AN EVALUATION OF METHYLCELLULOSE AND PAPER SEED RIBBONS FOR THE PRECISION SEEDING OF LETTUCE (LACTUCA SATIVA L.) AND OTHER VEGETABLES

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ABSTRACT

AN EVALUATION OF METHYLCELLULOSE AND PAPER SEED RIBBONS FOR THE PRECISION SEEDING OF LETTUCE (LACTUCA SATIVA L.) AND OTHER VEGETABLES

by Nicky Allan Smith

Individual plants of numerous agricultural crops must be spaced fairly accurately in the field for maximum yield and quality. Although the distance between individual wheat, oat, and corn plants, within certain limits, has little influence on yield or quality, accurate plant spacing is almost essential for lettuce, celery, cauliflower, and many high-value vegetable crops.

The thinning operation accounts for a sizeable portion of labor costs in the production of many small-seeded vegetable crops. Reducing the amount of seed used and uniformly spacing the quantity planted should result in a considerable saving in labor requirements.

This study evaluates two forms of seed ribbon or tape developed to achieve a uniform spacing of seed; plastic ribbon and paper ribbon. The plastic seed ribbon, composed of readily dissolvable methylcellulose, was used to place lettuce seed at intervals of 14, 7, and 3 1/2 inches in organic and mineral soils on commercial farms and in other experimental plots.

Placement of the ribbon in the soil was by means of specially built or adapted planters provided by two commercial firms.

Precision spacing of the seed reduced drastically the time required for thinning, varying directly with the seed interval. However, if weeding and thinning were performed simultaneously, as they usually are, time-saving benefits of spaced seeding became insignificant as the weed population increased.

At harvest, the lettuce stand from ribbon seedings was below that achieved by direct seeding; 90% of the ideal population was considered as acceptable commercially.

Spacing the same number of seeds to correspond with the desired final mature plant population resulted in an average stand of 47.58%. In other words, more than 50% of the seed loci were not occupied with plants at harvest due to undetermined causes.

The methylcellulose seed ribbon in contrast to a standard seed sowing procedure resulted in a higher percentage of lettuce heads harvested, heavier average weight per head, and sturdier growth.

Other experiments were conducted with plastic and paper seed ribbons to evaluate associated physiological phenomena. Delayed thinning of lettuce resulted in reduced fresh weight of foliage and roots.

The number of seedlings emerging increased as the number of seeds was increased per locus (1, 2, and 4) under conditions of soil crusting but not when the soil was covered with polyethylene. When the surface of the soil was compressed at 1/2, 2, 5, or 10 psi, seedling emergence was reduced by 5 and 10 psi but not significantly so under conditions of these experiments.

Emergence from the paper ribbon for tomato, cauliflower, lettuce, and celery in the greenhouse was significantly lower than from check plantings but considerably higher than was experienced in the field trials with tomatoes. Laboratory control of moisture and careful placement of ribbon partially contributed to this better emergence.

Varying the level of soil moisture from 11% to field capacity plus 8 mm. of water did not affect total emergence from methylcellulose seed ribbon.

When individual seeds of radish were precision spaced one inch from adjacent seeds, 65.79% of the harvested radishes measured 16-30 mm., a median marketable range, whereas when seed was distributed at random in the row, the percentage was 49.45. In other words, precision spacing markedly increased root diameter uniformity.

Methylcellulose and paper seed ribbons or tapes were used successfully to space vegetable seeds at fairly precise intervals in the soil. Under field conditions, however, emergence was generally no greater than 50% indicating that precision seeding to a final desired plant population with these ribbon materials would be impractical. Precision seeding to reduce the thinning-labor requirement, rather than to eliminate it, was practical only if in-the-row weed populations were low.

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INTRODUCTION

The system of private enterprise in American agriculture is irrevocably committed to exploiting every opportunity to increase returns by reducing costs. The research efforts of American industry and agricultural experiment stations are directed toward providing improved means of achieving such economic objectives.

Because labor costs of production comprised the overwhelming portion of final costs, the history of modern advancements in agricultural production has been a recapitulation of successive onslaughts on labor costs.

The precision spacing of seed evaluated in this thesis is a new method of seeding offered to reduce labor costs. Occasionally an innovation is introduced that does not reduce costs; it is justified because the buyer is willing to pay for the improvement.

Without being presumptive or anticipatory, it appears that precision spacing of seed is inevitable; it is primarily a question of method. Any study of methods of spacing soon expands into an assessment of the pertinent environmental phenomena. Thus the scope of this thesis is marked out.

REVIEW OF LITERATURE

Since the time man gave up nomadic existence and became an agriculturist, he has exercised some control over placement of seed and the rate of its distribution. Whether man used his hand or mechanical equipment to distribute seeds, he adjusted the method to the times and current knowledge. Always the quantitative variation in seeding has been primary while the specific distribution pattern of the seed on the soil surface has been largely incidental or secondary.

Control of Seeding Rate.

Equipment.--Until recently, in a mechanical planter, control of distribution of quantity of seed has been largely by regulation of the aperture through which the seed flowed. The seeding rate was heavy so that subsequently an adequate stand emerged from the least dense portions of the row (Harvey, 1958). This resulted in an excessive density of seedlings elsewhere in the row which required special thinning for crops like sugar beets and lettuce.

Recently, to reduce thinning to a minimum, more precision in seeding has been demanded. Harvey (1958) has designated the minimum for sugar beets as being the preservation of a pattern of distribution. Frakes (1959) suggested, for sugar beets, that seeds be distributed four inches apart.

Harvey (1958) stated that up to 30% of the seed groupings could be doubles without affecting subsequent yield significantly.

With such a clarification of requirements for seeding, precision seeders were developed and marketed. Robertson (1957) and Maddox (1958) have described these for turnip seeding in Scotland. It is, however, in the sugar beet industry that some of the most rapid developments have taken place in precision seeders (Bainer, 1947; Bjerkan, 1947). Marx (1959) used a commercial version of a precision seeder for planting canning peas. Sweetman (1957) designed a suction operated seeder to distribute clover seed uniformly. It was tried experimentally for lettuce, carrot, parsnip, and wheat.

For precision seeders to operate at maximum efficiency, Maddox (1958) cited the need for correctly sized seed. Bainer (1947) and Bjerkan (1947) similarly used sized sugar beet seed.

Pelleting. --A planter adapted for planting uniform sized sugar beet seed can readily be used for pelleted seed of tomato (Bainer, 1947). Carolus (1949) pointed out the possibilities of pelleting. In pelleting the seed has been artificially made more uniform in size (Carolus, 1954) by addition of clays or other substances. Wolf (1953) studied seedings made with pelleted seed of cabbage, endive, lettuce, and onion. Zink (1955, 1956) studied the use of pelletized lettuce seed. Pursley (1960) reported that pelleted seed

was still being tried by commercial growers for lettuce and onion.

When pelleted seed was used, emergence of seedlings was delayed (Carolus, 1949; Zink, 1956). Brendler, Zink, and Crane (1955) reported an average saving in thinning time of 33 1/3% for lettuce. Use of pelleted seed resulted in no consistent effect on yield of lettuce (Zink, 1955, 1956). Zink (1955) stated that there was no difference in head size of lettuce or its maturity. Carolus (1949) mentioned better stands, more rapid maturity, and more vigor. Zink (1956) hypothesized that if pelleted seed was planted less seed was required. Hence better seed could be used, such as mosaic-tested lettuce seed. Wolf (1953) and Harvey (1958) concluded that pelleting of seed adversely affected emergence. Bainer (1947) reported the use of a John Deere No. 66 drill for planting twenty acres with pelleted tomato seed. So favorable was the reception to this by growers that the following year several hundred acres were planted in this manner. Despite certain attractive features of pelleted seed, the practice is not widely used.

Seed population and spacing.--Plant populations on a unit of area as an acre have been the subject of numerous investigations (Dunyan *et al.*, 1958; Coons, 1948). Often the seed distribution was in predetermined row widths dictated largely by existing tillage or harvesting equipment.

Surveying the reports on spacing for sugar beets, Coons (1948) stated that a final recommendation for optimum spacing allotments could not be made. Spacing depends on a host of factors (Paponov, 1959; Coons, 1948) of

which a single factor cannot be detached from the complex and evaluated (Coons, 1948). Coons warned against drawing conclusions from any experiments in which the stands were poor. Warne (1951b) similarly stated that for crops dependent on plant population, varietal comparison is valid only if identical stands are compared either actual or computed from a regression of yield on plant density.

While it is laudable and theoretically essential to study a plant in totality with all factors under control, modern methods of scientific investigation are based on the selection of one factor and varying that factor. Hence, variety and species can be selected as a valid variable.

Corn has been the subject of considerable investigation on plant population due, in large part, to its great economic importance. Dunyan, Lang, and Pendleton (1958) have recently summarized many findings. Grain production increased with increasing population from 4, 000 to 20, 000 plants per acre while size and weight of individual ear decreased. This inverse relationship is even more pertinent when yield per acre is compared with weight of total ears per plant.

An increase in the number of plants is correlated with a retardation of plant development as measured, for example, by the time interval between tasseling and silking. Increasing the number of plants from one to five per hill decreased leaf area per plant by 30%. Dunyan *et al.* cited evidence that plants spaced singly out yielded those in hills with a greater difference under more favorable conditions. The corn plant compensates somewhat for adjacent gaps but never completely. That this ability to compensate is considerable is confirmed by the feasibility of wide-row corn recommendations. Many factors enter into corn development as they do for any other plant.

Bailey (1941) observed a similar response in sweet corn as Dunyan et al. reported for field corn. Pickett (1944) favored spaced over a hill system but stated that yields were nearly the same.

Sugar beets, like corn, has been the subject of considerable research regarding yield and plant population.

Deming (1940) obtained significantly higher gross yields with a spacing of 20 x 10 inches (single plants) as compared to a spacing of 20 x 20 inches (double plants).

In agreement with statements of other investigators (Larsen, 1943), Harvey (1958) stated that regularity of plants was of critical importance to yield. He warned that precision spacing by drills or otherwise must result in an adequate number of plants in the thinnest portions of rows.

Frakes (1959) outlined recommendations for spacing plants with precision drills and monogerm sugar beet seed. Ultimate plant population was deemed to be eight inches apart with spacing of seed at four inches apart. He warned that within these limits, emergence must be at least 80 percent with no concentration of its failure in any one area.

In a study by Hunter-Smith and Williams (1927) using "mangolds" and

kale in addition to sugar beets, these investigators concluded that a decrease in distance between plants resulted in an increase in yield and a decrease in size of individual roots. Other investigators reported similarly for carrots (Ward, 1959), garlic (Couto, 1958), and onion (Das and Dhyani, 1956).

Coons (1948) attempted to summarize the reports of various investigators and to place their conclusions in proper perspective. An equidistant or square area per plant appeared with seeming regularity when optimum yields were analyzed for exact plant spacing. Frequently row widths exceeded this due to the preference for wider rows permitting machines to operate more efficiently. Coons concluded that a good even stand was a prerequisite for maximum yield of acceptable roots. The presence of even one root or one gap affects yield, although it is compensated for or masked by variation.

Various legumes of commercial importance have also been investigated. Wiggans (1939) observed that uniformity of plant arrangement increased yields of soybeans despite a compensating effect by the plants. Hardenburg (1942) worked with four field bean varieties and found but slight advantage in favor of spacing when there was a constant plant population per foot of row.

Larson and Peng-Fi (1948) found for lima beans that the more regularly shaped area (i. e. square) was associated with higher yields.

While there is mounting evidence that uniform spacing of plant population is highly important for maximum yields, there are results that appear

to contradict or at least to cast doubt on this conclusion. Perhaps, this contradiction is more apparent than real, and hence its amplification and resolution is pertinent.

While not always stated or specifically qualified, conclusions that arrangement was inconsequential were usually based on variations in plant population that were either not wide or could be obscured by inherent variables. This is logical from the practical point of view. Thus contradictory results in themselves do not negate the general hypothesis that spacing and yield are related.

Warne (1951c) observed that for yield of globe beet there was no practical arrangement that was more especially advantageous. The variances used were twelve spacings of which four were row widths and three were thinning distances in the row along with two manurial treatments.

Somos (1957) obtained no difference in weight of individual fruits of tomato at time of ripening as a result of spacing under greenhouse conditions. Holland (1957) and Holland and Campbell (1958) reported no significant difference in total yield per acre for cannery tomatoes whether plants were arranged singly or in "clumps". About three times as many plants were present in the "clump" plots as in plots with single plants.

Sprague and Farris (1931) took issue with Engledon over his conclusion that yields per acre are determined largely by the uniformity with which the seed is spaced in the row and went so far as to say that for seeding tests of barley, variations of seed spacing up to 40% in consecutive sections of rows could be ignored. They seeded consecutive feet of row at 6, 9, 11, or 14 pecks per acre to compare with a seeding at a uniform 10 pecks per acre. The yields from the heavier seeded portions of a row could conceivably counterbalance the more lightly seeded portions. Also this was a comparison at only one seeding rate; namely, at 10 pecks per acre.

Pickett (1944), speaking of sweet corn, stated that when the number per linear foot of row was the same, the number per hill, whether 1, 2, 3, or 4, did not affect yield significantly.

Maddox (1958) expressed the view that different plant populations, again within limits, did not affect yields of turnips. For soybeans, Wiggans (1939) believed that maximum yield occurred with uniform distribution but said that within wide ranges of plant population per square foot there was little effect on net increase because of compensating ability. Marx (1959) observed a similar compensating effect in canning peas. Others reaching similar conclusions were Hardenburg (1942) with field beans, Deming (1940) with sugar beets, and Peterson and Haber (1948) with Irish Cobbler potatoes.

Such disparate inferences foreshadow operation of fundamental factors exercising far-reaching influences. Separation and evaluation of each where possible is pertinent.

Broadly speaking, many, if not all, investigators would concede that a multitude of factors operate to affect plant growth and yield. For corn, Dunyan et al. (1958) have mentioned climate, season, soil, variety, availability of nutrients, as well as population. Deming (1940) has singled out water and fertility as over-riding factors. Bailey (1941) listed soil and climate as variables.

While these prevail as broad factors, it is in plant competition between individual plants that each factor affects plant growth and development. Therefore, a study of the reaction of the individual plant to environmental factors is necessary.

Warne (1951a) lamented that precise information in literature on "inter-plant" competition was meager. He was interested particularly in maximum number and weight of intermediate sized below-ground portions of root vegetables; an objective with practical usefulness (Warne, 1951a, 1951b, 1951c, 1953).

Coons (1948) concluded that the number of plants and unit length of row were related as cause and effect. A significant linear positive correlation exists between weight of sugar beets and stand. Each plant or gap makes a contribution. If a gap occurs, it is compensated for in growth by adjoining beets even to the extent of 96.2 percent (Coons, 1948; Warne, 1951b). On the other hand, Deming (1940) compared one plant on 400 square inches with two plants on the same area and obtained no difference in yield. Thus it appears that Coons (1948) was justified in saying that it was the number of hills and their spacing that was important rather than the number of plants. Yet Harvey (1958) cited Frakes as warning against more than 30% doubles so as not to affect yield.

