primarily by Eastern European investigators. The nomenclature used is very ambiguous and appears to have been designed to designate source and action. This makes mechanical retrieval nearly impossible unless one is aware of all possible names (See Clarification of Nomenclature).

Few people in the U. S. are aware of the potential use of naphthenic acids and their salts as plant growth regulators. The only published reports in Western Literature are by D. J. Wort and associates at the University of British Columbia, Vancouver, Canada. This overshadowed by the hundreds of published reports in the Eastern European countries which are basically hidden in Biological and Chemical Abstracts.

Because of the diverse nature of action on biological systems, the sheer mass of published reports and the large number of

abstracts, this review is presented in two parts. The first part of the review will deal primarily with work available in published form. The history, chemistry, commercial uses, and the findings of Western workers are discussed with regard to the physiological and metabolic effects on plant growth and development. Abstracts will be used sparingly to clarify points presented by the Western workers, since interpretations from abstracted material is not only difficult but often misleading. The second part of the review is based on the organism tested. This portion is presented alphabetically by organism and lists the type of application, concentration, responses, and reference, where information is available.

## INTRODUCTION

Naphthenic acids are monocarboxylic acids of the naphthene (alicyclic) series of hydrocarbons and are naturally occurring components of crude petroleum. According to Jolly (194), $R(CH_2)_nCOOH$ may serve as a general formula, where R is an alicyclic nucleus composed of one or more rings. These rings may be cyclopentane (five-membered), cyclohexane or cycloheptane, though normally cyclopentanes predominate. The carboxyl group is not normally attached directly to the alicyclic ring, but is separated from the ring by an aliphatic side chain composed of one or more methylene groups. Goldstein and Waddams (131) have stated that the naphthenic

acid mixture contains a wide variety of substituted cyclopentanes and cyclohexanes.

Markovinoff and Oglobin in 1883 (265) proposed the name naphthenic acids for the $C_{11}H_{20}O_8$ acids (of unknown structure) which had been recovered previously by Hell and Medinger in 1874 (182) from Rumanian crude oil. At present the term naphthenic acid is used to denote the carboxylic acids occurring in and recovered from petroleum.

Commercial naphthenic acids are also referred to by the term 'petroleum acid'. This is somewhat applicable as this mixture contains all the acidic components of the crude petroleum and varying amounts of non-acidic components, which are mostly hydrocarbons. The characteristic odor of this mixture (which varies with crude source and degree of refinement) is probably due to the contamination of aliphatic acids, phenols, and sulfur compounds.

The composition of naphththenic acids vary with source and degree of refinement. Using gas-liquid chromatography, Eider (110) found as many as 60 components in Venezuelan crude oil. Bock and Behrends (83) using gas-liquid chormatography, mass spectrometry, and fractional distillation procedures on an acid fraction from an Austrian crude have shown it contained 120 different compounds, but 50% of this sample could be accounted for by 20 compounds. 3-methyl and 3-ethyl branched chain fatty acids were positively

identified. Small but detectable amounts of substituted cyclopentyl and cyclohexyl acids were also noted. Seifert et al. (344, 345, 346) observed that 2. 5% by weight of California crude oil was comprised of carboxylic acids. The results of this work shows that terpenoid, polynuclear saturated, and polynuclear aromatic compounds occur naturally in petroleum. The acid content of American crudes varies from 0. 03 to 3. 0% (194)

Naphthenic acids are readily soluble in nonpolar solvents and insoluble in water; however, the lower molecular weight components e. g. cyclopentane and cyclohexanecarboxylic acid, are slightly soluble in water. The solubility of sodium naphthenate (Mwt. 300) in water is 20, 30, and 40 g/100 ml at 20, 50, and 100 C, respectively (66).

Extraction of naphthenic acid from crude oil or diesel oil can be accomplished in several ways. Treatment with alkali provides probably the easiest method of extraction. The acid content of the oil determines the quantity of alkali to be added. The fraction is shaken with a slight excess of sodium or potassium hydroxide for about 15 minutes to 1 hour. The resultant emulsion is left to stand for several hours. The aqueous layer which has been formed is allowed to settle and contains the naphthenic acids as their potassium or sodium salts.

Large amounts of naphthenic acids are recovered and used

annually. In 1970, 4,000 tons were imported to meet the need of 17,500 tons used in the United States. They are used commercially as lubricants, driers in oil based paints, catalysts, preservatives, corrosion inhibitors, emulsifiers, and as a thickener for napalm explosives.

The first known reported use of naphthenic acid as a metabolic stimulant on any biological system was in 1921 when Neuberg and Sandberg found that potassium naphthenate stimulated the alcoholic sugar splitting activity of yeast. D. M. Huseinov presented the first paper in the U. S. on the effects of this acid mixture on plant systems. In his report to the 7th International Congress of Soil Science, held at Madison, Wisconsin in 1960, he noted that agronomic work had began about 1950 in the USSR. Published reports of the action of naphthenates as plant growth regulators, in the Western Hemisphere, began in the late 1960's in the laboratory of D. J. Wort and associates at the University of British Columbia, Vancouver, Canada.

## EFFECTS OF NAPHTHENATE ON VEGETATIVE AND REPRODUCTIVE GROWTH

Rate of application and stage of ontogeny of a plant can condition the response to a specific growth regulator. Wort (405) reported that a single foliar application of 5000 ppm potassium naphthenate

(KNap) to 2-week-old bush bean plants to be the most effective in stimulation of vegetative growth, as measured as fresh and dry weight of foliage, 4 weeks after treatment. This treatment at the primary, leaf stage also resulted in increases of 20% in green pod yield, measured 7 weeks after treatment, and ripe seed production (8%). Applications of sodium naphthenate (NaNap) resulted in similar response and since no stimulation was obtained by a comparable application of KCl, Wort suggests that the anion, naphthenate, rather than the cation, was responsible for stimulation.

Multiple applications of naphthenate which included treatment of bush bean plants at the primary, leaf stage of growth were equally effective, though slightly less effective than the single application. Similar results have been reported by Wort and Hughes (407) on Early Warba potato plants. Though repeated applications of naphthenate resulted in over-all increases in tuber yield, compared with the yield of untreated plants, the increases lacked statistical significance. A single foliar application of 5000 ppm KNap, 33 days before digging, when the potatoes were 20-cm high, resulted in both significantly increased weight of saleable tubers and total tubers per plant (42%).

Wort and Patel (410) have observed that the application of KNap as a foliar dust (applied to give 250 and 500g KNap/hectare) and as a foliar spray (5000 ppm) or to the soil (0.01 and 0.1g KNap/1800 g

soil) to 14-day-old bush bean plants resulted in significant, uniform (23-26%) increases in yield of green pods per plant. The authors suggest that these methods of application are equally effective. 12.1% increases in yield were also observed from a 12 hour soaking of bean seeds in 0.001% KNap solutions. Increases in yield obtained from treatment with emulsions of naphthenic acids (HNap) did not differ significantly from the controls.

Fattah (114) and Fattah and Wort (117) have shown that the responses of bush bean plants to naphthenate application can be affected by light and temperature. They found the stimulative effect of KNap on both vegetative (plant height, fresh and dry weights of roots, stems, and leaves; number of leaflets, leaf area) and reproductive growth (number and weight of green pods per plant) was evident at higher temperatures (26 constant, 26/21 C) and light intensities (1500 and 1000 ft-c). They suggest that the larger number of pods may have been the result of more vigorous pollen germination and the reduced abscission of young fruits. They also noted that generally only those plants grown at the lowest light intensities (500 ft-c) failed to produce a significant fresh or dry weight response to treatment.

Wort and Patel (412) have found the leaf production of two cultivars of sugar beets could be statistically enhanced by KNap application. Foliar applications of 50-100 ppm KNap or the soaking

of seed in 10 ppm KNap for 12 hours significantly increased the leaf production of sugar beets. Of particular importance is their observation that neither type of application under conditions simulating a cold, relatively overcast, 61-day spring period produced significant changes in leaf production. They suggest that stimulation by naphthenate would appear to be dependent on a relatively high and possibly constant rate of metabolism.

The growth of seedlings of Douglas fir, western hemlock, lodgepole pine, sitka spruce (bare root planted), and Douglas fir planted in Walter's bullets, has been shown by Wort and Kozak (408) to have been favorably affected when sprayed with 5000 ppm KNap. Application at a stage in which the terminal bud was well opened, with the lateral buds open and the growth of the stem begun, resulted in statistically greater growth of all species. Respraying, the third year with 5000 ppm KNap, resulted in no significant change in the amount of growth of any species.

Being aware that the naphthenic acid mixture contained numerous acids (83, 110, 344, 345, 346) Wort and Patel (409) observed the effect of several cycloalkanecarboxylic acids on the growth of bush beans. Though many of these numerically increased the yield of green pods, only cyclohexanecarboxylic acid (CHCA) produced yields which were statistically greater. $1 \times 10^{-2}$M and $2 \times 10^{-2}$M potassium cyclohexanecarboxylate (KCHC) produced 35 and 24%

increases, respectively. Wheat seed soaked for 12 hours in 0. 01 and 0. 001% KNap produced 9 and 12% more grain, respectively. The vegetative growth of bush bean, radish, sugar beet, maize, and spring wheat was enhanced by a single foliar application of KNap. The reproductive growth of bush bean was stimulated as green pods and ripe seed yield were increased 23 and 25%, respectively. It has been suggested by Wort (405) that the increase in weight of pods and seeds per plant was the result of larger pods which contained more seeds, rather than a greater number of pods per plant.

## EFFECT ON NAPHTHENATE ON PHYSIOLOGICAL AND BIOCHEMICAL PROCESSES

### Carbon Assimilation

Fattah (114) reported that applications of 0. 5% KNap to the foliage of 14-day-old bush beans grown at 26 C under three light intensities (1500, 1000, and 500 ft-c) resulted in statistically significant increases in photosynthesis 7, 14, and 21 days after treatment. Fattah and Wort (118) noted that dark respiration was also significantly increased at the end of these three time periods under all three light intensities. Chu (97) found a 9. 7% increase in the respiratory rate of tomato 4 weeks after application of 0. 5% KNap even though 2 weeks after application respiration was decreased.

Accompanying the reports of alteration of carbon assimilation

are results suggesting that the primary and secondary photosynthetic pigments are also affected. Significant increases in chlorophyll a content of bush beans due to KNap treatment have been observed by Fattah (114), 2 and 3 weeks after treatment while chlorophyll b and carotenoids were only slightly affected. Chu (97) observed only minor increases in chlorophyll a and b whereas carotenoid pigments were increased 1.4 to 13.8% in tomato. Fattah (114) has noted that the total pigment content of bush beans was significantly increased 3 weeks after treatment.

Nucleic Acids

Increases in nucleic acid content have resulted from KNap application. Wort et al. (415) have reported significant increases (22%) in RNA content of bush bean leaves, 1, 2, and 3 weeks after treatment. Fattah (115) suggests more RNA synthesis in KNap-treated plants since more $^{32}P$ was incorporated into 28S, 18S, and 4S RNA than in untreated plants.

Though in one study, Wort et al. (415) have reported no affect on DNA content, in another study Wort (406) has observed a 17% increase in DNA content. This increase did not appear to be the result of more cells, but rather a greater content of non-nuclear DNA. Padmanabhan (296) has reported CHCA localized near the chloroplast and the reported RNA increases suggests that stimulation

may have some base at the genetic level.

Enzyme Activity

Fattah (118) observed stimulation of nitrate reductase, glutamic-pyruvic transaminase, phosphoglyceric kinase, and phosphorylase (28-43%) in naphthenate-treated bush bean plants. Chu (97) has reported the increased activity of phosphorylase in tomato, but the activities of nitrate reductase, phosphoglyceric kinase, and succinic dehydrogenase were reduced as a result of KNap treatment. Wort et al. (406, 415) has noted significant increases (as high as 175%) in nitrate reductase activity in bush beans. Concomitant to this increase, Wort et al. (406, 415) has reported significant increases in glutamic oxidase (103%), glutamic-oxaloacetic transaminase, glutamic synthetase, ascorbic acid oxidase, and cytochrome oxidase (167%); a slight non-significant decrease was noted in glutamic acid dehydrogenase activity. No increase in enzyme activity followed in vitro addition of KNap. Enzyme protein was greater by 10-20% in treated plants. The incorporation of $^{14}$C-L-leucine by leaves of treated bush bean plants has been shown to be increased (406, 414) or unaffected (415, 416).

