THE ADAPTATION OF GLOBE ARTICHOKE (CYNARA SCOLYMUS L.) TO ANNUAL CULTURE

Thesis for the Degree of Ph. D.
MICHIGAN STATE UNIVERSITY
PANTAZIS ALEXANDROS A. GERAKIS
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Shigeimi Honma
Major professor

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ABSTRACT

THE ADAPTATION OF GLOBE ARTICHOKE (CYNARA SCOLYMUS L.) TO ANNUAL CULTURE

by Pantazis Alexandros A. Gerakis

The possibility of growing globe artichoke (Cynara scolymus L.) as an annual crop in Michigan organic soils was the object of this study.

Seed vernalization by presoaking in water for 48 hours and exposing to temperatures from 35 to 45F for periods longer than 15 days under conditions of adequate moisture and oxygen resulted in a higher percentage of plants which produced buds. Mean daily air temperatures above 65 F immediately after sowing vernalized seed nullified vernalization while temperatures 50 to 65 F for a week had no effect. Temperatures below 50 F vernalized the plants. Fully vernalized plants were not devernalized even when subjected to temperatures higher than 120 F. Seed environment during vernalization was critical. Seed treatment with CCC lowered the effectiveness of vernalization.

The use of gibberellin (gibberellic acid 3) substituted the need of cold treatment in many plants although its effectiveness was influenced by the time of application.

Vernalization and gibberellin had a similar effect on the leaf morphology. Plants vernalized and treated with gibberellin bolted after the formation of the 10th leaf.

An increase or decrease in the nutrient solution concentration of most of the nutrient elements tested affected both the concentration in the leaves and the growth and appearance of the plants grown in solutions. Leaf lobes were more suitable for sampling than the leaf midribs.

Field experiments on a Houghton muck soil showed a marked response of globe artichoke to nitrogen as measured from the fresh plant weight.

Spacing studies showed that a spacing of 2 x 2 feet was feasible for plants grown annually in fertilized and irrigated organic soil since the larger spacings did not increase appreciably the total fresh plant weight and the main bud weight.

By utilizing seed vernalization and by keeping seedlings at optimum temperature and light, the reproductive cycle can be shortened to 6.5 months, i.e., from the beginning of the cold treatment to the harvest of mature seeds.

This study clearly indicated that globe artichoke can be grown commercially as an annual crop on Michigan organic soils.

THE ADAPTATION OF GLOBE ARTICHOKE (*CYNARA SCOLYMUS* L.) TO ANNUAL CULTURE

By

Pantazis Alexandros A. Gerakis

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INTRODUCTION

Globe artichoke (Cynara scolymus L.)* is not a well known vegetable in the United States being grown predominantly in California where 50% is consumed locally. The crop is grown as a perennial and is propagated from cuttings.

The annual culture of artichoke through vernalization in areas where temperatures prevent overwintering of the plant has been practiced in the past by horticulturists in northern Russia. This practice has received little attention by scientists. Recent preliminary studies at Michigan State University suggested that artichoke could be induced to flower in one year by seedling or seed vernalization and that organic soils provided a better environment for growth than mineral soils.

The object of the present study was to investigate methods for growing artichoke as an annual crop on Michigan organic soils. The study was made in three parts. First, the phenomenon of seed vernalization as expressed in artichoke was studied to determine the appropriate technique to induce flowering through the use of natural cold, artificial chilling or growth regulators. Second, the nutritional aspects of

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*For brevity, in this study artichoke will be used instead of globe artichoke.

artichoke adaptation were studied to learn the plant's nutritional requirements on organic soils and the effect of different nutritional environments on the nutrient composition of the leaves. Third, the growth of artichoke at high plant populations was evaluated.

LITERATURE REVIEW

General

The phenomenon of vernalization as commonly understood is the acquisition of a plant of the ability to hasten or promote flowering by an exposure to low temperature. In this study this interpretation of vernalization will be used. Several reviews on the subject have been published since 1960 (21, 42, 70, 84, 86, 107). The early concepts on the related phenomena of vernalization and photoperiodism are discussed in a book edited by Murneek and Whyte (67).

Vernalization is not equally effective at all stages of growth. In the case of the biennial Hyoscyamus niger Sarkar (87) reported that seed and seedlings younger than 10 days could not be vernalized. Vernalization was effective in 10-day old seedlings and increased rapidly up to the age of 30 days. No further increase of the effect of the cold treatment was observed up to 110-day old plants. According to Wellensiek (107), this plant and other biennials, had a "juvenile phase" during which they were unvernalizable. In other biennials like Daucus carota and Lunaria biennis seed vernalization alone did not lead to flowering but needed further plant vernalization at a more mature stage. The two treatments had an additive effect. Studies with Cheiranthus

allionii and Arabidopsis thaliana showed variable sensitivity in different growth stages (5, 70). Generally, sensitivity increased with age (21).

Wellensiek (107) emphasized the variable requirements for seed vernalization as summarized by Napp-Zinn (70) and Chouard (21). Although the optimal temperature for most plants was slightly above 0 C, temperatures as high as 15 C and as low as -8 C have been reported to be effective. Temperature was closely related to the duration of the treatment and it was generally longer with lower temperature. For winter rye (Secale cereale) vernalization for 6 weeks was equally effective at all temperatures between 1 C and 7 C (81).

Grant (31) found in winter wheat that seed vernalization duration from 5 to 8 weeks was more effective than longer or shorter periods. The extremes were 4 days and 110 days (107). Another prerequisite for seed vernalization was that the seed should be sufficiently moist. Although Sen and Chakravarti (90, 92) showed that mustard seed which did not split the seed coat could be vernalized to a limited degree this did not suggest (84) that the embryo remained dormant. Ample supply of oxygen must be provided during vernalization (34). From a practical viewpoint, the vernalized seed at the end of the treatment should show limited sprouting, because sprouted seeds are difficult to handle.

With respect to the locus of vernalization, it was shown (24, 21a, 103) that it was the stem apex. Purvis (79) demonstrated by vernalizing apices from excised embryos that the meristem itself could receive the vernalization stimulus. Wellensiek (106) demonstrated that both isolated leaves and isolated roots of Lunaria biennis could be vernalized and concluded that vernalization took place only when dividing cells were present during the cold treatment. He further suggested that the vernalized condition was transmissable from cell to cell by mitosis. In Lunaria biennis physiological chimera occured consisting of both vernalized and unvernalized parts.

Seed vernalization has been shown to have a marked effect on the morphology of the seedlings. In winter cereals, Thimann and Lane (102) and Hansel (37) noted a shortening of the first leaf. Konovalov (48) showed that the early leaves of vernalized cereals emerged earlier and matured more rapidly than the controls. Purvis and Hatcher (83) found shortening of the lamina in winter rye, reduction of the final length of the coleoptiles and absence of hairs on the first leaf sheaths as a result of the cold treatment. Chakravarti (17) reported that all cold treated plants of Brassica campestris, Eruca sativa, Lens esculenta, Cicer arietinum, Lathyrus odoratus and Pisum sativum, were in a

more mature anatomical condition than unvernalized plants of equal age. In Lolium rigidum and Lolium perenne, vernalization did not influence the growth in the vegetative phase but induced earlier heading and a greater proportion of reproductive tillers. Comparison of vernalized (reproductive) and unvernalized (vegetative) plants showed increased reproductive development to be associated with higher growth rates, lower tillering, and greater weight per tiller. However, a minimum number of leaves had to appear before flowering occured which was not influenced by the vernalization treatment, while the time required for the appearance of the minimum number of leaves could be influenced by environmental factors such as nutrition and temperature (84).

Photoperiod may interact strongly with vernalization. In winter rye, both cold and short day treatments shortened the vegetative phase but a period of long days was necessary for flowering to be completed (81). Vlitos and Mendt (104) experimenting with vernalized spinach seed grown under different photoperiods found that the critical photoperiod necessary for flowering fell from 14 to 8 hours as a result of vernalization. Rappaport and Wittwer (85) demonstrated that the flower promoting effects of seed vernalization in lettuce could be nullified if followed by short photoperiods. In

Cheiranthus allionii, Barendse (4) showed that plants subjected to short days before the cold treatment were difficult to vernalize. Wellensiek (107) differentiated between the effect of photoperiod in seed and plant vernalization. Seed vernalization should be followed by long days to be effective while plant vernalization should be followed by long days or is insensitive to day length. The author concluded that long days always favored vernalization whereas short days could be either harmful or neutral.

Devernalization or the loss of ability to flower after vernalization, could be caused by a variety of factors, namely, by drying and storing the seed, by exposure to continuous high temperature (35 C), and by anaerobic conditions (34, 82). Sen and Chakravarti (91) found that sprouted mustard seed was devernalized by dry storage while unsprouted was not. In winter rye the effectiveness of devernalization by exposure to high temperature was inversely proportional to the duration of the cold treatment (82). When vernalization was achieved, an exposure of the seed to 15 to 20 C for a few days before exposing to 35 C fixed the vernalized state. In Cheiranthus allionii partial devernalization in older plants was effected by exposure to 35 C while 20 C stabilized the vernalization (4). Similarly, the Hyoscyamus niger devernalization could

be effected provided that the exposure to 35 C was made immediately after vernalization. An interval of 3 to 4 days at 20 C was sufficient to fix the vernalized state. In Chrysanthemum morifolium the vernalized condition was stable to high temperature but could be reversed by exposure to low light intensity. Devernalization by weak light was complete at 28 C but did not occur at relatively low temperatures (18 C). Therefore, in this plant devernalization acted as a combination of both high temperature and low light (88, 89).

The variability to the response to vernalization and devernalization processes encountered within species was explained genetically. Different varieties and strains of various plants e.g., of turnips (Brassica campestris) (109), clary (Salvia sclarea) (59), spinach (Spinacia oleracea) (98, 47), cabbage (Brassica oleracea var. capitata) (68) and Cheiranthus allionii (5), showed unequal sensitivity to cold treatment. Detailed genetic studies on the mode of inheritance of the cold requirement were made in many plants, e.g., winter rye (78), winter wheat (35) and peas (2).

Vernalization has failed to achieve the practical importance in crop production anticipated by the very early workers in the field. Vernalization (and devernalization) was used successfully as a tool for two main purposes. First,

to shorten the reproductive cycle for accelerating breeding programs e.g., carrots (Daucus carota) (49,25), lentils (Lens esculenta) (95), cabbage (69) spinach (45, 46, 47), beets (Beta vulgaris) (6), and second to select against high sensitivity to vernalization, e.g.,celery (Apium graveolens) (44), onions (Alium cepa) (50), lettuce (Lactuca sativa) (105).

The role of auxins in the flower induction process has been established in many plants. Thimann and Lane (102) accelerated flowering by soaking various seeds with synthetic auxins. Hatcher (41) suggested that auxin was not involved in the vernalization process of winter rye. Clark and Kerns (22) effected acceleration of flowering in pineapple whereas Green and Fuller (32) found retardation in petunias. Leopold and Guernsey (55) found that acceleration or retardation of flowering was an interaction between concentration and temperature. Chakravarti and Pillai (18) found acceleration of flowering in turnips by spraying seedlings with IAA, IBA, NAA, 2,4-D and TIBA, and retardation when the same auxins were used to soak vernalized or unvernalized seed. Kagawa (46) noted acceleration of flowering by treating spinach seed with NAA. Chakravarti (20) reported positive results for mustard when seed was partially vernalized and no effect when the seed was fully vernalized. Burg and Burg (11)

demonstrated the association between auxin treatment and ethylene formation in relation to the flowering of pineapple.

Gibberellin-like substances were found to be closely related to flowering and vernalization. The discovery by Lang (52) that repeated applications of gibberellin could induce flowering in the cold-requiring biennial Hyoscyamus niger was followed by work with other biennials (9, 14, 25, 30, 53, 57, 99, 111). This work was reviewed by Wittwer and Bukovac (115) who concluded that gibberellin accelerated flowering in cold-requiring biennials only when the biennial characteristic was very weak or when the photoperiodic requirement for flowering was satisfied, they were maintained at temperatures slightly above those inductive for flower formation, they were treated after the cold requirement was partially satisfied. Some varieties of Daucus carota, Digitalis purpurea and Matthiola incana were exceptions. With truly biennial cold-requiring sugar beet varieties, gibberellin was ineffective unless the plants were simultaneously or subsequently grown under long photoperiod, temperatures were maintained within 2 to 3 C of those normally inductive and repeated doses of gibberellin were applied. Extensive stem elongation preceded flower formation in other species. Wittwer and Bukovac (112) reported that most cold requiring biennials of economic importance followed the pattern of sugar beet regarding the response to gibberellin.