While these are the quantitative variations in gross morphology that are expressed in size and weight, internal changes (Somos, 1954) occur which may be termed qualitative but which are measured quantitatively.

For sugar beets not only is tonnage required but percentage sugar per acre is a more pertinent economic criterion. High sugar percentage is correlated with increasing density of plants; conversely, sugar content decreases as spacing is increased. Sugar content varies with maturity, nitrogen, and water. Crowded plants remain physiologically young longer under conditions of low nitrogen and low moisture; growth is retarded, even if accompanied by warm sunny weather, when photosynthesis continues thereby building desired sugars. Apparently inhibition of growth accelerates qualitative changes rather than the same type of growth being resumed at some later date. In this inhibition, a new and different stage is hastened or initiated whereas in temporary cessation there is merely a time delay.

While Coons (1948) has stated that the sugar beet plant responds to these environmental factors in this manner, other investigators with other plants have obtained different results and conclusions. Dunyan *et al.* (1958) stated that reduced space by increase in population retarded development. Bailey (1941) agreed with Dunyan *et al.* for sweet corn stating that wide spacing provided earlier harvest by 1 to 2 days. Warne (1951b) stated that the globe beet remained physiologically younger in a thick planting. From these

observations of Coons and Warne it is not without hazard to infer that spacing *per se* affects development and consequently date of maturity. Spacing may vary the conditions under which a plant may deplete moisture and nutrients which in turn may cause the developmental changes. Thus an experiment based on spacing becomes an experiment with camouflaged levels of nutrition and moisture availability unless care is used to assure the same amount of nutrients and water to all plants under variable spacing.

Paponov (1959) studied the influence of spacing on plant development and reported work with lettuce, radish, tomato, cucumber, dill, and borage conducted from 1951 to 1958. Increasing plant density of lettuce resulted in delay in onset of bolting and flowering. Action of fertile soil was similar to decreased density, i.e. hastening of flowering. In cucumbers, denser planting resulted in larger percentage of male flowers. In tomatoes, restricting the root system by pot culture resulted in higher placement of the first floral cluster in terms of leaves subtending that cluster.

Paponov also observed that the "area of feeding" (plant density) did not affect the first two clusters as much as it did the third and fourth cluster. Maturation of fruit occurred in reverse order, that is, ripening proceeded more rapidly on soil of lower fertility or restricted root systems.

Paponov believed that under crowding the mechanism of action was the same as under low fertility i.e. essentially one of nutrition. Thus, at greater plant density, a lower nutrient supply would be available to each plant.

Paponov cited instances in Russian literature of earlier flowering and maturation in wheat due to lower moisture levels. But strangely, he concluded with no further evidence, that despite these data, it could not be said that lowering of moisture levels hastens development of annuals.

Winter (1952) also stated that reduction in growth rate delays later stages of development and flowering of both cauliflower and lettuce.

Increasing population of corn plants (Dunyan et al., 1958) increased suckering and barrenness while grouping corn plants reduced lodging perhaps due to the mutual physical support. Increasing the spacing of lettuce increased bolting as well as "hearting" according to Winter (1952). Kokuskina-Saveleva (1957) claimed that increasing the number of squash and cucumber plants per unit of area resulted in deeper rooting with consequent greater uptake of water and hence greater yield.

Banga and DeBruyn (1956) thought plant population influenced root shape; at wider spacings older carrots were more pointed as they matured and enlarged.

Seed germination.--No account of pre-emergence plant population control and spacing would be complete without consideration of the phenomena associated with the germination of the seed.

Standard conditions have been outlined by the Association of Official Seed Analysts (Rules for Testing Seeds, 1954; U. S. D. A., 1952) for germination (Jones, 1927) of lettuce seed. Numerous environmental factors

affect germination of seeds chief among which are temperature, light, aeration, and moisture. Thompson (1938) and Heydecker (1959) classified the factors as temperature, "moisture supply/air supply", and mechanical obstruction.

Post-harvest dormancy of lettuce seed is due to immaturity at harvest (Thompson, 1938; Harrington and Thompson, 1951) which will disappear with ordinary storage. This dormancy exists in the two layers below the outer two of the seed (Bohn and Whitaker, 1951). Light has a variable effect depending on the wave length (Shuck, 1934; Leggatt, 1948; Borthwick et al., 1954). The response of lettuce seed to light during germination can be altered by temperature (Borthwick and Robbins, 1928), by nitrates (Shuck, 1934), and by hormone-like substances. In fact, light was deemed so important that Shuck (1936) thought failure of lettuce seed to germinate in muck was due primarily to the exclusion of light by the dark organic soil

Temperatures over 25° C when combined with high moisture levels are inhibitory to the germination of lettuce seed varying to some extent with the particular variety and other factors (Borthwick and Robbins, 1928). However, if the seed is not in a state of dormancy the lettuce seed germinates under a wide range of temperatures from about 4° to 20° C (Shuck, 1933; Borthwick and Robbins, 1928; Thompson, 1938).

Heydecker (1958) observed that lettuce seed swelled in 15% carbon dioxide but did not germinate. He stated that the maximum concentration

of carbon dioxide present in the soil at any one location would be 4 percent (Heydecker, 1958). Lettuce does have a high oxygen requirement (Thompson, 1934) which may not be satisfied due to puddling of the soil as follows dashing rains (Thompson, 1934). Stout (1959) reported a similar effect on the soil by the passage of equipment.

Moisture can be critical in seed germination. At certain low moisture levels germination does not occur while at optimum levels maximum germination takes place. At intermediate levels germination depends on many factors, among them the interaction of species and variety with moisture levels.

Doneen and MacGillivray (1943) divided vegetable seeds into four groups based upon the percentage of germination at or near the permanent wilting point of Yolo fine sandy loam (8.6%). The seeds of most vegetables germinated well at levels of moisture close to the permanent wilting point of the soil. Hansen lettuce was one of the several classified in a group fairly sensitive to lower levels of soil moisture. It would appear that Heydecker (1954, 1956) agreed with this for he classified lettuce as more sensitive than cabbage, carrot, and onion seeds to soil moisture. Doneen and MacGillivray (1943) found celery to be the most sensitive to soil moisture of all vegetable seeds they germinated (Taylor, 1951). They subscribed to the generalization that seeds germinated faster at higher moisture levels than at lower levels of soil moisture. Ayers (1952) reported that for Spanish onion, total ger-

mination as well as speed of germination decreased with decreasing soil moisture.

Heydecker (1954) found that optimum soil moisture for germination of cabbage, lettuce, carrot, and onion seed was slightly below field capacity. Suput (1953, 1954) preferred to express soil moisture in terms of soil moisture capacity or a certain percentage of this soil moisture capacity when the soil was not completely saturated. Thus Suput considered 19-25% as minimum soil moisture capacity for germination of soybeans, vetch, sunflower, flax, hemp, and turnip. Optimum level was 25 to 60% with 40 to 45% for turnip, vetch, and sunflower; and 35 to 45% for flax and hemp. Observations of Toole et al. (1947) are in agreement with this when for sugar beets they obtained poor germination at 60% soil moisture and much better germination at 40%.

A common method of expressing soil moisture is percentage on an oven dry basis (O. D. B.). This provides a uniform quantitative basis but does not reflect the action of physical forces. Stout et al. (1956) cited Hunter and Dexter to the effect that segmented sugar beet seed balls germinated only between 12 and 21% soil moisture (O. D. B.). Stout (1955) obtained 90% germination for sugar beets at 12 to 21% soil moisture (O. D. B.); below 12%, emergence was reduced; and at 6 to 9% there was no visible germination.

Hunter and Erikson (1952) reported that minimum soil moisture (O. D. B.)

for sugar beets was 4.4-5.45 to 17.7% depending on soil texture and soil type. They presented evidence to support their contention that soil moisture tension was a more reliable and appropriate indicator of soil moisture for seed germination. Soil tension compensates automatically for differences in soil texture and soil type. They observed that each species they tested attained its own specific seed moisture percentage before germination. This varied from 26.5% for rice to 50% for soybeans. They found comparable seed germination at different levels of soil moisture for different soil types. When these levels of soil moisture were compared with soil moisture tension curves for the particular soils, it was observed that the levels of soil moisture were about the same. These could be expressed in atmospheres of soil tension which did not vary from soil to soil. This is a logical method of expression inasmuch as 1/3 atmosphere is equivalent to field capacity and the permanent wilting point is at 15 atmospheres of tension. This system agrees with some results reported by Satoo (1948) when seeds of three species of woody plants germinated at 50% soil moisture or eight atmospheres in terms of soil tension.

Placement of vegetable seed into the ground usually is accompanied by compression of the soil surface by press wheels. This compression of the soil is a factor in seed germination as mentioned above when Thompson (1934) cited a reduction in oxygen movement due to puddling. Stout *et al.* (1960) surveyed the literature on sugar beet germination as influenced by soil com-

pression and concluded that the reduced germination was due to either reduced movement of gases or to the physical obstruction of the soil. Hanks and Thorp (1957) thought that the latter could limit seedling emergence. In a study of "moisture x pressure" and consequently crusting interaction, it was observed that pressures above five pounds per square inch (psi) reduced germination and this was accentuated by reductions in soil moisture. Conversely, at high soil moisture, crusting from pressure did not inhibit seedling emergence.

To circumvent the difficulties associated with compression and its consequence, crusting due to drying (Ray et al., 1952; Stout and Snyder, 1957), several investigators favored the old practice of compressing the seed and covering this with loose soil (Hollis and Burkhardt, 1959; Heydecker, 1954; Hollis, 1960; Marx, 1959; and Stout et al., 1960). Heydecker (1954) stated that this method accelerates germination. Hollis (1960) stated that more uniformity of maturation results because of less in-row competition as more plants are of the same size. Hollis and Burkhardt (1959) cited other quantitative variations in favor of seed firming. Hollis (1960) stated that best results occurred in light sandy soil and that seed firming could not replace good seed beds, high organic matter, and low clay content.

Control by Post-emergence Plant Spacing

Thinning.--Thinning emerged seedlings is one method of achieving desired spacing at maturity. Spacing at this time eliminates some of the hazards that occur during the interval between seeding and thinning so population after thinning becomes solely dependent upon subsequent incidents.

Hand thinning.--Hand thinning is the oldest of methods and is still being used to a great extent on some crops. Bainer (1947) estimated that 20 to 30 man-hours were required per acre of sugar beets for hand thinning. In discussing pelleted seed and precision planters, Nissley (1955) mentioned that it cost from \$40 to \$60 to thin an acre of carrots. Currently, carrots like radishes are not thinned but the effect of spacing is achieved by scattering of the seed in a band at seeding. Zink (1956) stated that thinning of direct seeded head lettuce required 22.5 hours or 43% of the labor of production.

Many factors, political and economic, predicate an increasing shortage of capable field hands to perform the tedious thinning at competitive rates.

Mechanical thinning.--Mechanical thinners have ranged from short-handled hoes to modern mechanical machines. The object in thinning is to remove the excess of plants which frequently amounts to 60 to 90% of the plant population (Carolus, 1949). Many thinning operations are, to a large extent, subject to the control and judgment of man. Man can be the source of 8 to 9% reduction in yield just in the variation in hand thinning efficiency (Warne, 1949).

Mechanical thinners have been described for sugar beets by Harvey (1958), Bainer (1947), Maughan, Wood and Chittey (1959), Frakes (1959), and Coons (1948); for turnips by Maddox (1958) and Robertson (1957); and for lettuce by Brendler *et al.* (1955), and Zink (1956). Guzman (1957) experimented with chemical thinning.

Physiological effect of thinning.--The thinning operation has a physiological effect on the plants that remain. In addition, this effect varies with the time at which the thinning is performed. Zink (1955) reported that delayed thinning injured the root system. Warne (1951a) thought he detected an influence on yield governed by the time of thinning. Weaver and Bruner (1927) thought that "blocking out" of plants in "middle areas" (space between plants) was not harmful to the plants that remained but the thinning of the remaining plants in the hill to single plants could be.

Maddox observed that when turnips were not hoed, they were firmer in the ground at harvest and more upright in growth. Zink (1956) mentioned damage to root systems of lettuce if plants remained thick in the row.

Direct seeding and transplanting.--Some of the reactions of plants to spacing can be observed by a study of their behavior under conditions of direct seeding and transplanting (Vinnik, 1960).

Numerous reports attest to the favorable effect of direct seeding. Zlatkowsky (1953) experienced best results with direct seeding of cauliflower, kohlrabi, lettuce, and celeriac. For Corrales-Macedo (1955a), *Capsicum*

directly seeded out-yielded transplants and matured three weeks earlier. Tomatoes responded in a like manner (1955b). Apparently this reaction of tomatoes is normal, for Holmberg and Minges (1952) reported that field seeding of tomatoes in Yolo county, California, was becoming commonplace. Maddox (1958) compared spaced turnips with singled (thinned) turnips and stated that the former were sturdier and made more vigorous growth.

Conversely, transplanting was unfavorable to lettuce as well as cauliflower, kohlrabi, and celeriac (Zlatkowsky, 1953). Winter (1952) reported a reduction in the number of plants reaching marketable size when transplanted.

Dullforce (1954) examined the retarding effect of thinning in some detail and concluded that "pricking out" was not detrimental to lettuce if the seedling was not disturbed. If, however, it was damaged, then there was an effect. Furthermore, Dullforce concluded that transplanting need not be a shock which retards the plants if the plants are not injured and provided the external conditions are the same as for the check plants with which the transplants are being compared.

METHODS AND MATERIALS - GENERAL

Seed Ribbon

The seeds of various vegetable crops were enveloped in two types of materials prepared in ribbon form.[1] These were subjected to tests and evaluated.

Plastic seed ribbon.--Lettuce seed was folded within three layers, each two mils in thickness, of Methocel,[2] designated as Experimental Plastic Q-830.20 film (Dow Chemical Company, Midland, Michigan, 1957; Minnesota Mining and Manufacturing Company, (3M), Saint Paul, Minnesota, letter 5 October 1959). An eight percent solution of Methocel was extruded onto the ribbon to serve as an adhesive for both retaining the seed and maintaining closure of the ribbon fold (3M, letter 9 November 1959). Water solubility was 37 seconds/2 mil at 77° F. for this two mil thickness methylcellulose ribbon (Dow Chemical Company, 1957; 3M, letter 5 October 1959).

Lettuce seed was placed in the methylcellulose seed ribbon at intervals of 3 1/2, 7, and 14 inches. Each ribbon contained but one spacing of the lettuce seed. Precision of seed spacing was checked and in Table 1 is

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[1]Process developed and performed by the Minnesota Mining and Manufacturing Company, St. Paul, Minnesota.

[2]Registered trademark of the Dow Chemical Company, Midland, Michigan.

TABLE 1.--Distribution of Lettuce Seed in Methylcellulose Ribbon.[a]

Seed Interval	Average Skips	Average[b] Multiples
14 inches	1.2%	19.6%
7 inches	1.8%	21.0%
3 1/2 inches	2.25%	21.5%

[a]From data sheet dated 4 April 1959 (Thermofax), enclosure to 3M letter dated 3 June 1959 from Dr. R. J. Klug.