Protein and Amino Acid Metabolism

Protein content has been shown to be increased, 26% (406),

and 15.3% (415), in the leaves of naphthenate-treated bush bean leaves. Comparison of the hydrolysates of the protein (%'s of 16 individual amino acids) of treated and untreated bush bean leaves have shown numerous differences. Wort et al. (415) noted greater percentages of glutamic acid, glycine, and proline and smaller values of arginine, lysine, tyrosine, and leucine in the protein hydrolysates of treated plants. The content of ethanol-soluble (free) amino acids were shown to be greater by 7.5%. Major changes in these amino acids were greater percentages of arginine, and lysine and smaller values for glutamic acid, serine, and proline. Padmanabhan (297) has also reported increased levels of several amino acids. In the case of hydrolysates of ethanol-insoluble material (amino acids in protein), Padmanabhan (297) found KCHC to influence the incorporation of more amino acids than KNap. KCHC significantly increased aspartic acid, glutamic acid, and alanine, while KNap application resulted in statistical increases in alanine incorporation. The feeding of $^{35}SO_4$ to bush bean plants has been shown by Peirson (302, 303) to result in more labelled S incorporated into protein, suggesting the increase of sulfur containing amino acids.

Severson (350, 351) reported studies of the metabolism of $^{14}C$-glucose by bean root tips treated with KNap and KCHC. Incorporation of labelled glucose was stimulated by both these compounds, with KCHC exerting a somewhat greater response. Analyses of 10

ethanol-soluble amino acids from these treated plants showed that the incorporation of $^{14}C$ from $^{14}C$-glucose to be greater, in all cases, in treated plants, KNap and KCHC significantly increased serine and valine levels while isoleucine/leucine was only significantly increased by KNap treatment.

Ascorbic Acid

KNap application has resulted in increases in the ascorbic acid content of the pods of treated bush bean plants grown under different temperature and light conditions (114, 116). The effectiveness of KNap varied with light and temperature conditions. Increases in light intensity not only increased the ascorbic acid content of controls but resulted in significant increases of ascorbic acid content in treated plants. Moreover, Fattah (144, 116) has reported that the ascorbic acid loss in pods from treated plants during storage was reduced in comparison to untreated plants. Fattah suggests that KNap may have a protective action against ascorbic acid loss during storage.

Chu (97) has found decreased ascorbic acid content in the mature fruits of tomato plants treated with KNap. But KNap treatment increased reducing sugars, sucrose, and total sugars in these fruits. Additionally, the loss of sugars during storage from fruits of KNap-treated plants was less than that in untreated plants.

Though Chu (97) did not observe increased ascorbic acid content

in tomato fruit as did Fattah (114, 116) in bush bean pods (which may be due to environmental or species differences), the decreased loss of sugars during storage suggests that KNap may have some retarding action on respiration in the fruit of treated plants.

Nutrient Uptake

Peirson (302) reported significantly more $^{35}S$ was detected in the leaves of naphthenate-treated bush bean plants fed radioactive sulfur, even though a slight increase in uptake was nonsignificant. His results (302) indicate that KCHC application stimulated the incorporation of $^{35}S$ into protein (303). In contrast to $^{35}S$ uptake and distribution, $^{45}Ca$ showed slightly reduced uptake while significantly more was retained in the roots than untreated plants. In complete nutrient solution, S, Ca, and Mg showed no significant increase in uptake. Severson and Wort (353) observed that $^{32}P$ uptake in bush beans was not significantly changed by KNap treatment, though it was slightly less in treated plants. Though uptake was unchanged, greater movement to the leaves was observed in treated plants. In complete nutrient solution this was slight but in phosphate free nutrient solutions it was significant. Though Pierson (302) concluded that increased growth was not the result of improved mineral nutrition of S, Ca, or Mg and Severson's data suggests (350, 353) this in the case of P, stimulation may have been partly affected by

significant patterns of redistribution within the plant, as shown by both authors.

## PLANT METABOLISM OF NAPHTHENIC ACIDS

### Structure

In a study of naphthenic and cycloalkanecarboxylic acids, Wort and Patel (409) felt that the presence of a saturated 6-carbon ring in the lower molecular weight cycloalkanecarboxylic acids is necessary for stimulation of plant growth. They also suggested that this may be true of the naphthenic acid mixture which is composed of these acids. They have shown (411) that the effectiveness of these monocarboxylic acids decreased as the number of methylene groups in the side chain increased from 0 to 3. In essence, effective compounds contained an H-saturated 6-carbon ring with a single carboxyl group attached directly to the ring or separated from it by no more than one methylene group.

### Metabolism

Severson reported (350) that KCHC-7$^{14}$C when administered to leaf disks in the light or to roots of intact seedlings in the dark was rapidly converted to a mixture of two conjugated metabolites, the glucose ester and the aspartic acid amide. Comparative thin

layer chromatography (350, 352) revealed that 1-cyclohexanecarbonyl-B-D-glucose and N-cyclohexanecarbonyl-L-aspartic acid appeared to be the glucose and aspartic acid conjugates, respectively. Padmanabhan (296) has additionally observed an unknown metabolite "Y". Results of amino acid analysis of acid hydrolysates of several unidentified metabolites by Severson (350) strongly suggests that KCHC-7-$^{14}$C may also be conjugated with low molecular weight polypeptides. It has not been ascertained if the unidentified metabolite "Y" is contained in this group.

In time course studies using KCHC-7-$^{14}$C, Padmanabhan (296) has shown that the glucose conjugate was the first metabolite to be formed (1/8 hour after leaves were treated with labelled CHCA as the K salt). The aspartate conjugate and the unidentified metabolite "Y" could be detected about 1 hour after treatment. No free acid (CHCA) was detected (350) 8 hours after application (296). CHCA was decarboxylated by bean plants and Padmanabhan (296) found that the $^{14}CO_2$ released during a period of 7 days accounted for 33% of the activity absorbed.

Four weeks after treatment, the glucose and aspartate conjugates and the unknown metabolite "Y" could still be detected. This suggests that the metabolites, and not the free acid, are responsible for the metabolic activity of naphthenates. It has been additionally suggested (296, 350, 352) that the metabolites of CHCA are not

merely detoxification products.

Distribution and Movement

Foliar applications of KCHC-7-$^{14}$C to the primary leaves of bush bean plants have shown that the major fraction of ethanol-soluble $^{14}$C activity is retained in these leaves (296). After 1 week, Padmanabhan (296) observed that 72% of the total $^{14}$C activity remained in these primary leaves. Leaves showed the highest activity and the plant fractions composed of buds, flowers, and pods contained the lowest activity. This pattern of distribution of activity was observed at 1, 2, 3, and 4 weeks after treatment and the glucose and aspartate conjugates and the unknown metabolite "Y" were still detected by Padmanabhan (296). Twenty-four hours after KCHC-7-$^{14}$C was spotted on the midrib of a primary bean leaf she found less than 1% of the total $^{14}$C activity in the roots.

Padmanabhan (296) reported the distribution of activity following application of labelled KCHC to primary leaves, involved both basipetal and acropetal transport. The basipetal movement occurred in the phloem and the acropetal, in the xylem and phloem. She also noted that the translocation of CHCA appeared to be favored by light and suggests that energy in the form of ATP was required for translocation. It appears in the dark that the addition of glucose favored translocation, perhaps serving as a source of ATP via respiration.

The provision of aspartate in the dark slightly favored translocation. The occurrence of both glucose and aspartate conjugates and the concomitant absence of free KCHC in the aerial portion of the plant following feeding of labelled KCHC to roots of intact bush bean seedlings (350) also suggests acropetal transport after conjugation.

Localization

In addition to being found predominantly in the leaves, radioactivity from labelled CHCA has been shown to be localized in the chloroplast of the cells. CHCA-conjugates have been found by Padmanabhan in the ethanol extract of these organelles. This suggests that the chloroplast represents an important site of action of CHCA (296).

Interaction with Endogenous Regulators

Loh (248, 249) suggests that KNap has at least two properties of auxin. He observed significant stimulation of adventitious rooting of Phaseolus vulgaris L. stems and increases in the straight growth test of dark grown Alaska pea stem segments, though less effective than IAA. Additionally, Loh (248, 250) observed an increase (140.5%) in the content of IAA in KNap-treated bush beans, suggesting an augmentation of IAA biosynthesis.

Marcus and Goldwaite (264) have reported that cyclopentanecarboxylic acid (CPCA) had activity antagonistic to gibberelin (GA). They noted antagonism for $d_5$ dwarf maize growth, Rumex leaf disc senescence, and amylase production in barley half-seeds. They also showed that the inhibitory effect on dwarf maize could be overcome by simultaneous application of saturating doses of $GA_3$ or $GA_7$. The lack of activity in their studies of zeatin-inhibited senescence in the Rumex system and auxin-promoted growth of oat coleoptiles adds some specificity for GA-induced effects.

KNap contains both cyclopentane and cyclohexanecarboxylic acids. An interesting point now arises in the literature as the response of two monocotyledons (corn and wheat in this study) may be attributed to GA-antagonism but the two dicotyledons (peas and beans also in this study) are believed to be auxinic responses. It would appear that the KNap mixture contains both weak GA-antagonistic and IAA-promoting activities. This suggests that specific responses may be dependent on the relative levels of endogenous regulators.

## MECHANISM AND MODE OF ACTION

It has been shown that naphthenate application can beneficially enhance nutritional quality and yield in plants. Wort et al. (416) suggest that "greater growth appears to stem from enhanced production of ATP, reduced nucleotides, and photosynthetate, greater

availability of keto acids for amination, and high specific activity of anabolic enzymes, particularly those of N metabolism." The reported alterations in nucleic acid levels due to naphthenate treatment (115, 406, 415) coupled with the aforementioned effects is suggestive of a mechanism of action involving a genetic and metabolic phase. It has not been ascertained how specific the mechanism of action is but it is apparent the mode of action is general and could possibly be effected by the levels of endogenous regulators in the plant.

The lack of in vitro stimulation in enzyme systems (415) and the work of Severson (350, 352) and Padmanabhan (296) suggests that the conjugates of naphthenic acids and not the free acid are responsible for this stimulation.

The effects of naphthenates on growth, development, yield, and chemical composition of plants are presented in summarized form in Table 1. Because of possible differences in homeotherms vs. poikilotherms, the effects of naphthenates on the warm-blooded members, and cold-blooded members of the Animal Kingdom are presented in Tables 2 and 3, respectively. Table 4 presents the effects of naphthenates on microorganisms.

Table 1. Effects of naphthenates on growth, development, yield, and chemical composition of PLANTS.

| ORGANISM | METHOD OF APPLICATION | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|---|
| Alfalfa | seed soak<br>foliar | 0.005% | saline soils-growth development, yield, root system (+) | (60) |
| Alfalfa | seed soak | 0.005% | saline soils-water balance<br>yield 5.5 fold in $SO_4$<br>" 2.1 fold in Cl | (61) |
| Alfalfa | foliar<br>seed soak<br>foliar | 0.05-0.005%<br>0.05%<br>--- | yield 9-40% (+) hay<br>yield 23-33% (+) "<br>yield seeds (+) | (166) |
| Alfalfa | seed soak | 0.01% | yield hay (+) | (167) |
| Alfalfa | --- | --- | --- | (189) |
| Alfalfa | seed treatment | 0.005-0.05% | yield and quality (+) | (190) |
| Alfalfa | growing media | 0.00005-0.0005% | nodule number, fresh wt. | (267) |
| Alfalfa | --- | 0.0005%<br>0.05% | nodules (+)<br>nodules (-) | (384) |
| Apple | foliar | 0.05% | growth and productivity (+) | (339) |
| Apple | --- | 0.004% | seedlings growth, development | (340) |
| Apple | foliar<br>soil | 0.005%<br>0.1% | catalase activity, sugars & nitrogenous compds (+)<br>" | (373) |

Table 1. (Continued)

| ORGANISM | METHOD OF APPLICATION | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|---|
| Apple | with fertilizer | 0.1% | leaf protein (+) at 1 month at 1.5 months decreases | (374) |
| Apple (Chinese) | --- | --- | drought resistance (+) | (369) |
| Apple | paste | 0.6% CuNap | control apple scab | (399) |
| Apricot | foliar | 0.05% | growth, productivity (+) | (339) |
| Ash (green) | --- | 0.005% | resistance to salinity | ( 25) |
| Ash | soil | 50-200g/ha | lower transpiration rate, saline soil, growth shoots up to 640% | ( 26) |
| Ash | soil | 1.8, 3.6, 7.2/ tree | enzymes:catalase, polyphenoloxidase, I-reducing (+, -) depending on time and rate. | ( 29) |
| Ash | foliar | 0.05% | chlorophyll, sugar, photosynthesis, and no. flowers and fruits (+) | (237) |
| Ash | soil | 500g/ha | root growth 1st yr. shoot 2nd yr. (+) | (270) |
| Aubergines | soil<br>foliar<br>foliar | 100g/ha<br>0.005%<br>0.05% | 110% (+)<br>75% (+)<br>25% (+) | (187) |
| Barley | seed soak | --- | yield 23.7% (+) | ( 78) |