Work with other plants, annuals and biennials, demonstrated that gibberellin could act additively to other inductive factors like seed vernalization and photoperiod (10, 5). In turnips gibberellin was less effective in inducing earliness than vernalization (19).

Gibberellin augmented the effect of vernalization in inducing earliness in the dwarf Telephone pea (64) but did not influence the vernalizing effect in Brassica oleracea (69).

The variability of response to applied gibberellins and especially the lack of response of some plants was partly attributed to the specificity of the different gibberellins (61) for some gibberellins caused flower initiation and stem elongation, others only stem elongation and still others neither. Cajhahjan and his co-workers (12, 13) established that vernalization increased the amount of endogenous gibberellin-like substances which were found previously to exist in the plant (108).

Some other growth regulators which were shown to be associated with the promotion of the flowering process were maleic hydrazide (110), 2,4-D and TIBA (18). Other chemicals like CCC (chlorocholine chloride) were shown to retard the growth of many plants primarily among the Dicotyledonae (15)

and accelerate flower initiation. Zeevart and Lang (116) found that application of CCC in Bryophyllum daigremontianum suppressed both the stem-elongating and the flower-inducing effects of short photoperiods by decreasing the level of the physiologically active gibberellin below that which was normally required for flower initiation and stem elongation. Guenther (35) noted an inhibitory effect of CCC on the development of vernalized winter and summer cereals which was more pronounced when CCC was added before cold treatment and decreased with the delay in CCC addition.

Artichoke

One of the earliest reports on artichoke vernalization was by Panov (72) who described the annual culture of the plant in the Leningrad area during the first part of this century. The vernalization technique used consisted of exposing sprouted seed (with a sprout 1 to 1.5 cm long) to snow in January for 10 to 12 days followed by sowing in the greenhouse and transplanting in the field in May. Seed harvested in September was not mature. Panov suggested the perennial culture of artichoke in the warmer southern regions of USSR and recommended the restoration of the annual culture from seed in the northern regions. Shilova (94) reported an

optimum vernalization requirement of 0 to 5 C for 8 to 12 days and an optimum temperature for growth and development of the plant of 18 to 28 C. The bolting percentage from vernalized seed for the two Russian varieties was 84 to 90%. Bonnet (7) subjected pregerminated seed of the variety Gros Vert de Laon and Macau de Montauban (with a sprout 1 mm long) to 1 C for 15, 30, and 45 days and found an advancement in the reproductive stage by 2 months, a 30-day period being the optimum vernalization duration, and pointed out the usefulness of this method to shorten development and obtain seed in a year. He also reported that dry seed subjected to cold was not vernalizable. Tavernetti (101) and Sims (97) mentioned the possibility of propagating from seed but rejected it as impractical due to the low quality of the buds. The idea of growing artichoke commercially from seed in Michigan organic soils was initiated by Markarian at Michigan State University. Preliminary results (40) indicated that artichoke grown on organic soil from vernalized seed could be a commercially promising vegetable crop. Seed and plant vernalization was successful in early sowings, whereas, late sowings were devernalized.

No detailed study has been published on the effect of photoperiod after the cold treatment on flower induction and

development of artichoke. Harwood and Markarian (40) observed the effect of day length during the vernalization of young plants (after vernalization all plants grew under long days) and reported that bolting increased as day length during plant vernalization increased from 13 to 18 hours. They noted that an 8-hour day length during plant vernalization produced more bolters then the 13- and 18-hour periods. The authors concluded from this observation that Purple Early could be termed a facultative short day variety. Pochard (74) believed that there is no evidence that day length plays an important role in the induction of bolting, at least on the cuttings, because in the southern regions of France the main crop is grown during the winter while in the northern (Brittany) it is in June and July.

The effects of maleic hydrazide and gibberellin on artichoke were studied by Bonnet (7). He found that sprays of 500 ppm maleic hydrazide were toxic to plants while lower concentrations had no effect on the suckers. Also, gibberellin applications of 0 to 20 ppm did not promote the earliness of bolting. Pochard (73) noted marked structural changes especially on the leaves and 5 to 15 days earlier appearance of bolters as a result of repeated gibberellin applications. The alteration gibberellin caused on the buds made them, according to the author, unmarketable. It must be pointed out that both of the above studies concerned perennial culture.

All the available information on the nutrient requirements of artichoke pertains to perennial culture on mineral soils. Foury (29) reported that artichoke could do well in a great variety of soils. The author quoted Simonneau's opinion (96) that in Algeria artichokes did well on heavy grey clays covered by a halophilous vegetation and with a NaCl content of 0.8 to 3.0%. In France, growers prefer "terres motteuses", that is, soils sufficiently heavy and of good structure. Mercuri (60) observed that sandy soils were not particularly good for the variety Castellamare. Bonnet (7) found no effect of added mineral nutrients on earliness and yield of buds. Barbut (3) noticed no fertilized effect on the number of buds harvested but only a positve effect of potassium on mean bud weight. Millela (62) reported an effect of potassium on earliness. He also found increased yields from 300 kg/ha ammonium sulphate, 700 kg/ha superphosphate and 300 kg/ha potassium sulphate. Polano (75) obtained the highest yield from nitrogen applied at several dosages within the year. Sims et al. (97) reported that in California, manure was found very essential so that many growers apply 10 to 12 tons of manure per acre in addition to nitrogen from commercial fertilizers. Nitrogen is sometimes applied through irrigation water between May and November at a rate of

30 lb/acre of nitrogen per month. With regard to other nutrients Foury (29) referred to the special role of magnesium in Brittany and the possibility that certain bud deformities encountered in the Southeast of France may be due to boron deficiency. Eaton (27) sampled leaf laminae from plants grown in sand culture and found boron deficiency symptoms at 38 ppm while normal plants contained 112 ppm. Toxicity symptoms were associated with 238 to 1358 ppm. No values for other nutrients have been reported.

VERNALIZATION STUDIES

Effect of Vernalization Temperature and Duration

Procedure

Two experiments were sown on May 6 to determine the optimum vernalization temperature and duration, one at Stockbridge, Michigan and the other in the Michigan State University Muck Experimental Farm.

The Stockbridge experiment compared four temperatures, 32, 35, 40 and 45 F. Seed was presoaked for 4 days and placed in punctured bags with moist peat. The duration was 3 weeks. The design was a randomized block with four replications.

The Muck Farm experiment tested the same four temperatures together with four vernalization durations (7, 14, 21 and 28 days). Seed was presoaked for 2 days. A split plot design was utilized with four replications. The main treatments were durations and the subsidiary temperatures.

Both experiments had single row plots 30 feet long with 15 plants per row. Rows were spaced 36 inches apart. The variety Violetto di Bologna from Ansaloni, Bologna, Italy was used in all experiments to be discussed in this study. It must be pointed out that the seed was ununiform genetically.

Mean daily air temperatures for Stockbridge and the Muck Farm for the period April to October 1967 are shown in the Appendix I. Soil temperatures at a depth of 3.5 inches taken at the Muck Farm were 46 F to 52 F for April, 48 F to 52 F from May 1 to May 15, 50 F to 60 F from May 16 to May 29 and 60 F to 68 from May 30 to June 5.

Observations on bolting were taken once or twice a week. A plant was noted as a bolter the day when it showed a "button" in the center of the rosette.

Multiple comparisons between treatment means were based on Duncan's Multiple Range Test.

Results and Discussion

At Stockbridge, vernalization temperatures had no effect on bolting or bud weight (Table 1).

The experiment at the Michigan State University Muck Farm indicated that seed vernalization temperatures of 35, 40 and 45 F were more effective in inducing bolting than 32 F (Table 2). There were no differences between 35, 40 and 45 F. Seed vernalized for 14, 21 and 28 days did not differ in the number of bolters. Vernalization period of 7 days produced fewer bolters than the longer durations.

The low effectiveness of the 32 F temperature may be due to the slower germination compared to the higher temperatures.

Table 1. The effect of vernalization temperature on bolting and bud weight of globe artichoke (Stockbridge)

Temperature (°F)	Bolting Percentage	Mean Bud Weight (g)	
		Main	Laterals
32	32.3	144.5	64.7
35	38.0	117.8	78.8
40	24.2	182.5	88.1
45	28.1	135.3	80.4

Table 2. The effect of vernalization duration and vernalization temperatures on bolting percentage and mean weight of the main bud of globe artichoke (Muck Farm)

	Bolting Percentage	Mean weight of the Main Bud (g)
Vernalization Durations (days)		
7	12.8 a[1]	75.6 a
14	26.5 b	112.2 a
21	23.9 b	90.5 a
28	28.1 b	93.5 a
Temperatures (°F)		
32	15.6 a	88.3 a
35	20.3 ab	97.6 a
40	22.9 ab	95.7 a
45	32.3 b	89.6 a

[1]Values followed by uncommon letters are significantly different at the 0.05 level.

The higher the temperature the faster the growth of the embryo and, since dividing cells are the locus of the vernalization stimulus (106) the higher temperatures were more effective in vernalization. The reason no temperature effect was observed in the Stockbridge experiment where seed was presoaked for 4 days instead of 2, may have been the more advanced germination stage of the seed prior to exposure to the cold treatment.

Effect of Duration of Cold Treatment, Sowing Date and Gibberellin

Procedure

The effect of sowing dates on vernalized and unvernalized seed and gibberellin treatment of plants grown from unvernalized seed was studied in a factorial experiment conducted at Stockbridge. There were 10 main treatments consisting of sowing dates starting April 1 and weekly thereafter until June 3 and 10 sub-treatments consisting of 8 seed vernalization durations (2, 4, 7, 15, 21, 28, 35 and 42 days at 40 F), one gibberellin treatment on plants grown from unvernalized seed and the control.

Each sub-plot was a single row 25 feet long with 12 plants per row. Rows were spaced 36 inches apart. Seed was pre-soaked for 48 hours and placed in punctured plastic bags filled

with peat moist enough to let water through fingers on gentle pressure. Seed removed at the end of 2-, 4-, and 7-day treatments did not show any splitting of the pericarp; the 15-day treatment had about one third of the seed showing signs of slight split tips; and 21- and 28-day treatments produced sprouts less than 3 mm long while the 35- and 42-day treatments produced sprouts ranging from 3 to 10 mm long. Due to poor soil conditions, sowing for the April 1, 8, and 15 dates were made in 2.5 inch peat pots filled with organic soil and were placed in a cold frame. The potted plants of April 1 and 8 were transplanted to the field on April 29 while those of April 15 were left unplanted by error and dried out for 48 hours before they were planted. All seed sown in the peat pots had germinated prior to transplanting. Sowing after April 22 was made directly in the field.

Initial gibberellin applications were made for all sowing dates on July 6, except for the last two of May 27 and June 3 which began on July 14, and were continued weekly until the end of August. One hundred ppm of the potassium salt of gibberellic acid -3 was sprayed to runoff on the rosette. The same formulation was used throughout this study. Observations were made once or twice a week for bolters, bud weight, and morphological characteristics for buds and plants until October 12 when the experiment was terminated due to frost.

The morphological characteristics were rated on a scale of 1 (smallest) to 10 (largest) for plant size and 5 (maximum length) to 1 (spineless) for leaf spines, 5 (fully purple) to 1 (fully green) for bract color and 5 to 1 for leaf lobation (Figure 1) bract shape (Figure 2) and bud firmness (Figure 3).

Non-orthogonal comparisons were made on treatments with analysis of variance.

Results from the April 15 sowing date were not included since they were erratic due to the very uneven growth. Since vernalization durations of 2 to 15 days and 21 to 42 days gave similar results, they were grouped as "short" and "long" durations, respectively.