[b]Multiples were practically all doubles with remainder triples.

presented the frequency of skips, doubles, and triples for the three spacings. It varied but slightly between tapes. Skips and multiples when taken together accounted for almost one-fourth (20.8 to 23.75%) of the seed locations.

Paper seed ribbon.--For experiments in 1960, seeds of lettuce, cauliflower, tomato, and celery were placed[1] between a backing of unbleached sulfite crepe with high wet-strength and a facing of 15 pound lightweight tissue with no wet-strength (3M, conversation 15 June 1960 with Mr. H. D. Roussopoulos).

Seeds

Lettuce.--Seed of lettuce (*Lactuca sativa* var. *capitata* cv. Cornell 456[2]) was purchased (catalogue No. 508, Lot No. 1352) from Joseph Harris

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[1]Process developed and performed by the Minnesota Mining and Manufacturing Company, St. Paul, Minnesota.

[2]Nomenclature based on Thompson (1939); Standardized Plant Names (1942); International Code of Botanical Nomenclature (Stockholm code) (1952); International Code of Botanical Nomenclature (Paris code) (1954); and International Code of Nomenclature of Cultivated Plants (1958).

Company, Incorporated, Moreton Farm, Rochester, New York. The tag attached to the seed bag listed the 1959 germination by test as 96%. During the course of these experiments several tests for germination were conducted by the seed laboratory at Michigan State University, East Lansing, Michigan. In Table 2 is presented the percentage germination of this lettuce seed. The naked seed, either natural or made thus by washing off the methylcellulose, showed high germination percentage (86 to 98%) in 1959 and 1960. If the methylcellulose was left in contact with the seed, then germination dropped to 38%.

TABLE 2.--Germination of Lettuce (Cv. Cornell 456, Lot No. 1352) on Top of Blotters in Covered Petri Dish at 20°C.[a]

Condition of Seed	Date Started	Percentage of Germination on Day After Start						
		2	3	4	6	7	8	9
Regular seed without any treatment	4/20/59	11	44	47	68	77	84	93
Seed with methylcellulose seed ribbon	4/20/59	1	4	8	23	30	35	38
Seed with methylcellulose ribbon washed off	4/20/59	70	75	84	90	90	91	92
Regular seed washed with water	4/22/59	97	-	99				
Seed with methylcellulose ribbon washed off	4/22/59	70	-	86				
Regular seed without any treatment	3/27/60	-	98					

[a]Grateful appreciation is expressed to Dr. George P. Steinbauer, Department of Botany and Plant Pathology under whose supervision these determinations were made.

Cauliflower, tomato, and celery.--Seeds of cauliflower (*Brassica oleracea* var. *botrytis* cv. Snowball Imperial), tomato (*Lycopersicon esculentum* var. *commune* cv. Fireball), and celery (*Apium graveolens* var. *dulce* cv. Utah 52-70) were purchased from Joseph Harris Company, Inc., Rochester, New York in 1960. Additional information imprinted on the seed containers by the seedsman is given in Table 3. The celery seed was not hot water treated.

TABLE 3.--Additional Information on Vegetable Seed.

Vegetable	Cultivar	Catalogue Number	Lot Number	Germination in Test 1960
Cauliflower[a]	Snowball Imperial	339	466	88%
Celery	Utah 52-70	384	531	92%
Tomato[a]	Fireball	861	1466	96%

[a]Hot water treated.

Radish.--Seed of radish (*Raphanus sativus* cv. Early Scarlet Globe) was purchased at Sears Roebuck and Company store, Frandor Shopping Center, Lansing, Michigan. Packets contained information that in January, 1960 test, seed possessed germination of 75%. Also, seed had been treated with the fungicide chloranil (tetrachloroquinone).

Location of Experimental Plots

Schonfeld farm.--The first field planting of lettuce was made in the spring of 1959 at the Schonfeld farm five miles north northeast of Imlay City, Michigan (about 50 miles north of Detroit).

Anderson farm.--The second field planting of head lettuce was made at the Anderson farm five miles east of Imlay City or about 45 miles north of Detroit, Michigan.

Michigan State University Experimental Muck Farm.--Two plantings at the Michigan State University Muck Farm located eleven miles north northeast of Michigan State University, East Lansing, Michigan. The June planting was factorial in design for soil moisture, depth of planting, and method of seeding. The July planting was for method of seeding only.

Greenhouse.--The greenhouse experiments were conducted in the Michigan State University Plant Science Greenhouse, Farm Lane, East Lansing, Michigan.

Field experiments.--Field experiments on tomato flowering and radish root development were conducted at the Michigan State University Horticulture Farm, East Lansing, Michigan.

Other field trials.--The location of other experimental plots in 1959 and 1960 will be mentioned when the particular experiment is discussed.

Planters

A specially designed ribbon planter (Model QAMC 424)[1], Figure 1 (upper left) was used to place the seed ribbon into the ground on plots at the Schonfeld and Anderson farms.

A subsequent modification (QFE 2012 and QFE 2013)[2] mounted as paired units, Figure 1 (upper right) was used for lettuce and cucumber on plots planted during June, 1959 at the Michigan State University Muck Farm and the Michigan State University Horticulture Farm.

The later July 27, 1959 seeding was made with a Planet Jr.[3] modification[4] for seed ribbon planting similar to the model[4] portrayed in Figure 1 (lower left).

Check seedings with regular equipment were performed at the various locations as follows:

At the Schonfeld farm, a Cliff Wetzel seeder (made in St. Johns, Michigan) drawn by a D-2 Caterpillar crawler type tractor was used to roll the soil and seed the lettuce. The seeding mechanism on this custom-made seeder consisted of six modified Planet Jr. seeder units mounted behind the roller.

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[1]Designed, developed, and provided by the Farm Equipment Research and Engineering Center, International Harvester Company, Hinsdale, Illinois.

[2]Developed and provided by the Farm Equipment Research and Engineering Center, International Harvester Company, Hinsdale, Illinois.

[3]Trademark of S. L. Allen and Company, Inc., 3419 North 5th Street, Philadelphia, Pennsylvania.

[4]Adapted and provided by the Minnesota Mining and Manufacturing Company, St. Paul, Minnesota.

Figure 1

UPPER, left. Photograph of International Harvester experimental QAMC 424 seed ribbon planter in operation at Schonfeld farm, Imlay City, Michigan, April 30, 1959.

UPPER, right. Photograph of International Harvester experimental QFE 2012 and QFE 2013 seed ribbon planter being loaded with methylcellulose seed tape at Michigan State University Experimental Muck Farm, Laingsburg, Michigan, June 9, 1959.

LOWER, left. Photograph of Planet Jr. hand seeder modified by Minnesota Mining and Manufacturing Company for paper seed ribbon planting. 1960.

LOWER, right. Photograph of methylcellulose seed ribbon after placement in the soil (uncovered to show comparison).

Figure 1

At the Anderson farm, an Allis-Chalmers tractor mounted seeder was used.

At the Michigan State University Muck Farm, check rows in all plantings were made with a standard Planet Jr. hand seeder.

All other plantings, both ribbon and regular seedings, are described in the appropriate place.

Greenhouse soil

All greenhouse experiments were conducted by using a Lock sandy loam topsoil with the exception of the 1960 Greenhouse Plant Spacing Experiment. Snyder (1957) has given the textural analysis for this Lock sandy loam as 60.4% sand, 26.7% silt (less than 50 microns and more than 2 microns), and 12.9% clay (less than 2 microns). Snyder (1957) calculated and showed a soil moisture curve for this soil in terms of soil moisture percentage on an oven dry basis. From this curve and other illustrations, it appears that 1/3 atmosphere (field capacity) was at 16.2% and 15 atmospheres (permanent wilting point) was at slightly below 6% soil moisture.

The air dry soil was passed through a screen with 5 mesh to the inch. Soil moisture of the air dry soil was determined to be 1.16% on an oven dry basis as an average of 4 samples dried at 105°C.[1] Tap water was added to this soil to obtain the desired level of soil moisture on an oven dry basis.

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[1]Grateful acknowledgment is made for use of the facilities of the Soil Science Department, Michigan State University.

Moisture was evenly distributed to the soil and the soil was mixed further. The soil was then placed in a closed container to permit the soil to reach an equilibrium. At the beginning of each experiment, the soil was again passed through a 5 mesh screen and placed in plastic trays[1] which measured 7 x 11 x 2 1/2 inches inside dimensions.

Soil compression

The desired soil compression measured in pounds per square inch (psi) was obtained by use of the apparatus illustrated by Stout, Snyder, and Buchele (1960) (see Figure 2).

[1] Courtesy of the Minnesota Mining and Manufacturing Company, St. Paul, Minnesota.

Figure 2

Apparatus used to apply pressure onto soil surface

Michigan State University Photo 18076 - 4.

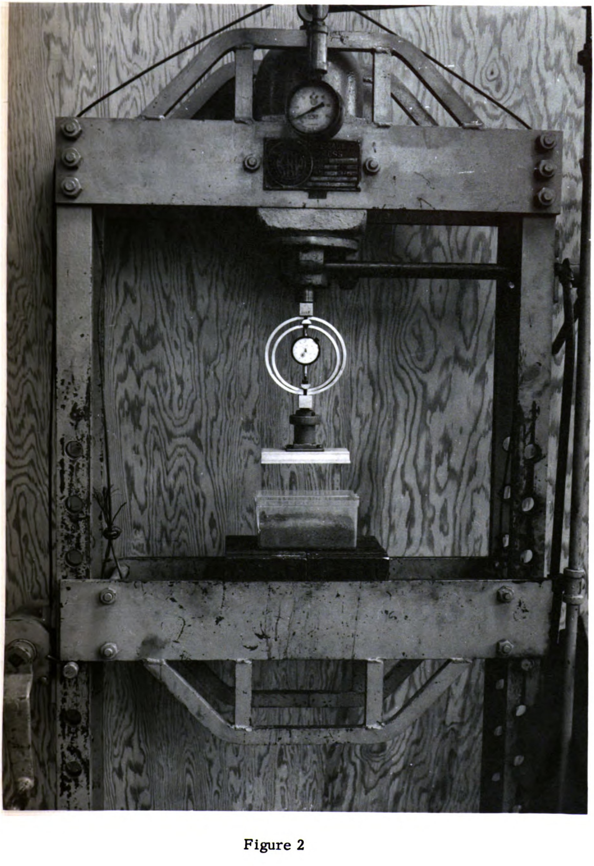

Figure 2

EXPERIMENTAL RESULTS

Field Experimental Trials - 1959

Experiment at Schonfeld Farm

Planting. --The Carlisle muck (Davis and Lucas, 1959) at the Schonfeld farm was plowed; 500 pounds of 5-10-20 fertilizer was broadcast and disced in; and the surface was made uniform by "floating". On April 30, 1959, four check rows and two guard rows were seeded at an estimated rate of 1/2 to 3/4 pound of lettuce seed per acre. Each of the rows in this experiment extended 2360 feet in a north-south direction. The next two westerly rows were planted with the seed ribbon in which the seed was spaced at 14 inches (14 inch ribbon). Starting at the north end, one round trip was made with the planter. The next two rows were planted in the same way, but with a ribbon in which the lettuce seed was spaced at 7 inches (7 inch ribbon). The next two rows were planted with a ribbon in which the seed was spaced at 3 1/2 inches (3 1/2 inch ribbon). Then the next six rows were planted as the six rows just completed, i.e. two rows with 14, 7, and 3 1/2 inch ribbons successively. Soil moisture appeared to be at an excellent level for germination. Soil temperature at 4 inches below the surface of the floated soil was 50°F. at 3 p.m. The seed ribbon was found at 3/8 to 5/8 inch below the pressed surface of the ground.

Thinning and weeding. --Thinning and weeding was done on all plots on May 25, 1959 by a pair of experienced Texas-Mexican, male adults who used short-handled hoes. The two adjacent rows of the same treatment were thinned and weeded at the same time (Figure 3, upper, left). Plants were thinned to 14 to 16 inches apart in the row. Each worker worked on every treatment in both replicates. Time varied from 10 to 18 minutes. This time was adjusted for a uniform distance to permit comparison. In Table 4 is presented the mean time for two replicates and two workers for each treatment. The pertinent portion of statistical analysis is included for comparison of means.

TABLE 4. --Effect of Method of Seeding and/or Spacing on Thinning and Weeding Time for Head Lettuce at Schonfeld Farm.

Method of Seeding	Time[a] (Minutes)
Check seeding	13.05
14 inch ribbon	11.99
7 inch ribbon	12.23
3 1/2 inch ribbon	12.33
L.S.D. 05	0.93

[a]Average time for thinning and weeding two adjacent 150-foot rows (total - 300 feet). Average of two replicates.

Figure 3

UPPER, left. Photograph of thinning head lettuce at Schonfeld farm, Imlay City, Michigan, May 25, 1959 (seeded April 30, 1959). The row on either side of the laborer's left foot was seeded with 14 inch methylcellulose seed ribbon. All rows to the right of these two rows were seeded with custom-made Wetzel seeder. The two rows to the left of the 14 inch seed ribbon were seeded with 7 inch methylcellulose seed ribbon. The next two rows to the left of these were seeded with 3 1/2 inch methylcellulose seed ribbon.

UPPER, right. Photograph of thinning head lettuce at the Anderson farm, Imlay City, Michigan, June 18, 1959 (seeded May 28, 1959).

LOWER, left. Photograph of plots at Michigan State University Experimental Muck Farm, Laingsburg, Michigan, 1959, before thinning of head lettuce but after weeding.

LOWER, right. Photograph of plots at Michigan State University Experimental Muck Farm, Laingsburg, Michigan, 1959, in close up showing irregular emergence of lettuce seedlings.

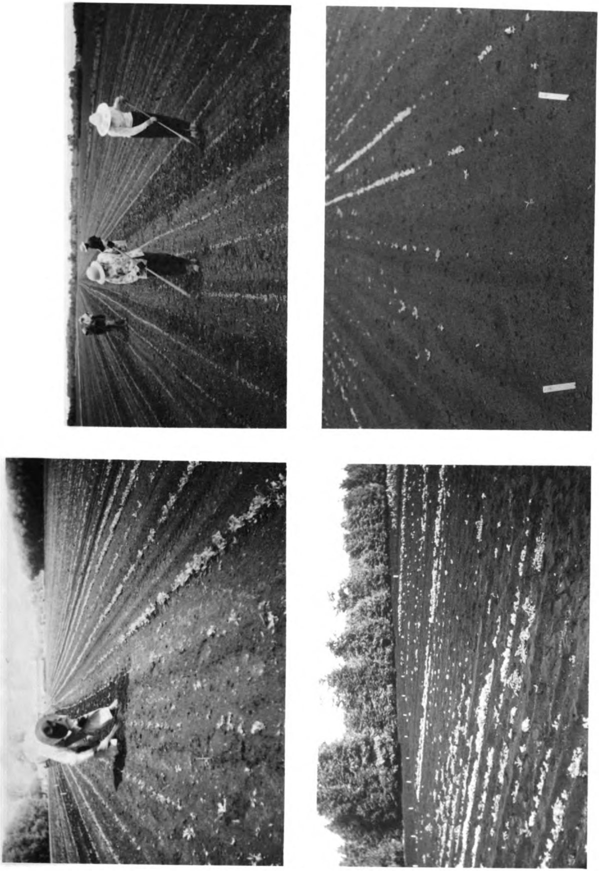

Figure 3

Harvest.--Four harvest plots were selected, each one hundred feet in length and extending across all rows, treatments, and replicates. Thus, each harvest plot of each treatment in each replicate consisted of two adjacent 100-foot rows. On July 8, 1959, two regular experienced Texas-Mexican cutting crews each consisting of one male cutter and one female packer did the cutting and packing for commercial shipment. Weights and counts were made of all lettuce harvested.