Table 1. (Continued)

| ORGANISM | METHOD OF APPLICATION | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|---|
| Barley | foliar | 0.005-0.05% | at tillering yield (+) | |
| | soil | 50-200g/ha | yield (+) | |
| | seed soak | 0.005-0.01% | (0) | ( 79) |
| Barley | seed treatment | 1-2 g, 5g/100kg | yield, grain protein (+) and cellulose (-) | |
| | foliar | 0.03-0.05% | less effective | ( 90) |
| Barley (malt) | --- | 0.01% | amylolytic activity (+) | (119) |
| Barley (malt) | seed soak then spray | 0.01%, 30 hr. 0.005%, 24-48 hr later | germination rate, (+) yeast formation, shortened malt cycle | (224) |
| Barley | --- | --- | Lvov origin less than Baku pet. | (335) |
| Barley | seed | 0.04-0.07% | yield, protein (+) | |
| | 2 foliar appl. | 625-1250 g/ha | " " " | (402) |
| Bean (sprouts) | foliar | 0.5% | yield 21% (+) | ( 66) |
| Bean (bush, snap) | Ph.D. Thesis | | Growth, metabolic responses | (114) |
| Bean (bush, snap) | foliar | 5000 ppm | RNA synthesis (+) | (115) |
| Bean (bush, snap) | foliar | 5000 ppm | ascorbic acid content (+) | (116) |
| Bean (bush, snap) | foliar | 5000 ppm | photosynthesis, dark respiration enzyme activities (+) | (118) |

Table 1. (Continued)

| ORGANISM | METHOD OF APPLICATION | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|---|
| Bean (bush, snap) | foliar | 5000 ppm | dry, fresh wt. -shoots, roots (+) plant ht., leaf area, yield (+) | (117) |
| Bean | seed soak | 0.001% | root length (+) | (136) |
| Bean | seed soak | 0.01-0.05%/12 hr. | pot exp. -size and chlorophyll content leaves, yield (+) field exp. -(o) | (140) |
| Bean | seed treatment | 0.005-0.05% | growth, leaf size, chlorophyll content, seed yield (+) seed from plants protein (+), amino acids (-) | (141) |
| Bean | --- | 0.0005%<br>0.05%<br>0.0005-0.05% | ammonia uptake (+)<br>P absorption (+)<br>nitrate absorption (+) | (164) |
| Bean | --- | --- | germination, growth, develop. (+) | (228) |
| Bean (fodder) | seed soak | 0.01% | yield 13-30% (+) | (231) |
| Bean (bush, snap) | M. S. Thesis | | effect on IAA synthesis and degradation | (248) |
| Bean (bush, snap) | immersion stems | 10&100 ppm/6hr. | root initiation 46, 153% (+) | (249) |
| Bean (bush, snap) | seed soak | 100 ppm/12 hr. | 140. 5% (+) IAA synthesis at 14d. | (250) |
| Bean | --- | --- | growth (+), preparation of NaNap | (319) |

Table 1. (Continued)

| ORGANISM | METHOD OF APPLICATION | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|---|
| Bean (kidney) | seedling | 10, 20, 40 ug/seed. | fresh & dry wts. (+) | (320) |
| Bean (bush, snap) | Ph.D Thesis | | uptake of S, Ca, Mg by KCHC | (302) |
| Bean (bush, snap) | --- | --- | uptake S (o), distribution (+) protein S (+) | (303) |
| Bean | seed soak | 0.01-0.0001% | growth, development (o) | (328) |
| Bean (bush, snap) | Ph.D thesis | | P metabolism, KCHC metabolism glucose uptake by excised roots | (350) |
| Bean (bush, snap) | root tips | $1x10^{-5}$M KCHC or KNap | $CO_2$ production (+) amino acids more $^{14}C$, conjugated form active | (351) |
| Bean (bush, snap) | --- | --- | metabolism of KCHC | (352) |
| Bean (bush, snap) | foliar | 0.5% | P-uptake (o), distribution (+) | (353) |
| Bean (green) | hydroponically | --- | yield (+) | (380) |
| Bean (bush, snap) | foliar | range of | fresh, dry wts. (+)-pod yield 20% (+), seed 8% (+) | (405) |
| Bean (bush, snap) | foliar | 0.5% | protein 26% (+), DNA 17% and RNA 22% (+), incorporation of $^{14}C$-leucine 6% (+), nitrate reductase act. 175%, glutamic-oxidase 103% (+), pod wt 30% & ripe seed 21% (+) | (406) |

Table 1. (Continued)

| ORGANISM | METHOD OF APPLICATION | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|---|
| Bean (bush, snap) | foliar | 0.05% KNap | leaf wts-fresh & dry (+), pods & ripe seed (+) | |
| | foliar | $1x10^{-1}$ M KCHC | pod yield (+) | (409) |
| Bean (bush, snap) | foliar | dust KNap | 23.4% (+) | |
| | foliar | HNap emulsions | (+) but not significant | |
| | soil | 0.01, 0.1g KNap to 1800g soil | 26.5% (+) | |
| | seed soak | 0.001% | 12.1% (+) | (410) |
| Bean (bush, snap) | foliar | 10mM Series of different acids | Only cyclohexanecarboxylic and cyclohexylacetic acid--pods (+) | (411) |
| Bean (bush, snap) | foliar | 20mM | several enzymes (+), leaf protein 15.3% (+), amino acids altered, DNA(o) but RNA (+) | |
| | cell-free ext. | 1μM | (o) | (415) |
| Bean (bush, snap) | Ph.D Thesis | | Distribution, metabolism, localization of KCHC. | (296) |
| Beans (bush, snap) | foliar | 0.5% KNap | conjugates with glucose & aspartic acid active form, photosynthesis dark respiration, 8 enzymes, metabolism all (+) | (416) |
| Beet (fodder) | foliar | 0.004% | seed yield, high germination of seeds, 1st gen. root crop (+) | (49) |

Table 1. (Continued)

| ORGANISM | METHOD OF APPLICATION | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|---|
| Beet (seed) | --- | --- | seed yield (+) differential sensitivity to application | (217) |
| Beet | seed soak | 0.05% | germination (+) | (428) |
| Beet | presowing | --- | yield (+) N content (+) | (430) |
| Beet | seed soak | 0.005-0.05%/12hr | germination rate, growth, yield (+) | (431) |
| Beet (sugar) | foliar | --- | sugar content | ( 48) |
| Beet (sugar) | foliar | 0.004% | seed yield, high germination of seeds, 1st gen. root crop (+) | ( 49) |
| Beet (sugar) | foliar | 0.5% | yield 8% (+) higher sugar content | ( 66) |
| Beet (sugar) | presowing | --- | yield 20.9% (+) | ( 78) |
| Beet (sugar) | presowing<br>sprinkling | 0.005-0.05%/6hr<br>0.01%/400 liters | yield (+)<br>yield 34.5% (+) | (123) |
| Beet (sugar | seed soak | --- | yield 29-44% & sugar 0.4-0.7% (+) | (139) |
| Beet (sugar) | seed treatment | --- | root yield (+) | (140) |
| Beet (sugar) | seed soak | 0.01%?15hr | yield, protein, sugar contents (+) | (200) |
| Beet (sugar) | foliar | 0.005%, 500 liters/ha | growth (+) | (216) |

Table 1. (Continued)

| ORGANISM | METHOD OF APPLICATION | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|---|
| Beet (sugar) | presowing | 0.005% emulsion<br>3 liters/100 kg seeds | yield 8% (+) | (225) |
| Beet (sugar) | with fertilizer | --- | yield (+) | |
| | seed soak | 0.01-0.05% | less effective | (230) |
| Beet (sugar) | seed soak | --- | yield (+) | (231) |
| Beet (sugar) | --- | --- | max. yield 50.8% (+), tables-yield | (272) |
| Beet (sugar) | soil | 100-200kg/ha | yield (+) | |
| | foliar | 0.05-0.1% | yield (+) | (273) |
| Beet (sugar) | foliar | 0.05% | yield 6% (+) | (281) |
| beet (sugar) | foliar | 0.5% | leaf-fresh & dry wt. (+) | (409) |
| Beet (sugar) | foliar | 100 ppm | leaf production (+) | |
| | seed soak | 10 ppm | " " " | |
| | either method | either rate | (o) when changing environment | (412) |
| Beet (sugar) | seed wetting | 0.01 & 0.005% | yield, protein, chlorophyll (+) | (418) |
| Beet (sugar) | foliar | 0.005% | sugar content (+) | (421) |
| Beet (sugar) | soil | 100g/ha | yield (+) | (427) |
| Birch | cuttings | 0.004-0.005%/6hr | survival & growth (+) | (270) |

Table 1. (Continued)

| ORGANISM | METHOD OF APPLICATION | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|---|
| Birch | foliar | series | increased P compds to meristem | (434) |
| Buckthorn (sea) | seed treatment | 0.005-0.05% | germination rate & growth | (364) |
| Cabbage | --- | --- | yield | ( 13) |
| Cabbage | foliar | 25-100 kg/ha | yield 12-27%, ripening, N & P (+) | ( 52) |
| Cabbage | with fertilizer<br>foliar | ---<br>--- | yield 15-26% (+)<br>" 12-28% "<br>wt. roots, N, P, Vitamin C, sugar (+) | ( 53) |
| Cabbage | with fertilizer<br>foliar | 50-100g/ha<br>50-250g/ha | yield 30-52% (+)<br>yield 25-100% (+) | ( 54) |
| Cabbage | wetting 24-36 hr | --- | yield 30% (+) | ( 57) |
| Cabbage | soil<br>foliar | ---<br>0.001-0.005% | leaf no., size, chlorophyll, sugar,<br>yield (+), cellulose (-) | ( 58) |
| Cabbage | foliar | --- | effective | (126) |
| Cabbage | --- | --- | yield (+) | (157) |
| Cabbage | --- | --- | yield 15-19% (+) | (160) |
| Cabbage | soil | --- | yield 206% (+) | (161) |

Table 1. (Continued)

| ORGANISM | METHOD OF APPLICATION | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|---|
| Cabbage | soil | 50g/ha | yield 30% (+) | |
| | foliar | 0.005% | " 20% " | (187) |
| Cabbage | seed soak | 0.0001-0.001% | moisture content (+) | (229) |
| Cabbage | seed soak | 0.0001-0.01% | moisture content, respiration (+) | (234) |
| Cabbage | foliar | 0.01% | yield 17% (+) | (285) |
| Cabbage | foliar | 0.02% | optimum rate for yield (+) | (366) |
| Cabbage | presowing | --- | yield (+) | (430) |
| Cabbage | seed treatment | 0.005-0.05%/12hr | yield (+) | (431) |
| Cabbage | soil | 250g/ha | yield (+) | (436) |
| Cabbage | with fertilizer | --- | early 8-12.6%, late crop 14-24% | ( 59) |
| Carrot | foliar | 0.005% | yield (+) | ( 13) |
| Carrot | --- | --- | growth, metabolism, yield (+) | ( 57) |
| Carrot | foliar | 0.001-0.005% | leaf no., size, chlorophyll, yield sugar contents (+) | ( 58) |
| Carrot | foliar | 0.005% | yield 20% | ( 59) |
| Carrot | seed soak | 0.005% | growth, yield (+) | (216) |

Table 1. (Continued)

| ORGANISM | METHOD OF APPLICATION | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|---|
| Carrot | seed soak | 0.01% | yield (+) | (231) |
| Carrot | seed soak | 0.01%/2-24hr | yield & quality generally (+) | (300) |
| Carrot | foliar | 0.005% | carotene (+) | (421) |
| Carrot | seed soak | series | germination, yield (+) | (428) |
| Carrot | presowing | --- | yield (+) | (430) |
| Carrot | seed treatment | 0.005-0.05% | yield (+) | (431) |
| Cherry | foliar | 0.05% | respiration rate, ascorbic acid content of leaves & fruit yield (+) | ( 96) |
| Cherry | foliar | 0.05% | fruit, ascorbic acid content (+) | (273) |
| Cherry | cuttings | 0.01% | root formation (+) | (316) |
| Cherry | cuttings | 0.005%/6-24 hr | root formation & growth (+) | (376) |
| Clover | seed soak | 0.01%/2-24hr | growth, yield, quality (+) | (300) |
| Clover (white, sweet) | seed soak | 0.01-0.0001%/3.5hr | fresh, dry wts. -root length, plant height(+) | (328) |
| Corn | presowing | 0.005% | yield (+), different responses to saline depending on type | ( 61) |
| Corn | foliar | 0.5% | yield 12%(+) | ( 66) |