Results and Discussion

Gibberellin treated plants gave higher bolting percentages compared to other treatments for all sowing dates (Figure 4). Gibberellin induced more than 90% bolting when applied on plants sown from May 10 to May 20 (neutral temperatures) and 40% on plants sown under the devernalizing conditions of May 27 and June 3 (Figure 4). These data showed that the effect of gibberellin on bolting of artichoke was additive. A comparison of the bolting percentages between plants (grown from unvernalized seed) treated with gibberellin

Figure 1. The rating of leaf lobation, 5 to 1 (left to right)

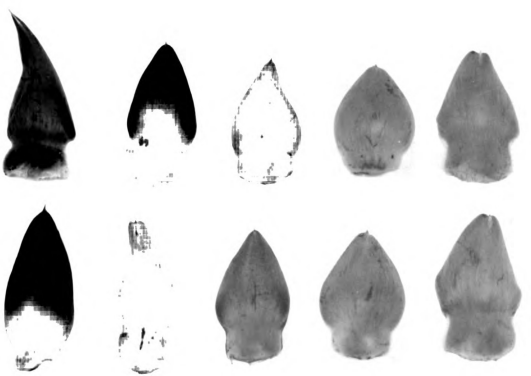

Figure 2. The rating of bract shape, 5 to 1 (left to right columns)

Figure 3. The rating of bud firmness, 5 to 1 (left to right columns)

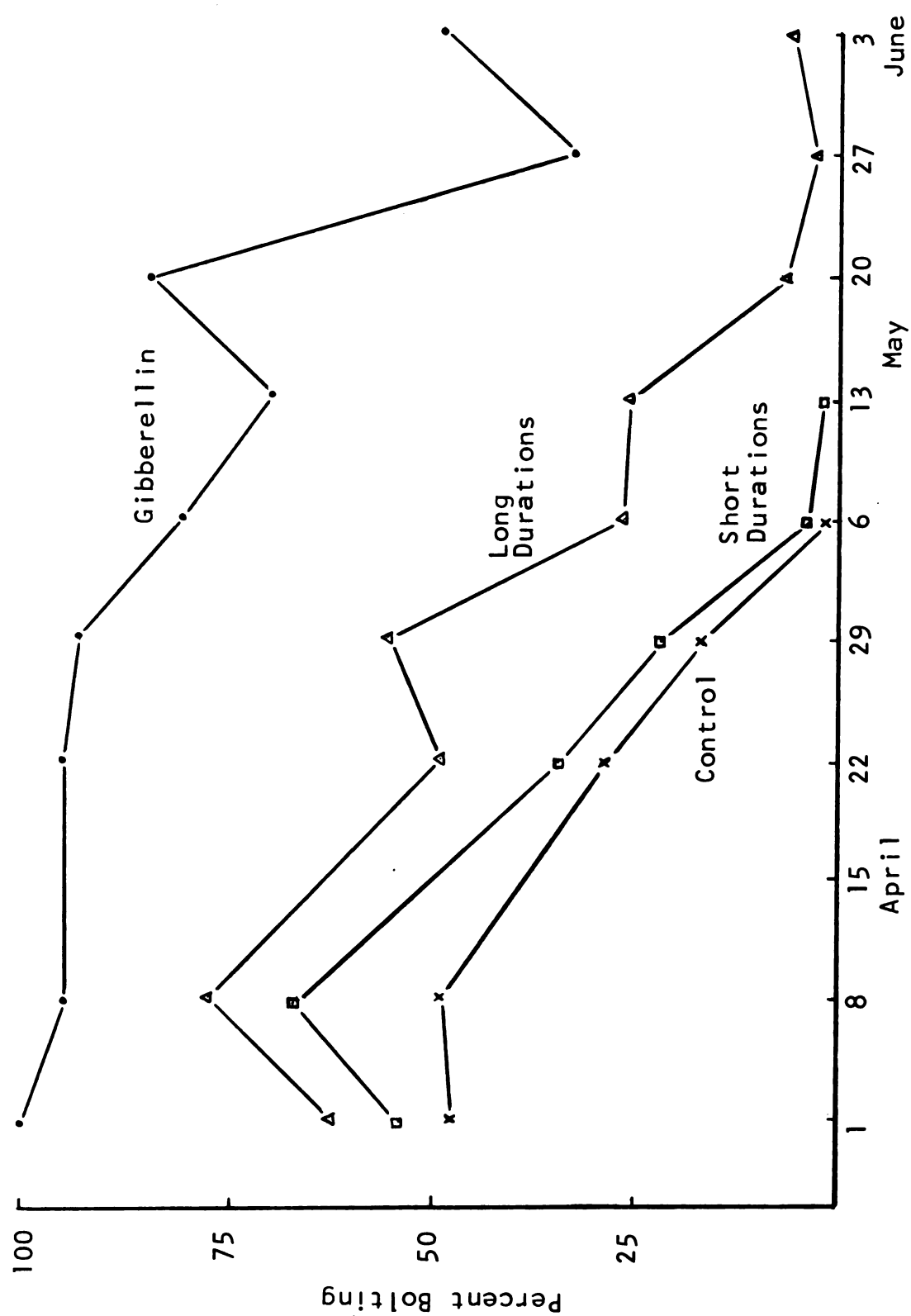

Figure 4. The effect of sowing dates, duration of cold treatment and gibberellin on bolting of globe artichoke.

and plants (grown from unvernalized seed) untreated suggested that gibberellin acted not only additively to the cold treatment but it substituted for the cold requirement in about 40% of the population (Figure 4). Therefore, artichoke belongs to the group of plants such as Daucus carota, Digitalis purpurea and Matthiola incana (115) which have varieties where gibberellin could substitute for a cold treatment.

No differences were found between the unvernalized lots and those resulting from short periods of cold no matter when they were sown indicating that in artichoke, as in most plants (84, 107) the embryo must at least split the pericarp to be vernalized.

Seed treated with long periods of cold produced the same number of bolters as seed treated with short periods for all the April sowing dates and for the May 27 and June 3 sowing dates. A higher number of bolters was obtained from the long durations for the May 6, 13 and 20 sowing dates than from the short durations. It appeares that temperatures below 50 F induced flowering. Temperatures between 50 F and 65 F did not induce flowering but favored flower initiation of induced plants. Temperatures above 65 F seem to nullify the flower induction if they follow immediately after the cold treatment.

This devernalizing value of 65 F is much lower than the value of 95 F reported for winter rye (82), Hyoscyamus niger (87) and Cheiranthus alionii (5).

The data also suggest that under the seed vernalization conditions described, the threshold for bolting was a cold period between 15 and 21 days.

Although devernalizing temperatures followed the June 3 sowing, a few bolters were observed from the vernalized seed indicating the presence of genetic variability to bolting sensitivity in the population used which is in agreement with studies with other plants (109, 98, 47, 68, 44, 5).

No differences were found among long and short periods of cold treatments while plants treated with gibberellin required an average of about 50% more days to bolt compared to the cold treatments (Table 3, and Figure 5). This does not suggest that gibberellin delayed bolting but that gibberellin was applied at an advanced stage of growth. Days to bolting generally decreased as the sowing season progressed due to the progressively increasing temperatures which caused the acceleration of growth.

Leaf counts on a random number of plants showed that probably 10 true leaves was the minimum number required before the buds appeared.

Table 3. The response of globe artichoke to sowing dates, seed vernalization durations and gibberellin treatment of plants.

	Days to Bolting	Mean Weight(g)		Mean Number of Laterals Per Bolted Plant
		Main Bud	Laterals	
Sowing Dates				
April 1	111	90.2	68.9	2.83
April 8	105	78.4	63.4	2.89
April 22	98	112.7	70.1	2.46
April 29	90	106.6	69.8	2.79
Vernalization Durations and Gibberellin				
Control	97	87.0	68.3	2.72
2 days	98	103.2	70.3	2.27
4 "	99	122.4	65.4	2.99
7 "	94	83.0	66.0	3.29
15 "	98	100.6	64.0	3.32
21 "	91	109.2	77.2	2.99
28 "	94	103.5	70.0	3.26
35 "	90	88.6	67.6	2.99
42 "	91	79.5	63.7	2.74
Gibberellin	158[1/]	93.3	68.4	0.89[1/]

[1/] F value for difference between this treatment and others is significant at 0.01 level.

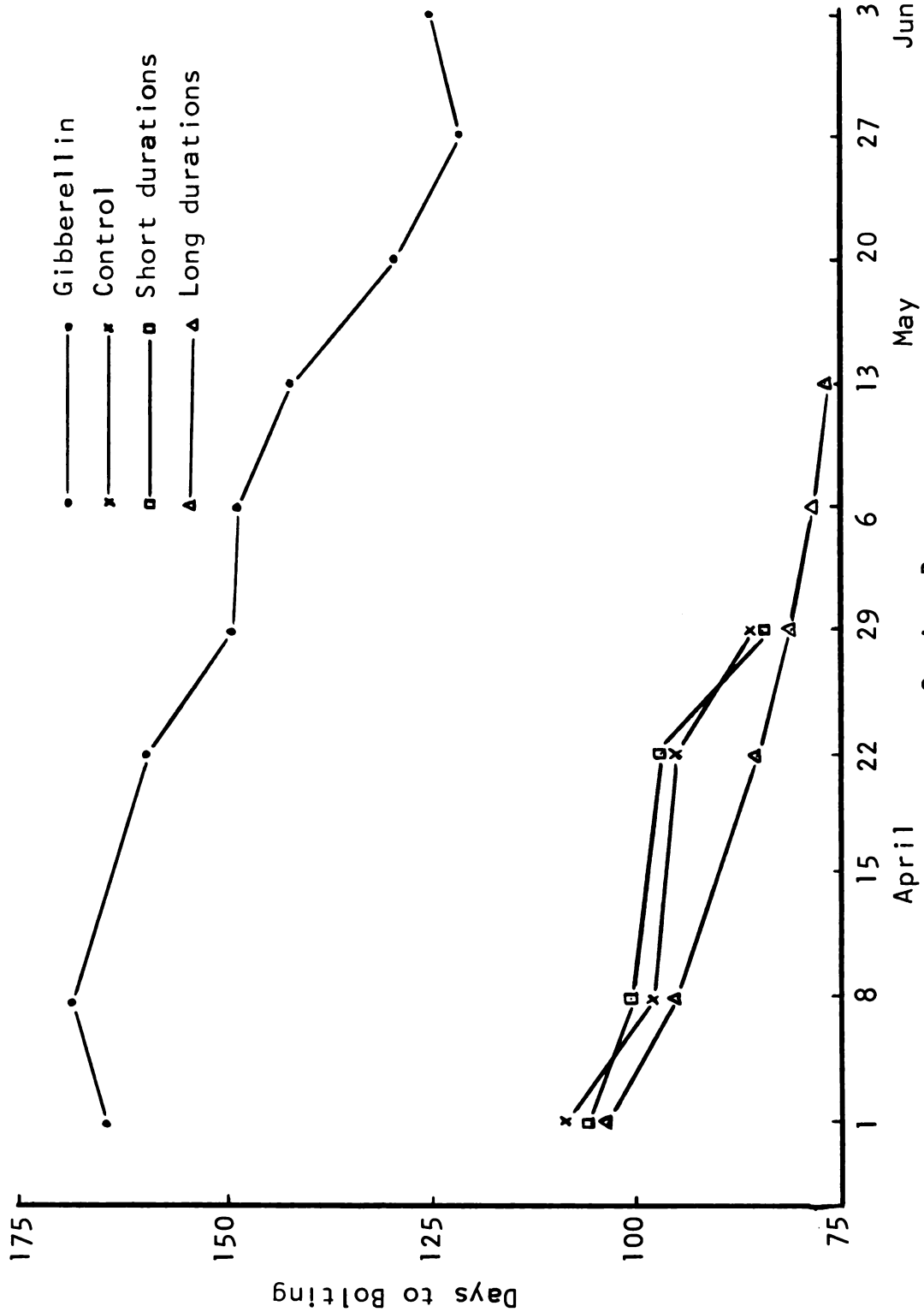

Figure 5. The effect of sowing dates, duration of cold treatment and gibberellin on the earliness of bolting of globe artichoke

No differences were found between treatments for the weight of the main and the lateral buds indicating that these characteristics were not influenced by the cold treatment and gibberellin.

Gibberellin treated plants had a lower number of lateral buds per bolted plant as compared to other treatments. This was because this group of plants bolted late and since the experiment was terminated October 12, it was not possible to observe the lateral buds.

Correlations between various morphological characters and plant responses showed that the degree of leaf lobation could be a sign of the reproductive maturity of the plant (Table 4). The appearance of some unlobed leaves preceded or accompanied the appearance of the bud. Regardless of vernalization, the first true leaves were unlobed. Thereafter, the number of lobed leaves produced before bolting and the degree of lobation appear to be associated with the effectiveness of vernalization. Non-bolters produced only lobed leaves after the first four. Although it has been shown in Ranunculus hirtus (28) and Armoracia rusticana (71) that several environmental factors influence the reversion to, or the appearance of, juvenile type leaves, the explanation that in artichoke the degree of lobation is strongly influenced by vernalization is supported by the work of

Table 4. The relationship between plant and bud characteristics to earliness of bolting of globe artichoke (simple linear correlation coefficients).