One full case (24 heads) was selected at random from each treatment in each harvest plot and replicate for subsequent cutting open and rating for degree of tipburn (Grogan et al., 1955). Thus, 768 heads were examined for degree of tipburn, a physiological disease of head lettuce. Each plant not harvested in the harvest plots was counted and classified as to reason for not being harvested on the basis of visual observation.

Results.--From the thinning and weeding times presented in Table 4, it appeared that the only significant difference in time was between the check seeding and the 14 inch ribbon. However, the difference was significant only at the 5 percent level.

The total number of plants per treatment that survived until harvest is listed in Table 5. There was no significant difference between the number of plants at harvest when the check seeding was compared with either the 7 or 3 1/2 inch ribbon. However, in the 14 inch ribbon plots, there were significantly (1% level) fewer plants at harvest than in any one of the other treatment plots either ribbon or regular.

TABLE 5.--Effect of Method of Seeding and/or Spacing on Survival, Harvest, and Percentage Harvested of Head Lettuce at Schonfeld Farm (Average of Two Replicates).

Method of Seeding and/or Spacing	Number[a] of Plants	Number of[b] Heads Harvested	Percentage[c] Harvested
Check seeding	519	299.5	57.71
14 inch ribbon	386	239.5	62.05
7 inch ribbon	491	314.0	63.95
3 1/2 inch ribbon	526	377.0	71.67
L.S.D. 05	59	75.3	12.45
L.S.D. 01	84	138.3	--

[a]Total number of plants present at harvest on eight 100-foot rows.

[b]Total number of heads harvested from eight 100-foot rows.

[c]Percentage of lettuce stand harvested from eight 100-foot rows.

Out of this stand at harvest, the number of heads that were of market acceptability and thus were harvested is given in Table 5. The total yield from the 3 1/2 inch ribbon (377 heads) was significantly different only at the 5% level from the regular planting (299.5 heads). The greatest difference was between the different spacings of seed in the ribbon plantings particularly the 14 inch ribbon when compared to the other two.

The relationship between the number of heads harvested and the total number of plants present at harvest is given in Table 5 as percentage harvested. There was a significant difference only between the 3 1/2 inch ribbon

and the check seeding. Nevertheless, the percentage harvested was greater for each ribbon planting than for the check.

The total weight of lettuce harvested is presented in Table 6. In large part, the weights reflect the number of heads harvested.

Calculation of average weight per harvested head from data presented in Tables 5 and 6 are given in Table 6. There was a significant difference (5% level) in weight per head of lettuce between the check seeding and any one of the ribbon plantings. Furthermore, there is no significant difference between any one of the ribbon plantings.

Tipburn evaluation was performed by rating the internal appearance of a head as either acceptable or non-acceptable for sale. In the acceptable group were included those heads that contained no trace of internal browning or only light tan-colored traces at the margins of the innermost leaves. Included in the non-acceptable group were those heads with darker leaf margins or slimy decay. Treatment means for this latter non-acceptable grouping are listed in the fourth column of Table 6 with conversion into percentage of inspected heads in the fifth column of Table 6.

A class comparison between the check seeding vs. the three ribbon spacings at a single degree of freedom resulted in a significant difference (F value - 13.64; F 05 - 10.13). Thus there was significantly more tipburn in the ribbon plantings than in the check seeding. The reason for this is not readily apparent.

TABLE 6. --Effect of Method of Seeding and/or Spacing on Total Weight, Average Weight per Head, and Tipburn of Harvested Lettuce at Schonfeld Farm (Average of Two Replicates).

Method of Seeding and/or Spacing	Total Weight[a] (Pounds)	Weight per Head[b] (Pounds)	Heads with[c] Tipburn	Percentage[d] of Tipburn
Check seeding	495.8	1.655	2.88	12.00
14 inch ribbon	437.3	1.826	6.75	28.13
7 inch ribbon	577.8	1.840	8.38	34.92
3 1/2 inch ribbon	710.5	1.885	7.63	31.79
L.S.D. 05	160.3	0.141	4.97	
L.S.D. 01	N.S.	N.S.	N.S.	

[a]Weight of all lettuce harvested from eight 100-foot rows.

[b]Computed average weight per head.

[c]Average number of heads per case (24 heads) affected with tipburn consisting of dark leaf margins and/or slimy decay (non-acceptable for market).

[d]Percentage of heads affected by this degree of tipburn.

Experiment at Anderson Farm

Planting.--The Spalding peat (Davis and Lucas, 1959) on the Anderson farm was plowed; 800 pounds of 5-20-20 fertilizer was broadcast and disced into the soil. Just before seeding, the soil surface was "floated" to assure a level seedbed. On May 28, 1959, the previously used Model QAMC 424 ribbon planter mounted on a tractor drawbar was used in the same manner as at the Schonfeld farm. Rows extended 2,510 feet in length in a north and south direction. The same three spacings of seed in the methylcellulose seed ribbon (14, 7, and 3 1/2 inches) were used. Depth of planting varied from 1/2 to 3/4 inch below the surface of the soil. The first two rows were planted by making a round trip with the tractor and ribbon planter burying the 14 inch ribbon. To the west, two more rows were planted with the 7 inch ribbon; and the next two with 3 1/2 inch ribbon. This same planting pattern was repeated for the next six rows to the west. The next or last six rows were seeded with the grower's regular seeding equipment which consisted of a tractor mounted Allis-Chalmers lettuce seeder.

Thinning and weeding.--On June 18, 1959, the plots were thinned and weeded at this time mainly because the check rows were so dense that thinning could not be delayed. Two Texas-Mexican female workers did the thinning and weeding when thinning labor requirements were determined (Figure 3; upper, right). As at the Schonfeld farm, each worker worked for 10 to 15 minutes on each treatment in both replicates. This time and distance

thinned and weeded was converted to a uniform 300 feet of double row and is presented in Table 7 for each treatment.

Harvesting. --Three harvest plots were selected at random, each one hundred feet in length and extending across all rows, treatments, and replicates. Two adjacent rows made up each treatment within each harvest plot in each of two replicates.

On July 30, 1959, two harvest crews, each consisting of an experienced Texas-Mexican cutter and packer, harvested all plots. Weight and number of heads of all harvested lettuce was recorded for subsequent analyses. For internal examination of individual heads, one case (24 heads) was selected at random from each treatment in each harvest plot of both replicates taken together. Thus 384 heads were broken open and rated for tipburn as at the Schonfeld farm. All plants present in harvest plots were counted on July 23, 1959 On July 30th, each plant not harvested was counted. All these data are presented in Table 7.

Results. --The time required to thin and weed the check plots was significantly greater than for any of the ribbon plantings. In addition, there was no significant difference between any one of the seed spacings in the ribbon plantings.

There was at least significantly fewer (5% level) plants surviving in the 14 inch ribbon plots than in the other ribbon plantings or particularly the check planting.

TABLE 7. --Effect of Method of Seeding and/or Spacing on Thinning and Weeding Time, Survival, Yield, Percentage Harvested, and Tipburn of Harvested Lettuce at Anderson Farm (Average of Two Replicates).

Method of Seeding and/or Spacing	Time[a] (Minutes)	Number[b] of Plants	Heads[b] Harvested	Percentage[c]	Heads with[d] Tipburn	Percentage[e] of Tipburn
Check seeding	21.15	496	312.5	63.00	0.00	0.00
14 inch ribbon	15.41	209	155.0	74.16	1.00	4.17
7 inch ribbon	14.00	383	261.5	68.28	0.33	1.39
3 1/2 inch ribbon	16.30	413	289.5	70.10	0.67	2.78
L.S.D. 05	3.03	96	55.7	N.S.	N.S.	
L.S.D. 01	4.26	176	102.3			

[a]Time adjusted for 600 feet of row consisting of two adjacent rows each 300 feet long.

[b]Total number for three harvest plots of two 100-foot rows each.

[c]Percentage of lettuce stand harvested from six 100-foot rows.

[d]Average number of heads per case (24 heads) affected with tipburn consisting of dark leaf margins and/or slimy decay (non-acceptable for market).

[e]Percentage of heads examined affected by this degree of tipburn.

The number of heads harvested from the 14 inch ribbon plots was significantly lower than other ribbon plots and particularly the check planting. Also, there was no significant difference between the yield from the regular seeding as compared to either the 7 or 3 1/2 inch ribbon.

As is apparent in the fifth column of Table 7, there was no significant difference between any of the percentages of lettuce stand harvested. However, the percentages in the ribbon plots were greater than the check by almost 8% on the average. This was an interesting and seemingly consistent difference. There was no difference in amount of tipburn.

The total weights of lettuce harvested are given in Table 8. Since in large part they represented the number of heads harvested, it was not surprising that significance is approximately that given for the number of heads harvested.

The weight per harvested head was computed and is given in Table 8. Although there was no difference between any of the weights, the average weight per head in each of the ribbon plantings was greater than in the check planting.

TABLE 8.--Effect of Method of Seeding and/or Spacing on Total Weight and Average Weight per Head of Harvested Lettuce at Anderson Farm (Average of Two Replicates).

Method of Seeding and/or Spacing	Total Weight[a] (Pounds)	Weight per Head[b] (Pounds)
Check seeding	564.5	1.803
14 inch ribbon	286.3	1.848
7 inch ribbon	517.5	1.899
3 1/2 inch ribbon	508.3	1.829
L.S.D. 05	132.6	N.S.
L.S.D. 01	243.6	- -

[a]Weight of all lettuce harvested from six 100-foot rows.

[b]Computed average weight per head.

Experiments at Michigan State University Experimental Muck Farm

Design.--The 1/4 acre was divided into three replicates. A regular split plot design was used. The main plots were either irrigated or not irrigated immediately after planting. The sub-plots were planted either shallow or deep within the limits of the planter. The sub-subplots consisted of the check seeding and the three spacings of seed in the methylcellulose seed ribbon.

Planting.--The Houghton muck (Davis and Lucas, 1959) was plowed and disced a number of times to reduce soil moisture as much as possible to provide a drier than normally desired seed bed. Treatments were planted

on June 9, 1959, with the use of twin units of a modification of the ribbon planter. The irrigated plots received approximately one-half inch of water by sprinkler irrigation.

Thinning.--Weeds were removed from the plots prior to thinning. Therefore, the thinning labor requirement does not include weed removal. On July 7, 1959, this thinning was done by a semi-skilled local crew employed for the summer (Table 9). Since all rows were a uniform 54 feet long arranged in adjacent pairs, no adjustment of time was necessary.

Harvesting.--The lettuce that was ready to harvest was harvested on two dates; August 13 and 17, 1959.

Results.--While there was a significant difference between the times for thinning for the various seed ribbons, this difference was considerably smaller when compared to the difference between the regular seeding and any one of the ribbon seedings.

As for the number of plants surviving until harvest, the check plots contained significantly more plants (84.33) than even the 3 1/2 inch ribbon (68.33).

The number of heads harvested from the 14 inch ribbon plots was significantly less (5%) than from any of the plots. Conversely there was no significant difference in the number of heads at first harvest between the check planting and 3 1/2 or 7 inch ribbon.

For the first harvest, there was no significant difference between the

TABLE 9. --Effect of Method of Seeding and/or Spacing on Thinning Time, Survival, Yield at First and Total Harvest, and Percentage of First and Total Harvest of Head Lettuce at MSU Muck Farm.

Method of Seeding and/or Spacing	Time[a] (Minutes)	Number[b] of Plants	Heads[c] Harvested (1st Harvest)	Percent[d] Harvested (1st Harvest)	Total[e] Heads Harvested	Percent of[f] Total Plants Harvested
Check seeding	16.00	84.33	32.08	38.04	55.25	65.52
14 inch ribbon	1.63	38.42	22.67	59.00	28.33	73.74
7 inch ribbon	2.88	55.92	31.00	55.44	42.00	75.11
3 1/2 inch ribbon	5.88	68.33	36.83	53.90	50.50	73.91
L.S.D. 05	0.62	12.03	7.09	9.85	7.05	8.02
L.S.D. 01	0.84	16.31	9.63	13.39	9.56	10.87

[a] Time in minutes to thin (without weeding) two 54-foot rows (average of three replicates with four sub-plots per replicate).

[b] Number of plants per two 54-foot rows (average of three replicates with four sub-plots per replicate) obtained by summing the number of heads harvested on August 13, 1959 and number of heads harvested on August 17, 1959 plus number of plants not harvested on August 17, 1959.

[c] Number of heads harvested per two 54-foot rows (average of three replicates with four sub-plots per replicate) on August 13, 1959.

[d] Percentage of total stand harvested on August 13, 1959.

[e] Total number of heads harvested on August 13 and 17, 1959 per two 54-foot rows (average of three replicates with four sub-plots per replicate).

[f] Percentage of total stand harvested on August 13 and 17, 1959 per two 54-foot rows (average of three replicates with four sub-plots per replicate).

three spacings in the ribbon seedings. However, the percentage for each was significantly greater than for the check seeding. That is, a much higher percentage of the plants was harvested from the ribbon plots than from the regular seedings.

For total harvest there was no significant difference between the percentages in the ribbon plots. But the percentage harvested from any one of the ribbon plots was significantly greater (5%) than for the check seeding.

There was a significant effect of irrigation in increasing yield which is shown in Figure 4 (lower). This illustration also portrays the significant interaction of irrigation and treatments as expressed by yield. Most conspicuous in this interaction was the increase in yield of the 3 1/2 inch ribbon under irrigation, as compared with the check seeding, whereas in the case of no irrigation there was a decrease in yield, Figure 4 (lower).

Depth of planting had no significant effect on yield as is apparent from yield data presented in Figure 4 (upper).

A mid-summer planting of three replicates was made on July 27, 1959. The check seedings were made with a regular Planet Jr. hand seeder. The ribbon seedings, however, were made with a Planet Jr. hand seeder modified for ribbon placement. Irrigation and depth of planting were not variables in this experiment. The 14 inch and the 7 inch ribbons were used. Each treatment in each replicate consisted of two adjacent rows, each 45 feet in length.

Figure 4

UPPER Effect of planting depth on yield of lettuce at MSU Muck Farm. (Heads harvested is total for six 54-foot double rows.)

LOWER Effect of irrigation immediately after planting on yield of lettuce at MSU Muck Farm. (Heads harvested is total for six 54-foot double rows.)