Table 1. (Continued)

| ORGANISM | METHOD OF APPLICATION | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|---|
| Corn | seed soak | 0.005-0.01% | (o) | ( 79) |
| Corn | foliar | oil | inhibits C fixation | ( 99) |
| Corn | foliar | --- | aid uptake and translocation of atrazine | (100) |
| Corn | seed soak | 0.005%/12hr | plant height, yield, oxidizing enz | |
| | foliar | 0.005% | " " " " " | (109) |
| Corn | seed soak | 0.05% | sprouting vigor, growth (+) | (113) |
| Corn | --- | --- | effective | (126) |
| Corn | soil | 2.5mg/kg soil | transpiration (+), bound water (±) | |
| | soil | 10mg/kg soil | " (-), " " (o) | |
| | seed soak | 0.005% | " (-), " " (+) | |
| | seed soak | 0.05% | " (-), " " (+) | (154) |
| Corn | foliar | 0.005-5.0% | penetrate leaf rapidity, marked decrease in 1st 3 days | (162) |
| Corn | --- | 0.0005% | ammonia N uptake (+) | |
| | | 0.05% | P absorption (+) | |
| | | 0.0005-0.05% | nitrate N uptake (+) | (164) |
| Corn | presowing | 0.005% emulsion | sap more N, P, K, Mg | (192) |
| Corn | seed soak | 0.01, 0.01%/24hr. | (o) | (199) |

Table 1. (Continued)

| ORGANISM | METHOD OF APPLICATION | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|---|
| Corn | seed soak | 0.001-0.005%/24hr | chlorophyll, carotene, sugars ascorbic acid, growth rate (o) | (208) |
| Corn | seed soak | 0.005% | growth, yield (+) | (216) |
| Corn | presowing | 0.005% emulsion 3 liters/100 kg seed | yield 16% (+) | (225) |
| Corn | foliar | 0.005-0.01% | yield (+) | (228) |
| Corn | seed soak | 0.0001-0.001% | free and bound water (+) | (229) |
| Corn | seed soak | 0.01% | yield (+) | (231) |
| Corn | seed soak | 0.0001-0.01% | respiration, growth rates (+) | (234) |
| Corn | seed treatment soil | 0.005% 100g/ha | development, yield, starch content, N, P, K contents (+) transpiration rate (-) | (261) |
| Corn | --- | --- | GA antagonistic for: $d_5$ dwarf maize growth Rumex leaf disc senescence amylase production in barley effects overcome by simultaneous application of saturating doses of GA. zeatin-inhibited senescence in the Rumex system (o) auxin-promoted coleoptile (oat) growth (o) | (264) |

Table 1. (Continued)

| ORGANISM | METHOD OF APPLICATION | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|---|
| Corn | seed soak, foliar | --- | yield (+) | |
| | soil | | " " | (272) |
| Corn | foliar | 0.05% | yield 3.7% (+) | (281) |
| Corn | foliar | 0.005%/1000 liters/ha | protein, yield (+) cellulose (-) | (284) |
| Corn | seed treatment | 0.01%/2-24hr | growth, yield generally (+) | (300) |
| Corn | --- | --- | nutrient uptake (+) | (304) |
| Corn | seed soak | 0.005% optimum | stimulation (+) | (305) |
| Corn | water culture | --- | uptake N, P, K (+) | |
| | sand " | | less | |
| | soil " | | insignificant | (307) |
| Corn | seed soak | 0.007%/24hr | best aqueous cultures | |
| | " " | 0.01-0.015%/24hr | for sand cultures | (308) |
| Corn | seed | --- | need high level of fertility, lists changes to amino acids, root amino acid decrease, suggest protein synthesis | (309) |
| Corn | aqueous sol. | --- | development of radical surface, radical respiration (+), free amino acid content influenced, | |
| | sand culture | --- | coeff. of utilization of P (+) | (310) |

Table 1. (Continued)

| ORGANISM | METHOD OF APPLICATION | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|---|
| Corn | presowing | 0.007% best | N uptake (+), effect in following order: in water, sand, and soil cultures | (312) |
| Corn | --- | --- | growth coleoptiles (+) | (319) |
| Corn | --- | --- | different sources of compd, and oils extracted from, yield (+) | (321) |
| Corn | seed soak | 0.01-0.0001%/3.5hr | development and growth (+) | (328) |
| Corn | seed treatment | 0.05% | water, protein, sugar, starch, ascorbic acid content leaves (+) peroxidase (+), polyphenoloxidase (-), smut infection (-) yield (o) | (362) |
| Corn | seed soak | 0.02-0.04%/2hr | growth, root growth, yield (+) | (404) |
| Corn | foliar | 0.5% | leaf fresh and dry weight (+) | (409) |
| Corn | foliar & seed | 0.005% | yield, silage was more moist chlorophyll & protein, seed protein & starch (+) | (418) |
| Corn | foliar & seed | 0.005% | yield, kernel protein (+) | (419) |
| Cotton | presowing | 0.05-0.01% | yield 10-15% (+) | (20) |

Table 1. (Continued)

| ORGANISM | METHOD OF APPLICATION | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|---|
| Cotton | --- | --- | soil salinity, ascorbic acid content leaves, photosynthesis (+), differential response in $Cl^-$ vs. $SO_4^=$ conditions | ( 21) |
| Cotton | soil | --- | growth, chlorophyll content, peroxidase, polyphenoloxidase (+), catalase (o), carbohydrate metabolism, starch hydrolysis (+) | ( 30) |
| Cotton | sprinkling | 0.01%/500 liters/ha | photosynthesis (+) | ( 36) |
| Cotton | seed soak<br>foliar<br>soil | 0.01%/2hr<br>---<br>200g/ha | sugar, starch contents of leaves no. of bolls/plant, and yield (+), at all methods | ( 40) |
| Cotton | foliar | 0.05% | RNA, total N, protein N (+) | ( 44) |
| Cotton | foliar | 0.05% | RNA (o) | ( 45) |
| Cotton | presowing | 0.005% | salinity, differential response, bound water (+), yield 74-32% (+) | ( 61) |
| Cotton | seed soak | --- | germination | ( 63) |
| Cotton | foliar | 0.01% | growth, development, yield | ( 70) |
| Cotton | foliar | --- | P content in seeds (+) | ( 71) |

Table 1. (Continued)

| ORGANISM | METHOD OF APPLICATION | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|---|
| Cotton | foliar | 0.01% | respiration (+), differential response to fertilizer | ( 72) |
| Cotton | foliar | 0.005% | (Sh-8), differential response to fertilizer | ( 74) |
| Cotton | foliar | 0.01% | crude fiber yield (+), ascorbic acid & chlorophyll contents (+) | ( 75) |
| Cotton | seed treatment | 0.005-0.5% | growth, N, P, K uptake, yield (+) | ( 76) |
| Cotton | foliar | 0.005% | yield | (112) |
| Cotton | wetting seeds | 0.05% | vigor, yield | (113) |
| Cotton | soil | 200g/ha | total N, yield 7-23% (+) | (125) |
| Cotton | seed soak | 0.05%/1-2hr | yield 20-32% (+) | (126) |
| Cotton | --- | 0.01% | salt resistance, heat resistance | (129) |
| Cotton | --- | --- | carbohydrate metabolism, N metabolism, enzymes, respiration (+) | (152) |
| Cotton | --- | --- | total, inorganic, protein N (+) | (153) |
| Cotton | seed soak | weak | yield (+) | (157) |
| Cotton | --- | 0.0005% | ammonia N uptake | (164) |

Table 1. (Continued)

| ORGANISM | METHOD OF APPLICATION | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|---|
| Cotton | --- | --- | root development | (165) |
| Cotton | seed soak | 0.05% | yield (+) | |
| | foliar | 0.05-0.005% | " " | |
| | soil | 200g/ha | " " | (168) |
| Cotton | --- | --- | yield (o) | (170) |
| Cotton | seed soak | 0.0004-0.004% | length of sprout 136-145% (+) | |
| | soil | 100g-200g/ha | yield 16-23% (+) | |
| | foliar | 0.005, 0.01, 0.05% | yield 12, 31, 20% (+) | (187) |
| Cotton | soil | 200g/ha | --- | (201) |
| Cotton | soil | 300-400g/ha | yield, no. bolls/plant | (210 |
| Cotton | liquid culture | 0.1%/0.5-2ml | P uptake (+) | |
| | soil | 5-50mg/15kg | " " " | |
| | soil | 100g/ha | " " " | |
| | soil | 100g/ha | " " ", yield (+) | |
| | foliar | --- | " " (-) | (275) |
| Cotton | foliar | 300g/ha | yield (+) | (279) |
| Cotton | seed treatment, top dressed | 0.01% 100-400g/ha | accelerated 2-3 days, yield (+) | (283) |
| Cotton | seed soak | 0.01% | growth (+) | |
| | soil | 200 or 500g/ha | " " | (332) |

Table 1. (Continued)

| ORGANISM | METHOD OF APPLICATION | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|---|
| Cotton | seed soak | 0.01% | yield (+), flow sheet for manuf. | (354) |
| Cotton | foliar | 250g/ha | fiber (+) | (355) |
| Cotton | seed soak | 0.001-0.01% | germination, sprouting (+) | (359) |
| Cotton | foliar | 0.005, 0.0005% | yield (+), less ovary drop | (370) |
| Cotton | soil<br>foliar | 125-250g/ha<br>0.0025-0.025% | budding- yield, bolls/plant (+)<br>flowering- | (385) |
| Cotton | seed soak<br>soil | 0.05, 0.01, 0.005%<br>100-200g/ha | effects on transpiration& N contents, yield | (386) |
| Cranberry | cuttings | -- | root formation | (420) |
| Cucumber | --- | --- | protein leaves (-) | ( 41) |
| Cucumber | --- | 0.0004% | root length 7-96% (+), stalk 11-42% (+) | (165) |
| Cucumber | foliar | 0.005 & 0.05% | yield 36 & 40% (+) | (187) |
| Cucumber | foliar twice | 0.005% | best | (216) |
| Cucumber | foliar | 0.05% at bloom | yield 15-63% (+) | (262) |
| Cucumber | foliar | 0.005% | yield 48% (+) | (285) |

Table 1. (Continued)

| ORGANISM | METHOD OF APPLICATION | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|---|
| Cucumber | foliar | 0.0001% after boric acid | photosynthesis, leaf growth, no. female flowers (+) | (361) |
| Cucumber | foliar | 0.005% | optimum for growth | (366) |
| Cucumber | hydroponics | --- | yield (+) | (380) |
| Cucumber | seed soak | --- | foliage development, photosyn. | (400) |
| Cucumber | seed treatment or foliar | 0.005-0.05% 0.05-0.1% | germination rate, growth, yield (+) | (431) |
| Current (black) | cuttings | 0.01% | rooting 26%, shoots 107%, (+) | (316) |
| Current | cuttings | 0.005%/6-24 hr | accelerated root formation, stimulated root growth | (376) |
| Eggplant | --- | --- | leaf--nucleic acids (+), protein (-) | ( 41) |
| Eggplant | soil--foliar | several | effects on total wt., no. of branches, leaf area, shoot and root growth, (+) | ( 43) |
| Eggplant | foliar | 0.05% | decreased root wt. but more branching, shoot total wt. (+) | (171) |
| Eggplant | foliar | 0.05% | leaf--respiration intensity | (172) |
| Eggplant | foliar | 0.05% | I-reducing capacity | (173) |
| Eggplant | foliar | 0.005-0.05% | ascorbic acid leaf | (175) |

Table 1. (Continued)

| ORGANISM | METHOD OF APPLICATION | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|---|
| Eggplant | soil | 100-200kg/ha | yield (+) | |
| | foliar | 0.05-0.1% | " " | (273) |
| Eggplant | foliar | --- | amino acid composition effected | (356) |
| Eggplant | foliar | 0.05% | growth leaves (+), RNA (+) | (377) |
| Elm | cuttings | 0.004-0.005%/4-6hr | plant survival and growth (+) | (270) |
| Essential oil crops | | | | |
| Rosa gallica | cuttings | --- | (+), survival 23-33% (+) | (240) |
| Lavandula vera | foliar | 250g/ha | yield flowers, essential oil (+) | (240) |
| Trachyspermum copticum | foliar | --- | yield (o), thymol, essential oil (+) | (240) |
| Fir (Douglas) | foliar | 5000 ppm | growth (+) | (408) |
| Geranium | cuttings | 0.005%/6-24 hr | accelerated rooting, growth (+) | (376) |
| Grape | foliar | --- | (o) | ( 11) |
| Grape | several | --- | yield, quality (o or -) | ( 69) |
| Grape | fertilizer | 0.01% | yield (+) | ( 77) |
| Grape | foliar | 0.05% | leaf-ascorbic acid, respiration rate (+), yield (+) | ( 96) |
| Grape | slips | 0.005% | (-) | (101) |

