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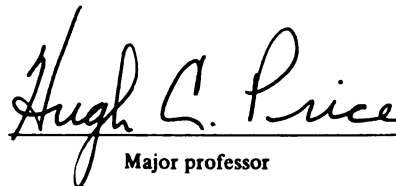
Effects of Waterlogging, Raised Beds and
Plant Population on Pickling Cucumbers

presented by

Alberto Medina-Mora

has been accepted towards fulfillment
of the requirements for

M.S. degree in Horticulture


Major professor

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EFFECTS OF WATERLOGGING, RAISED BEDS AND PLANT
POPULATION ON PICKLING CUCUMBERS

By

Alberto Medina-Mora

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
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ABSTRACT

EFFECTS OF WATERLOGGING, RAISED BEDS AND PLANT POPULATION ON PICKLING CUCUMBERS

By

Alberto Medina-Mora

Studies were conducted to determine the sensitivity of cucumber plants at various stages of development to different durations of waterlogging. Flooding at early stages resulted in lower biomass production than the same treatments later in plant ontogeny (prior to anthesis). There was a linear decrease in root length and leaf area as the duration of flooding increased from 1 to 4 days. Periods as short as 24 hr of soil anaerobic conditions were sufficient to produce a detrimental effect on growth.

In field studies there was no effect of bed type on growth or yield when moisture was not limiting. However, raised beds increased moisture stress, as indicated by the yield of deformed fruits, when no supplemental irrigation was provided. Root distribution in the soil profile was similar for plants grown on raised or flat beds. Plants grown on both raised and flat beds were able to recover from a 48-hr period of waterlogging with no detrimental effect on yield. The determinant cultivar Castlepik produced higher yields than the indeterminant cultivar Flurry. Both cultivars reached a maximum yield at 200,000 plants/ha, however, the yield of Flurry decreased at higher densities while Castlepik maintained the same.

To Carmen, my wife, for her love, support and understanding, especially in the last period of our thesis.

To my mother and father with all my gratitude.
Their love and principles have given me encouragement
in each new step of my life.

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CHAPTER I

LITERATURE REVIEW

I. ANAEROBIC CONDITIONS IN THE SOIL

Oxygen moves from the atmosphere to plant roots by diffusion through gas-filled soil pores and, subsequently, through water films separating the root surfaces from the gas phase. The air content in the soil is continuously changing under field conditions due to variations in soil water content. These variations are caused by water supplied at the soil surface, water movement in the soil, and uptake of water by the root system (Dasberg and Bakker, 1970).

Except for species that are structurally adapted to allow the internal transfer of oxygen by diffusion from the above ground parts, oxygen used in root respiration is supplied almost exclusively by the root environment (Drew, 1983). The primary mechanism of gas exchange in the soil is diffusion. Carbon dioxide from respiration moves from the living tissues via the soil air space to the atmosphere, while oxygen moves from the atmosphere into the tissues (Erickson, 1982).

Anaerobic conditions develop in the soil when roots and soil organisms use oxygen for respiration faster than

it can enter the soil. Since oxygen diffuses in water about 10^4 times more slowly than in air, the presence of water-filled pores is the main restriction to soil aeration. Furthermore, diffusion out of the soil of gases such as carbon dioxide will be diminished, and these can accumulate in the soil (Cannell and Jackson, 1981). Water-logging limits plant vegetative growth and yields by restricting the supply of oxygen, (Drew, 1983).

In aerobic respiration, the usual terminal electron acceptor is molecular oxygen from the environment. Oxygen is combined with hydrogen ions to form water; the other end product is carbon dioxide. When soil is waterlogged, many microorganisms use other substances from their environment as terminal acceptors of electrons. Some reduction reactions are: nitrate to nitrite, to nitrous oxide, to nitrogen gas; manganic to manganous ions; ferric to ferrous ions; and sulfate to sulfide. Roots are unable to do this, but the soil which surrounds them will become increasingly reduced biochemically as anaerobic microorganisms sequentially deplete it of oxidized constituents by donating electrons (Cannell and Jackson, 1981).

In anaerobic conditions, organic substrates are not broken down completely to carbon dioxide. Incompletely oxidized intermediates and end products of attenuated pathways of respiration can accumulate in waterlogged soil. They include lactic acid, ethanol, acetaldehyde and aliphatic acids (Cannell and Jackson, 1981; Ponnamperna, 1984).

II. MECHANISMS OF PLANT INJURY INDUCED BY OXYGEN DEFICIENCY

Plants have a requirement for rapid gaseous exchange with their environment and for sufficient water to satisfy the needs of growth and transpiration. Both excess and deficiency of water lead to stress and consequently to loss of productive potential or even death.

The occurrence and extent of any response depend on many interrelated factors such as species and cultivar, age or stage of development, the duration and depth of flooding, the soil type, and the temperature and light conditions during flooding (Jackson and Drew, 1984).

Injury to roots.

Under temperate conditions, aerobic respiration of plant roots and soil microorganisms in well-drained soils, consumes between 5 and 24 g of oxygen for each square meter of land surface per day (Russell, 1973).

Letey et al. (1962), working with several species, concluded that low soil oxygen is most detrimental during early stages of growth because the root system has not sufficiently developed. It must be emphasized that these experiments were conducted only on the vegetative stage of growth.

In a series of experiments, Cannell et al. (1979) pointed out that pea plants are more susceptible to water-logging at flowering stage than at earlier stages. Root

growth rates were severely reduced by waterlogging at the later periods of growth. In other studies carried out with soybeans, Stanley and co-workers (1980) found that roots that became submerged during the vegetative stage immediately ceased extension but resumed growth at the earlier rate once the soil was drained. With flooding immediately after flowering, before pod set, roots below the water table stopped growing and decomposed when the soil was drained. Flooding after pod set caused virtual cessation of root growth both above and below the water table. The authors mentioned two types of root tolerance to flooding, depending upon growth stage: a) individual root tolerance at preflowering period; and b) development of new roots during the postflowering stage.

The development of adventitious roots is thought to be important for plant survival after waterlogging. According to de Witt (1978), shoot growth of sunflower and tomato plants is resumed as soon as adventitious roots are formed.

Kahn et al. (1985) found that adventitious roots, in black beans, became the dominant root components in plants flooded for up to seven days and then allowed to recover for seven days. They concluded that beans recover from flooding by the partitioning of dry matter to the roots, especially adventitious roots. These results agree with other studies reported by Jackson (1955) working with beans, and by Kramer (1951) with several species.

Although lack of oxygen is the primary factor for

changes in metabolism of roots and soil micro-organisms, oxygen deficiency may not always be the immediate cause of root injury (Drew, 1983). Anaerobic respiration of roots gives rise to end products that are potentially harmful when accumulated in large concentrations. According to Kawase (1981), oxygen deficiency in the root system forces plants to switch their respiration from aerobic to anaerobic, resulting in low yield of ATP, accumulation of toxic products, and rapid depletion of organic compounds. Absorption and translocation of water and nutrients in roots are slowed by the limited available energy.

Injury to shoots.