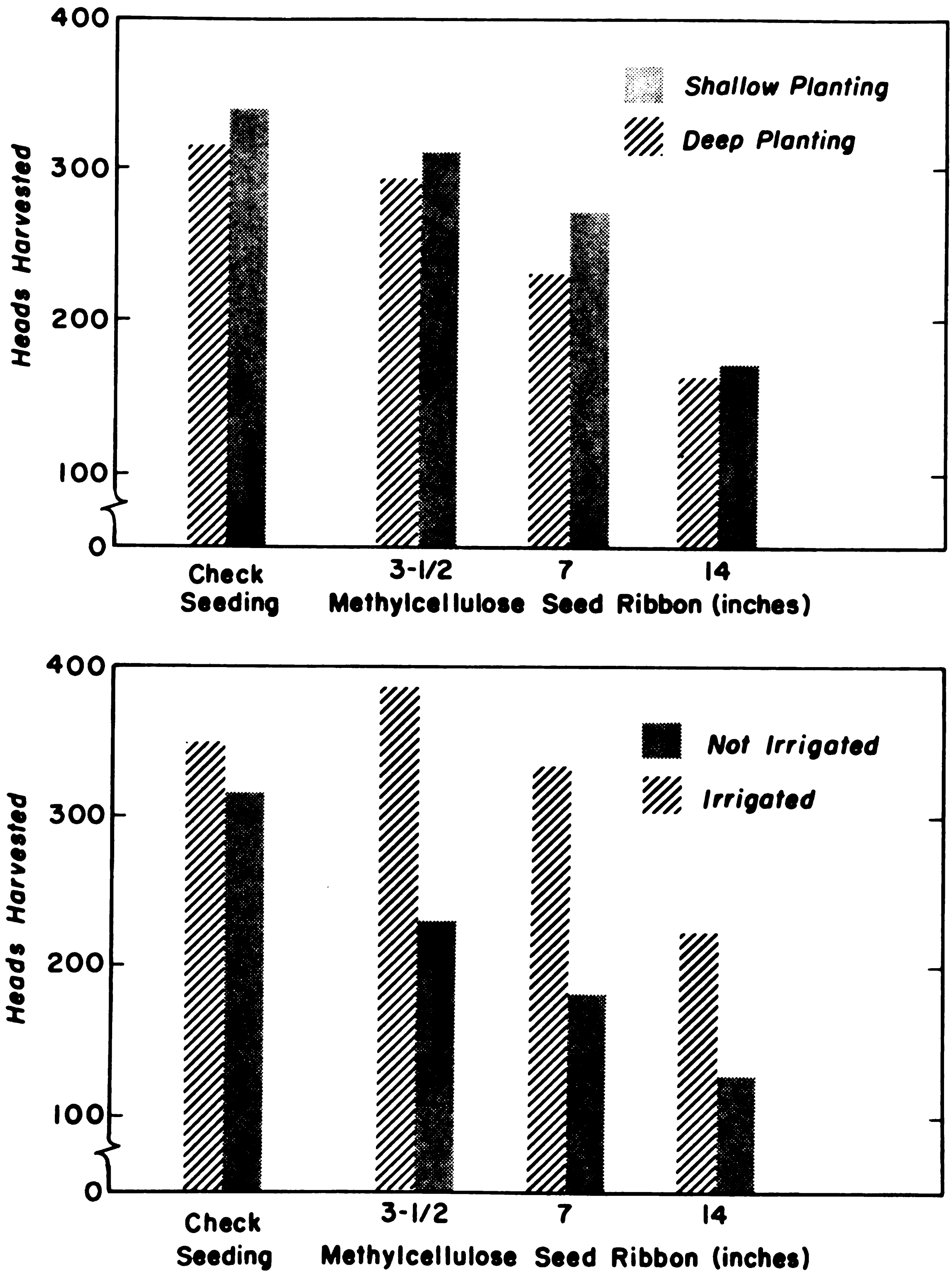
400
300
200
100
0
Heads Harvested
Shallow Planting
Deep Planting
Check
Seeding
3-1/2
7
14
Methylcellulose Seed Ribbon (inches)
400
300
200
100
0
Heads Harvested
Not Irrigated
Irrigated
Check
Seeding
3-1/2
7
14
Methylcellulose Seed Ribbon (inches)

Figure 4

The lettuce plants in all plots were thinned to a 14 inch interval on August 24, 1959. On September 27, just before a killing frost close to maturity of the lettuce, a count was made of the plants established. These data are presented in Table 10. There was a significant difference between the number of plants established in all treatments. The number of plants established in the check rows most nearly approached the theoretical ideal. The lowest number of plants established was in the plots where the 14 inch ribbon was used.

Other Field Experiments - 1959

Michigan State University Horticulture Farm - 1959.--On June 17, 1959, replicate plots were planted of lettuce on an upland mineral soil The check plots were planted with a Planet Jr. seeder and the 7 inch ribbon was placed by the tape planter used at the Michigan State University Muck Farm.

On July 7, 1959, the stand was considered to be so poor as to be commercially unacceptable in all ribbon plots (Figure 10, upper, left) and was acceptable in the check plots. Due to the highly irregular stand and disease, yield data were not obtained.

Cucumber trials - 1959.--Plantings were made with seed ribbon of cucumber variety Early Hybrid on muck at Schonfeld farm near Imlay City, on muck at the Michigan State University Muck Farm, and on mineral soil at the Michigan State University Horticulture Farm, at East Lansing, Michigan.

TABLE 10.--Number of Lettuce Plants Established on September 27, 1959, as Affected by Method of Seeding and/or Spacing at MSU Muck Farm.

Method of Seeding and/or Spacing	Number of Plants[a] Established
Check seeding	72
14 inch ribbon	40
7 inch ribbon	54
L.S.D. 05	13.5
Ideal population	77

[a]Number of plants established per two 54-foot rows after thinning to 14 inches apart on August 24, 1959.

[b]Number of plants per two 54-foot rows if each plant was present and spaced exactly 14 inches apart in the row.

On June 18, 1959, the plots at the Schonfeld farm were observed. Cucumber plants had emerged in the direct seeded check rows and were up to 1 1/2 inches in height, whereas in the ribbon planted row, no emergence had occurred but many seedlings were just breaking the soil surface. On July 6, 1959, plants in both treatments appeared to be at about the same stage of development.

The plots at the Michigan State University Muck Farm were planted on June 9, 1959. Of the three replicates, two were irrigated when the adjacent lettuce plots were irrigated and one replicate was not irrigated. All plants were thinned on July 7, 1959. After thinning a count of the stand

revealed that there remained an average of 106 plants on 108 feet of row (two adjacent rows 54 feet in length) in the regular seeding. On the other hand, in the ribbon plots, the average stand was 55 plants. This consisted of 40 in the non-irrigated replicate and 50 and 86 plants in the two irrigated replicates. Thus the stand did not vary to any great extent whether the plants were irrigated or not for the regular seeding. However, in the ribbon plots, the stand in the non-irrigated plot was one-half or less that in the irrigated plot. Also, the stand in the ribbon plots was about one-half that in the regular seeding.

Plots at the Michigan State University Horticulture Farm were planted on June 17, 1959. On July 8, 1959, it was observed that stand was low in the ribbon plots and was fairly high in the check plots. The check plots were thinned on July 10, 1959, but the ribbon plots were not thinned. The count after thinning revealed that there were 27.4 plants (average) left per 52-foot plot in ribbon plots as compared to 50.7 plants (average) in the regular seeding.

Greenhouse Experiments - 1960

Plant spacing experiment.--On March 24, 1960, a special soil mix consisting of 50% muck and 50% sandy loam topsoil was placed in plastic trays (7 x 11 x 2 1/2 inches), filling them to the brim. Trays were gently tapped to settle the soil about one-half inch. Spacing and thinning treatment number 1 (Table 11) consisted of distributing single seeds at 2 x 2 intervals in three

TABLE 11.--Effect of Time of Spacing on Fresh Weight of Foliage and Roots of Head Lettuce.

Treatment Number	Time of Spacing	Fresh Weight[a] (Grams)
1	Precision spaced	60.7
2	Thinned at one week[b]	66.7
3	Thinned at two weeks[b]	48.3
4	Thinned at three weeks[b]	40.3
L.S.D. 05		20.95

[a]Average fresh weight per replicate of three replicates of 14 plants each of lettuce seeded March 24, 1960 and harvested May 9, 1960.

[b]Thinned at indicated number of weeks after emergence.

rows in the trays. For treatment numbers 2, 3, and 4 (Table 11) the seeds were distributed in three rows at normal seeding density of 8 to 9 seeds per inch of linear distance. The seeds were covered to a depth of one-half inch and the trays covered with clear polyethylene film until after emergence. The seedlings that had emerged were thinned to the desired 2 x 2 inch interval at either one week after emergence, two weeks after emergence, or three weeks after emergence. All thinning was done by cutting the extra seedlings at ground level to avoid disturbing the roots of the remaining plants.

On May 9, 1960, 46 days after seeding, the lettuce plants were harvested. The foliage and roots of 14 plants per tray replicate were weighed

after adhering soil had been removed by washing and the plants sponged dry with toweling. The average weight per replicate per treatment is presented in Table 11.

In the analysis of variance, when the source of variance was apportioned to a single degree of freedom, the linear relationship between treatments was significant (F value - 8.35; F 05 - 5.99).

There was no significant difference between the average weight of plants thinned three weeks after emergence as compared to the weight of those plants thinned two weeks after emergence. Also, there was no significant difference between precision spacing of seed at the desired interval as compared to thinning at one week after emergence. However, the average weight of plants thinned at three weeks after emergence was significantly lower (5% level) when compared with the weight of plants thinned at one week after emergence.

Soil crust experiments.--The Lock sandy loam soil was placed in plastic trays on April 9, 1960. The full trays were gently tapped to settle the soil about one-half inch. In each tray seedings of lettuce were made at loci 1 1/2 inches apart in rows two inches apart. Each locus consisted of either one seed, two seeds, or four seeds. Trays were refilled with soil. Of the six trays, three were subjected to slight surface pressure (1/2 psi) and the remaining three trays to 7 psi. The trays were covered with polyethylene film for two days. After the film was removed, the soil surface dried to a

hard crust. The last observation was made on May 9, 1960.

Analysis of variance disclosed that under the conditions of this experiment, there was no significant difference in number of seedlings emerging between the compression of the soil surface at 1/2 psi as compared with 7 psi (F value - 0.37; F 05 - 18.51). When apportioned to a single degree of freedom, there was a significant linear relationship of emergence and number of seeds per location (F value - 35.91; F 01 - 11.26). The average number of hills at which there was emergence of seedlings is given in Table 12 according to the number of seeds placed in a hill.

There was no significant difference in number of hills at which there was emergence when one seed per hill was compared to two seeds. But there was a significant difference when four seeds per hill were compared to one or two seeds.

On August 7, 1960, a similar experiment was initiated. The same soil was similarly placed in the plastic trays. Each of the three rows in each tray contained the same number of seeds (12 seeds) but the arrangement of seeds per row was either singly, of six hills of 2 seeds per hill, or three hills of 4 seeds per hill. Soil in all trays was compressed at 4 psi. Trays were covered with polyethylene and stored under a greenhouse growing bench. The trays remained covered continuously except for one twelve hour period. Final count of the number of plants that had emerged was made on August 21, 1960. Data on seedlings emerging presented in Table 13 indicate no significant influence of seed grouping.

TABLE 12.--Effect of Number of Seeds per Locus on Emergence of Lettuce Seedlings.

Seeds per Locus	Number of Hills[a] Seedlings Emerged	Percentage of Hills with Seedlings Emerged
One	1.50	30.0
Two	2.00	40.0
Four	3.67	73.4
L.S.D. 05	0.83	
L.S.D. 01	1.20	

[a]Average number of hills at which seedlings emerged based on average of three replicates with each replicate at two soil surface pressures.

TABLE 13.--Effect of Number of Seeds per Hill on Seedling Emergence.

Seeds per Hill	Seedlings Emerged[a]	Percentage Emerged
One	10.33	86.08
Two	10.00	83.33
Four	11.33	94.42
L.S.D. 05	3.29	

[a]Average number of seedlings that had emerged (average of three replicates - 12 seeds per replicate per treatment).

Soil Compaction Experiments

Determination was made of the emergence of seedlings of lettuce, cauliflower, tomato, and celery under four different surface pressures (1/2, 2, 5, and 10 psi) applied to the soil in which seed was planted either in normal form or in a paper ribbon previously described. In addition, for lettuce, the methylcellulose seed ribbon was also used. Rows in the trays were two inches apart. Seeds were spaced one inch apart in the rows. For both ribbon plantings, the ribbon was cut into sections about one inch in length with the seed approximately in the center of this one inch strip. There were three replicates for each pressure.

The trays were filled to the top with the Lock Sandy loam soil, tapped to settle, evened, seeded, and refilled to the top before the particular pressure was applied with a hydraulic press. Trays were kept covered with several layers of polyethylene film to reduce evaporation of moisture. Germination was determined under greenhouse conditions.

Lettuce.--Preparation and seeding was accomplished on April 2, 1960. Nine seeds placed in one row in each tray constituted a treatment. Rows were randomized and each tray contained all three treatments. Final observation of the number of plants that had emerged was made on April 30, 1960.

The number of plants that emerged is presented in Tables 14 and 15. A significantly greater number of seedlings had emerged per replicate from the regular seeding than from either the methylcellulose or paper seed ribbon plots.

TABLE 14.--Effect of Method of Seeding on Emergence of Lettuce Seedlings.

Method of Seeding	Seedlings Emerged[a]	Percentage Emerged
Check seeding	6.75	75.00
Methylcellulose ribbon	3.83	42.56
Paper seed ribbon	4.50	50.00
L.S.D. 05	1.22	
L.S.D. 01	1.68	

[a]Number of seedlings that emerged per replicate out of nine seeds (average of three replicates at four soil pressures).

TABLE 15.--Effect of Compression and Method of Seeding on Emergence of Lettuce Seedlings.

Method of Seeding	Percentage Emergence[a]				
	1/2 psi	2 psi	5 psi	10 psi	Average
Check seeding	81.48	81.48	77.78	59.26	75.00
Methylcellulose ribbon	40.74	55.56	37.04	37.04	42.60
Paper ribbon	51.85	59.26	37.04	51.85	50.00
Average	58.02	65.43	50.62	49.38	55.86

[a]Three replicates with nine seeds per replicate.

There was no significant difference in the number of seedlings that emerged under any of the various pressures applied to the surface of the soil even when the source of variance was apportioned to a single degree of freedom for a linear relationship or even when a class comparison was made of (1/2 plus 2 psi) vs. (5 plus 10 psi) at a single degree of freedom (F value - 4.67; F 05 - 5.99).

Cauliflower and tomato.--Preparation and seeding was completed on April 30, 1960. Rows in each tray were 1 1/2 inches apart and there were four rows per tray. These consisted of two rows of cauliflower and two rows of tomato. Each row consisted of nine seeds of either regular seed or paper seed ribbon. In the case of the paper seed ribbon, the high wet-strength paper was placed flat on the surface of the soil so the tissue side was facing upward when covered with soil. Four different surface pressures as described previously were involved.

Results of experiment are presented for cauliflower and tomato in Figure 5. A significantly greater number of seedlings emerged from the check seeding in comparison with the paper ribbon seeding for both cauliflower (F value - 21.92; F 01 - 11.26) and tomato (F value - 19.19; F 01 - 11.26).