Table 1. (Continued)

| ORGANISM | METHOD OF APPLICATION | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|---|
| Grape | soil | --- | catalase, ascorbic acid and chlorophyll contents, photosynthesis pith favored over wood parenchyma, less rooting ability, total production (-) | (197) |
| Grape | emulsions, paste | 0.2-0.3, 0.2-0.8% | less than Bordeaux for mildew | (209) |
| Grape | foliar | 0.05% | initial decrease in metabolism then increase, yield 10% and sugar 1.6% (+) | (218) |
| Grape | foliar | --- | --- | (219) |
| Grape | sprinkling | 0.05% emulsion | yield 37% (+) | (225) |
| Grape | --- | --- | pigments (+), physiological activity strong but short duration, economically (o) | (247) |
| Grape | several | --- | yield (+) | (272) |
| Grape | foliar | 0.05% | fruits, ascorbic acid (+) | (273) |
| Grape | cuttings<br>" | 0.005% 1-3 days<br>0.05% | rooting, growth (+)<br>generally toxic | (360) |
| Grape | foliar | 0.05% | yield, sugar contents, (+), flower drop (-) | (381) |
| Grape | foliar/flowers | 0.005% | yield 15.8% sugar content 1.5% | (382) |
| Grape | --- | --- | sugar in leaves (+) | (387) |

Table 1. (Continued)

| ORGANISM | METHOD OF APPLICATION | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|---|
| Grape | --- | --- | sugars and tannins | (388) |
| Grape | --- | 0.05% | rooting | (393) |
| Grape | --- | --- | sugar content (+) | (421) |
| Gooseberry | green cuttings | --- | rooting (+) | (233) |
| Gooseberry | green cuttings | 0.01% | rooting (+) shoot (+) | (316) |
| Hemlock | foliar | 5000 ppm | growth (+) | (408) |
| Hemp | foliar | --- | growth (+) but less than GA | (193) |
| Hemp | seed soak | 0.01%/2-24hr | growth, yield, quality (+) | (300) |
| Larch | seed treatment | 0.02-0.05% | germination rate, seedling root and shoot growth (+) | (390) |
| Lemon | foliar | 1.75% oil-aq. | transpiration (-) | (329) |
| Lilac | soil | 40mg/$m^2$ | shoot, leaf growth, photosyn. (+) | (221) |
| Lime | foliar | 1.75% oil-aq. | transpiration (-) | (329) |
| Lime (small-leaved) | foliar<br>soil | 0.01% 3 times<br>50ml sol to pot | height 122.7%, diam. stem 70.4%, wt. stem 55.5%, wt. leaves 25% wt. roots 42%, whole plant 40% | (434) |

Table 1. (Continued)

| ORGANISM | METHOD OF APPLICATION | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|---|
| Linden (trees) | soil | 3g/tree | growth (+) | |
| | foliar | 0.003% | " " | (315) |
| Locust (tree) | soil | 50-200g/ha | salinity, growth 58% (+) | ( 26) |
| Lupine | presowing | 0.05% | N-content (+) | (312) |
| Maple | soil/fertilizer | 500g/ha | root growth 1st yr, shoot 2nd yr | (270) |
| Maple (Norway) | foliar | several | transport of P to meristem ( +) | (434) |
| Melon (Musk) | seed soak | 0.00012% | yield, sugar content (+) | |
| | foliar | 0.00012% | " " " " | |
| | soil | 50cc/ha | " " " " | ( 13) |
| Melon (Musk) | seed soak | 0.01% | sugar content, yield (+) | ( 56) |
| Melon (Musk) | seed soak | 0.0005-0.01%/24-36 hr | yield, metabolism, growth | ( 57) |
| Melon | appl. to seeds | 0.00012-0.005% | yield, no. & size leaves | ( 58) |
| Melon | soil | --- | yield 44% (+) | |
| | foliar | 0.0005% | most effective | ( 59) |
| Melon (Musk) | foliar | 0.02% | stimulation | (366) |
| Melon (Water) | foliar | 0.05% | stimulation | (366) |
| Melon | foliar | 0.05% | sugar (+) | (421) |

Table 1. (Continued)

| ORGANISM | METHOD OF APPLICATION | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|---|
| Millet | foliar | 0.01% | salinity, heat resistance (+) | (129) |
| Millet | seed treatment | 0.04-0.07% | yield, protein content (+) | |
| | foliar | 625-1250g/ha | " " " " | (402) |
| Millet | foliar | 0.01% | (o) | |
| | seed soak | 0.01% | delayed development | (435) |
| Mulberry (white) | --- | 0.005% | salinity resistance (+) | ( 25) |
| Mulberry | soil | 75-150g/ha | root system development (+) | |
| | soil | 5 or 10mg/plant | " " " " | |
| | foliar | 0.005-0.0005% | " " " " | (155) |
| Mulberry | soil | 150g/ha | RNA, protein, chlorophyll contents | |
| | foliar | 0.005% | of the leaves (+) | (156) |
| Mulberry | soil | 75-150g/ha | root system, moisture statis | |
| | foliar | 0.005-0.0005% | " " " " | (268) |
| Oak | soil | 50-200 g/ha | moisture statis, growth ( +) | ( 26) |
| Oak | soil | 1.8-7.2 mg/tree | salinity, enzymes: polyphenol-oxidase, peroxidase, catalase, I-reducing power (variable) | ( 29) |
| Oak | seed soak | --- | growth (+) | (213) |
| Oak | foliar | 0.05% | leaf-sugar, chlorophyll, photosynthesis | (237) |

Table 1. (Continued)

| ORGANISM | METHOD OF APPLICATION | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|---|
| Oat | foliar | 0.01% | green mass 10-14% (+) | ( 18) |
| Oat | foliar | 0.01% | grain yield (+) | ( 19) |
| Oat | seed treatment | 0.04-0.07% | yield, protein content (+) | |
| | foliar | 625-1250g/ha | " " " | (402) |
| Olive | soil | 75-150g/ha | root system development (+) | |
| | soil | 5 or 10mg/plant | " " " " | |
| | foliar | 0.005-0.0005% | " " " " | (155) |
| Olive | foliar | 0.01% | fruit drop, fruit yield 70% (+) | (241) |
| Olive | soil | 75-150g/ha | catalase (+), water content | |
| | foliar | 0.0005-0.005% | leaves, root-shoot growth (+) | |
| | soil | 450g/ha | inhibitory | (269) |
| Onion | --- | --- | seed yield (+) | ( 13) |
| Onion | seed appl. | 0.00012-0.005% | no., size, chlorophyll, sugar | |
| | soil | 50-250 ml/ha | contents of leaves and plant | |
| | foliar | 0.001-0.005% | yield (+) | ( 58) |
| Onion | to nutrient sol. | 0.0001-0.005% | growth, nutrient uptake, effect more artificial media than soil | (108) |
| Onion | seed soak | --- | less mutations from radiation | (147) |
| Onion | seed soak | --- | mitosis stimulation, radioprotective | (148) |

Table 1. (Continued)

| ORGANISM | METHOD OF APPLICATION | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|---|
| Onion | seed treatment | --- | root cell mitotic activity, no. binucleated cells (+) | (149) |
| Onion | seed treatment | --- | mitotic activity, root length (+) | (150) |
| Onion | seed treatment | --- | radiation protection (+) | (151) |
| Onion | --- | --- | root system development (+) | (165) |
| Onion | --- | --- | root length 166% (+) | (187) |
| Onion | seed treatment | --- | germination (+), yield (+) | (428) |
| Onion | presowing | 100g/ha | yield, N in plants (+) | (430) |
| Onion | seed treatment<br>foliar | 0.005-0.05%/12hr<br>0.05-0.1% | germination rate, growth, yield (+) | (431) |
| Pagoda (Japanese-tree) | seed treatment | 0.005% | salinity, water content (+) | ( 28) |
| Pastures | foliar | 0.005-0.05% | protein content (-), increased legumes over grasses | (258) |
| Pastures | foliar | 0.01% | productivity (+), botanical composition (o) | (293) |
| Pear | foliar | 0.05% | leaf-respiration rate, ascorbic acid content, fruit yield (+) | ( 96) |
| Pear | foliar | 0.05% | ascorbic acid, fruit yield (+) | (273) |

Table 1. (Continued)

| ORGANISM | METHOD OF APPLICATION | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|---|
| Pea | with fertilizer | 100ml/ha | N content, yield 20%, rhizobium development (+) | ( 37) |
| Pea | foliar | 0.005-0.05% | yield ( o) | |
| | soil | 50-200g/ha | " " | |
| | seed soak | 0.005-0.01% | " " | ( 79) |
| Pea | foliar | 0.005-5.0% | rapid penetration of leaves, marked decrease 1st 3 days | (162) |
| Pea | --- | 0.0005% | ammonia N uptake (+) | |
| | --- | 0.0005-0.05% | nitrate N absorption ( +) | |
| | --- | 0.05% | P uptake (+) | (164) |
| Pea | --- | 0.0004% | root system development (+) | (165) |
| Pea | --- | --- | germination, growth, development | (228) |
| Pea | presowing | 0.01% | cyclohexanol-yield, carbohydrate content (+) | |
| | " | 0.01% | cyclohexanone-yield " " " | |
| | " | 0.001% | cyclohexanone oxime-yield" " " | (245) |
| Pea | immersion | 1-10 ppm | internode elongation of dark grown seedlings | (249) |
| Pea | seed treatment | 0.0005-0.005% | yield, N content of peas | |
| | foliar | 0.0005-0.005% | " " " " " | (267) |
| Pea | various | --- | tables of efficiency of yield | (272) |
| Pea | seed treatment | 0.01%/2-24hr | generally-yield, growth, quality (+) | (300) |

Table 1. (Continued)

| ORGANISM | METHOD OF APPLICATION | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|---|
| Pea | seed soak | 0.01-0.0001%/3.5hr | stimulation (o) | (328) |
| Pea | --- | --- | source affected activity | (335) |
| Pea | --- | --- | chlorophyll content (+) | (419) |
| Pepper | hydroponics | --- | yield (+) | (380) |
| Perilla | leaves | --- | root formation (+) | (420) |
| Phellodendron amurense | foliar | 0.0001-0.0007% | pollen maturation, leaf chlorophyll, sugar contents, photosynthetic activity (+) | (237) |
| Phlox | cuttings | --- | root formation (+) | (420) |
| Plum | foliar | 0.05% | leaf-respiration rate, ascorbic acid content, yield of fruits (+) | ( 96) |
| Plum | foliar | 0.05% | ascorbic acid content, yield (+) | (273) |
| Picea abies | watering | 5mg/liter sol. | height (+) | (223) |
| Pine | seed treatment | 0.005% | salinity, water balance | ( 28) |
| Pine | foliar | 0.008-0.012% | root and shoot growth | (105) |
| Pinus sylvestris | preplant | --- | rootability (+), growth (o or -) | (132) |
| Pine | foliar | --- | height (+) | (213) |

Table 1. (Continued)

| ORGANISM | METHOD OF APPLICATION | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|---|
| Pine | --- | --- | oleoresin flow 20% (+) | (222) |
| Pine | watering | 5mg/liter sol. | height (+) | (223) |
| Pine | soil | 0.01% | height (+) | (314) |
| Pinus sylvestris | soil | 0.01% | growth and development (+) | (358) |
| Pine | seed<br>" | 1000 ppm<br>100 ppm | germination and energy (-)<br>germination and energy (+) | (368) |
| Pine (Scotch) | --- | --- | drought resistance, growth (+) | (369) |
| Pine | seed treatment | 0.02-0.05% | germination rate, growth (+) | (390) |
| Pine (lodgepole) | foliar | 5000 ppm | growth (+) | (408) |
| Pine | foliar | 500g/ha | growth, N and P absorption (+) | (433) |
| Pine (Scotch) | foliar | 0.12-0.25% | growth, P transport to meristem | (434) |
| Popular | slip soak | 0.0001-0.001%/24hr | effect was species-dependent | (191) |
| Popular | cuttings | 0.004-0.005%/4-hhr | plant survival and growth (+) | (270) |
| Popular | cuttings | --- | stimulation of rooting (o) | (420) |
| Potato | --- | --- | yield 28-29% (+) | ( 13) |
| Potato | foliar | 125g/ha | tuber yield, starch (+) | ( 14) |

Table 1. (Continued)

| ORGANISM | METHOD OF APPLICATION | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|---|
| Potato | soil<br>then foliar | 250-500ml/ha<br>125ml/ha 3 times | leaf-chlorophyll, N, P contents<br>photosynthesis rate (+)<br>tuber-yield, starch, N, P, contents (+) | ( 15) |
| Potato | soil | 500ml/ha | leaf-respiration, chlorophyll (+)<br>tuber-yield, starch, protein contents (+) | ( 16) |
| Potato | foliar | 0.05% | yield 17% (+) | ( 66) |
| Potato | foliar | 0.005% | pollen fertility (o), yield, starch,<br>ascorbic acid contents (+) | (102) |
| Potato | foliar | 0.005% | tuber yield, starch content (+) | (140) |
| Potato | soaked tubers | 0.005% | activity of proteolytic enzymes<br>in sprouting tubers | (142) |
| Potato | several | several | leaf-vitamin C, catalase (+)<br>chlorophyll, carotene (o)<br>tuber-yield (+) | (143) |
| Potato | --- | --- | not effective (o) | (170) |
| Potato | foliar | 0.002-0.02% | yield (+) | (234) |
| Potato | --- | --- | yields some varieties 48% (+) | (235) |
| Potato | soaked tubers | 0.0005%/1hr | yield 17.4% (+), no. shoots, assimilating<br>surface, chlorophyll, respiration (+) | (242) |