Jackson and Drew (1984) distinguish three types of internal flow between roots and shoots: 1) an increase in supply of substances from the flooded roots or soil to the shoot (positive messages), 2) a decreased supply of substances to the shoot (negative messages), and 3) an accumulation in the shoot of substances usually transported down to the roots (accumulation messages). Water, carbohydrates, inorganic nutrients, hormones or their precursors, and toxins are the substances most involved.

Cannell and Jackson (1981) pointed out that the effects of flooding rapidly extend beyond the roots to the shoot system, and these effects can be expressed in one or more of the following symptoms: epinastic curvature, wilting, chlorosis, abscission, slow rates of growth,

hypertrophic swelling and senescence.

Epinasty of leaf petiole is one of the most understood responses of shoots to soil waterlogging. Flooding induces epinasty in potato, tomato, sunflower and probably many other species. According to Crocker, Palmer and other authors cited by Jackson and Drew (1984), petiole epinasty in tomato and sunflower comprises an acceleration of growth in the adaxial (upper) half of the petiole causing the leaves to swing downward. Bradford and Hsiao (1982) suggest that leaf epinasty in tomato may have beneficial effects on plant water balance by reducing light interception.

Jackson and Campbell (1975) found that, when tomato plants are waterlogged, petiole epinasty develops in association with increases in ethylene in the shoot. They suggested that increases in soil ethylene and movement of the gas to the shoot system are factors contributing to the development of epinasty.

Bradford and Dilley (1978) reported reductions in root and shoot weight, epinasty and chlorosis in waterlogged treated tomatoes. The authors concluded that depriving the root of oxygen is sufficient to cause accelerated ethylene synthesis by tomato shoots; therefore, the primary cause of flooding-induced ethylene is deprivation of oxygen to the root, not ethylene production by microorganisms or blockage of ethylene escape from the root.

Flooding can cause rapid wilting in a wide range of

species, in both field and controlled conditions and sometimes within a few hours. The effect is accentuated by conditions conducive to fast transpiration (Jackson and Drew, 1984).

Wilting, a form of physiological drought, is thought to be induced by an increase in resistance to water flow in the roots. Metabolic energy seems to be required to maintain the low resistance needed to prevent wilting. In some species, stomata close soon after waterlogging, thus preventing wilting. Stomatal closure may be triggered by an initial increase in water stress in the leaves, resulting from the larger resistance to water movement (Cannell and Jackson, 1981; Drew, 1983).

Evidence indicates that abscisic acid (ABA) is involved in the endogenous control of stomatal aperture. Wright, cited by Bradford and Yang (1981), found a correlation between increases in abscisic acid content of leaves from waterlogged plants and stomatal closure.

Wilting is determined by a combination of circumstances, including the duration and intensity of the initial phase of high resistance to water movement through roots, the temperature and humidity of the air that determine evaporative demand, and the timing of stomatal closure.

Uptake of certain nutrients is thought to occur across membranes and against chemical potential gradients, therefore, energy must be expended to move the ions.

Because the source of this energy is ATP derived mainly from aerobic respiration, in the absence of oxygen, nutrient absorption is reduced (Cannell and Jackson, 1981).

In a study of nitrogen deficiency and chlorosis in flooded barley plants, Drew and Sisworo (1977) reported that after two days, nitrogen uptake by flooded plants almost ceased and an internal re-translocation of nitrogen from older to younger leaves then took place. The decline in the nitrogen content of the lower leaves preceded chlorosis, indicating that these symptoms were a result of nitrogen depletion. The authors observed that nitrogen fertilizer taken up by well aerated roots prevented chlorosis.

Abscission of leaves and other organs commonly occurs in many plants. The additional ethylene in flooded plants may partially explain the premature abscission of leaves, flowers and young fruits reported in several species exposed to waterlogged soils (Jackson and Drew, 1984). Cannell et al. (1979) reported yield losses in green peas due to abscission of flowers and immature pods as a response to waterlogging at later stages of growth.

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CHAPTER II

EFFECTS OF WATERLOGGING ON GROWTH OF PICKLING CUCUMBERS

ABSTRACT

Studies were conducted to determine the sensitivity of cucumber plants at various stages of development to different durations of waterlogging. Flooding at early stages resulted in lower leaf area and biomass accumulation than the same treatments later in plant ontogeny (prior to anthesis). No differences were found in root length due to waterlogging at different stages. There was a linear decrease in root length, leaf area and biomass production as the duration of flooding increased from 2 to 8 days in the first study, and from 1 to 4 days in the second. Periods as short as 24 hr of soil anaerobic conditions were sufficient to produce a detrimental effect on growth.

INTRODUCTION

Michigan and the surrounding states in the Midwest are major producers of pickling cucumbers. Climate and soils of the region are in general appropriate for cucumber production.

Some of the problems that growers confront frequently are periods of drought stress and soil waterlogging. Anaerobic conditions develop when water accumulates in the root zone, and the diffusion of oxygen to the roots is limited. Periods of heavy rain, over-irrigation and poor soil drainage are factors that contribute to the development of waterlogging.

Characteristic symptoms of waterlogging developed by certain species include: chlorosis, leaf epinasty, wilting, growth rate reductions and senescence. However, the response of plants to anaerobic conditions is affected by the species and cultivar, the stage of development, the soil type, and the environmental conditions during waterlogging (Cannell and Jackson, 1981; Jackson and Drew, 1984).

The objective of this study was to determine the susceptibility of cucumber plants, at different stages of growth, to several durations of waterlogging.

MATERIALS AND METHODS

Experiment 1.

Seeds of pickling cucumber (Cucumis sativus cv Tamor) were sown in the greenhouse in a pasteurized soil-sand mix (3:1) in 20 cm pots at weekly intervals for 9 weeks, starting on December 27, 1985. Seedlings were thinned to one per pot at the first true leaf stage. The minimum temperature in the greenhouse was 19° C while the maximum varied with ambient conditions up to 33° C. The plants were irrigated daily or as required and fertilized with a solution of 200 ppm of 20-20-20 once a week.

Waterlogging was accomplished by placing the pots in a bath filled with water to the soil surface level. Within a replication, all treatments were initiated at the same time, therefore, the environmental conditions during the exposure to the flooding treatments were the same for all the plants, but not the conditions throughout the growing period, because of the one-week interval in planting dates.

The stages of growth and chronological age at the time of waterlogging were: 1) 1st true leaf (18 days), 2) 3d true leaf (25 days), and 3) 6th true leaf (32 days). The pots were allowed to drain and subsequently watered as required.

The duration of waterlogging conditions were: 1) control (no waterlogging), 2) 2 days, 3) 4 days, 4) 6 days, and 5) 8 days.

The experimental design was a split plot with 3 replications over time and 5 subsamples per treatment. The stage of growth was assigned to the main plot and the duration to the subplot.

Experiment 2.

On March 24, 1987, seeds of pickling cucumber cv Flurry were sown in 20 cm clay pots filled with the same soil media as the previous experiment. Temperature control, irrigation, fertilization and thinning practices were performed the same way as described before.

The plants were subjected to waterlogging by placing the pots inside of empty 25 cm clay pots lined with plastic bags and filled with water. Water entered the 20 cm pots through the drainage holes and filled the pots to the top of the soil. This method of flooding individual pots provided better control of the water level than the one described for the first experiment.

The stages of growth and chronological age at the time of waterlogging were: 1) 2nd true leaf (19 days), and 2) 6th true leaf (30 days). The pots were allowed to drain and subsequently irrigated as required.