	Leaf Lobation	Size of Spines	Bract Color	Bud Firmness	Bract Shape	Plant Size	Weight of Main Bud	Weight of Lateral Bud
Size of spines	.047							
Bract color	.327**	.097						
Bud firmness	-.388**	.032	-.253**					
Bract shape	-.003	.457**	-.114	.117				
Plant size (on August 21)	.656**	.066	.294	-.308**	-.108			
Weight of main bud	.123	.086	.227**	-.019	-.109	.254*		
Weight of lateral bud	-.177	.128	-.065	.116	-.051	.089	.180	
Days to bolting	.731**	.143	.335**	-.460**	-.070	.613**	.172	-.189

*Significant at the 0.05 level
** Significant at the 0.01 level
*** Significant at the 0.001 level

Chakravarti (17) who reported for several species that cold treated plants were in a more mature anatomical condition than unvernalized plants of equal age. The association between the effects of gibberellin-like substances and vernalization was suggested in artichoke by the decrease in leaf lobation induced by gibberellin sprays on unvernalized plants. Pochard's report (73) on the morphological effects of gibberellin on artichoke is in agreement with the present results.

The correlation between days to bolting and plant size agrees with Harwood and Markarian (40) who noticed that late and non-bolters continued their vegetative growth until the end of the growing season. Plant size had some association with main bud weight but no association with lateral bud weight.

Effect of Growth Regulators

Procedure

Two experiments were carried out at the Muck Farm in 1967 to find out whether gibberellin and various other growth regulators could replace the cold treatment. The first experiment studied the effects of seed treated at various concentrations of gibberellin (GA), NAA, ALAR, maleic hydrazide (MH) and N^6BA on bolting. Seed was soaked with the

above chemicals for 3 days in Petri dishes at room temperature. This seed was sown in the field on June 1 together with seed soaked in distilled water for the same period, vernalized seed (40 F for 4 weeks) and dry seed (control).

In the other experiment different concentrations of gibberellin, NAA, N^6BA, 2,4-D, TIBA and calcium carbide powder were applied on unvernalized plants. Sowing was carried out on May 30. The application of chemicals began on July 28 (when plants had six to eight leaves) and was followed at weekly intervals until the middle of September. Application was by spraying to runoff on the rosette for the regulators and by placing one teaspoonful per plant on the rosette of calcium carbide. Multiple comparisons between treatment means were based on Tukey's w-procedure.

Results and Discussion

In the experiment studying the effect of seed treatment with growth regulators no plants bolted until the middle of October. Emergence percentages showed that the highest concentrations of gibberellin, NAA and maleic hydrazide depressed emergence compared to the control whereas the low and intermediate concentrations of all chemicals enhanced emergence by increasing both the speed of emergence and the final emergence (Table 5). Soaking in water had no effect

Table 5. The effect of presoaking globe artichoke seed with growth regulators on emergence.

Treatments		Days after sowing				
Chemicals and Concentrations (ppm)		8		12		16
		Emergence Percentage	Percent of Final	Emergence Percentage	Percent of Final	Final Emergence Percentage
GA	10	18	35	42	81	52
"	100	24	41	50	86	58
"	1000	20	54	33	89	37
"	5000	4	20	13	65	20
NAA	10	29	49	52	88	59
"	100	26	43	48	79	61
"	1000	1	14	5	71	7
Alar	10	13	30	49	100	49
"	100	11	25	40	91	44
"	1000	7	22	25	78	32
MH	10	14	25	45	82	55
"	100	14	26	47	89	53
"	1000	3	15	15	75	20
N^6BA	1	9	19	37	79	47
"	10	9	24	31	84	37
"	100	7	17	31	76	41
Water soaked		15	27	47	85	45
Vernalization		28	49	52	91	57
Control (dry)		8	23	24	71	34
						W.05=23 W.01=27

while vernalization had the same enhancing effect as the low and intermediate concentrations of the chemicals, suggesting a probable association between vernalization and growth regulator effect.

In the experiment studying the effect of growth regulators on plants two successive applications of 2,4-D at 100 ppm killed the plants while a lower concentration produced serious malformations and hardening of the leaf tissue similar to the symptoms described for artichoke by Prota (75). All gibberellin concentrations induced marked chlorosis and the leaves became more erect. Leaf tissue nutrient analysis data from gibberellin treated and untreated plants indicated a decrease in the nutrient composition due to gibberellin for all nutrients except N and P (Table 6). This decrease could be attributed to the sudden growth acceleration induced by the gibberellin treatment. The decrease was greater for Mn, Na, Ca and Cu.

The reason gibberellin did cause bolting to the plants grown at Stockbridge whereas it was ineffective on the Muck Farm plants - although both groups of plants were sown on almost the same date - could be the earlier treatment of the plants grown at Stockbridge and the difference in maximum daily temperatures between the two locations for September which were 72.1 F for Stockbridge and 83.2 F for the Muck Farm.

Table 6. The effect of repeated gibberellin applications on the nutrient composition of globe artichoke leaf tissue.

Sample[1] Number	Treatment	N %	P %	K %	Ca %	Mg %	Na ppm	Mn ppm	Fe ppm	Cu ppm	B ppm	Zn ppm	Al ppm
1	Control	3.44	0.572	4.30	1.79	0.25	730	40	159	6.5	41.7	10	88
2	Gibberellin	3.40	0.447	3.50	1.24	0.18	381	20	144	5.1	35.4	9	69
Difference (%)		-1	-22	-19	-31	-28	-48	-50	-9	-22	-15	-1	-22
3	Control	3.64	0.438	4.60	1.72	0.24	590	43	254	7.9	46.0	26	107
4	Gibberellin	3.70	0.478	3.60	1.40	0.21	422	28	183	5.8	40.4	10	82
Difference (%)		+1	+9	-22	-19	-12	-28	-35	-28	-27	-12	-61	-23
Mean Difference (%)		0	-7	-20	-25	-20	-38	-43	-19	-25	-14	-32	-23

[1]Each sample is composite of 10 plants.

Conditions During Vernalization and Effect of Gibberellin

Procedure

Results obtained from a previous experiment showed that the critical period for flower induction of artichoke through vernalization and use of gibberellin was the period of germination.

Although the maintenance of proper seed environment during vernalization was always a point of special attention some of the variability noted in the previous experiments may have been due to undetected differences in seed environment such as moisture and oxygen.

An experiment to study first the effect of low oxygen environment during seed vernalization, second the effect of a growth retardant and, third the importance of germination stage was conducted in the greenhouse. Gibberellin treatment of plants was also included to test the interaction with the above factors. Plants were grown at a temperature of 50 F to 65 F which a previous field trial indicated to be neutral regarding vernalization and devernalization.

The factors and treatments were:

Seed environment during vernalization

1. Normal oxygen environment
2. Low oxygen environment
3. Normal oxygen environment plus CCC (Chloro-choline chloride)

Germination stage at sowing

1. Sprouted seed
2. Unsprouted seed

Gibberellin treatment of plants

1. No gibberellin
2. Gibberellin

The treatments were arranged in a randomized block design with 12 treatment combinations replicated twice. Each treatment combination consisted of six 1-cubic foot pots filled with organic soil. The seed was soaked for 48 hours in room temperature and were placed in a punctured open plastic bag with moist peat so as to insure good aeration (for the normal oxygen treatment) while the low oxygen treatment seed was placed in a 500 ml Pyrex flask half filled with moist peat. The flask was flushed with nitrogen for 5 minutes and sealed. In the CCC treatment the seed was placed in a punctured open plastic bag with peat but instead of water, a solution of 100 ppm of CCC was used to moisten the peat. All three seed

lots were then placed at 40 F temperature for 25 days. At the end of this period, seed from each treatment was divided into sprouted (with a sprout 5 to 10 mm long) and unsprouted (with slightly split pericarp) lots and was sown on November 29.

The temperature of the greenhouse for the first 4 weeks was kept between 50 F and 65 F. Gibberellin sprays at 100 ppm on the rosette to runoff began on February 19 and continued weekly to April 8.

Non-orthogonal comparisons were made on treatments with analysis of variance.

Results and Discussion

Plants from sprouted seed grew faster than plants from unsprouted seed as was shown by a visual size rating made February 11 before gibberellin application started (Table 7).

Bolting percentage data indicated an interaction between seed environment and gibberellin treatments (Figure 6). Gibberellin increased bolting percentage only when applied to plants grown from normally vernalized seed while it was ineffective on plants from seed vernalized at low oxygen environment or from seed treated with CCC. Vernalization under normal oxygen did not exhibit greater effectiveness

Table 7. The effect of seed environment, germination stage and gibberellin on bolting, earliness and bud and plant characteristics of globe artichoke

	Bolting %	Days to Bolting	Weight per plant (g)		Weight of main bud (g)	Stalk Length (cm)	Plant Size Ratings on February 11 (before GA sprays)
			Fresh	Air-dry			
Seed environment during vernalization							
1. Normal oxygen	64.8*	113	60.6	14.1	54.7	26	4.4
2. Low oxygen	45.5	117	58.9	13.7	54.3	22	5.3
3. CCC	30.5	123	69.5	15.7	50.7	19	5.1
Germination stage at sowing							
1. Sprouted seeds	49.8	116	57.6	13.5	53.4	23	5.6*
2. Unsprouted seeds	43.9	119	68.4*	15.5	53.0	22	4.3
Gibberellin treatment of plants							
1. No gibberellin	35.4	106	62.8	14.4	69.0*	27*	
2. Gibberellin	58.4*	130**	63.2	14.7	37.4	18	
Interactions							
1. Seed environment x germination stage		*	*				
2. Seed environment x gibberellin treatment	*	*					

* Significant at the 0.05 level.
** Significant at the 0.001 level.

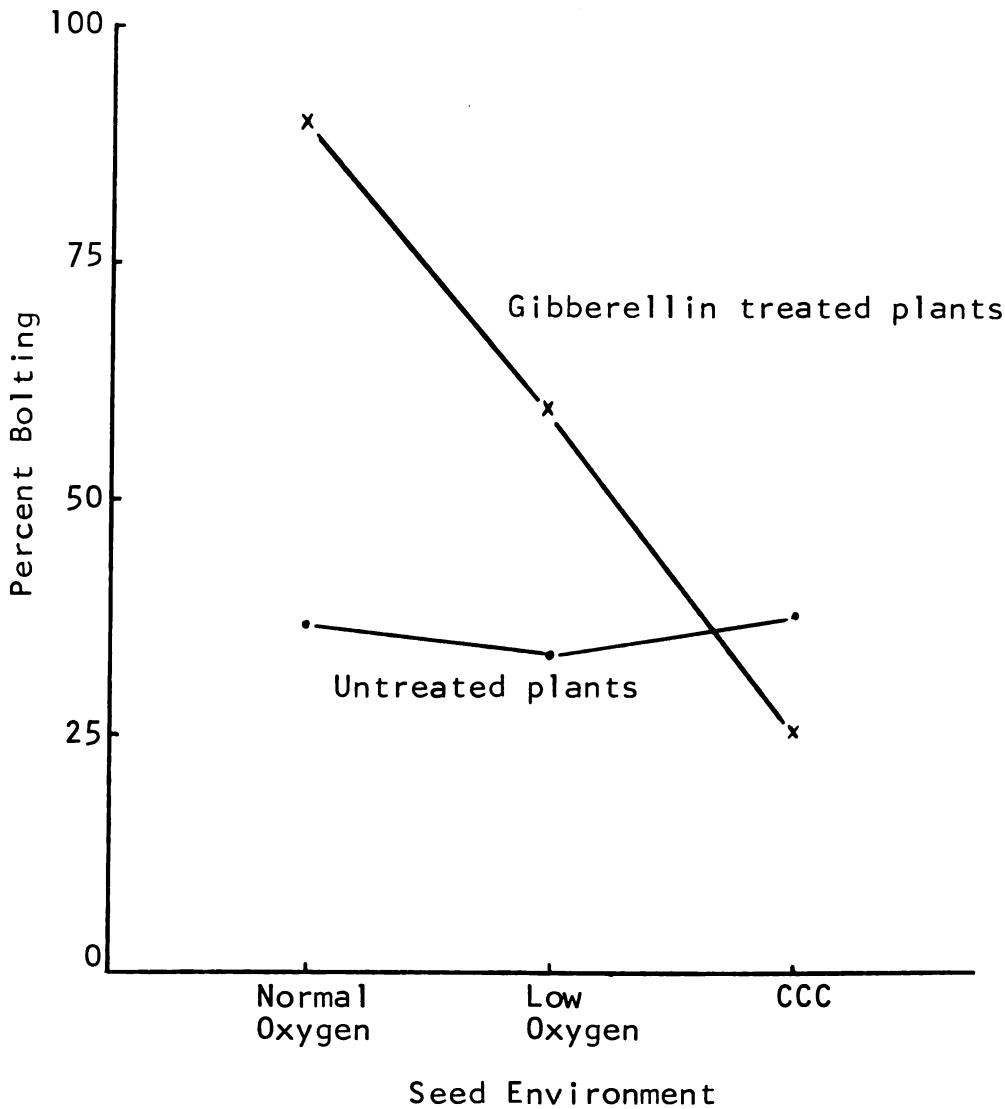

Figure 6. The effect of seed environment during vernalization and gibberellin treatment of plants, on bolting of globe artichoke.

compared to seed vernalized under low oxygen and vernalized with CCC except when these plants were subsequently treated with gibberellin. These results do not agree with the principle of ample supply of oxygen as a basic prerequisite for vernalization (34) probably because the low oxygen level in this experiment was not low enough to prevent vernalization. Nonetheless, the inhibitory effect of low oxygen became evident after treating the plants with gibberellin since gibberellin was more effective on plants grown from normally vernalized seed than on plants grown from seed vernalized under low oxygen environment. The interaction of seed environment treatments with gibberellin indicated that normal seed environment produced plants nearer to the threshold for bolting, compared to the other seed environment treatments. The interaction is another manifestation of the additivity of the vernalization and gibberellin effects encountered previously in this study.