Table 1. (Continued)

| ORGANISM | METHOD OF APPLICATION | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|---|
| Potato | tuber treated | 0.001% | for breaking dormancy, but best in combination with thiourea | (253) |
| Potato | tuber treated | 0.001% | thiourea added increased: yield dormancy break, chlorophyll (+) | (254) |
| Potato | foliar<br>soil | 0.005%<br>200g/ha | yield 12.4% (+) starch content (+)<br>yield 6.5% (+) " " " | (394) |
| Potato | foliar | 5000 ppm | tubers/plant, fresh weight (+) | (407) |
| Potato | foliar | --- | starch content (+) | (421) |
| Potato | soil<br>foliar | 250g/ha<br>0.005% | growth (+)<br>" " | (436) |
| Privet | cuttings | --- | root formation | (420) |
| Prunus padus | foliar<br>foliar | 0.0001-0.0007%<br>0.05% | maturation (+)<br>leaf-chlorophyll, sugar content photosynthetic activity, no. of flowers (+) | (237) |
| Psammophytes | seedlings | 0.001% | --- | (133) |
| Pumpkin | seed soak | --- | yield, quality | (400) |
| Pumpkin | foliar | 0.005% | sugar content (+) | (421) |
| Radish | foliar | 5000 ppm | tap root fresh wt. 13.5% (+) | (409) |

Table 1. (Continued)

| ORGANISM | METHOD OF APPLICATION | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|---|
| Rice | foliar | 0.005% | yield 28% (+) | (187) |
| Rice | foliar<br>watering | 0.05%<br>410g/ha | best<br>yield (+) | (262) |
| Rice | foliar | 0.05% | yield 13% | (285) |
| Rice | seed treatment | 10, 20, 40μg/seed | fresh, dry wts of roots (+) length roots (o) | (320) |
| Robinia pseudoacacia | soil | 1.8, 7.2mg/tree | salinity, enzyme activity alteration | ( 29) |
| Robinia pseudoacacia | seed soak | 0.005-0.05%/4hr | germination rate (+) | (270) |
| Sorbus | foliar | 0.05% | leaf-chlorophyll, sugar content photosynthetic activity, no. flowers and fruits (+) | (237) |
| Soybean | several | several | yield (+) | (272) |
| Spindle-tree | cuttings | --- | root formation (+) | (420) |
| Spirea | cuttings<br>cuttings | 300mg/liter<br>150mg/liter | lignified cuttings root formation (+)<br>green cuttings root formation (+) | (326) |
| Spruce | seed soak | 0.02-0.05%<br>8, 16, 48hr | germination rate, root and shoot growth (+) | (390) |
| Spruce (Sitka) | foliar | 5000 ppm | growth (+) | (408) |

Table 1. (Continued)

| ORGANISM | METHOD OF APPLICATION | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|---|
| Spruce | foliar | 500g/ha | root and shoot growth, N, P, uptake (+) | (433) |
| Strawberry | soil | 2.5-25.0g/linear meter | survival (+) | (196) |
| Sugar cane | foliar | oil & CuNap | yield of sugar (+) | (177) |
| Sunflower | seed soak | 0.01, 0.005% | stem size, flower no., seed wt., oil yield (+) | (226) |
| Sunflower | seed soak | 0.02-0.04%/2hr | pots- growth (+)<br>field- root growth, water balance, yield (+) | (404) |
| Syringa josikaea | root soak | 50mg/liter | height (+) | (223) |
| Tangerine | foliar | 0.05% | yield 18.6-21.2% (+), pulp, sugar content, av. wt. fruit, (+), acid content (-) | (266) |
| Tea | soil | 100, 200g/ha<br>0.005, 0.01, 0.05% | leaf yield 25, 39% (+)<br>yield 19, 24, 39% (+) | (187) |
| Tea | soil<br>foliar | 250g/ha<br>0.05% 3 times | leaf yield 22%, N uptake, tannin content (+) | (260) |
| Tea | foliar | 0.05% | green leaves 30-39% (+) | (262) |
| Tea | foliar | 0.005% | green leaves 24-25% (+) | (285) |
| Tobacco | soil<br>foliar<br>seed soak | 0.63ml/100kg<br>0.005%<br>0.005%/3hr | yield of leaves 17-30% (+), growth<br>survival in field (+)<br>most effective means of appl. | ( 1) |

Table 1. (Continued)

| ORGANISM | METHOD OF APPLICATION | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|---|
| Tobacco | seed soak | 0.005-0.05%/3-6hr | yield 12-17% (+) | |
| | foliar | 0.05-0.005% at 2.51 liters/ha | yield 25-31% (+) | |
| | soil | 25-50g/100kg | yield 11-13% (+) | ( 17) |
| Tobacco | foliar or soak | --- | (o) | (124) |
| Tobacco | foliar or soak | --- | (o) | (146) |
| Tobacco | --- | --- | | (220) |
| Tobacco | soil | 50-100g/ha | growth and development (+) | |
| | foliar | 0.005-0.01% | best mode of appl., leaf protein, carbohydrate, P, K contents (+), nicotine, total N (o) | (422) |
| Tobacco | foliar | --- | yield 35% (+) | (423) |
| Tomato | soil | 250cc/ha | best, yield (+) | ( 13) |
| Tomato | foliar | 0.1-0.005% | water statis, free water | ( 31) |
| Tomato | soil | 50-100g/ha | yield 30-37% (+), sugar, dry substances, | |
| | foliar | 0.005% at 500 liters/ha | ascorbic acid (+) | ( 35) |
| Tomato | --- | --- | nucleic acids, protein | ( 41) |
| Tomato | --- | --- | yield (+) | ( 57) |
| Tomato | seed soak | 0.00012-0.005% | leaves-number, size, chlorophyll and sugar | |
| | soil | 50-250g/ha | contents (+), fruit-ascorbic acid content (+) | ( 58) |

Table 1. (Continued)

| ORGANISM | METHOD OF APPLICATION | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|---|
| Tomato | seed soak | 0.005% | seedling crop 60.7% (+) | ( 59) |
| Tomato | soil top dress<br>soil at planting | 100-500g/ha<br>" " " | growth, yield (+)<br>(o) | ( 85) |
| Tomato | M. S. Thesis | --- | growth and biochemical responses | ( 97) |
| Tomato | --- | --- | yield (+) | (157) |
| Tomato | soil | --- | yield 22-32% (+) | (160) |
| Tomato | soil | --- | yield up to 138% | (161) |
| Tomato | foliar | 0.05% 2 times | respiration (+), varied over years | (172) |
| Tomato | foliar | 0.05% | I-reducing capacity, varied over time, less effective than GA | (173) |
| Tomato | foliar | 0.05% | carbohydrate content (o) | (174) |
| Tomato | foliar | 0.005-0.05% | leaf-ascorbic acid (+) | (175) |
| Tomato | foliar | --- | above ground growth, ascorbic acid, dry substances, yield 15-20%, resistance to high temp. (+) | (179) |
| Tomato | soil<br>foliar | 50g, 300g/ha<br>0.005, 0.05% | yield 36, 33% (+)<br>yield 50, 40% (+) | (187) |

Table 1. (Continued)

| ORGANISM | METHOD OF APPLICATION | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|---|
| Tomato | foliar | 0.05% | RNA, DNA, total and protein N contents of growing leaves (+), older leaves (o) | (259) |
| Tomato | soil | 250ml/0.05%/plant | yield 39% (+) | (262) |
| Tomato | foliar | 0.05% | yield 46% (+) | (285) |
| Tomato | foliar | 0.005% | yield 18.8% (+), proteins and nucleic acid changes | (298) |
| Tomato | foliar | 0.005% | may act as allosteric effector | (299) |
| Tomato | foliar | 0.005% | (o) | (327) |
| Tomato | foliar | 0.02% | growth (+), maturation (o) | (366) |
| Tomato | hydroponically | --- | yield (+) | (380) |
| Tomato | foliar | 0.05% | yield (+) | (428) |
| Tomato | seed treatment<br>foliar | 0.005-0.05%/12hr<br>0.05-0.1% | germination rate, growth (+)<br>leaf-respiration rate, chlorophyll protein contents (+) | (431) |
| Trees (Unspecified) | --- | 0.0001-0.0007% | pollen production (+) stunted pollen tube growth | (236) |
| Trefoil | seed soak | 0.01-0.0001% | growth and development (+) | (328) |
| Ulmus | seed soak | 0.005-0.05% | germination rate (+), seedling growth (o) | (270) |

Table 1. (Continued)

| ORGANISM | METHOD OF APPLICATION | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|---|
| Vetch | seed treatment | weak sol/2hr | yield (+) | (157) |
| Vicia faba | --- | 0.1% | inhibited mitotic activity | |
| | --- | 0.001-0.0001% | stimulated " " | ( 24) |
| Vicia faba | foliar | 0.005-0.05% | fresh wt., lipid, cellulose contents (+), protein content (-) | (258) |
| Weeds | foliar | 0.005-0.1% | foxtail-with ammonium nitrate yield 23% green mass (+) | ( 18) |
| Weeds | foliar | 0.1% | foxtail-yield (-) | ( 19) |
| Weeds | foliar | 10-20% | herbicidal to Chenopodium, Lathyrus, Carex gracilis, Cichorium--protein RNA, DNA contents (-) | ( 42) |
| Weeds | foliar | 10-20% | herbicidal to basket withe (Tournefortia sp.), camelthorn (Alhagi camelorum, and dodder (Cuscuta sp.) | ( 88) |
| Weeds | --- | 0.0001-0.01% | growth and germination (+) | (205) |
| Weeds | foliar | 20% | --- | (243) |
| Weeds | foliar | 5-10% | weed killing effects | (429) |
| Weeds | --- | --- | --- | (432) |

Table 1. (Continued)

| ORGANISM | METHOD OF APPLICATION | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|---|
| Wheat | --- | --- | various fractions, showed biological activity, total green mass (+) | ( 50) |
| Wheat (winter) | soil | 4-10kg/ha | grain yield and protein content (+) | ( 55) |
| Wheat | foliar to grain | --- | sprouted 29% (+) | ( 66) |
| Wheat (winter) | seed treatment | 5g/100kg | yield, protein (+), cellulose (-) | ( 90) |
| Wheat (winter) | seed treatment,<br>foliar | 0.2-0.6%<br>0.05% | yield 19-37% (+) | (126) |
| Wheat | hydroponically | --- | several fractions varied results attempt to explain diversities and fluctuations with crude NGS prepns | (138) |
| Wheat | foliar | 0.005-5.0% | penetrated leaves rapidly, content markedly decreases 1st 3 days | (162) |
| Wheat | foliar | 0.0005%<br>0.05%<br>0.0005-0.05% | ammonia N uptake (+)<br>P uptake (+)<br>nitrate N uptake (+) | (164) |
| Wheat (winter) | --- | --- | (o) | (170) |
| Wheat (winter) | soil<br>foliar<br>seed | 200g/ha<br>0.05%<br>0.04% | yield 5-15% | (178) |

Table 1. (Continued)

| ORGANISM | METHOD OF APPLICATION | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|---|
| Wheat (winter | seed soak | 0.1, 0.01, 0.0001, 0.0001% 3 days | root length of sprout, (-), (o), (-), (+), resp. | |
| | seed soak | 0.005, 0.01, 0.05% for 6, 12, 24hrs | root length all (+), but 6hr best | |
| | seed soak | 0.0004% | root length of sprout 193% (+) | (187) |
| Wheat | --- | --- | --- | (211) |
| Wheat (winter) | foliar | 0.05% | interaction with N and time of appl. had effects on: respiration, peroxidase, catalase, ascorbic acid, pH, glucose, maltose, sucrose, hemicellulose contents and yield | (215) |
| Wheat (winter) | several | --- | max. yield 31% (+) | (272) |
| Wheat (winter) | foliar | 0.05% | yield 10.7% (+) | (281) |
| Wheat (winter) | seed wetting | 0.005 or 0.05% | yield (+), protein (-) | (306) |
| Wheat | --- | --- | growth (+) | (319) |
| Wheat | --- | --- | different fractions and sources | (335) |
| Wheat (winter) | --- | 0.04% | manufacturing of NaNap, yield 30% (+) | (354) |
| Wheat (spring) | seed applied | 0.04-0.07% | yield and protein content (+) | |
| | foliar | 0.04-0.07% | " " " " " | (402) |
| Wheat (spring) | foliar | 0.5% | grain yield and fresh wt. | (409) |