Duration of waterlogging was accomplished by removing the plants from the pots filled with water at the following

times: 1) control (no waterlogging), 2) 1 day, 3) 2 days, and 4) 4 days.

The experimental design was a 2x4 factorial in a randomized complete block with 4 replications and 2 observations per treatment. To minimize differences in growth due to environmental factors, all treatments and replications were established on the same day.

Data Collection.

For experiment 1, the plants were harvested at the 46th day of growth during the flowering stage. The plants were partitioned into leaves, stems and roots. Stems and leaves were dried at 66° C for 96 hr and dry weights were recorded. The roots were washed to separate the soil material with the hydropneumatic elutriation system described by Smucker et al. (1982). Roots were stored at 4° C in a solution of 20% ethanol until length could be measured. Root length was determined by the root intersection method described by Newman (1966). Root biomass was recorded after drying the samples at 66° C for 96 hr.

In experiment 2, the plants were harvested at the 35th day of growth. The plant material was partitioned into leaf, stem and root components for dry weight determination. Root length and biomass were determined by the procedures already described. Leaf area, was determined with a leaf area meter (LI-COR Model LI-3000).

RESULTS AND DISCUSSION

Shoot growth.

Plant growth was adversely affected by soil anaerobic conditions. In experiment 1 there was a linear decrease in leaf, stem and total biomass by increasing the duration of waterlogging from 0 to 8 days (Table 1).

There were, however, no differences in growth between plants waterlogged at different stages of development (data not shown). It is hypothesized that treatment design (stage of growth as main plot) was not sensitive enough to detect growth differences among stages.

Table 1. Effect of duration of waterlogging on biomass accumulation, experiment 1.

Days	Dry wt (g)		
	Leaf	Stem	Total
0	2.72 ^Z	1.05	3.77
2	2.26	0.86	3.12
4	2.25	0.93	3.17
6	2.13	0.84	2.97
8	1.96	0.82	2.78
Linear	** (86) ^Y	** (65)	** (82)
Quadratic	NS	NS	NS

^ZEach figure is the mean of 3 stages of growth x 5 subsamples x 3 replications.

^YPercent from the total variance.

In experiment 2, plants subjected to waterlogging at the 2nd leaf stage had less leaf area and biomass than plants subjected to a similar treatment at the 6th true leaf stage (Table 2). It is suggested that the plants that have not developed an extensive root system have less ability to withstand anaerobic conditions. The data indicated that growth rates were more affected at this stage than in a later stage. These results agree with several reports on various species (Letey et al., 1962, Watson et al., 1976).

Table 2. Effect of waterlogging at two different stages on leaf area and biomass accumulation, experiment 2.

Stage	Leaf area (cm ²)	Dry wt (g)		
		Leaf	Stem	Total
2nd true-leaf	1118 ^Z	3.61	1.75	5.36
6th true-leaf	1310	4.51	2.23	6.75
F test	**	**	**	**

^ZEach figure is the mean of 4 durations x 2 subsamples x 4 replications.

Plants exposed to 1 day of flooding showed symptoms of wilting and accumulated less biomass than the control (Table 3). Jackson and Drew (1984) reported that under certain conditions, a few hrs of soil anaerobic conditions have a detrimental effect on growth and productivity. Cannell et al. (1979) working with peas found that 24 hr of waterlogging just before flowering restricted growth and yield.

Table 3. Effect of duration of waterlogging on leaf area and biomass accumulation, experiment 2.

Days	Leaf area (cm ²)	Dry wt (g)		
		Leaf	Stem	Total
0	1553 ^Z	5.23	2.59	7.83
1	1294	4.23	2.05	6.28
2	1102	3.62	1.79	5.41
4	908	3.16	1.54	4.70
Linear	** (94) ^Y	** (88)	** (88)	** (88)
Quadratic	NS	** (12)	** (12)	** (12)
Cubic	NS	NS	NS	NS

^ZEach figure is the mean of 2 stages of growth x 2 subsamples x 4 replications.

^YPercent from the total variance.

For all the growth components measured, most of the response to duration of flooding was linear. The significant quadratic response detected for biomass production indicates that during the first 2 days of anaerobic conditions growth was slightly more affected than from 2 to 4 days of flooding.

Although the plants were more susceptible to waterlogging at the early stage of development, no significant interaction between stage and duration was detected.

Root growth.

There were no differences in root growth due to the stage of development at which the plants were exposed to the waterlogging treatments (Table 4).

Table 4. Effect of waterlogging at different growth stages on root growth.

	Experiment 1 ^z		Experiment 2 ^y	
	Length (m)	Dry wt (g)	Length (m)	Dry wt (g)
Stage				
1st T.L.	11.8	0.51		
2nd T.L.			22.1	0.82
3d T.L.	10.5	0.57		
6th T.L.	9.8	0.51	25.1	0.72
F test	NS	NS	NS	NS

^zEach figure is the mean of 5 durations x 5 subsamples x 2 replicates.

^yEach figure is the mean of 4 durations x 4 replicates.

These data, consistent in both years, suggest that after the plants were subjected to waterlogging during the early stages of growth, a significant amount of carbohydrates was translocated to the root system. Kahn et al. (1985), reported that beans recovered from flooding injury by partitioning dry matter to the roots, especially adventitious roots. It is also suggested that the root hairs, which did not account for root length, were affected by the waterlogging treatments.

In experiment 1, plants subjected to longer durations of waterlogging produced considerable less root biomass than the control (Table 5). In experiment 2, one day of waterlogging was sufficient to affect final root growth (Table 6).

Table 5. Effect of duration of waterlogging on root growth components, experiment 1.

		Length (m)	Dry wt (g)
Days	0	14.3 ^Z	0.66
	2	10.7	0.55
	4	11.4	0.55
	6	9.1	0.47
	8	8.1	0.43
Linear		** (87) ^Y	** (94)
Quadratic		NS	NS

^ZEach figure is the mean of 3 stages of growth x 5 subsamples x 2 replications.

^YPercent from the total variance.

Table 6. Effect of duration of waterlogging on root growth components, experiment 2.