Gibberellin treated plants from low oxygen and CCC treated seed took longer to bolt than treated plants from normally vernalized seed (Figure 7). Untreated plants bolted simultaneously indicating again that both low oxygen environment and CCC during the vernalization process had a depressing effect on flower induction. Another interaction for days to

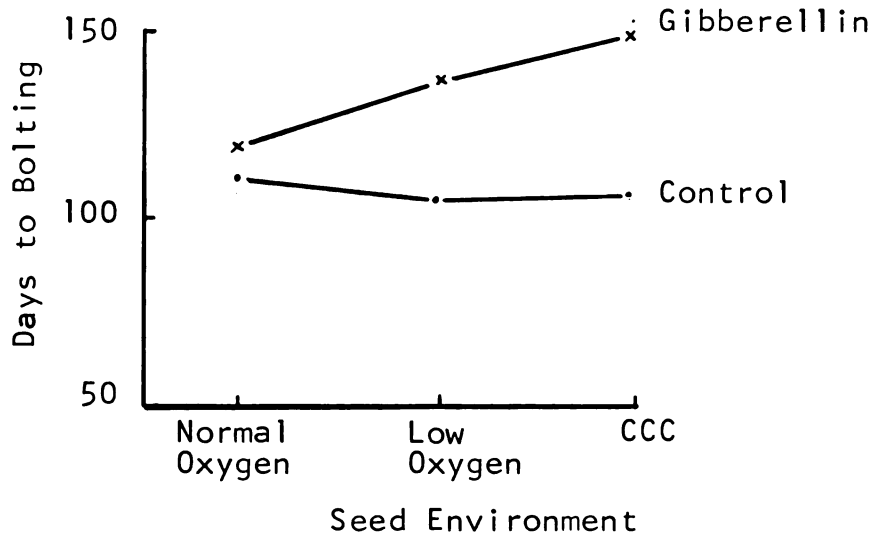

Figure 7. The effect of seed environment during vernalization and gibberellin treatment of plants on earliness of bolting of globe artichoke.

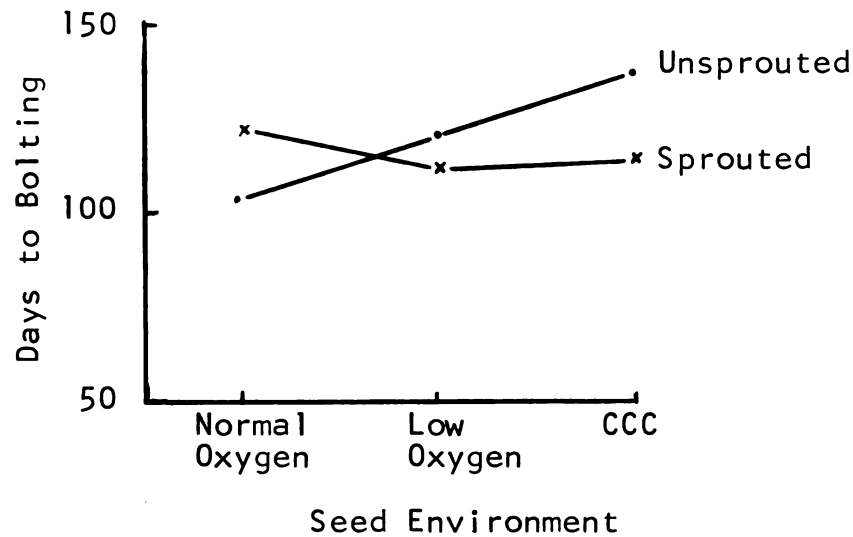

Figure 8. The effect of seed environment during vernalization and germination stage at sowing on earliness of bolting of globe artichoke.

bolting was found between seed environment and germination stage (Figure 8). Irrespective of the seed environment during vernalization, plants from sprouted seed bolted simultaneously. Unsprouted seed vernalized under normal oxygen environment bolted earlier than plants from unsprouted seed vernalized under low oxygen and under CCC environment indicating that the longer the sprout the larger the quantity of dividing cells, the higher the production of flower inducing substances, therefore the earlier the bolting. These results are in agreement with other workers who demonstrated the importance of dividing cells as a prerequisite for vernalization (79, 106).

The inhibitory effect of CCC on bolting could be explained by considering this substance to be an antimetabolite in the flower induction process (16) rather than as a specific antagonist for endogenous gibberellins.

No matter how effective the various treatments in inducing bolting and earliness, leaf counts confirmed the previous observation that the minimum number of true leaves prior to bolting was 10.

No differences between treatments were found for fresh and air-dry weights per plant.

Plants treated with gibberellin produced smaller main buds compared to the control, which is in agreement with the findings of Pochard (73) in artichoke but does not agree with the field results described earlier in this study. Perhaps under the restricted root development conditions of the container, the plant could not keep up with the fast reproductive rate induced by gibberellin and this resulted in smaller buds.

Contrary to the marked stalk elongation observed in many plants as a result of gibberellin application (115) in this experiment gibberellin treated plants produced buds with a shorter stalk than the control. This is probably due to first, in artichoke, bud formation precedes seed stalk elongation and, second, gibberellin applications were discontinued on bud appearance.

Plant size seems associated with the number of leaves produced rather than with the size (Table 8). Weight of bud was associated with the size of the plant in opposition to the results found in field experiments due perhaps to the different soil conditions. Size appeared more closely related to fresh than dry weight since at the time of rating no bolters were observed.

Table 8. Relationship between growth, development and plant and bud characteristics to earliness of globe artichoke (simple linear correlation coefficients).

	Plant Size[1]	Leaves per plant	Days to Bolting	Stalk length	Weight of main bud	Fresh Weight
Leaves per plant[1]	0.805***					
Days to bolting	-0.338**	-0.291*				
Stalk length	0.279*	0.161	-0.596			
Weight of main bud	0.477**	0.381**	-0.614**	0.621**		
Fresh weight	0.348**	0.311*	0.140	0.273*	0.165	
Air dry weight	0.322*	0.289*	0.090	0.360**	0.331**	0.873**

[1]Records taken on February 17 before gibberellin application
* Significant at the 0.05 level
** Significant at the 0.01 level
***Significant at the 0.001 level.

Plant morphological differences between treatments were observed 7 days after emergence. About 90% of the seedlings grown from sprouted seed vernalized normally had cup-shaped cotyledons similar to the ones described by Linser et al. (58) in Galinsoga parviflora and Melandrium album, whereas the presence of such seedlings in the other treatments was sporadic. In Linser's report the appearance of such leaf structure was a result of application of 2,4-D. In artichoke it was probably due to low light intensity since such a phenomenon was not observed in the field. It seems that low light intensity interacted with the substances present only in fully vernalized seed to produce this anomaly.

In this experiment the first mature seed was obtained in the middle of May indicating that for breeding purposes the reproductive cycle could be shortened to 6.5 months.

Effect of High Temperature

Procedure

From field experiments discussed earlier the devernalizing effect of high temperature following vernalization was obvious. To explore the subject further two experiments were conducted.

In the first, 20 plants of approximately equal size (four to five leaves) and vigor grown from vernalized seed sown November 29, were selected. The plants were grown from the beginning under neutral temperatures (50 F to 65 F).

On February 17, 10 plants were placed under 240 watt infra-red heating bulbs, one bulb per plant, for 1 week. The other 10 were used as control and were grown under temperatures not exceeding 70 F. Some leaf burning was noticed at the end of the 1 week treatment on the heated plants. The soil was kept sufficiently moist during the period of the treatment. Maximum daily air temperatures exceeded 120 F in the immediate plant environment.

In the other experiment, vernalized seed was sown in 100 peat pots on November 29 and kept under neutral temperatures (50 F to 65 F). On December 7, 50 plants were moved to another greenhouse and transplanted in 1-cubic foot pots. A temperature of 70 F to 75 F was maintained in this house while 50 other plants were transplanted in similar pots at the same date and kept at a temperature of 50 F to 65 F.

Results and Discussion

In the first experiment where high temperatures from infra-red bulbs were applied, after the completion of the heat treatment the plants looked stunted and never resumed their previous vigor and growth rate. Bolting started March 25 in the heated plants and April 4 in the control. Bolting was 40% in the treated and 20% in the control while fresh and dry weights were respectively 25 g/plant and 5 g/plant for the heated plants and 80 g/plant and 16 g/plant for the control.

The experiment showed the ineffectiveness of temperatures as high as 120 F to devernalize plants which were grown from vernalized seed under neutral temperatures for 80 days.

In the second experiment where two different greenhouse temperatures were compared, a faster growth rate of the plants in the warm house was evident 1 week after transplanting. The first bolters in the warm house were recorded February 3 while in the cool house, February 18. No difference in the bolting percentage was found between the two treatments indicating that temperatures 50 F to 65 F may have stabilized the effect of cold treatment when the plants were placed subsequently in devernalizing temperatures of 70 F to 75 F.

Effect of Photoperiod

Procedure

To find the effect of day length after seed vernalization 24 plants from vernalized seed sown November 29, were kept under a natural short-day period until December 27 followed by a 15-hour day until February 9. At this time, no bolters were visible and growth was fairly uniform. On February 9, half of them were placed under 8-hour and the other half under 16-hour day in the same house at temperatures between 60 F and 70 F.

Results and Discussion

Bolters in both groups appeared February 19 at an approximately equal frequency. By the beginning of March the short-day group showed more vigorous growth and by April 15 the difference was very marked. Plant weights were sampled and the short-day group had a total of 1,550 g fresh weight while the long-day group had only 224 g indicating that although artichoke may be considered a photoperiodically insensitive plant in its reproductive processes (74), short photoperiod enhanced its vegetative growth.

Another indication of the lack of response of artichoke to photoperiod is the following observation. All plants sown on November 29 in the greenhouse were kept under natural short day length until December 27. At that date they were placed under artificial light for a 15-hour day length. These plants showed a similar bolting pattern as those planted in the field under the long days of April and May indicating that artichoke was not sensitive to photoperiodism since, as reported by other workers (85, 4, 107), in long day plants short days following seed vernalization tend to nullify the effects of the cold treatment.

Conclusions

Cold treatment for less than 15 days at 40 F was ineffective while 15 to 21 days seemed the threshold for bolting. Best bolting results were obtained with 21 to 42 days duration. Seed vernalization temperatures between 35 F and 45 F were equally effective.

Mean daily temperatures above 65 F immediately after sowing of vernalized seed appeared to nullify the vernalized state while temperatures 50 F to 65 F for a week after sowing had no nullifying effect and seemed to stabilize the vernalized state. Temperatures below 50 F vernalized the plants. Fully vernalized plants did not lose the vernalized state even when subjected to temperatures higher than 120 F for 1 week.

The seed environment during vernalization of artichoke was critical. Low oxygen environment lowered, considerably, the effectiveness of the cold treatment. Seed treatment with CCC, inhibited vernalization.

Gibberellin replaced completely the cold requirement in a large number of plants. Its effectiveness was influenced by the time of application.

Vernalization and gibberellin caused similar alterations in the morphology of the artichoke leaves. Bud characteristics were not associated with plant size for plants grown in the field nor were they affected by vernalization treatments.

The reproductive process in artichoke was not influenced by short day length. The latter appeared to enhance the vegetative growth.

No matter how effective the vernalization the minimum number of true leaves before bolting was 10.

By vernalizing the seed as described and by keeping the seedlings at proper temperatures the reproductive cycle can be shortened to 6.5 months (beginning of cold treatment to harvest of mature seed).

NUTRITION STUDIES

Effect of Nutritional Environment on Leaf Composition

Procedure

To obtain information on the concentration of several nutrients in the artichoke leaves, as influenced by various nutritional environments, an experiment was conducted with nutrient solutions in the greenhouse. Leaf sampling techniques were also investigated.