Table 2. Effects of naphthenates on the warm blooded members of the ANIMAL KINGDOM.

| ORGANISM | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|
| Buffalo | 1, 3, 5mg/kg<br>10mg/kg | blood amylase activity 10.4, 15.4, 21.2% (+), resp.<br>" " " 29.1% (-) | ( 33) |
| Buffalo | --- | development of rumen microflora stimulated | (271) |
| Cattle | 3-6mg/kg | stimulate rumen bacteria, spermatogenesis and quality of semen in bulls | ( 32) |
| Cattle | 3-5mg/kg<br>5-10mg/kg<br>--- | 10-30 day old calves-wt. gains 21-29% (+), Hb 7-11% (+)<br>bulls spermatoza 1.5 fold (+)<br>cows 20-25% higher birth rate | ( 34) |
| Cattle | 3-5mg/kg | wt. 21-36% (+), Hb and gamma globulin (+) | ( 65) |
| Cattle | --- | wt. gains and feeding efficiency (+) | (104) |
| Cattle | 2-3mg/kg | wt. gains (+) | (347) |
| Cattle | --- | cyclohexanecarboxylic acid found in urine, not determined if product of rumen bacteria or animal | (375) |
| Cattle | --- | removal of hydrocarbons and phenols increases biological activity of prep. | (395) |
| Cat | 50mg/kg | development of hysteriosis inhibited | ( 84) |
| Cat | --- | alteration of blood-brain barrier | (292) |
| Chicken | 1-4mg/kg<br>0.05mg/kg<br>--- | 10 day old chickens wt gain (+)<br>older fowl<br>hens-no. and wt. of eggs (+) | ( 23) |

Table 2. (Continued)

| ORGANISM | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|
| Chicken | 3mg/kg | body wt., egg production, blood glucose and inorg. P (-), lactic acid in blood (+) | (214) |
| Chicken | 0.05mg/kg | bone marrow activity (+), liver cells some with 2 nuclei, capillaries dilated | (276) |
| Chicken | 3mg/day | chicks-wt gain 7.2% (+), liver glycogen 3 fold (+), 3-PGA (+) in liver and muscles | (403) |
| Dog | 2mg/kg | diuresis stimulated | ( 46) |
| Dog | 1, 2% ointment | burn healing (+) | (202) |
| Dog | 1-1.5ml of 0.5%/kg wt. | gastric juice 10-12% (-), digestive power 90% (+) | (325) |
| Dog | --- | wt. gain (+) | (347) |
| Dog | --- | EtOH resorption and growth (+) | (348) |
| Human | --- | treatment of gastroduodenal peptic ulcers | ( 67) |
| Human | --- | AMCHA or aminomethylcyclohexanecarboxylic acid use in treatment of hemophilia | (128) |
| Human | --- | AMCHA or aminomethylcyclohexanecarboxylic acid reduction in blood loss after surgery | (256) |
| Guinea pig | --- | stimulation of titer formation | (398) |
| Mice | --- | Cobalt naphthenate is carcinogenic | (289) |

Table 2. (Continued)

| ORGANISM | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|
| Mice | --- | Cobalt naphthenate is carcinogenic, rapid, dynamic | (290) |
| Mice | --- | does not contain a folliculin-like estrogenic hormone | (383) |
| Mice | --- | $L.D._{50}$ for mice 1310mg/kg | (397) |
| Mice | 0.5mg/kg | stimulated central nervous system of older mice | (424) |
| Pig | 3-6mg/kg | growth (+) | ( 32) |
| Pig | 3mg/kg | wt. gain 10-17% (+) | ( 66) |
| Pig | --- | wt. gain (+) | (104) |
| Pig | several | wt. gain (+) | (287) |
| Poultry | 3mg/kg<br>0.005mg/kg | wt. gain 15% (+)<br>egg yield 20% (+) | ( 66) |
| Poultry | 5mg/head | wt. gain 13.3% 1st mo., 3% 2nd mo. (+),egg laying capacity 31.3% (+) | (288) |
| Poultry | --- | growth, egg laying (+) | (331) |
| Rabbit | --- | Brown-Pearce rabbit carcinoma inhibition or resorbed tumor | ( 4) |
| Rabbit | 10mg/kg | Brown-Pearce rabbit carcinoma, extent and size of metastases (-) | ( 8) |
| Rabbit | 10mg/kg | leukoblastic, erythroblastic, and thrombocyte function stimulated | ( 9) |
| Rabbit | 10-20mg/kg | leukocytes and thrombocytes (+) | ( 10) |

Table 2. (Continued)

| ORGANISM | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|
| Rabbit | --- | live wt. 14-23% (+) | ( 23) |
| Rabbit | --- | Brown-Pearce rabbit carcinoma inhibition, rbs's (+) | ( 38) |
| Rabbit | 0.01g/kg | naphthene hydrocarbons-Hb, rbc's, wbc's (-) lymphocytes (+) | ( 68) |
| Rabbit | 0.01-2%/1ml | Brown-Pearce rabbit carcinoma, tumor growth (+), metastasis (+) | (144) |
| Rabbit | --- | Brown-Pearce rabbit carcinoma | (145) |
| Rabbit | --- | effect on autonomic nervous system | (169) |
| Rabbit | 1, 2% ointment | burn healing (+) | (202) |
| Rabbit | 20mg/kg | different fractions affected-wt. gain, level of Hb, rbc's, wbc's | (251) |
| Rabbit | 5mg/kg<br>20mg/kg | leukocytes (+), wt gain 18-20% (+)<br>rbc's and wbc's and wt. gain 20-22% (-) | (252) |
| Rabbit | aerosol 14% HNap | 400-100,000 particles/ml air-lung edema and emphysema | (255) |
| Rabbit | --- | --- | (347) |
| Rabbit | $10^{-5}$ | accelerated growth and differentiation of cultivated rabbit kidney epithelium | (363) |
| Rabbit | skin appl. | hyperemia | (397) |
| Rat | 0.5-50mg/kg | transplanted M-1 sarcoma-tumor growth, metastasis (-) | ( 2) |

Table 2. (Continued)

| ORGANISM | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|
| Rat | 5mg/kg | acute radiation sickness-surviving animal (+), leukocytes recovered more rapidly | ( 3) |
| Rat | --- | M-1 sarcoma with preceding x-ray, protect hemopoietic tissue, inhibition of tumor growth | ( 5) |
| Rat | 100mg/kg | uptake of I was greater for 45 days after treat. | ( 6) |
| Rat | 8-10mg/kg | more rapid restoration of leukocytes and thrombocytes | ( 7) |
| Rat | mud | penetration through skin, found in muscle | (120) |
| Rat | 50mg/kg | did not effect invasion of muscle by Trichinella | (122) |
| Rat | 10-20mg/kg | rat sarcoma M-1, inhibition effect on most rats | (176) |
| Rat | --- | liver glycogen and rbc's (+) | (212) |
| Rat | --- | metabolic rate of nucleic acids and free nucleotides (+) | (294) |
| Rat | --- | wt. gain | (347) |
| Rat | --- | cholesterol level, B-lipoprotein level, antherogenic index, proportion of cholesterol to phospholipids (-), tissue respiration (+) | (378) |
| Rat | --- | $L.D._{50}$ 5200mg/kg for rats | (397) |
| Rat | 0.25 or 2.5mg/kg | weak sedative effect on old rats, serum cholesterol level (+), premature aging (o) | (424) |

Table 2. (Continued)

| ORGANISM | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|
| Sheep | --- | live wt. 12-18% (+) | ( 23) |
| Sheep | 0.5, 1, 2, 3, 5mg/kg | av. wt. gains 3.4, 12.4, 21.6, 28.4, 11.1% (+) resp | ( 34) |
| Unspecified | --- | ? use in endometritis | (330) |
| Unspecified | 10% emulsion | restoration of skin affected by B-radiation (+) | (392) |

Table 3. Effects of naphthenates on the cold blooded members of the ANIMAL KINGDOM.

| ORGANISM | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|
| Fish (Lepomis macrochirus) | --- | $L.D._{50}$ for soft water-5.79ppm at 18 C, 7.10ppm at 30 C - for hard water 7.15ppm at 18 C, 7.10 at 30 C | ( 92) |
| Fish (Lepomis macrochirus) | --- | no substantial interaction with several other toxic compounds. | ( 93) |
| Fish (rainbow trout) | 0.5mg/kg | wt. of fish 28% (+), food consumption 25% (-) | (244) |
| Fish (several) | 0.5mg/l | incubation period for eggs shortened, growth (+) | (278) |
| Fish (Atlantic salmon) | several | ranges of lethal concentrations for hatching | (338) |
| Fish (bluegill) | --- | effect of HNap under low oxygen concentrations | (341) |
| Fish (salmon) | --- | lethal and harmless concentrations set for CuNap, poisoning symptoms described | (349) |
| Frog | --- | demarcation potential of skeletal muscle (+) | ( 82) |
| Frog | --- | effect of heart-amplutide of systoles (+ or -) | (204) |
| Insect (bee) | --- | more young, larger | (130) |
| Insect (silkworm) | eggs incubated with 0.5% | productivity 3-12% (+), cocoon quality (+) | (263) |
| Insect (bee) | --- | no. bees, honey (+) | (274) |
| Insect (silkworm) (Bombyx mori) | 0.02% egg treat. | cocoon yield (+), leaf consumption (-) | (313) |

Table 4. Effects of naphthenates on MICROORGANISMS.

| ORGANISM | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|
| Algae | 1.1, 3.0% CuNap | inhibition of alga growth when pot dipped | (371) |
| Algae | 3.5% CuNap | inhibition of alga growth when pot dipped | (372) |
| Bacteria | 0.0005-0.001% | growth and nitrogen fixation (+) of: Azotobacter chroococcum, A. agile, A. vinelandii, Mycobacterium flavum, M. roseoalbum | (127) |
| Bacteria | --- | development of Azotobacter | (157) |
| Bacteria | 0.0001% | no. of Azotobacter cells (+) in 30 days | (165) |
| Bacteria | --- | Azotobacter (+) in soil | (188) |
| Bacteria | 200g/ha | activities (+) of: Azotobacter, Clostridium pasteurianium, Bacillus virgilus, B. mesentericus, B. megaterium | (201) |
| Bacteria | 0.0001-0.005% added to media | nodulation and growth (+) of: Rhizobium meliloti, R. leguminosarum | (267) |
| Bacteria | --- | --- | (277) |
| Bacteria | 0.0001% | respiration of Pseudomonas (+) | (359) |
| Bacteria | 1mg/l | growth of leptospires (+) | (389) |
| Fungi | $5x10^{-5}$ to $^{-4}$% | growth and formation of amylase (+) | ( 91) |
| Fungi | --- | --- | (137) |

Table 4. (Continued)

| ORGANISM | NAPHTHENATE CONCENTRATION | RESPONSE | REFERENCE |
|---|---|---|---|
| Fungi | --- | metal naphthenates poor fungicides | (342) |
| Yeast | --- | bread vol. (+), 0.001% of flour wt. fermentation time 50% (-) | (207) |
| Yeast | --- | alcoholic sugar splitting activity (+) | (286) |
| Yeast | 0.05% | bioassay by measurement of $CO_2$ evolved | (396) |
| Unspecified | 0.005% to rhizosphere | number microorganisms/gram soil (+) | ( 39) |
| Unspecified | --- | biological activity of soil (+) | ( 77) |
| Unspecified | 800g/ha to the soil | microbial activity (+) | (107) |

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# APPENDIX II

## PREPARATION OF AQUEOUS POTASSIUM NAPHTHENATE (KNap) SOLUTION FROM NAPHTHENIC ACID (HNap)

To prepare potassium naphthenate, the naphthenic acid (Practical) must be saponified or neutralized with KOH. A KOH solution is prepared by adding 2.1 grams of KOH to 17 ml of distilled water. This is added to a flask containing 5 grams of naphthenic acid (HNap) and shaken for 10 to 15 minutes. This should be allowed to stand for 5 minutes and then brought to a volume of 25 ml with distilled water. This solution now contains 250 mg KNap/ml. The dilution of 1 ml of this stock solution to 50 ml with distilled water results in a 5000 ppm KNap solution. The pH of this solution which is over 12.8 (has considerable buffering capacity) should be adjusted to pH 10 by addition of dilute HCl before final volume is reached.

NOTE: When the titration nears pH 10 the solution begins to become milky. Also care should be taken since the buffering capacity is gone and small additions produce large changes in pH.