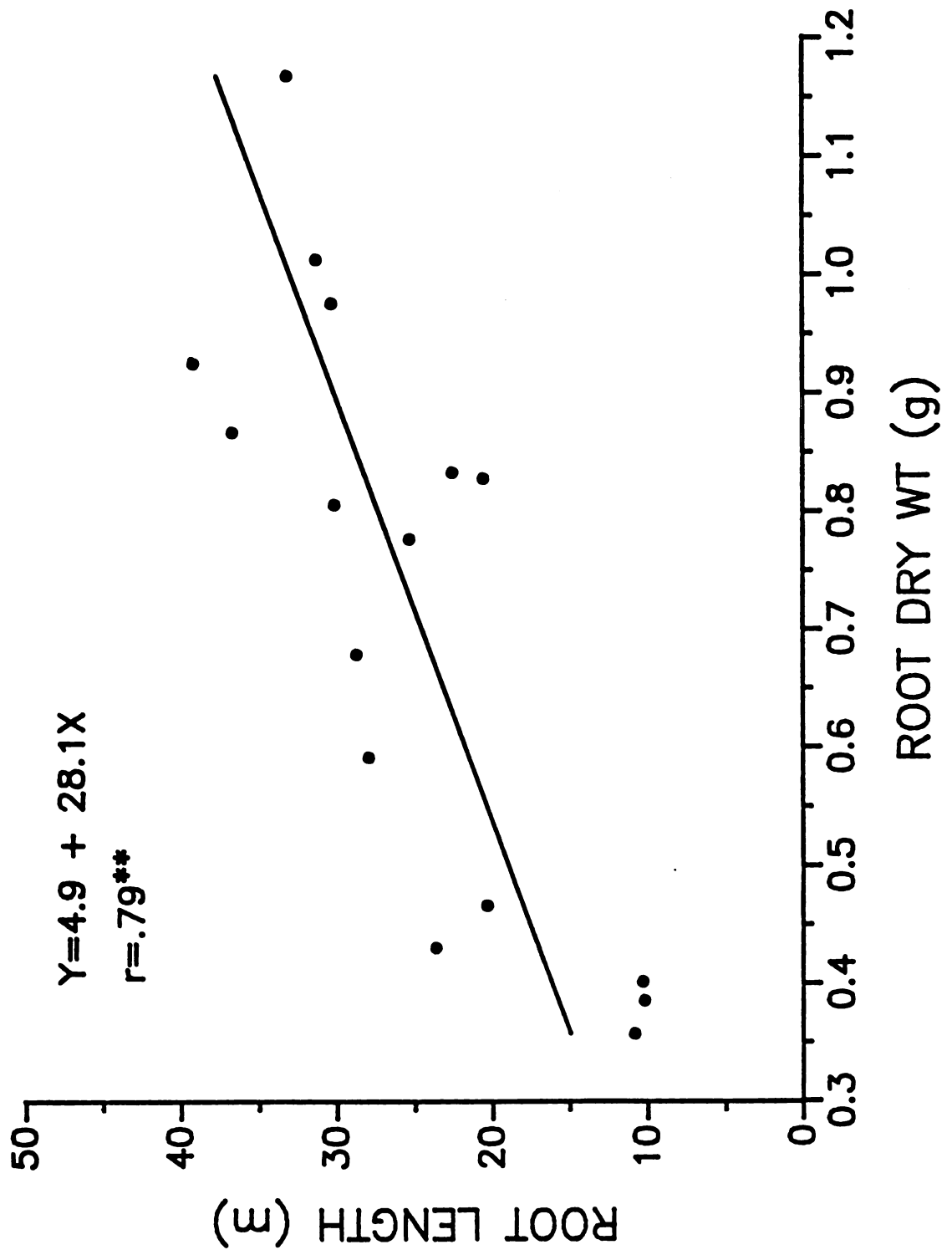
		Length (m)	Dry wt (g)
Days	0	30.2 ^Z	0.97
	1	22.3	0.82
	2	27.1	0.76
	4	14.6	0.53
Linear		** (74) ^Y	** (99)
Quadratic		NS	NS
Cubic		** (24)	NS

^ZEach figure is the mean of 2 stages of growth x 4 replicates.

^YPercent from the total variance.

Although the cubic response in root length to duration of flooding was significant, most of the variance accounted for a linear trend. Also, the decrease in root biomass was

Figure 1. Relationship between root biomass and root length, experiment 2. The correlation coefficient $r=0.79$ is significant at the .01 level.



highly linear. The intersection method is a valuable tool for root length determinations, however, the technique may have a high level of variability. There is a high degree of correlation between root dry wt and length, as indicated by the correlation coefficient (Figure 1).

It is hypothesized that the primary effect of flooding occurs in the root system, as it has been proposed by several authors (Kawase, 1981; Stanley et al., 1980). Low oxygen levels reduced aerobic respiration within the root cells, therefore, the rate of growth was reduced. Absorption and translocation of water and nutrients in roots might have been slowed by the limited energy available.

Other mechanisms of damage such as an accumulation of substances at toxic levels may have contributed, however they were not measured in this study. These mechanisms have been studied in other species by several authors (Bradford and Dilley, 1978; Fulton and Erickson, 1964; Jackson and Campbell, 1975; Jackson and Drew, 1984).

It is concluded that cucumber plants are highly sensitive to soil anaerobic conditions, and are affected by short periods of waterlogging. Under certain environmental conditions, 24 hr of anaerobic conditions are sufficient to affect shoot and root growth. The plants are more susceptible to waterlogging during the early stages of growth.

For further studies, it will be necessary to determine the mechanisms of damage generated from waterlogging and anaerobic respiration. Also, the influence of waterlogging on fruit set and internal quality will need further investigation.

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CHAPTER III

THE INFLUENCE OF RAISED BEDS, PLANT POPULATION AND WATERLOGGING ON GROWTH AND YIELD OF PICKLING CUCUMBERS GROWN ON A RIDDLES SANDY LOAM SOIL

ABSTRACT

Studies were conducted to determine the influence of raised-bed culture and plant populations on growth, root distribution and yield; and to evaluate raised beds as a method of alleviating waterlogging stress. There was no effect of bed type on growth or yield when moisture was not limiting. However, raised beds increased moisture stress, as indicated by the yield of deformed fruits, when no supplemental irrigation was provided. Root distribution in the soil profile was similar for plants grown on raised or flat beds. Plants grown on both raised and flat beds were able to recover from a 48-hr period of waterlogging with no detrimental effect on yield. The determinant cultivar Castlepik produced higher yields than the indeterminate cultivar Flurry. Both cultivars reached a maximum yield at 200,000 plants/ha, however, the yield of Flurry decreased at higher densities while Castlepik maintained the same.

INTRODUCTION

Pickling cucumbers for machine harvest are established at populations of 100,000 to 200,000 plants per hectare depending on soil type and the availability of irrigation. Cultivars currently grown do not produce more than 2 fruits per plant, thus yield is greatly influenced by plant density. As population increases, interplant competition and stress are increased, which may induce malformed fruits with internal defects if the stress is not alleviated. Cucumbers are sensitive to environmental stresses, therefore, it is important to have irrigation available for high density plantings specially on soils with poor water holding capacity.

A large percentage of production for mechanical harvest in Michigan is on silt/clay soils with relatively good water holding capacity. Some of these soils, however, have poor infiltration and drainage characteristics. Excessive precipitation during the growing season often causes soil waterlogging conditions for up to 48 hr or more. During these periods, plants have been observed to become chlorotic and growth slowed down.

In the Midwest, the interest on raised-bed culture has increased as a result of crop losses due to flooding stress however, no consistent results have been reported with the

use of raised beds. It also has been suggested by agriculture engineers that harvester efficiency could be increased with the use of raised beds.

The objectives of the study were: 1) to determine the influence of raised-bed culture and plant populations on plant growth, root distribution and yield; and 2) to evaluate raised beds as a method of alleviating water-logging stress.

MATERIALS AND METHODS

The studies were conducted at the Clarksville Horticulture Experiment Station of Michigan State University in 1986 and 1987. A preliminary experiment was established during the summer of 1985. The soil, of the Riddles series (RwB), is a well drained sandy loam with 2-6% of slope. It has a pH of 6.0, and high levels of P and K (M.S.U. Soil testing laboratory, May of 1986).