There was no significant difference between the emergence of seedlings at any soil compression for either cauliflower (F value - 0.67) or tomato (F value - 0.64). Figure 5 shows this more clearly.

Figure 5

UPPER Emergence of cauliflower seedlings as influenced by pressure applied to soil surface.

LOWER Emergence of tomato seedlings as influenced by pressure applied to soil surface.

To convert to percentage of seedlings emerged, multiply number of seedlings emerged by 3.704.

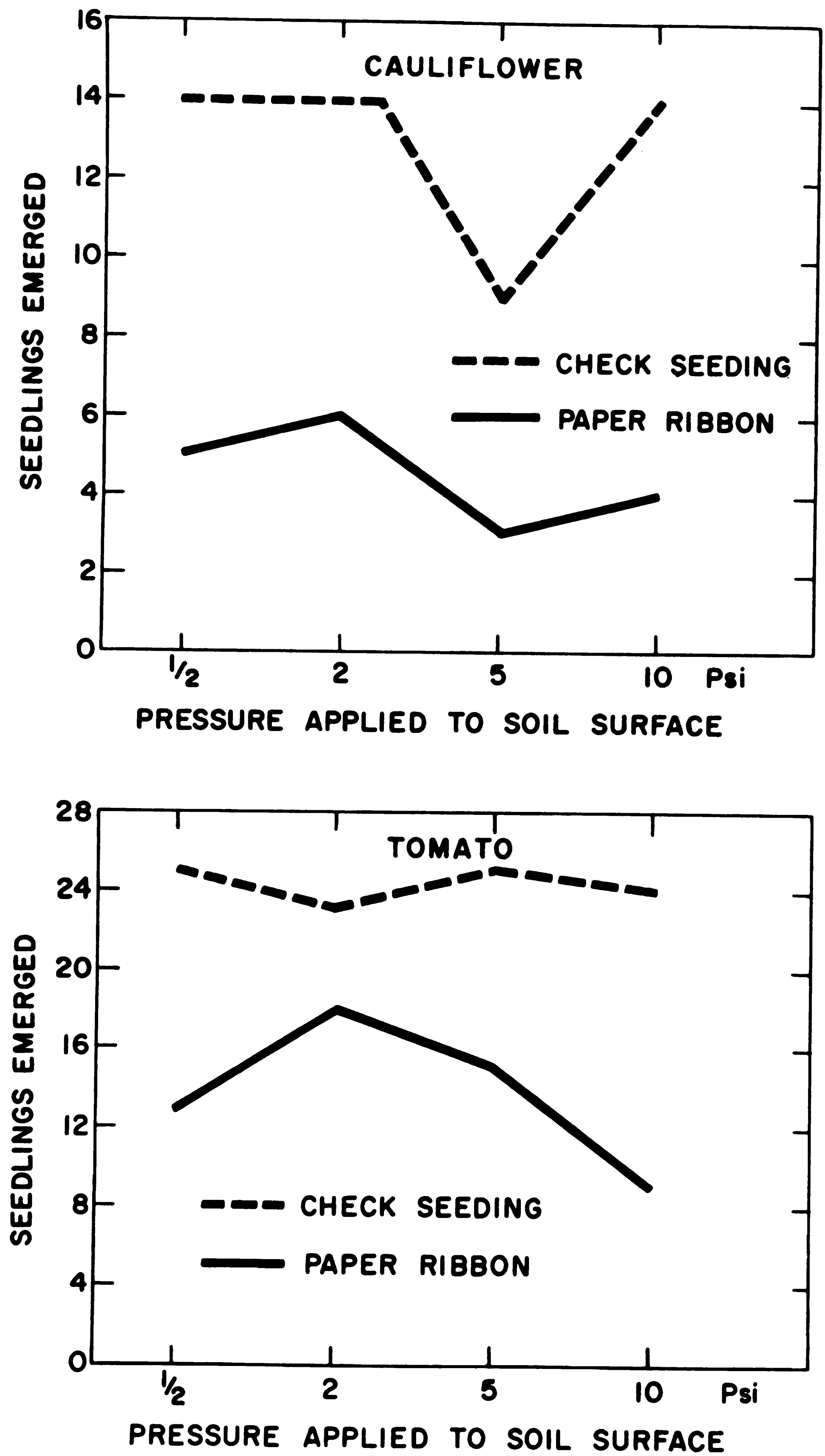
CAULIFLOWER
SEEDLINGS EMERGED
16
14
12
10
8
6
4
2
0
CHECK SEEDING
PAPER RIBBON
1/2
2
5
10
Psi
PRESSURE APPLIED TO SOIL SURFACE
TOMATO
SEEDLINGS EMERGED
28
24
20
16
12
8
4
0
CHECK SEEDING
PAPER RIBBON
1/2
2
5
10
Psi
PRESSURE APPLIED TO SOIL SURFACE

Figure 5

Celery.--An experiment with celery was initiated on June 11, 1960. Final count of seedlings that had emerged was made on July 18.

Data are presented in Figure 6 (upper) and Table 16. There was significantly greater number of seedlings that had emerged from the regular seeding than from the paper ribbon (F value - 6.53; F 01 - 6.23). Also, there was a significant linear relationship between seedling emergence and amount of soil compression at planting (F value - 7.54; F 05 - 5.99).

A class comparison made between 10 psi vs. (1/2, 2 and 5, psi) at a single degree of freedom showed that the relationship was very highly significant (F value - 103.20; F 01 - 13.74).

Soil Moisture Experiments

By the addition of tap water, the air dry Lock Sandy loam soil (permanent wilting point was slightly below 6%) was adjusted to moisture levels of 11% or 67.90% of field capacity (treatment 1); 13.5% or 75.66% of field capacity (treatment 2); 16% or near field capacity (treatment 3). For treatment (4), soil at "field capacity" prepared as for treatment (3) was used but immediately after all preparations, 4 mm. of water (175 ml.) per tray was sprinkled on the surface of the soil. For treatment (5), the soil at "field capacity" as for treatment (3) was used and treated as for treatment (4) but an additional 4 mm. of water was sprinkled on the surface 24 hours after the first application. There were three replications for all treatments.

Figure 6

UPPER. Emergence of celery seedlings as influenced by pressure applied to soil surface.

LOWER. Emergence of lettuce seedlings as influenced by levels of soil moisture.

To convert to percentage of seedlings emerged, multiply number of seedlings emerged by 3.704.

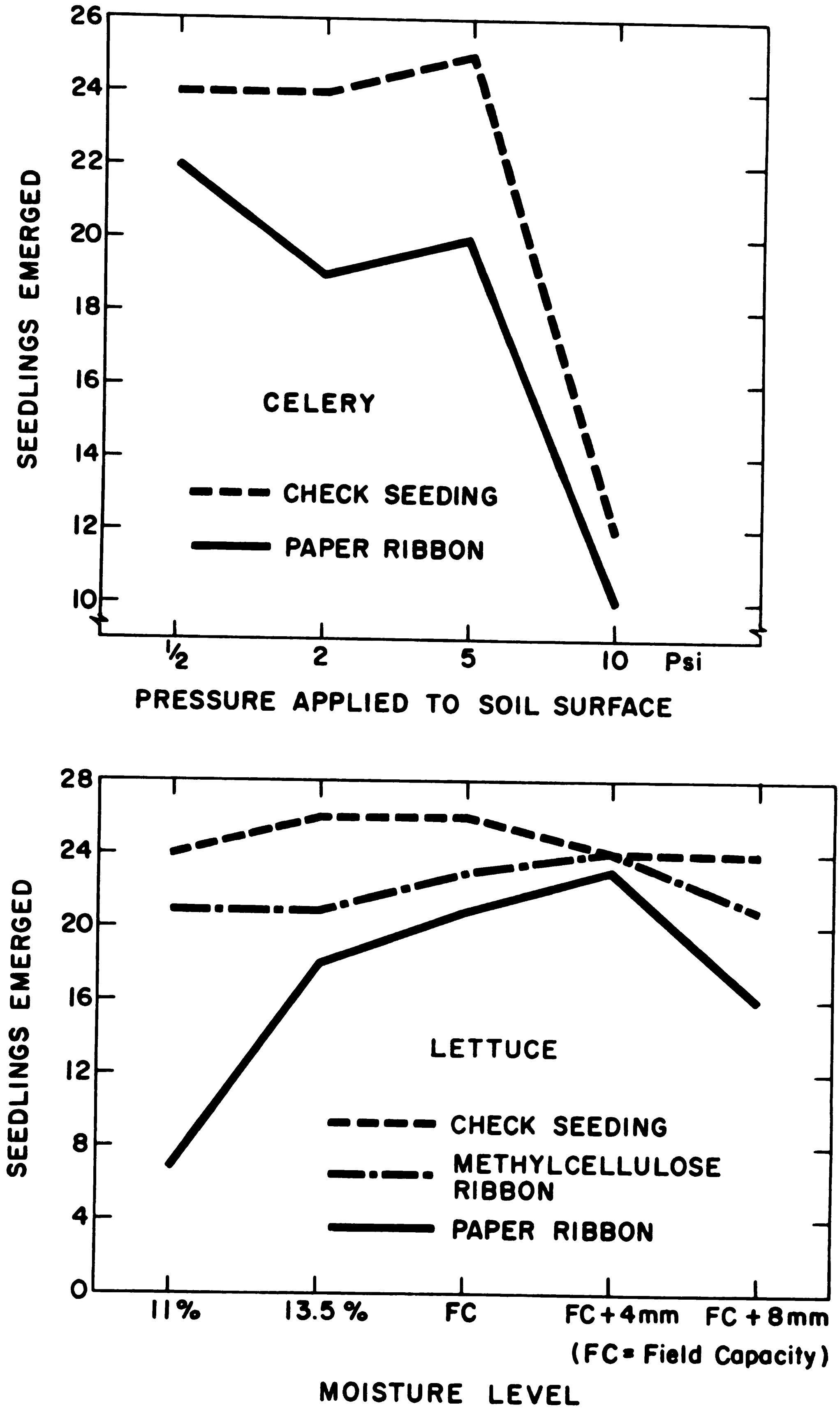
26
24
22
20
18
16
14
12
10
SEEDLINGS EMERGED
CELERY
CHECK SEEDING
PAPER RIBBON
½
2
5
10 Psi
PRESSURE APPLIED TO SOIL SURFACE
28
24
20
16
12
8
4
0
SEEDLINGS EMERGED
LETTUCE
CHECK SEEDING
METHYLCELLULOSE RIBBON
PAPER RIBBON
11%
13.5 %
FC
FC+4mm
FC + 8mm
(FC= Field Capacity)
MOISTURE LEVEL

Figure 6

TABLE 16.--Effect of Method of Seeding on Seedling Emergence of Celery.

Method of Seeding	Seedlings Emerged[a]	Percentage Emerged
Check seeding	7.08	78.67
Paper ribbon	5.92	65.78
L.S.D. 01	0.99	

[a]Number of seedlings from nine seeds per treatment (average of three replications with four pressures per replicate).

Preparation of the trays was in the usual manner - trays were filled full, settled, planted, refilled with soil, and the surface firmed at about 4 psi.

Lettuce.--On June 18, 1960, lettuce was planted as described above. In the randomized rows in each tray were placed the regular naked seeds, methylcellulose ribbon, and the high wet-strength paper seed ribbon. Each treatment consisted of nine seeds. After completion of seeding and before sprinkling of treatments (4) and (5), the trays were placed on overturned flats on the ground under concrete chrysanthemum benches. The trays were covered with polyethylene film. On July 5, 1960, the final count was made of the plants that had emerged. The average number of seedlings that emerged per treatment with levels of significance are presented in the last column of Table 17.

Emergence of seedlings at various moisture levels is presented as

TABLE 17.--Effect of Method of Seeding and Moisture Levels on Seedling Emergence of Lettuce.

Method of Seeding	Moisture Level					Average Percentage	Number Emerged
	11%	13.5%	FC	FC plus 4 mm	FC plus 8 mm		
Check seeding	88.90[a]	96.30	96.30	88.90	88.90	91.87	8.27[b]
Methylcellulose ribbon	77.78	77.78	85.19	88.90	77.78	81.46	7.33
Paper ribbon	25.93	66.67	77.78	85.19	59.26	62.98	5.67
L.S.D. 05							0.88
L.S.D. 01							1.20

[a]Seedling emergence under various moisture levels and average are expressed in percentage emerged (three replicates, with nine seeds per treatment per replicate).

[b]Number of seedlings emerged out of nine seeds per treatment (average of three replicates with five moisture levels per replicate).

FC - Field capacity.

percentage emergence in Table 17 and graphically as number of seedlings in Figure 6 (lower). The difference in seedling emergence at different soil moisture levels was not significant. All methods were significantly different from each other with the check giving the highest emergence and the paper ribbon the lowest.

Cauliflower and tomato.--Soil preparation and seeding was repeated as for lettuce in the previous experiment. On July 3, 1960, seed of cauliflower and tomato was placed in trays in each of which there was a regular seeding and a seeding with high wet-strength paper ribbon. Rows were randomized for each vegetable but not between vegetables. The trays were placed on the ground under a plant growing bench in the greenhouse. After the addition of water for treatments (4) and (5), the trays were covered with clear polyethylene film. Last count of emerged seedlings was made on July 18, 1960. The emergence of seedlings at various moisure levels for both vegetables are given as percentage emergence in Table 18 with average for method of seeding.

There was no significant difference in cumulative percentage of emergence of seedlings of either vegetable under any of the various moisture levels.

Fluctuations in soil moisture experiment.--The Lock Sandy loam soil, at field capacity, was placed in plastic trays as described previously. Thirteen seeds of untreated lettuce seed and thirteen seeds in methycellulose

TABLE 18.--Effect of Method of Seeding and Moisture Levels on Seedling Emergence.

Method of Seeding	Level of Moisture[a]					Average Percentage
	11%	13.5%	FC	FC plus 4 mm	FC plus 8 mm	
			Tomato (cultivar Fireball)			
Check seeding	92.60[b]	100.00	96.30	92.60	92.60	94.82
Paper ribbon	96.30	81.49	85.19	88.90	92.60	88.96
			Cauliflower (cultivar Snowball Imperial			
Check seeding	96.30	92.60	100.00	100.00	85.19	94.82
Paper ribbon	92.60	92.60	85.19	85.19	100.00	91.12

FC - Field capacity

[a]Refer to text for explanation of soil moisture levels.

[b]Seedling emergence is expressed as percentage emerged (average of three replicates with nine seeds per treatment).

ribbon were placed in each of three plastic trays. After the seeds were covered with soil, the surface of the soil was compressed with a pressure of slightly less than 4 psi. The trays were placed in a storage room at 32°F. for 1 1/2 hours to permit the methycellulose to begin to disintegrate. The trays, then, were removed and placed under the direct movement of air by a room fan for 17 hours. Then the trays were placed under a bench in the greenhouse. Four millimeters (175 ml. per tray) of tap water was sprinkled over the desiccated soil surface; and the trays were covered with polyethylene film. The experiment was commenced on July 3, 1960. The last count of seedlings that had emerged was made on July 18, 1960.