APPENDIX III

Daily maximum and minimum temperature, midmorning and midafternoon relative humidity and solar radiation at Hyslop Farm, Corvallis, Oregon, during April through September, 1974.

| Date | | Temperature (°F) | | Relative Humidity (%) | | Solar Radiation |
|---|---|---|---|---|---|---|
| | | Max | Min | 10 am | 4 pm | (Langleys) |
| April | 1 | 49 | 43 | 91 | 54 | 100 |
| | 2 | 53 | 40 | 98 | 70 | 170 |
| | 3 | 50 | 38 | 98 | 50 | 387 |
| | 4 | 52 | 38 | 97 | 50 | 100 |
| | 5 | 61 | 40 | 97 | 66 | 330 |
| | 6 | 55 | 41 | 78 | 49 | 326 |
| | 7 | 55 | 41 | 77 | 28 | 339 |
| | 8 | 62 | 44 | 87 | 54 | 300 |
| | 9 | 55 | 41 | 88 | 75 | 170 |
| | 10 | 46 | 37 | 72 | 54 | 176 |
| | 11 | 53 | 48 | 97 | 38 | 300 |
| | 12 | 51 | 30 | 68 | 33 | 302 |
| | 13 | 56 | 38 | 71 | 23 | 353 |
| | 14 | 65 | 40 | 55 | 20 | 339 |
| | 15 | 69 | 41 | 93 | 55 | 543 |
| | 16 | 56 | 36 | 72 | 29 | 357 |
| | 17 | 59 | 41 | 54 | 45 | 320 |
| | 18 | 63 | 42 | 66 | 44 | 270 |
| | 19 | 58 | 41 | 74 | 64 | 265 |
| | 20 | 55 | 43 | 88 | 44 | 265 |
| | 21 | 60 | 38 | 75 | 38 | 350 |
| | 22 | 65 | 45 | 68 | 58 | 340 |
| | 23 | 56 | 42 | 88 | 65 | 396 |
| | 24 | 54 | 43 | 72 | 33 | 474 |
| | 25 | 60 | 41 | 62 | 27 | 474 |
| | 26 | 61 | 40 | 65 | 77 | 348 |
| | 27 | 59 | 42 | 69 | 45 | 432 |
| | 28 | 59 | 44 | 63 | 44 | 354 |
| | 29 | 59 | 40 | 80 | 32 | 510 |
| | 30 | 70 | 42 | 59 | 37 | 474 |
| May | 1 | 66 | 45 | 37 | 43 | 366 |
| | 2 | 56 | 43 | 60 | 31 | 462 |
| | 3 | 60 | 38 | 57 | 28 | 596 |
| | 4 | 66 | 42 | 55 | 27 | 600 |
| | 5 | 74 | 43 | 53 | 26 | 516 |
| | 6 | 77 | 48 | 58 | 34 | 324 |
| | 7 | 73 | 45 | 44 | 33 | 468 |
| | 8 | 73 | 45 | 61 | 30 | 516 |
| | 9 | 67 | 46 | 75 | 49 | 222 |
| | 10 | 57 | 45 | 67 | 43 | 312 |
| | 11 | 63 | 45 | 96 | 50 | 396 |

APPENDIX III

(Continued)

| Date | Temperature (°F) Max | Min | Relative Humidity (%) 10 am | 4 pm | Solar Radiation (Langleys) |
|---|---|---|---|---|---|
| May 12 | 62 | 41 | 44 | 32 | 444 |
| 13 | 57 | 34 | 60 | 42 | 411 |
| 14 | 56 | 39 | 98 | 33 | 378 |
| 15 | 57 | 35 | 91 | 51 | 372 |
| 16 | 54 | 37 | 71 | 57 | 336 |
| 17 | 56 | 38 | 76 | 46 | 474 |
| 18 | 58 | 41 | 97 | 54 | 216 |
| 19 | 54 | 43 | 72 | 73 | 336 |
| 20 | 58 | 38 | 58 | 32 | 444 |
| 21 | 63 | 38 | 64 | 34 | 470 |
| 22 | 67 | 40 | 64 | 41 | 330 |
| 23 | 63 | 44 | 66 | 41 | 288 |
| 24 | 65 | 51 | 83 | 58 | 216 |
| 25 | 65 | 52 | 76 | 32 | 486 |
| 26 | 76 | 47 | 59 | 34 | 496 |
| 27 | 68 | 46 | 49 | 32 | 506 |
| 28 | 69 | 42 | 51 | 32 | 516 |
| 29 | 67 | 48 | 53 | 38 | 330 |
| 30 | 61 | 34 | 53 | 27 | 618 |
| 31 | 64 | 42 | 40 | 16 | 692 |
| June 1 | 75 | 47 | 32 | 18 | 654 |
| 2 | 80 | 48 | 51 | 29 | 480 |
| 3 | 81 | 45 | 70 | 31 | 388 |
| 4 | 70 | 52 | 98 | 78 | 258 |
| 5 | 62 | 52 | 64 | 66 | 150 |
| 6 | 99 | 50 | 50 | 50 | 462 |
| 7 | 62 | 44 | 36 | 27 | 582 |
| 8 | 65 | 42 | 46 | 18 | 714 |
| 9 | 72 | 48 | 52 | 22 | 696 |
| 10 | 76 | 45 | 43 | 16 | 686 |
| 11 | 85 | 51 | 35 | 26 | 546 |
| 12 | 86 | 50 | 43 | 26 | 612 |
| 13 | 86 | 48 | 56 | 31 | 624 |
| 14 | 82 | 45 | 61 | 46 | 306 |
| 15 | 67 | 55 | 65 | 42 | 350 |
| 16 | 70 | 56 | 66 | 32 | 660 |
| 17 | 83 | 48 | 36 | 14 | 630 |
| 18 | 89 | 52 | 52 | 27 | 606 |
| 19 | 82 | 53 | 54 | 45 | 468 |
| 20 | 69 | 42 | 43 | 24 | 662 |
| 21 | 77 | 50 | 46 | 21 | 624 |
| 22 | 83 | 49 | 66 | 47 | 330 |
| 23 | 69 | 48 | 43 | 17 | 720 |

APPENDIX III

(Continued)

| Date | Temperature (°F) Max | Min | Relative Humidity (%) 10 am | 4 pm | Solar Radiation (Langleys) |
|---|---|---|---|---|---|
| June 24 | 72 | 41 | 39 | 20 | 690 |
| 25 | 76 | 50 | 95 | 56 | 264 |
| 26 | 60 | 40 | 80 | 54 | 312 |
| 27 | 62 | 46 | 91 | 39 | 366 |
| 28 | 67 | 43 | 51 | 17 | 690 |
| 29 | 79 | 55 | 45 | 18 | 672 |
| 30 | 92 | 57 | 41 | 25 | 654 |
| July 1 | 85 | 51 | 62 | 43 | 285 |
| 2 | 66 | 44 | 54 | 29 | 522 |
| 3 | 71 | 44 | 37 | 12 | 663 |
| 4 | 84 | 55 | 58 | 26 | 474 |
| 5 | 78 | 54 | 96 | 49 | 270 |
| 6 | 68 | 50 | 50 | 24 | 417 |
| 7 | 73 | 49 | 42 | 24 | 498 |
| 8 | 72 | 53 | 81 | 89 | 294 |
| 9 | 68 | 51 | 70 | 68 | 210 |
| 10 | 61 | 52 | 58 | 38 | 414 |
| 11 | 67 | 51 | 42 | 34 | 494 |
| 12 | 69 | 44 | 44 | 21 | 640 |
| 13 | 75 | 48 | 41 | 17 | 648 |
| 14 | 83 | 45 | 28 | 36 | 645 |
| 15 | 76 | 49 | 52 | 35 | 441 |
| 16 | 70 | 50 | 40 | 41 | 300 |
| 17 | 74 | 52 | 97 | 69 | 183 |
| 18 | 69 | 50 | 88 | 64 | 174 |
| 19 | 71 | 55 | 74 | 38 | 501 |
| 20 | 75 | 55 | 50 | 21 | 634 |
| 21 | 83 | 50 | 44 | 14 | 561 |
| 22 | 82 | 49 | 34 | 36 | 593 |
| 23 | 81 | 52 | 41 | 26 | 624 |
| 24 | 75 | 50 | 42 | 23 | 638 |
| 25 | 82 | 53 | | | 644 |
| 26 | 84 | 54 | 35 | 25 | 522 |
| 27 | 88 | 54 | 23 | 16 | 546 |
| 28 | 91 | 55 | 30 | 15 | 571 |
| 29 | 94 | 61 | 47 | 27 | 564 |
| 30 | 83 | 56 | 45 | 11 | 594 |
| 31 | 95 | 58 | 33 | 13 | 588 |
| Aug 1 | 96 | 54 | 27 | 13 | 591 |
| 2 | 94 | 51 | 33 | 17 | 588 |
| 3 | 92 | 52 | 36 | 20 | 573 |
| 4 | 91 | 53 | 43 | 16 | 558 |

APPENDIX III

(Continued)

| Date | | Temperature (°F) Max | Min | Relative Humidity (%) 10 am | 4 pm | Solar Radiation (Langleys) |
|---|---|---|---|---|---|---|
| Aug | 5 | 89 | 51 | 30 | 24 | 536 |
| | 6 | 85 | 47 | 38 | 17 | 541 |
| | 7 | 78 | 44 | 40 | 23 | 574 |
| | 8 | 78 | 45 | 41 | 21 | 559 |
| | 9 | 79 | 45 | 36 | 15 | 565 |
| | 10 | 90 | 52 | 28 | 24 | 555 |
| | 11 | 87 | 44 | 46 | 24 | 564 |
| | 12 | 77 | 49 | 49 | 30 | 352 |
| | 13 | 72 | 48 | 72 | 38 | 350 |
| | 14 | 73 | 45 | 56 | 22 | 555 |
| | 15 | 78 | 43 | 52 | 21 | 540 |
| | 16 | 81 | 50 | 48 | 11 | 540 |
| | 17 | 86 | 47 | 54 | 32 | 540 |
| | 18 | 77 | 56 | 55 | 30 | 540 |
| | 19 | 72 | 56 | 84 | 56 | 140 |
| | 20 | 65 | 55 | 51 | 28 | 397 |
| | 21 | 73 | 49 | 42 | 18 | 472 |
| | 22 | 81 | 51 | 33 | 35 | 428 |
| | 23 | 85 | 53 | 46 | 27 | 438 |
| | 24 | 80 | 59 | 47 | 20 | 504 |
| | 25 | 86 | 60 | 45 | 13 | 511 |
| | 26 | 90 | 59 | 40 | 12 | 493 |
| | 27 | 91 | 55 | 36 | 21 | 416 |
| | 28 | 91 | 57 | 63 | 31 | 439 |
| | 29 | 84 | 58 | 88 | 46 | 345 |
| | 30 | 78 | 58 | 78 | 63 | 127 |
| | 31 | 68 | 59 | 80 | 42 | 286 |
| Sept | 1 | 77 | 53 | 78 | 23 | 356 |
| | 2 | 87 | 55 | 76 | 8 | 366 |
| | 3 | 91 | 53 | 97 | 55 | 186 |
| | 4 | 73 | 56 | 88 | 34 | 216 |
| | 5 | 75 | 52 | 83 | 25 | 432 |
| | 6 | 82 | 53 | 18 | 43 | 468 |
| | 7 | 82 | 50 | 18 | 72 | 450 |
| | 8 | 87 | 53 | 39 | 52 | 228 |
| | 9 | 76 | 59 | 88 | 58 | 150 |
| | 10 | 69 | 48 | 98 | 30 | 252 |
| | 11 | 75 | 47 | 73 | 11 | 438 |
| | 12 | 78 | 51 | 30 | 11 | 420 |
| | 13 | 82 | 55 | 18 | 8 | 444 |
| | 14 | 87 | 46 | 17 | 4 | 468 |
| | 15 | 91 | 41 | 65 | 13 | 450 |
| | 16 | 83 | 44 | 57 | 10 | 432 |

APPENDIX III

(Continued)

| Date | Temperature (°F) Max | Min | Relative Humidity (%) 10 am | 4 pm | Solar Radiation (Langleys) |
|---|---|---|---|---|---|
| Sept 17 | 87 | 43 | 47 | 13 | 432 |
| 18 | 87 | 46 | 46 | 14 | 420 |
| 19 | 89 | 53 | 47 | 10 | 420 |
| 20 | 94 | 48 | 56 | 5 | 402 |
| 21 | 95 | 49 | 40 | 6 | 378 |
| 22 | 94 | 47 | 52 | 9 | 384 |
| 23 | 92 | 49 | 26 | 11 | 372 |
| 24 | 92 | 48 | 31 | 5 | 378 |
| 25 | 97 | 43 | 44 | 17 | 348 |
| 26 | 89 | 44 | 52 | 19 | 328 |
| 27 | 73 | 38 | 54 | 12 | 378 |
| 28 | 74 | 41 | 54 | 24 | 384 |
| 29 | 75 | 44 | 57 | 16 | 360 |
| 30 | 76 | 38 | 43 | 16 | 348 |