1986 Planting.

The field had been in alfalfa production for the last 3 years. The soil was plowed in the spring of 1986, and disked several times to prevent regrowth of the alfalfa. The soil was fertilized with 16 Kg/ha of N, 18 of P, 227 of K, 19 of S, 23 of Mg, and 2 of B, as per soil test.

The seed beds were prepared on June 23, 1986. Raised beds, were formed over prepared flat beds with a Johnson bed shaper. The beginning bed dimensions were a base width of 1.68 m, a top width of 1.22 m, and a height of 20 cm.

On July 1, two commercial cultivars of pickling cucumber (Cucumis sativus), Flurry (indeterminant growth) and Castlepik (determinant growth) were sown with a Heath precision planter, 3 rows per bed at a density of 400,000 plants/ha. Ten days later, the seedlings were thinned to the pre-selected populations. No irrigation was provided throughout the 1986 growing season.

Bensulide (0,0-diisopropyl phosphorodithioate S-ester with N-(2-mercaptoethyl) benzenesulfonamide) + naptalan (N-1-naphthyl- phthalamic acid) at the rates of 4 + 6 Kg/ha (a1) were applied preemergence for control of grasses and broadleaf weeds. The plots were hand-weeded through the growing season in order to assure minimal competition from weeds.

The experimental design was a 2x2x4 factorial in a randomized complete block with four replications. The experimental unit consisted of three adjacent beds, with a length of 16 m. All plant samples and yield data was taken from the center bed. The factors studied were: 1) bed types, flat and raised; 2) cultivars, Flurry and Castlepik; and 3) plant densities, 100 000, 200 000, 300 000 and 400 000 plants per hectare.

1987 Planting.

The soil was plowed at the end of the summer of 1986 and winter wheat was sown. Fall raised beds were formed with a Johnson bed shaper. The remainder of the field was disked early in the spring, and fertilized with 75 Kg/ha of N (as NH_4NO_3) broadcast on May 12, 1987. To minimize soil compaction, the soil was worked only once after disking, with a Brillion cultimulcher to incorporate the N and prepare the flat beds. The spring beds were formed on May 15, and the fall beds reshaped on the day of seeding.

The field was irrigated with a sprinkle overhead system before the planting to insure enough moisture for seed germination. On June 4, cucumber seed cv Flurry was planted, having three rows per bed (36 cm between rows), and a density of 200,000 plants/ha. The herbicide chloramben-methyl ester (methyl ester of 3-amino-2,5-dichloro-benzoic acid) was applied at the rate of 2 Kg/ha (ai) immediately after seeding.

A trickle irrigation system was installed on June 8, to achieve the desired levels of moisture during the growing period. The system consisted of three PVC main lines (3.8 cm of diameter), laid out across the plots. Each line supplied water to a different moisture treatment. There were two irrigation lines (sections of T-tape tubing) per bed connected to the main system. The system had a

flow of 5 liters per minute per 100 m (0.4 GPM per 100 feet) and outlet holes every 30.48 cm.

There were four moisture treatments: 1) no irrigation; 2) Control, 4 to 5 cm of water per week throughout the season as required; 3) Flood I, same as control, plus a continual irrigation period of 48 hr at the 6th true-leaf stage (July 2-4); and 4) Flood II, same as control, plus a continual irrigation period of 48 hr at fruit set (July 17-19).

The experimental design was a split-plot with four replications. The three bed types were assigned to the main plots, and the moisture treatments to the subplots. The subplots consisted of three adjacent beds, each 1.68 m wide at the bottom, and 17 m long.

After the emergence of the seedlings the no-irrigated treatments were excluded from the experiment. Dry weather conditions during the first two weeks of growth caused lack of uniformity and low emergence. The statistical analysis, thus, included only three bed types and three moisture regimes.

Data collection.

Soil parameters.

Undisturbed soil samples from the different bed treatments were collected in both years to determine soil bulk density. In 1987, percent of air filled pores and

volumetric moisture content were calculated with the continuous water column device described by Leamer and Shaw (1941). The soil moisture characteristic curve, was determined by desorption (release of moisture). Soil samples were taken periodically throughout the growing seasons to determine moisture content by gravimetric method.

Growth measurements.

In both years, starting with the third week of growth, five plants per plot were harvested at weekly intervals to analyze growth. The plant material was partitioned into stem and leaf components. Number of nodes on the main stems and lateral stems per plant were recorded. The samples were dried at 66° C for 96 hr prior to determining dry weights.

Yield.

Starting on August 18, 1986, the plots were harvested when the plants had developed 3-10% of oversized fruits (>5.1 cm diameter). All the replicates for each treatment were harvested on the same day. The harvest was completed within a four day period. In 1987, all plots were harvested on July 22, and the percent oversized fruits was less than 3%.

In both years, once-over mechanical harvest was simulated by pulling the plants from an area of 8.4 m² (5 m x 1.68 m) of the center bed and collecting all the fruits.

The fruits were graded by size into different categories; number and weight for each size was recorded. Length:diameter ratios (L:D) were determined for fruits of the categories 2A (2.6 cm - 3.2 cm) and 3 (3.8 cm - 5.1 cm). Yield was evaluated in terms of fruit weight, fruit number and dollar value.

Root number and distribution.

After the yield evaluation was completed in August of 1986, an analysis, in situ, of root number and distribution was performed to evaluate the influence of bed types on root growth. The profile wall method, described by Bohn (1979), was selected for this purpose, after being evaluated in a preliminary study in 1985.

Trenches across the beds were dug mechanically, deep and wide enough to allow two persons collect the data. The walls were smoothed with a spade and a scraper. A sprayer was used to wash a thin layer of soil away from the profile wall and expose the roots.

To facilitate the root counting, a wooden frame of 70 cm x 100 cm, with a square grid net was construed. The size of the squares was 5 cm x 5 cm, as suggested by Bohn (1979) for plants with fibrous root systems. The number of visible roots was determined for each square.

RESULTS AND DISCUSSION

Yield, 1986.

Both cultivars had higher marketable yields and fruit number on flat than on raised beds (Tables 1 and 2). Harrison and Staub (1986) reported similar results from a two-year study with cucumbers; when there were significant differences due to bed effects, the highest yield and fruit number were found on plants grown in flat beds.

Table 1. The influence of bed type on yield and crop value of pickling cucumbers in 1986.

Bed	Yield (ton/ha)		PCIC \$/ha
	nubs/crooks	marketable	
Flat	6.1 ^Z	14.5	1574
Raised	7.1	12.8	1384
F test	*	*	*

^ZEach figure is the mean of 2 cultivars x 4 plant populations x 4 replications.

*Significant at the 5% level.

Table 2. The influence of bed type on fruit number of pickling cucumbers in 1986.

Bed	nubs/crooks	Fruits/m ²	total
		marketable	
Flat	15.9 ^Z	17.0	34.3
Raised	17.8	14.6	33.8
F test	*	**	NS

^ZEach figure is the mean of 2 cultivars x 4 plant populations x 4 replications.

NS,*,** (NS)Nonsignificant, or significant at the 5% or 1% level, respectively.