Seven week old artichoke seedlings of uniform size were grown in 15 different nutrient solutions (treatments). Each treatment was replicated three times. Each replication had two plants grown in 1 gallon jar. Solutions of the various treatments were as follows: Control (Hoagland Solution No. 2) (43) and two levels (minus and excess) of N, P, K, Ca, Mg, Mn and Fe (Table 9). The minus solutions lacked the nutrient under study except for minus N which contained 10% of the N of the control treatment.

Prior to planting in jars on January 20, all seedlings were grown in organic soil in the greenhouse. For 1 week prior to applying the treatments, all seedlings were grown in a complete solution. Solution changes were made weekly. The

Table 9. Effect of nutritional environment on the composition of leaf Lobes (L) and leaf midribs (M) of globe artichoke

Treatment	N(%)		P(%)		K(%)		Ca(%)		Mg(%)		Na(ppm)		Mn(ppm)		Fe(ppm)		Cu(ppm)		B(ppm)		Zn(ppm)		Al(ppm)	
	L	M	L	M	L	M	L	M	L	M	L	M	L	M	L	M	L	M	L	M	L	M	L	M
Control	5.06	2.40	1.031	0.770	5.81	2.84	1.84	1.38	0.49	0.37	575	2361	161	58	301	100	14.7	13.2	39.1	23.1	53	31	104	284
-N	2.66	1.07	1.036	0.853	6.53	6.76	1.54	1.27	0.34	0.21	730	852	70	70	147	53	13.3	14.0	35.3	26.3	44	39	115	105
3N	6.62	5.44	1.273	0.711	5.04	6.53	1.58	0.79	0.39	0.24	751	1242	160	53	308	83	10.7	10.2	58.5	21.2	43	20	167	448
-P	2.49	0.97	0.165	0.060	6.12	3.80	2.32	0.98	0.65	0.25	1241	852	91	25	353	177	30.0	6.5	91.5	22.4	0	0	278	113
5P	4.21	2.86	1.420	0.815	5.38	2.90	1.63	1.08	0.40	0.29	515	848	119	56	216	75	11.0	7.2	44.1	20.8	70	22	120	79
-K	5.92	3.95	1.785	1.245	2.72	3.82	2.31	1.66	0.57	0.57	1428	2045	159	125	175	143	16.3	14.7	68.0	32.0	103	55	161	148
5K	4.46	1.57	1.149	0.777	5.38	5.27	1.59	1.28	0.46	0.35	365	915	242	113	534	195	11.0	7.9	47.5	26.4	67	60	128	90
-Ca	4.10	3.70	1.506	1.089	5.21	7.44	0.76	0.42	1.24	0.60	847	1347	203	137	260	157	14.0	9.3	71.2	35.7	54	47	248	166
3Ca	3.96	1.45	0.847	0.460	3.91	3.00	1.39	1.44	0.29	0.15	391	533	60	31	217	53	10.3	5.8	55.4	23.4	47	33	170	63
-Mg	4.42	2.68	1.512	1.052	3.76	5.39	1.32	1.87	0.07	0.04	567	898	105	77	223	89	11.6	13.5	68.0	34.4	59	32	198	141
3Mg	4.18	2.08	0.786	0.567	3.62	2.66	0.33	0.38	0.35	0.25	468	473	43	39	156	98	7.4	6.5	39.8	21.5	34	27	92	34
-Mn	4.57	1.88	0.747	0.586	4.13	5.24	1.41	0.82	0.45	0.26	409	670	29	4	168	76	18.5	6.3	52.5	25.5	29	9	168	126
10Mn	4.69	2.95	1.071	0.763	3.89	5.09	0.77	0.56	0.33	0.18	498	585	395	223	190	73	11.2	5.3	31.1	16.6	49	14	143	76
-Fe	4.02	1.81	0.815	0.534	4.40	2.24	0.41	0.53	0.30	0.15	519	545	49	38	83	41	15.1	9.7	36.2	20.6	52	46	158	99
10Fe	4.61	2.83	1.631	0.798	4.98	5.54	1.53	0.97	0.45	0.40	1641	1997	103	54	335	118	10.0	10.2	62.0	29.1	57	46	197	174
W.05	1.88	2.08	0.333	0.521	2.50	1.61	1.12	0.78	0.34	0.23	168	964	135	85	194	118	12.2	N.S	35.7	N.S.	50	NS	123	N.S.
W.01	2.21	2.46	0.393	0.614	2.95	1.90	1.41	0.92	0.40	0.28	198	1135	159	101	228	139	14.4		42.1		60		145	
Coef. of Var.	14	29	10	25	18	36	29	23	26	38	24	31	34	40	27	44	36	56	23	27	33	33	25	28

sixth, seventh and eighth leaves from both plants in each jar were sampled and used for analysis. Two samples were taken from each leaf - one from the leaf lobes and the other from the midrib as soon as disorder symptoms appeared in each of the treatments as compared to the control.

Analysis of samples were made at the Michigan State University's Horticulture Department Plant Nutrition Laboratory by macro-Kjeldahl for N, by the flame photometer for K and by the emission photo-electric spectrometer (direct reading spectrograph), for P, Ca, Mg, Na, Mn, Fe, Cu, B, Zn and Al.

Multiple comparisons between treatment means were made by Tukey's w-procedure.

Results and Discussion

A comparison between the values from leaf lobes and midribs indicated that higher values for all nutrients except for Na were obtained from the former (Table 9). Leaf lobe samples were better indicators for the differences between the minus and the control for all nutrients except for Ca for which midrib samples showed greater sensitivity. Solutions with excess levels of N and K increased the concentration in the midrib samples while excess P solutions

influenced the leaf lobe composition only. Also, higher coefficients of variation were found for the midrib samples than for the leaf lobes. These results showed that leaf lobes would be generally preferable to midrib samples for nutrient element analysis in artichoke. Further discussion will be based on data from leaf lobes.

All of the minus treatments differed from the control. Only the excess levels of P and Mn differed from the control suggesting that these two elements accumulated in the artichoke when supplied in excess in the nutritional environment under the conditions of this study.

Nutrient interrelationships influenced leaf composition. Deficiency of P in the solution depressed the N composition of the leaves. Excess Ca and Mg decreased the concentration of P while excess of Fe increased it. Plants grown in solution where Mg was in excess contained less Ca than the control. An environment deficient in Ca caused higher accumulation of Mg indicating an increase in the uptake of Mg in a low Ca environment. A solution deficient in P and K increased the accumulation of Na. Excess Ca and Mg decreased the concentration of Mn but had no effect on the other trace elements. Excess K increased the concentration of Fe. Solutions deficient

in P increased the values for Cu, B and Al but depressed the concentration of Zn to a very low level. The levels of Zn were fairly constant between treatments except for the depressing effect of the minus P treatment and the enhancing effect of the minus K treatment.

Plants grown in solution lacking N were stunted. Older leaves were yellow. Excess N in the solution had no effect on the plant.

Solutions deficient in P produced plants which did not differ in size when compared to the control. Yellowing of lower leaves was similar to the pattern observed for N deficient plants. Excess P caused stunted growth.

Plants growing in solutions lacking K were very stunted having much smaller leaves than the control. Yellowing was noted over the entire leaf area of both the new and old leaves. Some of the leaf lobes of the older leaves were twisted. Excess K caused stunted growth and twisted leaf lobes.

Plants with symptoms of Ca deficiency were first to be noted. The new leaves showed the greatest effect which displayed a whitish color and were twisted. Plants showed signs of succumbing 15 days after the treatment was initiated. Excess Ca caused marginal chlorosis of leaves although the

plants were of normal size. This chlorosis may have been due to the lowering of the Mn content.

Mg deficiency symptoms appeared on the older leaves. They showed yellow intervenal spaces with dark green veins. The plants were stunted. Excess Mg symptoms were the same as for the excess Ca treatment.

Plants grown in an Fe deficient environment were of normal size. The lower leaves showed marginal yellowing. The new leaves were whitish. Excess Fe induced very stunted growth but no color change.

Excess Mn did not have any effect on the appearance or size of the plants.

The difference between the levels reported for B by Eaton (27) and the levels found by this study could be attributed to the different growing media, age of plants and possibly to a different sampling technique.

Effect of Different Levels of N, P and K Fertilizers

Procedure

To study the response of artichoke to N, P and K fertilizers and to correlate yield with soil P and K three experiments were conducted at the Muck Farm.

The first experiment studied three levels of N (0, 100, 200 lb/acre of N as ammonium sulphate) three of P (0, 100, 200 lb/acre of P_2O_5 as triple superphosphate) and three of K (0, 200, 400 lb/acre of K_2O as muriate of potash) combined factorially in a randomized block design with two replications.

In the other two single factor experiments, six levels of P (0, 50, 100, 150, 200 and 400 lb/acre of P_2O_5 as triple superphosphate) and six levels of K (0, 50, 100, 200, 400 and 800 lb/acre of K_2O as muriate of potash) were tested. The design was randomized block with two replications. Prior to fertilizer application soil samples were taken from each plot and were analyzed for P and K by the Michigan State University Soil Analysis Laboratory. Available P was extracted by 0.025 $\underline{N}$ HCl + 0.03 $\underline{N}$ NH_4F and available K by 1 $\underline{N}$ NH_4Ac. Soil:extractant ratio and shaking time was for both nutrients 1:8 and 1 minute respectively. These data were used in an attempt to apply the elasticity or mobility concept as expressed by the following expansion by Bray (8) of Mitscherlich's equation:

$$\log (A-Y) = \log A - c_1 b - cx$$

where, A = maximum possibility of yield when all nutrients are adequate but not in harmful excess; Y = yield when no P (or K) is applied but other nutrients are adequate; b = the

amount of available P (or K) present; c_1 = proportionality constant experimentally determined; c = efficiency factor of the method of applying the fertilizer and x = the quantity of fertilizer, of the form of nutrient b, that need be added for a desired percentage yield. Also, on the basis of the above formula the Baule units for P and K were determined A Baule unit of soil P (or K) is the amount of soil P (or K) necessary to produce a yield that is 50% of the maximum possible yield.

All fertilizer experiments had 3-row plots 24 feet long. Inter- and intra-row spacings were 3 and 2 feet, respectively. Records were taken from the middle row. Prior to sowing, all of the P and K fertilizer was applied when two-thirds of the N was applied prior to sowing and one-third 1 month after. All fertilizers were broadcast and disked in. Seed was pre-soaked for 48 hours and vernalized in moist peat at 40 F for 30 days and sown on May 12.

Plant size was rated visually on a scale from 1 (smallest) to 10 (largest) on July 24 and August 21. On July 24 intensity of chlorosis was rated on a scale from 1 (minimum chlorosis) to 10 (maximum chlorosis). Leaf lobes were collected for nutrient analysis on July 24 and August 21.

In the middle of June Mn deficiency symptoms appeared and were corrected by foliar application of manganese sulphate at 0.5 lb/acre elemental Mn.

Records were taken for bolting, fresh plant weight and weight of main and lateral buds. The plants were harvested and fresh weights were taken on September 17.

The soil type on which these experiments were conducted is described as Houghton muck. It is black to dark brown in color, granular and very friable and it is composed of fibrous plant remains consisting of grasses, sedges, reeds and other non-woody plants. The pH was 6.7.

Multiple comparisons between treatment means were based on Duncan's Multiple Range Test.

Results and Discussion

In the factorial experiment testing three levels of N, P and K no interactions were found between treatments for any of the observations taken (Table 10). The appearance of bolters was greater from the application of 100 lb/acre of N as compared to the control. Increase in the N rate above 100 lb/acre did not hasten the appearance of bolters. Nitrogen increased the fresh weight per plant although it had no effect on the weight of buds, indicating that bud

Table 10. Response of globe artichoke to various levels of N, P, and K fertilizers.