Cumulative emergence of seedlings is presented graphically in Figure 7. Coefficients of velocity of germination were determined according to the formula of Kotowski (1926):

$$\text{Coefficient of velocity} = 100 \times \frac{A_1 + A_2 \cdot \cdot + A_x}{A_1T_1 + A_2T_2 \, . \, . \, A_xT_x}$$

A = the number of seedlings pricked out.
T = the number of days after planting, corresponding to A.

The mean coefficient of velocity of germination for the regular seeding was 11.38 and 15.65 for the ribbon seeding. Thus germination of seed was more rapid (L. S. D. 05 - 2.48) for the methylcellulose seed ribbon.

Figure 7

Cumulative emergence of lettuce seedlings from methylcellulose seed ribbon and regular seeding after 17 hours desiccation of soil. Seedling emergence is sum of three replicates with 13 seeds per replicate.

To convert to percentage of emergence, multiply the number of seedlings emerged by 2. 56.

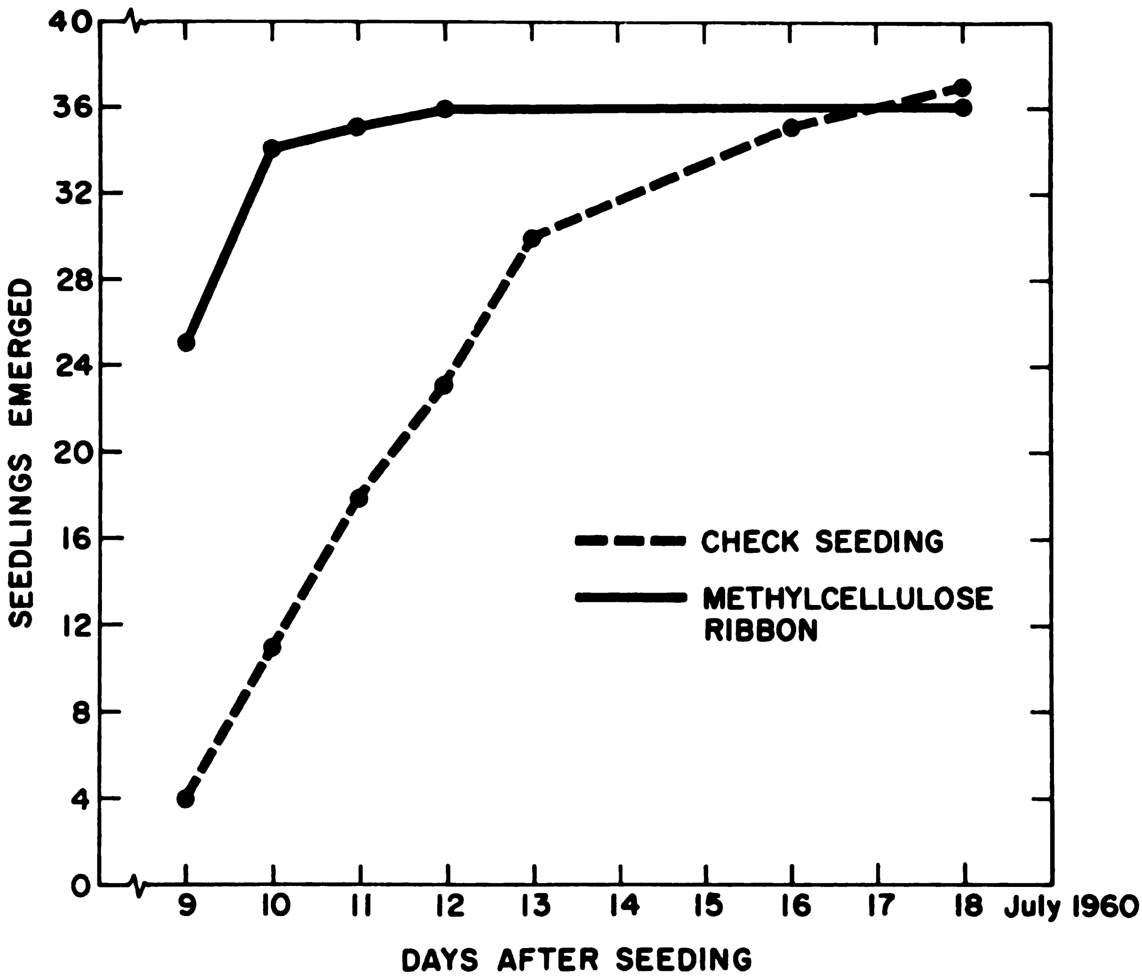

FIGURE 7

Cumulative emergence of lettuce seedlings as affected by fluctuations of soil moisture and method of seeding.

Field Experiments - 1960

Spacing of tomato experiment. --On May 18, 1960, two cultivars of tomato (Fireball and C-52) were direct seeded in mineral soil. On June 14, 1960, when the tomato plants were 2 1/2 inches high, sections of the row of each tomato variety were divided into three replicates each with three different arrangements of six tomato plants. Each replicate in each treatment consisted of six linear feet of row in which there were the six tomato plants grouped either singly at one foot apart, in doubles at two feet apart, or in triples at three feet apart. A record was made of the day on which the first three blossoms had fully expanded in the first floral cluster on the main stem of each plant. The last count for both varieties was made on July 18, 1960.

In Figure 8 is presented graphically the cumulative number of plants on which three blossoms in the first floral cluster on the main stem had fully opened for each of two tomato varieties.

In the early variety Fireball, blossoming was one day earlier in singles than in doubles which, in turn, was one day earlier than triples. A similar development occurred in the variety C-52, but the difference was not as pronounced particularly between doubles and triples. Thus, tomatoes thinned to groups of two and three flowered at apparently the same time as single plants.

Figure 8

UPPER. Cumulative number of tomato plants, cv. C-52, with three blossoms expanded in first floral cluster on main stem when grown as 1, 2, or 3 plants per hill.

LOWER. Cumulative number of tomato plants, cv. Fireball, with three blossoms expanded in first floral cluster on main stem when grown as 1, 2, or 3 plants per hill.

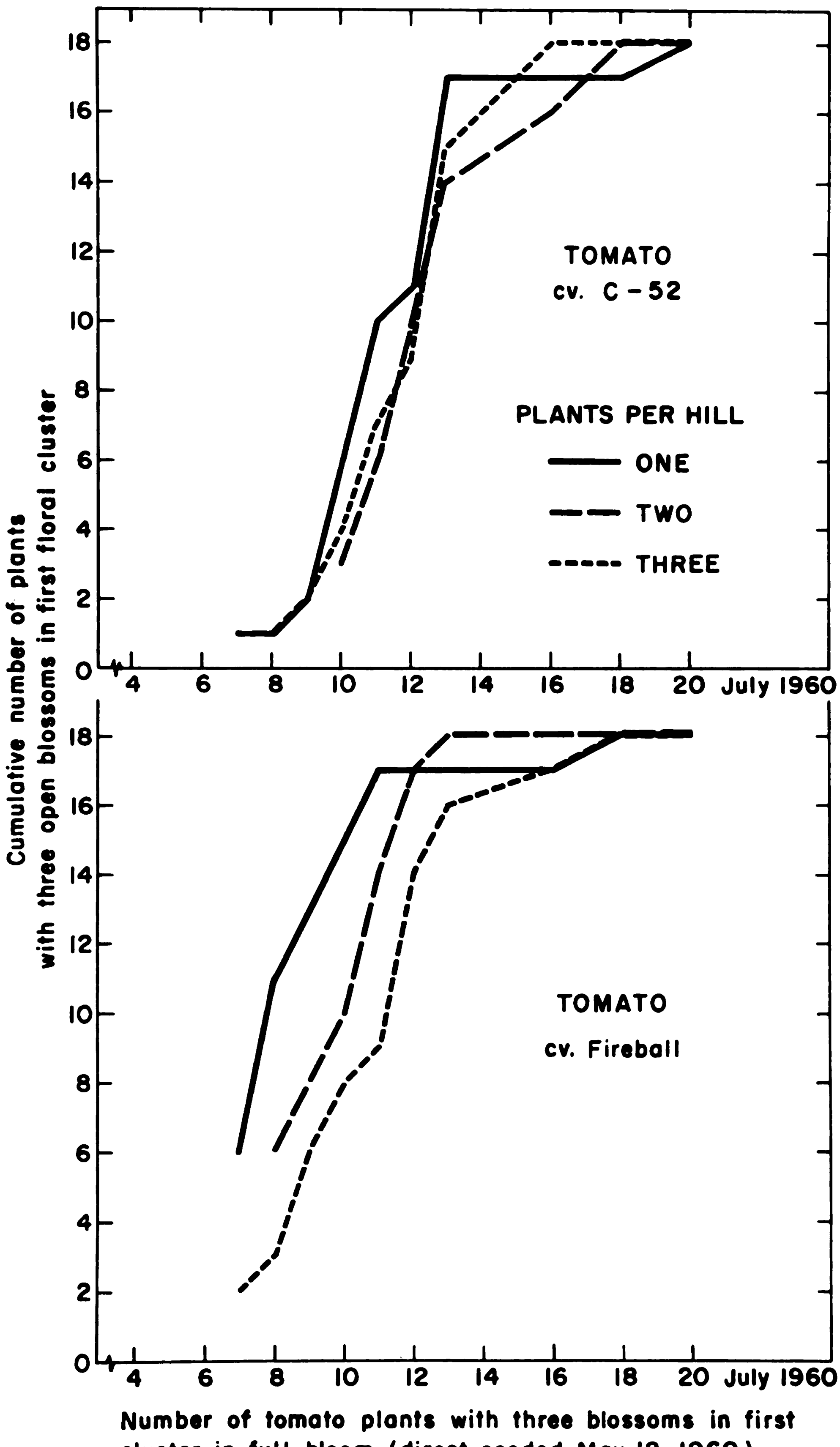
18
16
14
12
10
8
6
4
2
0
4
6
8
10
12
14
16
18
20 July 1960
TOMATO
cv. C-52
PLANTS PER HILL
ONE
TWO
THREE
TOMATO
cv. Fireball
Cumulative number of plants with three open blossoms in first floral cluster
Number of tomato plants with three blossoms in first cluster in full bloom (direct seeded May 18, 1960)

Figure 8

Spacing of radish seed experiment.--Two hundred and ten radish seeds were distributed over six linear feet of row in a cold frame as individual treatments per replicate. These sees were either distributed at random in a narrow band or placed in three rows one inch apart in the center row and slightly more than this in the outer two rows so that each seed was 1 to 1 1/4 inches from other seeds. The soil mix consisted of one-half muck and one-half loam top soil. Seeding and preparation was made on June 20, 1960. Almost all of the plants emerged on June 23, 1960. All plants were harvested on July 16, 1960.

Each harvested radish was measured to obtain the diameter at the widest portion of the "root". The distribution of the radishes on this basis is presented in Figure 9. The effect of depth of seeding on shape reported by Edmond (1933) was avoided by uniform placement of seed.

Paper Seed Ribbon Field Trials[1]

Derby farm field test.--At the S. H. Derby and Company farm, Woodside, Delaware, the paper seed ribbon was compared to the common method of seeding. On April 8, 1960, tomato cultivars Heinz 1370 and Purdue Dwarf were planted in replicate plots. For the check plots, a standard Planet Jr. hand seeder was used; for the ribbon plots, a modified Planet Jr. hand seeder was used. Heinz 1370 variety was seeded in five-foot rows, while Purdue Dwarf was planted in twenty-inch rows.

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[1]Field experiments involving the paper seed ribbon in Delaware, California, and Ohio were planned jointly with representatives of the Minnesota Mining and Manufacturing Company and Dr. H. J. Carew. The field planting and data-taking were accomplished by the cooperators.

Figure 9

Percentage distribution into size categories of radishes grown from seed distributed precisely or distributed at random in the row.

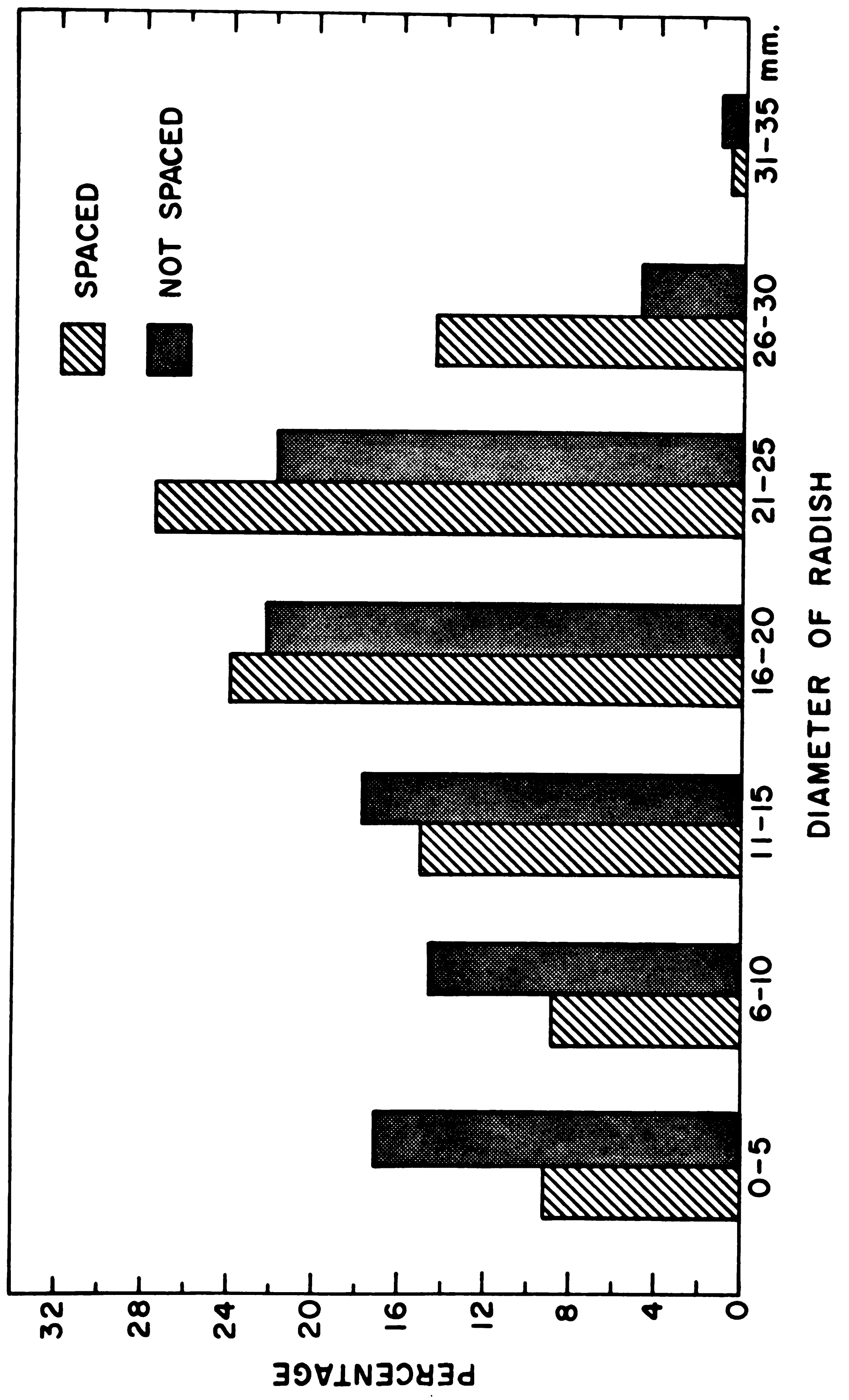
SPACED
NOT SPACED
PERCENTAGE
0
4
8
12
16
20
24
28
32
0-5
6-10
11-15
16-20
21-25
26-30
31-35 mm.
DIAMETER OF RADISH

Figure 9

Emergence was observed to be "very poor" in all of the ribbon plots. The percentage of emergence was reported to be 2-3% for Purdue Dwarf and 28% for Heinz 1370 (H. J. Heinz Company, letter 27 June 1960). The paper in the ribbon inhibited, physically or otherwise, the emergence and development of tops and particularly the roots of seedlings (Figure 10, lower left and right). On April 19, 1960, all of the ribbon plots were disced under because of the poor stand.