Raised beds had more soil surface exposed per unit area. It is suggested that the dry periods through the growing season may have stressed more the plants grown on raised beds, because more than 80% of the root system developed in the top 20 cm (Figures 11 and 12), and no irrigation was provided. This is supported by the fact that the number of nubs and crooks was higher for raised beds, but no differences were found in the total number of fruits due to bed types (Table 2).

Castlepick had higher yields and less off-shape fruits than Flurry (Tables 3 and 4). It is thus apparent that Flurry is more susceptible to drought stress than the determinant cultivar Castlepick. The interaction of bed x cultivar was not significant, thus the cultivars responded similarly on both bed types.

Table 3. The influence of cultivar on yield and crop value of pickling cucumbers in 1986.

Cultivar	Yield (ton/ha)		PCIC \$/ha
	nubs/crooks	marketable	
Flurry	8.4 ^Z	10.4	1106
Castlepick	4.8	16.9	1853
F test	**	**	**

^ZEach figure is the mean of 2 bed types x 4 plant populations x 4 replications.

**Significant at the 1% level.

Table 4. The influence of cultivar on fruit number of pickling cucumbers in 1986.

Cultivar	Fruits/m ²		total
	nubs/crooks	marketable	
Flurry	19.7 ^Z	10.9	32.1
Castlepik	13.9	20.7	36.1
F test	**	**	**

^ZEach figure is the mean of 2 bed types x 4 plant populations x 4 replications.

**Significant at the 1% level.

Increasing the plant population decreased earliness as indicated by the yield of oversized fruits (Figure 1). Cantliffe and Phatak (1975) reported similar responses to high population pressure.

Plant density also influenced the yield of marketable fruit and nubs/crooks, however, these responses were different for each cultivar (Figures 2 and 3). The marketable yield of Castlepik increased as the population increased to 200 000 plants per ha, and there was no change at higher populations. Flurry also reached its maximum yield at 200 000 plants per ha, however, yields decreased at higher populations (Figure 2).

The yield of nubs/crooks for Flurry increased linearly with increasing plant population, while Castlepik showed lower yields of nubs/crooks and a quadratic response with the high peak at 300 000 plants/ha (Figure 3). O'Sullivan (1980) also found that plant spacing significantly affected yields of off-shape fruits.

Figure 1. The influence of plant population on yield of oversized fruits (>5 cm diameter) in 1986.

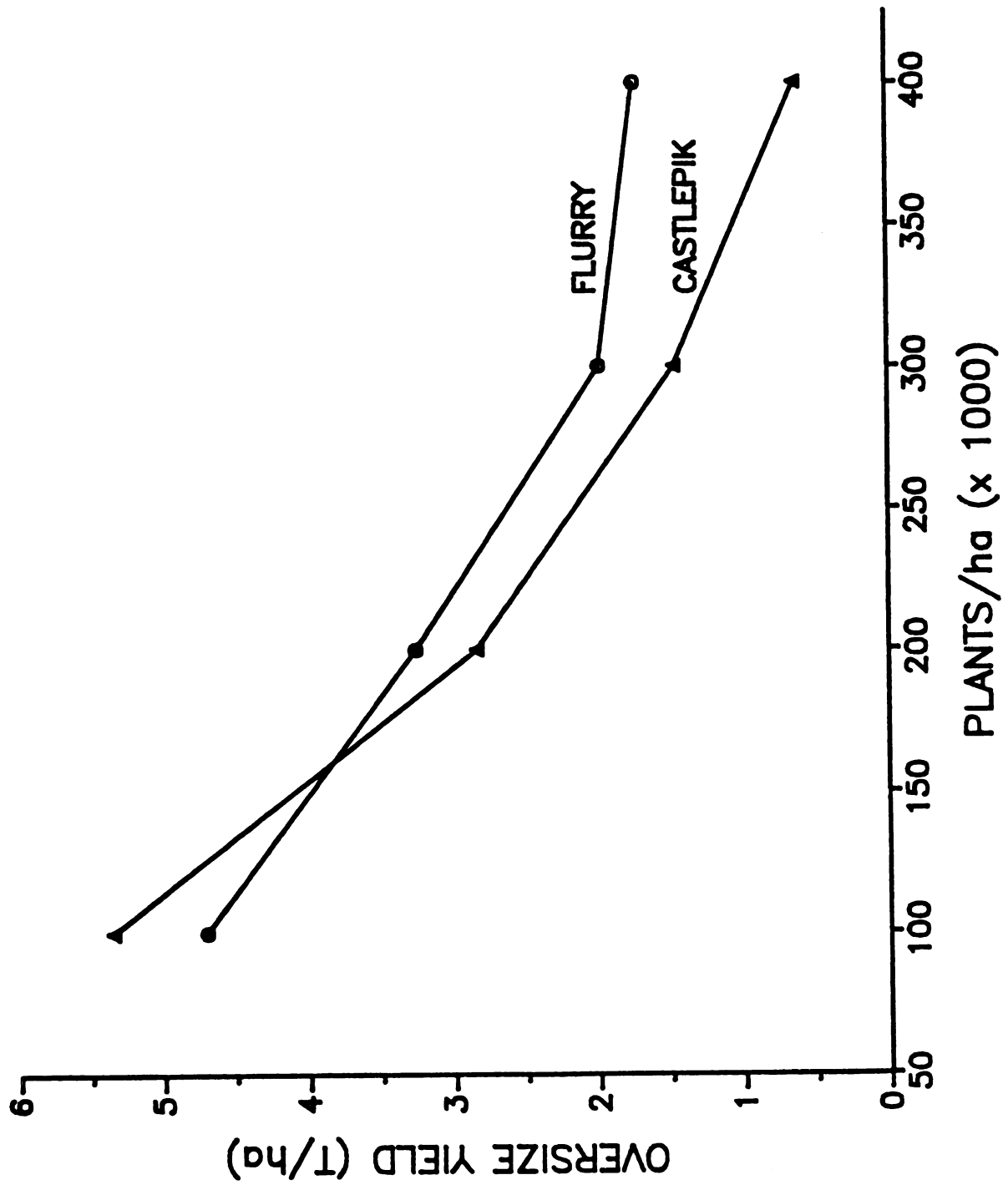


Figure 2. The influence of plant population on marketable yield in 1986.