Fertilizer Rates (lb/acre)	Bolting (%)	Fresh weight per plant (lb)	Weight of buds (g)		Plant Size		Intensity of Chlorosis (July 25)	Leaf N (%)		Leaf P (%)		Leaf K (%)	
			Main	Lateral	July 25	Aug. 21		July 24	Aug. 21	July 24	Aug. 21	July 24	Aug. 21
N													
0	15.7a[1/]	1.75a	82.3a	54.5a	3.9a	5.5a	7.1a	4.04a	3.58a	0.421a	0.402a	4.74a	3.95a
100	25.2b	3.25ab	117.0a	67.3a	6.5b	7.6b	4.2b	4.22a	3.45a	0.372b	0.399a	4.34a	3.74a
200	26.0b	4.28b	124.8a	72.5a	7.0b	8.1b	3.0c	4.39a	3.90a	0.378b	0.444a	4.56a	3.98a
P_2O_5													
0	17.5a	2.99a	108.5a	69.3a	5.2a	6.7a	5.3a	4.23a	3.55a	0.386a	0.396a	4.52a	3.90a
100	23.5a	3.49a	109.8a	65.7a	6.3a	7.4a	4.4a	4.20a	3.63a	0.379a	0.417a	4.45a	3.87a
200	25.6a	2.82a	105.5a	59.2a	5.8a	7.1a	4.5a	4.22a	3.43a	0.409b	0.432a	4.46a	3.91a
K_2O													
0	22.5a	3.10a	104.8a	66.1a	5.7a	7.0a	4.7a	4.27a	3.50a	0.394a	0.415a	3.99a	3.29a
200	21.6a	3.01a	98.0a	54.3a	5.8a	7.0a	5.0a	4.20a	3.57a	0.399a	0.408a	4.70a	4.07a
400	22.2a	3.19a	121.3a	73.8a	5.8a	7.1a	4.6a	4.19a	3.53a	0.378a	0.422a	4.95a	4.31a

[1/] Values followed by uncommon letters are significantly different at the 0.05 level.

weight was influenced by genetic rather than by environmental factors.

Plant size ratings showed that plant size was primarily influenced by N. A visual rating of chlorotic symptoms showed that the intensity decreased with increasing level of applied N. A correlation between intensity of chlorosis and nutrient concentrations in the leaves showed also the importance of N (Table 11).

The appearance of bolters, the fresh plant weight, and the bud weights, were not influenced by added P and K fertilizers indicating that the soil of that experiment had sufficient P and K for the normal growth of artichoke. The effect of the added nutrients was apparent in the leaf composition of N, P, and K in the samplings of both July 24 and August 21. The increase in the rate of the nutrient added was followed by an increase of its concentration in the leaf tissue, although the differences were significant only for the P values (Table 10). Increased N applications lowered the concentration of P in the leaves suggesting an antagonism between the two nutrients at those levels. The concentration of N and K in the leaves was higher on July 24 than on August 21. The reverse was true for P.

Table 11. Relationship between leaf nutrient composition and chlorosis in globe artichoke (simple linear correlation coefficients)

Nutrient	Chlorosis
N	-0.650***
K	0.216
P	0.465***
Na	-0.323*
Ca	-0.075
Mg	-0.223
Mn	-0.256
Fe	0.211
Cu	-0.030
B	-0.183
Zn	-0.077

*Significant at the 0.05 level

***Significant at the 0.001 level

The concentrations of Mg, Na, Fe, Cu, Zn and Al in the leaves decreased in the second sampling while Ca, Mn, and B increased (Table 12). Correlations between the values for each element from the first and second samplings were noted only for N, K, Na, Mg and Fe suggesting the importance of the stage of growth of the plant in taking samples and interpreting the data (Table 13).

Fresh weight per plant from the two single factor experiments and soil analysis data are shown in Table 14. By applying the data in Mitscherlich's formula as modified by Bray, the following two soil test correlation equations, for P and K, were established:

For P: $\log (A - Y) = \log A - 0.00905\ b - 0.00348\ x$

For K: $\log (A - Y) = \log A - 0.00411\ b - 0.00286\ x$

On the basis of these equations and assuming no other factors were limiting growth, predictions can be made for the yield of fresh plant weight of artichoke (var. Violetto di Bologna) when the P (or K) analyzed as described and the amount of fertilizer P (or K) are known. These equations hold true for Houghton muck soil, for broadcast fertilizer application, for 3-feet inter-row and 2-feet intra-row spacing and for optimum supply of all nutrients except the one tested. The Baule units for soil P and K were 33 and 73, respectively. The results from these two experiments must be looked upon with caution due to the variability in the soil values for K (Table 14).

Table 12. Leaf nutrient composition data from globe artichoke plants treated with three levels of N, P, and K fertilizers.

Fertilizer Treatments (lb/acre)	Ca (%)		Mg (%)		Na (ppm)		Mn (ppm)		Fe (ppm)		Cu (ppm)		B (ppm)		Zn (ppm)		Al (ppm)	
	July 24	Aug. 21	July 24	Aug. 21	July 24	Aug. 21	July 24	Aug. 21	July 24	Aug. 21	July 24	Aug. 21	July 24	Aug 21	July 24	Aug. 21	July 24	Aug. 21
N																		
0	2.04	2.26	.38	.35	1544	1436	91	159	286	266	22.2	9.9	36.0	42.4	32	31	1139	1048
100	1.95	1.99	.38	.34	1865	1747	117	149	272	195	28.7	9.2	37.1	44.0	36	27	1097	931
200	1.96	2.14	.39	.34	1865	1743	110	108	241	214	25.3	9.8	39.3	47.7	33	30	1229	856
P_2O_5																		
0	1.97	2.07	.37	.34	1734	1556	102	133	267	244	25.6	10.0	37.5	45.0	33	29	1199	991
100	1.99	2.29	.38	.34	1341	1620	108	131	262	213	24.8	9.3	37.3	45.6	34	28	1146	865
200	1.99	2.02	.39	.35	1763	1750	108	151	271	219	25.8	9.6	37.7	44.6	34	31	1242	978
K_2O																		
0	2.04	2.08	.41	.37	2436	2304	109	140	258	221	27.0	9.9	38.2	45.8	34	28	1127	985
200	1.96	2.25	.37	.33	1489	1404	95	145	274	217	24.1	9.8	37.0	43.9	32	29	1146	920
400	1.95	2.06	.36	.33	1350	1219	114	130	267	237	25.1	9.2	37.2	44.4	34	30	1192	929

Table 13. Relationship between the various nutrients in the globe artichoke leaves at two samplings (simple linear correlation coefficients).

	N_1	K_1	P_1	Na_1	Ca_1	Mg_1	Mn_1	Fe_1	Cu_1	B_1	Zn_1
K_1 [1]	-.287*										
P_1	-.154	.248									
Na_1	.456*‡	-.763*‡	-.166								
Ca_1	.001	.020	.067	.312							
Mg_1	.363**	-.419	-.006	.785*‡	-.711*‡						
Mn_1	-.002	.008	-.347*	.105	.240	.206					
Fe_1	-.308	.206	-.005	-.143	.267	.071	.171				
Cu_1	-.053	-.037	.190	-.021	.022	-.029	.116	-.166			
B_1	.306*	-.080	.306*	.048	.259	.191	.054	.007	.361		
Zn_1	-.093	.089	.319	-.073	.051	.008	.096	-.120	.908*‡	.403‡*	
N_2	.661*‡	-.189	-.288*	.329*	.057	.248	.008	-.121	-.257	.178	-.241
K_2	.220	.356**	.068	-.375**	-.146	-.163	-.004	.022	-.032	.190	.068
P_2	.390**	.083	.057	.056	-.001	.035	-.110	-.214	-.319	.046	-.010
Na_2	.436**	-.715*‡	-.142	.899**	.220	.687*‡	.003	-.181	-.062	-.118	.525**‡
Ca_2	-.394**	.076	.208	-.043	.021	.002	-.211	.101	-.257	-.544*‡	-.005
Mg_2	.054	-.320*	-.098	.455*‡	.148	.423*‡	.047	.004	-.223	-.431	.258
Mn_2	-.335*	-.072	.031	.032	-.000	.068	.157	.071	.024	-.320	-.351*
Fe_2	-.363**	.187	.237	-.264	-.129	-.220	-.167	.317	-.145	-.166	.081
Cu_2	-.021	-.163	.009	.089	.150	.096	-.134	.297*	.040	-.017	.141
B_2	.577*‡	-.227	-.129	.264	-.081	.115	-.021	-.269	-.287*	.224	.641*‡
Zn_2	.029	.128	.032	-.064	.010	.004	-.174	.059	-.159	-.058	.214

	Zn_1	N_2	K_2	P_2	Na_2	Ca_2	Mg_2	Mn_2	Fe_2	Cu_2	B_2	Zn_2
N_2	-.241											
K_2	.068	-.010										
P_2	-.222	.525**‡	-.005									
Na_2	-.131	.258	-.351*	.081								
Ca_2	-.280*	-.379	-.204	-.156	.141							
Mg_2	-.270	.028	-.279*	.168	.641*‡	.650*‡						
Mn_2	-.061	-.456*‡	-.132	-.474*‡	.214	.491*‡	.427*‡					
Fe_2	-.127	-.287	-.034	-.181	-.158	.439*‡	.180	.162				
Cu_2	-.069	.058	-.141	-.110	.085	.087	.146	.002	.238			
B_2	-.255	.684**	.058	.708*‡	.211	-.271	.108	-.398**	.264	-.118		
Zn_2	-.200	.104	-.040	.146	-.085	.102	.109	.166	.059	.359**	.077	

[1] Results from July 24 sampling are designated by subscript-1; from August 21 sampling by subscript-2.

* Significant at the 0.05 level

** Significant at the 0.01 level

*** Significant at the 0.001 level

Table 14. Effect of various levels of soil and broadcast P and K on the fresh plant weight of globe artichoke grown on a Houghton muck soil

Treatments	Fresh Weight per plant (lb)		Extractable P* in soil (lb/acre)		Extractable K** in soil (lb/acre)	
Phosphorus (lb/acre P_2O_5)	Rep I	Rep II	Rep I	Rep II	Rep I	Rep II
0	3.90	3.80	35	44	175	95
50	3.93	4.23	35	36	196	127
100	4.31	6.11	42	31	213	152
150	4.21	5.50	39	42	204	87
200	5.10	6.19	38	31	204	95
400	7.06	6.33	42	31	242	144
Potassium (lb/acre K_2O)						
0	4.96	4.70	25	35	190	103
50	5.08	5.00	36	35	144	80
100	5.15	5.06	42	41	243	87
200	5.05	5.30	36	31	196	135
400	5.20	5.18	49	32	182	92
800	5.25	5.33	52	44	221	95

*0.025 N HCl + 0.03 N NH_4F extractable
**1 N NH_4Ac extractable

Conclusions

Various nutrient solutions markedly influenced the leaf composition of the artichoke. All minus treatments differed from the control while only the excess levels of P and Mn differed from the control. Nutrient interrelationships between several nutrient elements were noted for the leaf composition. Deficiency symptoms were most characteristic for minus Ca and minus N. Leaf lobe samples reflected better the effect of the various nutritional environments than midrib samples.

Field experiments showed a marked response of artichoke to N as measured by the fresh plant weight. The P fertilizer treatments influenced the nutrient concentration of the leaves.

PLANT SPACING STUDIES

Procedure

To determine the density of plant population in Michigan organic soils, two experiments were conducted at the Muck Farm.

The first experiment was factorial of split plot design. The main treatments were two intra-row spacings (1 and 2 feet) and the sub-treatments were three inter-row spacings (2, 3, and 4 feet) arranged in randomized block with four replications. Each plot consisted of three rows 24 feet long. Sowing was carried out on May 13. Leaf samples for nutrient analysis were collected on August 24. Records were taken from the middle row for bolting, fresh plant weight and weight of main and lateral buds. The plants were harvested September 17. Multiple comparisons between treatments were based on Duncan's Multiple Range Test.

The second experiment tested 32 spacing treatments ranging from 1 to 15 square feet per plant replicated eight times. Layout of the treatments is shown in Figure 9 (1, 66). Sowing was carried out on May 13. Fresh weight observations were taken on September 17.