Fifer farm.--At the Fifer farm, Wyoming, Delaware, on April 8, 1960, tomato varieties 1370 and Purdue Dwarf were planted in the same manner as at the Derby farm. The percentage of emergence for Purdue Dwarf was 1-2% and for Heinz 1370 was 24% when counted on April 18, 1960 (H. J. Heinz Company, letter 27 June 1960). The same type of inhibition to growth was observed as previously. These plots were consequently disced under on April 19, 1960 so that no yield data were obtained from the ribbon plots.

Heinz farm.--At the H. J. Heinz farm, Fremont, Ohio, on April 21, 1960, tomato varieties Heinz 1370 and Purdue Dwarf were planted as at the Derby farm. Results were similar to those observed and reported for the Delaware experiments.

Michigan State University Horticulture Farm.--At the Michigan State University Horticulture Farm, East Lansing, Michigan, on April 29, 1960 and again on May 18, 1960, check seedings and ribbon seedings were made of the tomato cultivars Purdue Dwarf and Heinz 1370. The percentage of emergence

Figure 10

UPPER, left. Photograph of plots of head lettuce seeded with methlycellulose seed ribbon in upland mineral soil at Michigan State University Horticulture Farm, East Lansing, Michigan. 1959. In the foreground two rows on the left were seeded with 7 inch seed ribbons; the two rows on the right were seeded in the normal manner.

UPPER, right. Photograph of plots seeded with paper seed ribbon for tomato in Delaware. 1960. In the right foreground seeded with paper ribbon; in the left foreground seeded in the normal manner. Photo by 3M.

LOWER, left. Photograph of tomato seedlings and paper seed ribbon. Seedlings on left are deformed with limited root system; seedling on right is normal. Photo by 3M

LOWER, right. Photograph of tomato seedlings with paper seed ribbon uncovered in the soil. Seedling on the left is dwarfed with restricted root system; seedling on the right is normal. Photo by 3M.

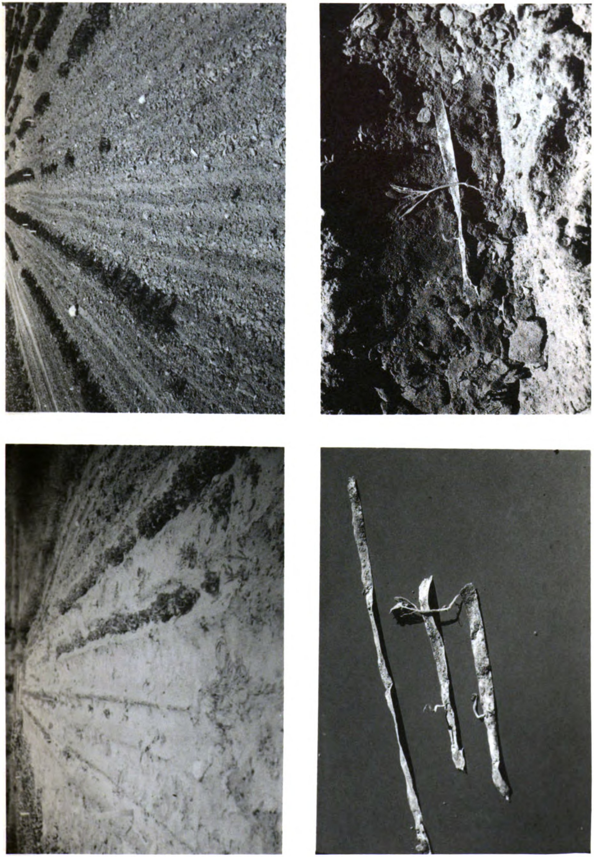

Figure 10

for the Purdue Dwarf was 17% and for the Heinz 1370 was 25%.

Fornaserro farm.--At the Thomas Fornaserro farm, Tracy, California, on May 12, 1960, check seedings and paper ribbon seedings were made with tomato variety Pearson VF. The reported low percentage for emergence from the ribbon plots was thought to be due to shallow planting resulting in seed drying during the intervals between irrigations (Underhill, personal correspondence, 1960).

DISCUSSION

The labor saving value of precision seeding was not realized under conditions of high weed population. Thus at the Schonfeld farm (high weed population) there was no great difference in thinning and weeding time between the seed ribbon and the standard plots, whereas at the Anderson farm (low weed population) the difference was appreciable. The methylcellulose seed ribbon, thus, offers another method of plant spacing as does pelleting (Zink, 1955, 1956; Brendler *et al.*, 1955), mechanical seeding (Coons, 1948), as well as post-emergence thinning (Maddox, 1958; Guzman, 1957).

The methylcellulose seed ribbon with lettuce seed spaced at 14 inch intervals provided an excellent criterion of plant mortality from all causes. Without adjustment for small number of skips and multiples, survival of lettuce until harvest on 4 plots at 3 farms varied from 40.64 to 56.29% (average - 47.58%). Presence of doubles was not considered serious for tomatoes (Holland, 1957; Holland and Campbell, 1958) but should be below 30% for sugar beets (Harvey, 1958). An emergence of 80% recommended by Frakes (1959) for sugar beets should be a minimum for lettuce with seed spacing if a satisfactory yield is to be realized based on about a 65% harvest percentage. A reduced seeding rate necessitates higher survival which investigators have attempted to secure with seed-level soil compression (Hollis and Burkhardt, 1959) and modern seeders (Marx, 1959). A 90% stand would have been

preferred as this approximated the stand in the check seedings.

The irregular occurrence of increased head size, total yield, and earlier maturity of lettuce obtained with precision seeding in these experiments has also been reported for pelleting (Carolus, 1954; Zink, 1955). Varying the depth of seeding produced no significant difference in yield. Heydecker (1956) obtained 90% or higher emergence with seed depths for lettuce varying from 1/2 to 1 1/8 inches. Increased weight per head in the ribbon plots could be related to the reduced population as has been found with sugar beets (Coons, 1948) or the larger "feeding area" as mentioned by Paponov (1959) for tomatoes.

In the Anderson and Schonfeld experiments, type of planting equipment was confounded with method of seeding. Subsequent experiments, however, demonstrated that type of equipment had no effect on the relative responses to seeding method. While all lettuce plots were on organic soils, mineral soils particularly if low in organic matter and/or high in clay content might respond with greater crusting (Stout, 1955, 1959; Hollis, 1960).

Irrigation after planting increased lettuce yields much more for the seed ribbon (particularly the 3 1/2 inch ribbon) than for the check seeding resulting in a significant interaction of irrigation and method of seeding and/or spacing. Since intimate association of methylcellulose with lettuce seed in a seed laboratory test resulted in reduced germination compared with no methylcellulose, the favorable response of seed in ribbon to irrigation was

thought to be due to washing away of physical inhibition to germination brought about by the methylcellulose. Consequently, greenhouse experiments were conducted to evaluate this conjecture and are discussed elsewhere.

For seeds of lettuce, cauliflower, and tomato (ribbon and regular), when soil pressures of 1/2, 2, 5, or 10 psi were applied immediately after planting, the resultant seedling emergence was not reduced significantly. This response is particularly noteworthy at the higher soil compressions because seed of sugar beet has been reported (Stout, 1955, 1959; Stout et al., 1956, 1960) as responding with lower germination at higher (5 and 10 psi) soil compressions than at lower (1/2 and 2 psi) soil compressions. For celery, however, a reduced seedling emergence occurred at the 10 psi soil compression. Doneen and MacGillivray (1943) placed celery in a class by itself because it responded with the smallest percentage of germination under moisture levels approaching permanent wilting point than any other vegetable seed tested inclusive of Hanson lettuce and Essar tomato. Stout (1959) and Stout et al. (1960) stated that compaction of soil resulted in reduced movement of soil water and gases.

When fresh weight of both foliage and "roots" of lettuce was used as a criterion there was no significant difference between spaced seeding (non-ribbon) and sowing thickly with subsequent thinning a short time after emergence (one week). If the thinning was delayed, fresh weight was reduced. Since lettuce is thinned commercially three weeks or longer after emergence,

a reduction in fresh weight could be anticipated. While it would appear that subsequent growth would compensate for this, there is reason to believe (Coons, 1948) that this is never complete under normal conditions.

Heydecker's (1954) conclusion that germination in soil near field capacity was higher than at other levels of soil moisture was in agreement with these results with lettuce, tomato, and cauliflower. Nevertheless, the paper ribbon showed more fluctuations in emergence percentages than did the methylcellulose ribbon.

When seeds of lettuce, in methylcellulose seed ribbon and natural, was planted in soil at field capacity and subjected to drying followed by re-wetting, the emergence of seedlings was more rapid from the seed ribbon than from check plots, although the total percentage of emergence was the same. Perhaps this response of the seed in the presence of the ribbon is related to the hydrophilic properties upon hydration of methylcellulose mentioned by Felber (1944) and Felber and Gardner (1944).

The lower seedling emergence of lettuce, tomato, cauliflower, and celery from the paper ribbon in contrast to standard seeding under variable moisture and soil compression as well as field tests with tomatoes could be related to the observed non-disintegration of the high wet-strength sulfite crepe backing.

Thinning of tomato plants to singles, doubles, and triples had little effect on time of flowering. This agrees with the findings of Dunyan *et al.* (1958)

for corn and Bailey (1941) for sweet corn. While the work of Holland (1957) and Holland and Campbell (1958) would appear to substantiate these findings with tomato, they compared "clumps" with single plants at unequal rather than identical plant populations per area.

A comparison of hand spacing of radish seed with equal numbers distributed at random over the same linear distance in the row, resulted in higher yields for spacing. This effect of larger plant parts when spaced and smaller when plants are thicker should be comparable to the effect that prevails in consecutive portions of rows under normal seeding and its attendant variation in number of plants per unit of length. This variation in sections of a row escapes notice when an entire row is considered in obtaining an average yield. This hand spacing of radish, also, resulted in 65.79% of the radishes measuring 16-30 millimeters in diameter, a median marketable size, compared to 49.45% when not spaced. Thus, spacing resulted in more pronounced grouping about the mean. This has economic significance if this is within the size range of a commercial grade. The conclusion of Sprague and Farris (1931) that up to 40% variation in plant density is permissible in consecutive sections of a row of barley is not necessarily in conflict as they were concerned with total yield rather than uniformity.

Theoretically, precision seeding should eliminate the need for plant thinning following emergence. However, in these field experiments, survival at time of harvest seldom exceeded 50%.

Therefore, precision seeding to a higher population in order to compensate for this plant mortality and yet to reduce thinning labor requirements by presenting the laborer with single plants rather than clumps would seem an acceptable compromise. This proves economically feasible, however, only if hand weeding of the crop is not necessary. Otherwise the thinning operation can be performed simultaneously with the weeding operation at only a slightly greater expenditure of time.

Until the factors accounting for the relatively high mortiality of lettuce seedlings in these experiments and in commercial crop production are brought under control, precision seeding to the final desired population appears to be impractical.

SUMMARY

Seed of lettuce (cv. Cornell 456) was spaced at 14, 7, and 3 1/2 inches in methylcellulose ribbon (tape) and planted in replicated field plots in organic and mineral soil. Lettuce, tomato, cauliflower, and celery were also spaced in a paper seed ribbon. Specially designed tape planters or modifications of existing seeders were used to place both types of ribbons in the soil.

Precision spacing with a methylcellulose seed ribbon resulted in reduced thinning and weeding time. Thinning time reductions were more significant as the weed population decreased.

If 90% of the mathematically ideal population is accepted as a commercial minimum after thinning (attained at 3 of 4 locations in check seedings) the average of the 90% ideal stand for 3 1/2 inch ribbon was 85.14%; for 7 inch ribbon - 76.81%; and for 14 inch ribbon - 52.73% of this acceptable minimum. When ribbon seeded lettuce (14 inch ribbon) was not thinned, 47.58% of the seed planted was present as plants at harvest. Thus, about one-half of the seeds planted were not present at harvest as mature plants.

In field experiments the highest yields, in general, were from the check or regular seedings followed by 3 1/2-, 7-, and 14-inch ribbon seedings in that order. However, of the plants present at harvest the lowest percentage was harvested from the check seedings. When two harvests of a single planting

were made, the percentage harvested from ribbon plots at first harvest was significantly higher indicating that plants matured more rapidly in ribbon plantings. The weight per harvested head was greater from the precision seeded plots than from the check plots. At one location, there was significantly more tipburn in the lettuce harvested from ribbon plots, but no explanation could be given.

In greenhouse experiments, delayed thinning (2 and 3 weeks after emergence) of ordinary lettuce stands resulted in smaller plants as measured by fresh weight (46 days after seeding) than earlier thinning or precision spacing. When lettuce seeds were arranged in 1, 2, or 4 per hill, the germination percentage was not altered if surface soil moisture was satisfactory. When the soil surface after seeding was compressed at 1/2, 2, 5, or 10 psi, germination of lettuce, cauliflower, and tomato (seed ribbon and regular) was not affected but germination of celery was affected at higher soil compressions (5 and 10 psi).

Levels of soil moisture did not affect germination of lettuce, cauliflower, and tomato seed in ribbon and regular seedings. Subjecting methylcellulose seed ribbon to wetting, drying, and rewetting resulted in more rapid germination of lettuce but not percentage germination.

When direct-seeded tomato plants (cv. Fireball and C-52) were thinned to singles, doubles, and triples with six plants per six linear feet of row, the date of opening of the first three blossoms in the first cluster was approximately

the same in the doubles and triples as in the singles.

Precision spacing of radish seed resulted in greater uniformity in size of edible portion.

Thus, precision spacing of individual tomato plants appeared not to be necessary for highest yields. With lettuce, celery, radish, and cauliflower, however, where uniformity of plant shape is as important as total yield, individual plant spacing is desirable for greater marketable yields.

Methylcellulose and paper seed ribbons or tapes were used successfully to space vegetable seeds at fairly precise intervals in the soil. Under the conditions of these experiments, however, emergence was generally no greater than 50% indicating that precision seeding to a final desired plant population with these ribbon materials would be impractical. Precision seeding to reduce the thinning-labor requirement, rather than to eliminate it, would be practical only if in-the-row weed populations were low.

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