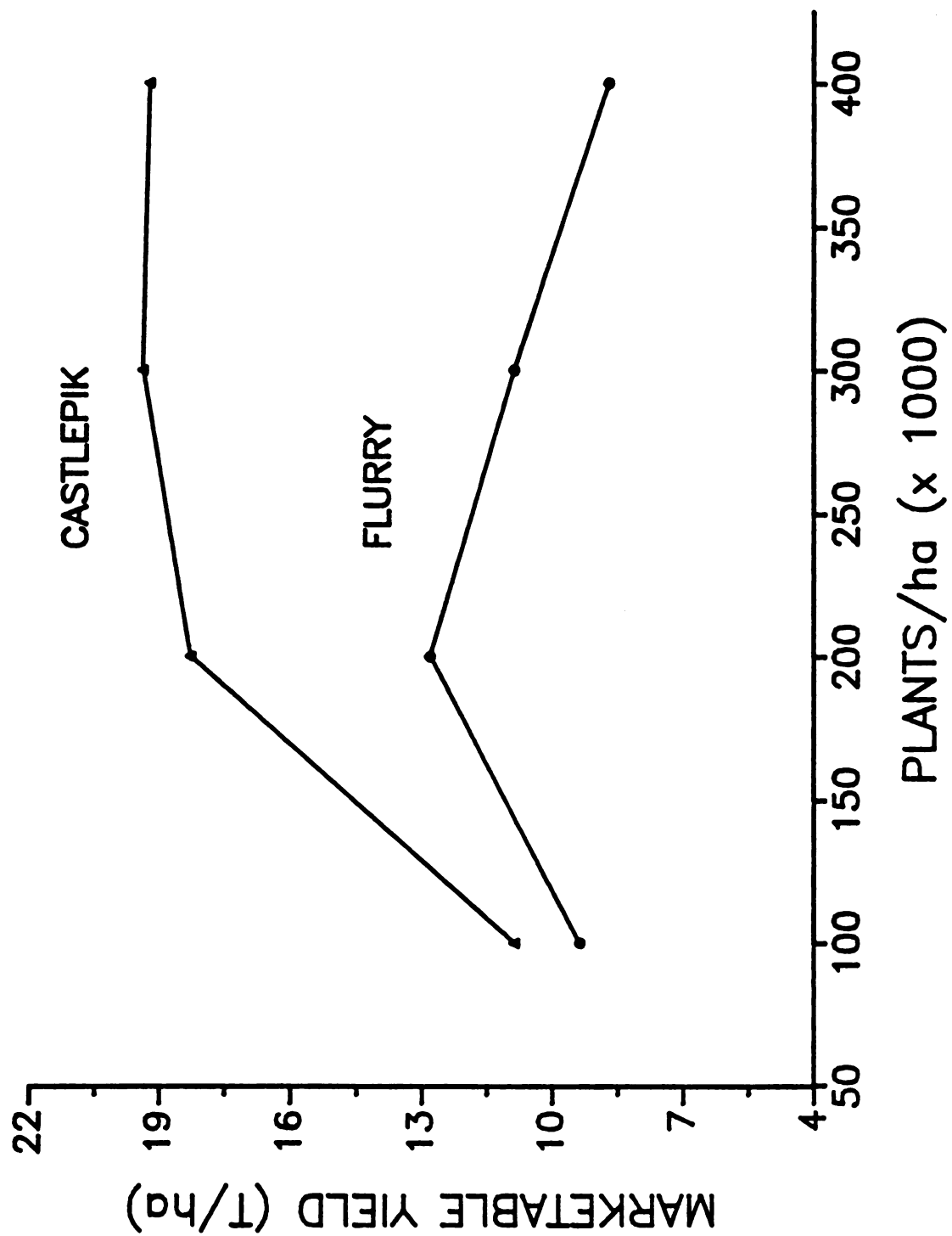
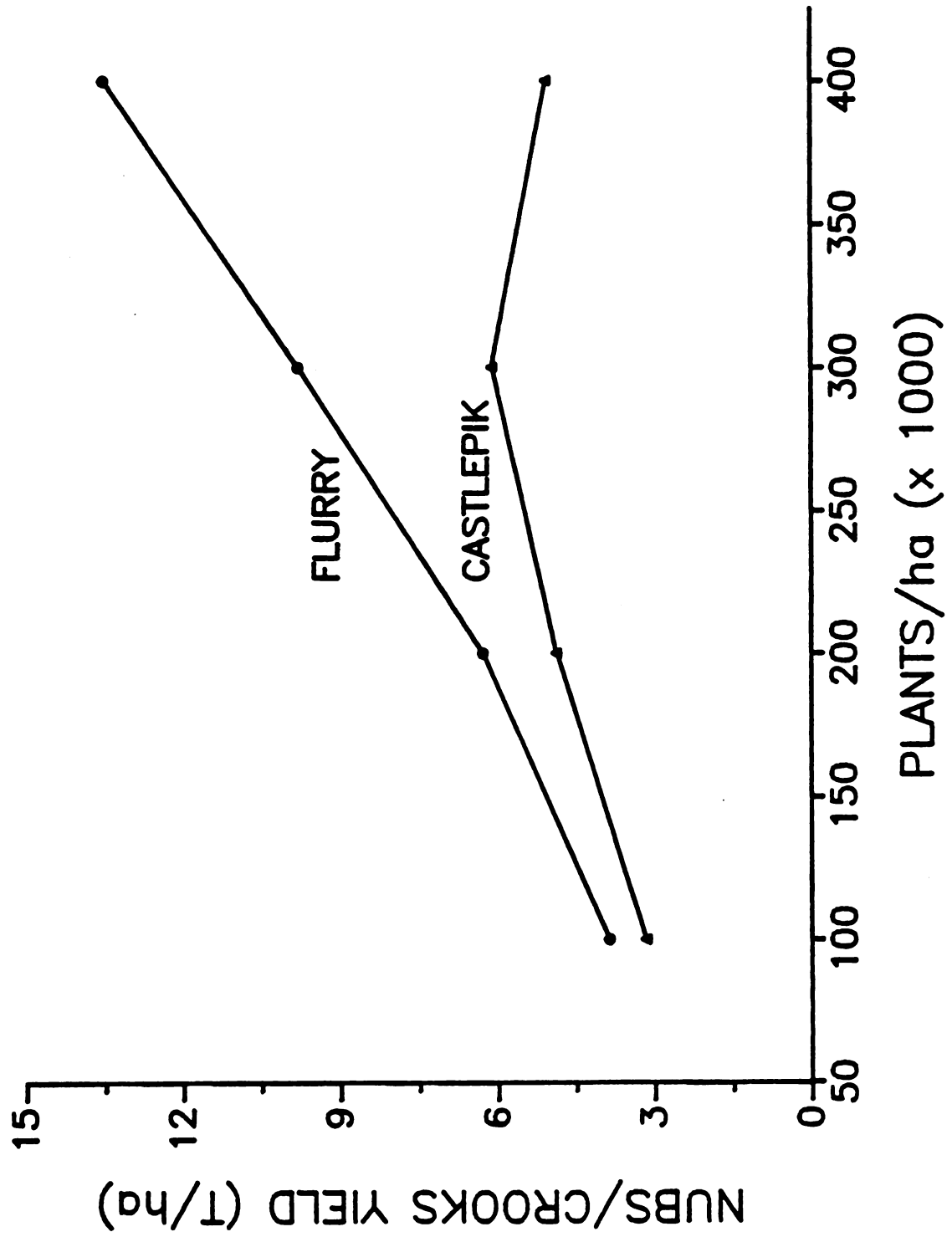


Figure 3. The influence of plant population on yield of nubs/crooks in 1986.



These results provide evidence that factors, in addition to plant population pressure, such as moisture and nutrient availability, may have been limiting the yield of Castlepik. During the stage of fruit set and development, there were high moisture deficits. The indeterminant growth habit of Flurry limits its possibilities of success at high population, specially without supplemental irrigation.

Several authors (Tan, et al., 1983; Motes, 1975; Cantliffe and Phatak, 1975) have indicated that irrigation is essential in pickling cucumbers, as plant densities are increased. It is suggested that raised-bed culture makes irrigation even more critical. O'Sullivan (1980) did not find yield responses to irrigation, but pointed out, that during his research adequate rainfall prior to harvest ensure that lack of water was not a limiting factor on yield.