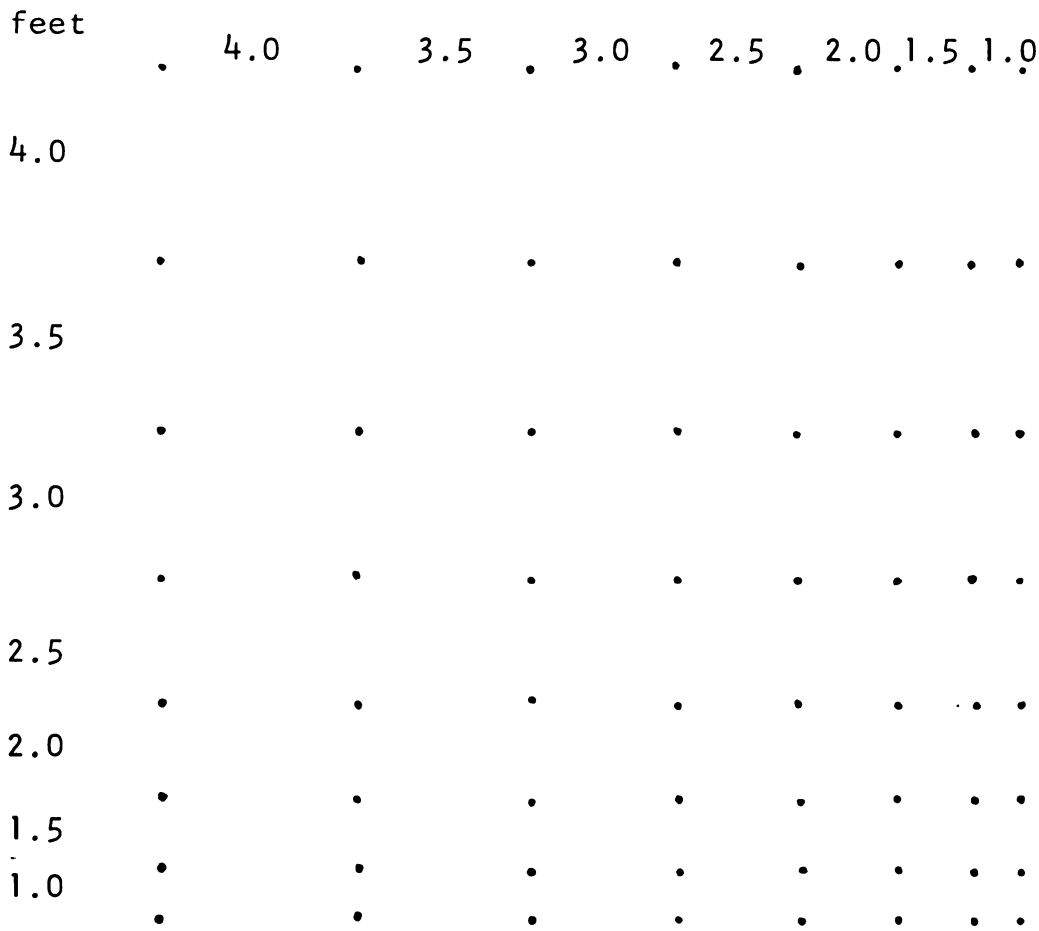

Figure 9. The plant layout of one block of the two dimensional arithmetic design used for globe artichoke spacing studies. All blocks had identical arrangement of plants.

In both experiments, prior to sowing, 100, 150 and 200 lb/acre of N, P_2O_5 and K_2O, respectively were broadcast and disked in. Six weeks after sowing, a side-dressing with 50 lb/acre of N was applied. Seed presoaked for 48 hours and vernalized in moist peat at 40 F for 30 days was sown.

Results and Discussion

In the factorial experiment no interaction between intra- and inter-row treatments was found for all the various characters studied (Table 15). Two foot intra-row spacing gave higher values for all characters as compared to the 1 foot spacing but the difference was significant only for fresh plant weight and weight of main bud. Values for fresh plant weight and leaf P and K increased as the inter-row spacing increased but the differences were not significant. The data suggested that intra-row spacing under the conditions of the experiment was more critical than inter-row.

In the second experiment no bolters were noted due to the late sowing. Fresh plant weight per acre did not change appreciably when the area per plant increased from 5 to 15 square feet (Figure 10).

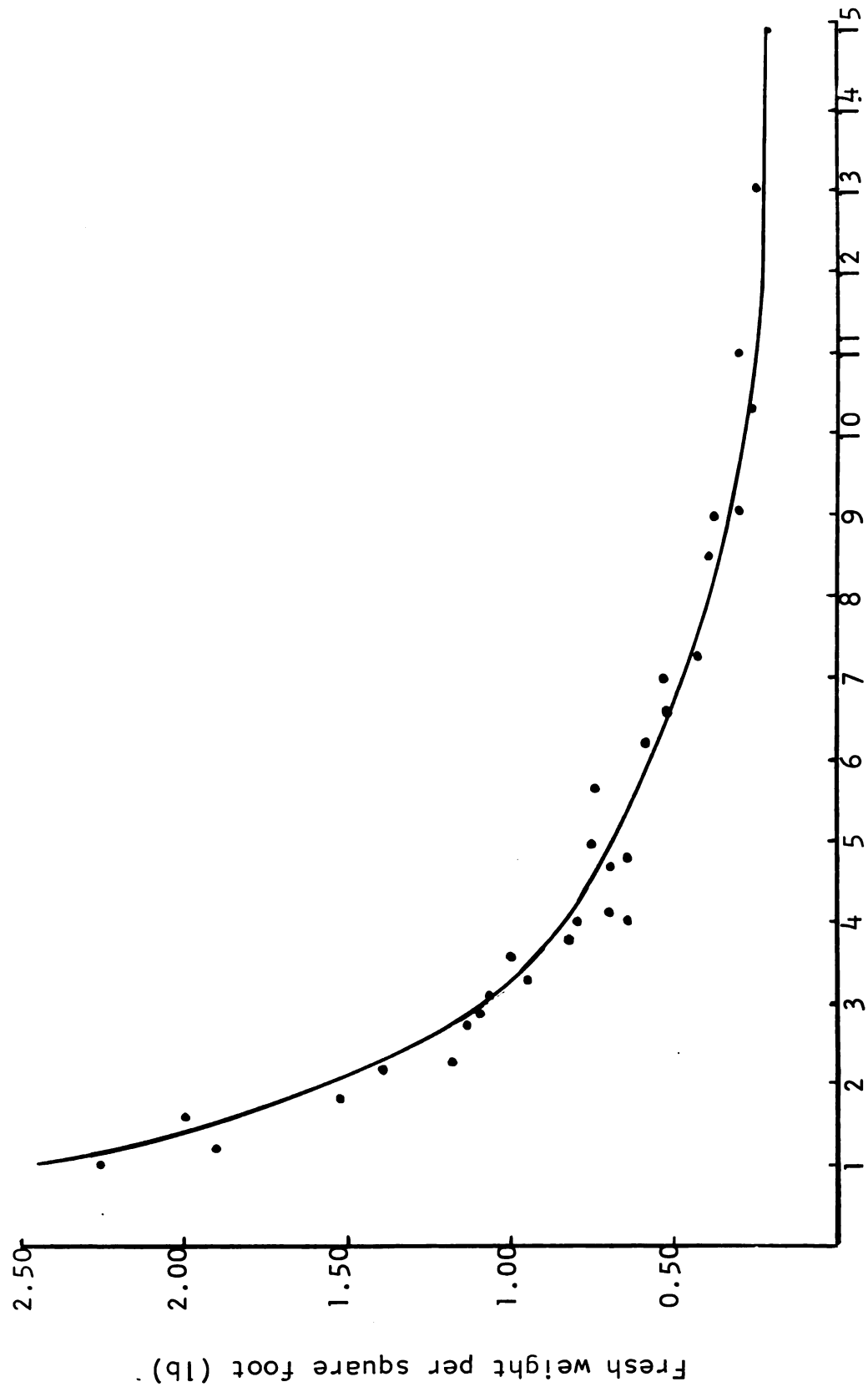

Figure 10. The effect of spacing on the fresh plant weight of globe artichoke.

Table 15. The response of globe artichoke to intra-row and inter-row spacing.

Spacing Treatments (feet)	Bolting (%)	Fresh Weight (lb/ plant)	Weight of Main bud (g)	Weight of Lateral bud (g)	Plant Size on Aug. 3	Leaf N %	Leaf P %	Leaf K %
Intra-Row								
1	15.4a[1]	3.98a	93.4a	59.1a	7.3a	4.01a	0.443a	3.91a
2	17.7a	5.34b	130.8b	64.7a	7.8a	4.15a	0.450a	3.98a
Inter-Row								
2	18.1a	4.41a	109.5a	56.0a	7.4a	4.17a	0.431a	3.81a
3	13.4a	4.73a	121.2a	76.9a	7.6a	4.00a	0.444a	3.96a
4	18.3a	5.10a	105.7a	53.0a	7.6a	4.07a	0.464a	4.07a

[1]Values followed by uncommon letters are significantly different at the 0.05 level

Conclusions

Two-foot intra-row spacing gave higher yields of fresh plant weight and main bud weight as compared to 1 foot. No differences were found between inter-row spacings of 2, 3 and 4 feet.

Fresh weight appeared to increase with increasing area per plant to about 5 square feet.

A spacing of about 2 x 2 feet was adequate for artichoke when grown as an annual plant on sufficiently fertilized and irrigated organic soil. This spacing would give 10,900 plants/acre or 32,700 buds/acre assuming that all plants will bolt and produce three buds. Figure 11 shows one bud from a perennial California plantation and 14 buds from annual culture at the Muck Farm.

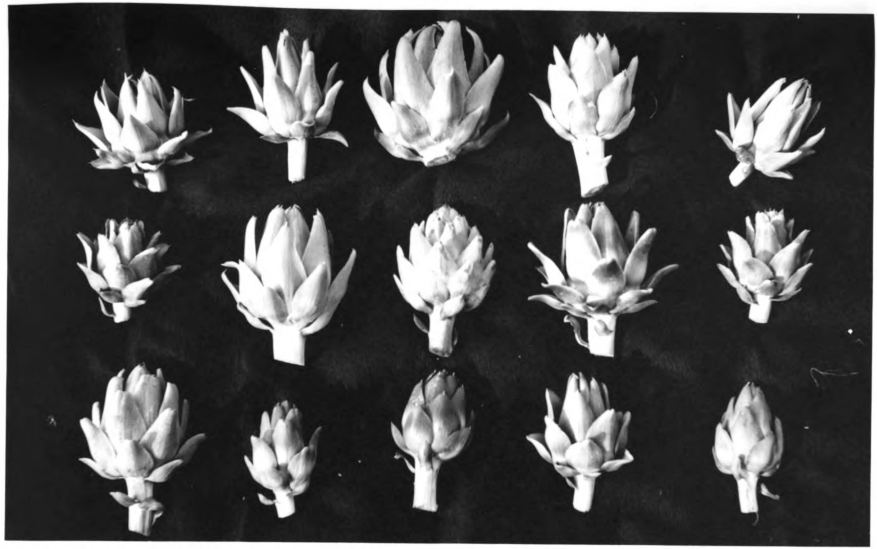

Figure 11. Fourteen randomly selected buds from annual culture of globe artichoke at the Michigan State University Muck Farm compared to a bud from a perennial California plantation (middle).

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BIBLIOGRAPHY

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APPENDIX

Appendix Table 1. Mean daily temperature for Stockbridge[1] (SB) and Muck Farm (MF) in 1967.

Day	April		May		June		July		August		September		October	
	SB	MF	SB	MF	SB	MF	SB	MF	SB	MF	SB	MF	SB	MF
1	62	63[2]	67	70	62	60	76	79	73	73	59	58	53	69
2	59	63[2]	54	50	63	64	71	78	77	78	77	78	61	63
3	43	49[2]	42	43	72	68	66	63	74	72	62	63	70	85
4	39	45	42	44	69	67	60	62	71	69	66	64	72	82
5	57	57	46	47	74	72	60	62	65	65	67	66	62	81
6	50	48	47	48	74	76	63	67	68	67	68	64	56	66
7	40	39	51	53	74	74	68	69	71	75	68	65	49	60
8	38	47	48	51	74	78	76	76	69	69	70	66	64	76
9	58	60	52	46	76	76	80	80	75	77	65	67	48	66
10	50	46	48	45	76	78	76	78	65	68	56	55	46	63
11	36	41	49	47	74	75	76	79	59	58	56	70	42	59
12	36	42	48	46[2]	78	79	67	71	62	59	59	73	46	62
13	49	50	54	52[2]	78	78	63	62	66	60	66	81	51	68
14	62	63	56	52[2]	78	79	56	59	69	66	67	83	59	72
15	58	60	50	50[2]	84	82	60	68	69	69	65	79	55	70
16	58	59	50	50	83	84	66	65	73	73	69	81	58	69
17	62	65	58	55	72	68	70	69	75	74	68	81	54	67
18	44	50	63	59	68	68	71	73	73	80	69	81	47	59
19	45	46	62	69	65	66[2]	70	72	68	66	70	84	43	60
20	47	49	50	56	70	63[2]	68	70	64	68	71	84	45	60
21	56	60	49	47	68	70	74	74	65	67	67	78	45	58
22	49	49	49	53	68	66	77	77	65	62	53	69	45	61
23	40	45	48	47	69	69	78	81	62	59	52	67	57	73
24	36	40	61	62	73	75	79	80	65	63	52	68	61	75
25	39	42	63	64	61	72	75	72	72	69	54	69	50	64
26	45	41	62	65	65	72	70	69	72	73	68	81	38	57
27	43	44	66	66	69	71	75	73	61	64	60	64	39	54
28	48	46	62	63	65	68	78	74	66	69	44	61	36	50
29	50	58	61	62	68	72	69	74	68	67	40	59	40	48
30	60	62	58	55	71	75	72	73	64	63	47	64	55	61
31			58	54			71	74	54	59			56	67

[1]Average from Milford and Ann Arbor stations.
[2]East Lansing recordings.


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