Yield, 1987.

In 1987 there were no effects of bed types on marketable or nubs/crooks yield (Tables 5 and 6). It is suggested that, unlike the previous year, adequate moisture levels throughout the growing season prevented moisture stress conditions.

There are several studies about the effects of raised beds on strawberry yield (Buckley and Moore, 1982; Goulart, 1986; Hancock and Roueche, 1983), however, no consistent trends have been reported, suggesting that the bed effects are influenced by environmental conditions.

Table 5. The influence of bed type on yield, and crop value of pickling cucumbers in 1987.

Bed	Yield (Ton/ha)		PCIC \$/ha
	nubs/crooks	marketable	
Fall	1.6 ^Z	9.8	1172
Spring	1.6	10.8	1366
Flat	1.5	11.3	1377
F test	NS	NS	NS

^ZEach figure is the mean of 3 moisture levels x 4 replications.
(NS)Nonsignificant.

Table 6. The influence of bed type on fruit number of pickling cucumbers in 1987.

Bed	Fruits/m ²		total
	nubs/crooks	marketable	
Fall	5.4 ^Z	11.4	17.3
Spring	4.7	13.4	18.5
Flat	5.7	12.9	19.1
F test	NS	NS	NS

^ZEach figure is the mean of 3 moisture levels x 4 replications.
(NS)Nonsignificant.

The moisture treatments did not influence marketable yield, however, the yield of nubs/crooks was lower for the plants subjected to flooding at fruit set (Flood II) than for the others (Table 7). In terms of number of marketable fruits, the plants exposed to early flooding (Flood I) were the most negatively affected (Table 8).

The effect of moisture on yield of oversized fruit was

modified by the bed treatments. The interaction did not follow any expected trend (data not presented).

Table 7. The influence of moisture levels on yield and crop value of pickling cucumbers in 1987.

	Yield (Ton/ha)		PCIC \$/ha
	nubs/crooks	marketable	
Moisture			
Control	1.9 ^Z	10.8	1309
Flood I	1.5	9.3	1163
Flood II	1.3	11.7	1445
LSD (.05)	0.4	NS	NS

^ZEach figure is the mean of 3 bed types x 4 replications.
(NS)Nonsignificant

Table 8. The influence of moisture levels on fruit number of pickling cucumbers in 1987.

	Fruits/m ²		Total
	nubs/crooks	marketable	
Moisture			
Control	5.6 ^Z	12.5	18.6
Flood I	5.9	11.2	17.3
Flood II	4.3	14.0	18.9
LSD.05	1.1	2.0	NS

^ZEach figure is the mean of 3 bed types x 4 replications.
(NS)Nonsignificant

Fruit length:diameter ratios.

Bed type did not influence length:diameter (L:D) ratios in 1986 or 1987 (data not presented). In 1986,

Flurry had higher L:D ratios on both 2A and 3 than Castlepik (Table 9). Plant densities did not affect the ratios of 2A fruits, but the L:D of number 3 were smaller at lower plant populations (Table 10). Cantliffe and Phatak (1975) found similar results, which they attributed to the high number of fruits per plant. In 1987, the moisture treatments did not affect L:D ratios (data not presented).

Table 9. The influence of cultivar on length:diameter (L:D) ratios in 1986.

Cultivar	L:D ratio	
	2 A	3
Flurry	2.9 ^Z	2.5
Castlepik	2.5	2.3
F test	**	**

^ZEach figure is the mean of 2 bed types x 4 plant populations x 4 replications.

**Significant at the 1% level.

Table 10. Effect of plant population on length:diameter (L:D) ratios in 1986.

Plants/ha	L:D ratio	
	2 A	3
100 000	2.7 ^Z	2.3
200 000	2.7	2.4
300 000	2.7	2.3
400 000	2.7	2.4
Pop linear	NS	*
Pop quadratic	NS	NS

^ZEach figure is the mean of 2 bed types x 2 cultivars x 4 replications.

NS,* (NS)Nonsignificant or significant at the 5% level.

Growth and development.

In 1986, the influence of population pressure became evident in the field 4 weeks after planting, when competition between plants for moisture and nutrients was reflected on growth. By increasing the population levels there was a decrease in leaf and stem dry weight of individual plants (Figures 4 and 5), however this effect was compensated by the higher number of plants per unit area. Both cultivars showed similar responses to plant density, and were not affected by bed types (data not shown).

Plant development was delayed by increasing the density, as reflected by the number of nodes per plant in the main stem (Figure 6) and the number of oversized fruit (Figure 1).

Castlepick developed more lateral stems than Flurry, however, the response to population pressure was different for each cultivar (Figure 7).

The development of lateral stems represents an important potential yield component in cucumbers; in certain cultivars it affects the number of fruits set per plant. The linear relationship between fruit number and lateral stems showed a higher correlation for Castlepick than for Flurry (Figure 8). The fruit number in Flurry does not appear to be as highly related to lateral branching as it is in Castlepick.

In 1987 plant growth was not affected by bed or

Figure 4. Effect of population on leaf biomass accumulation per plant throughout the growing period in 1986.

Figure 5. Effect of population on stem biomass accumulation per plant throughout the growing period in 1986.

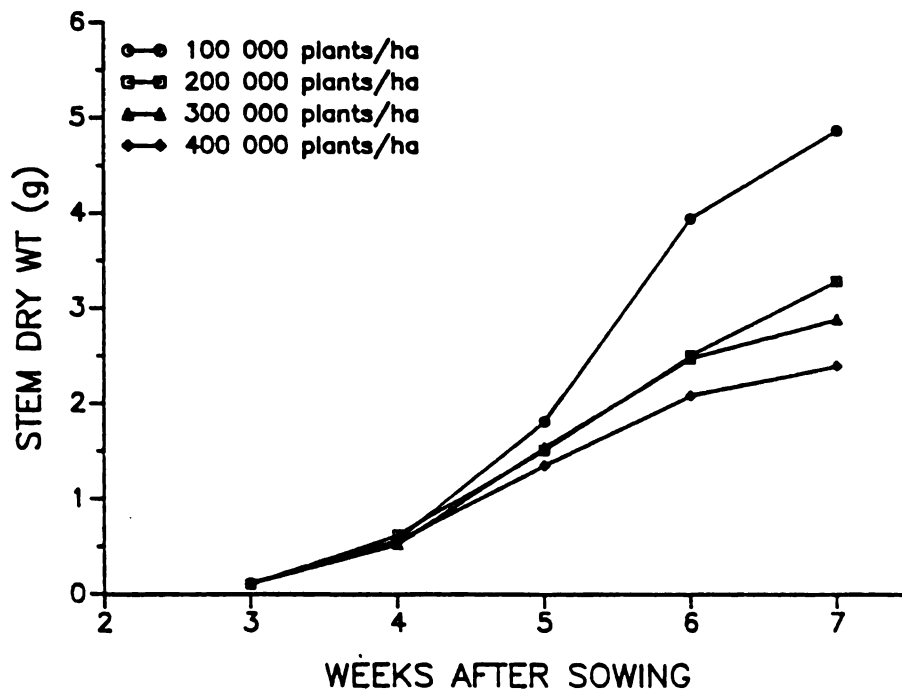
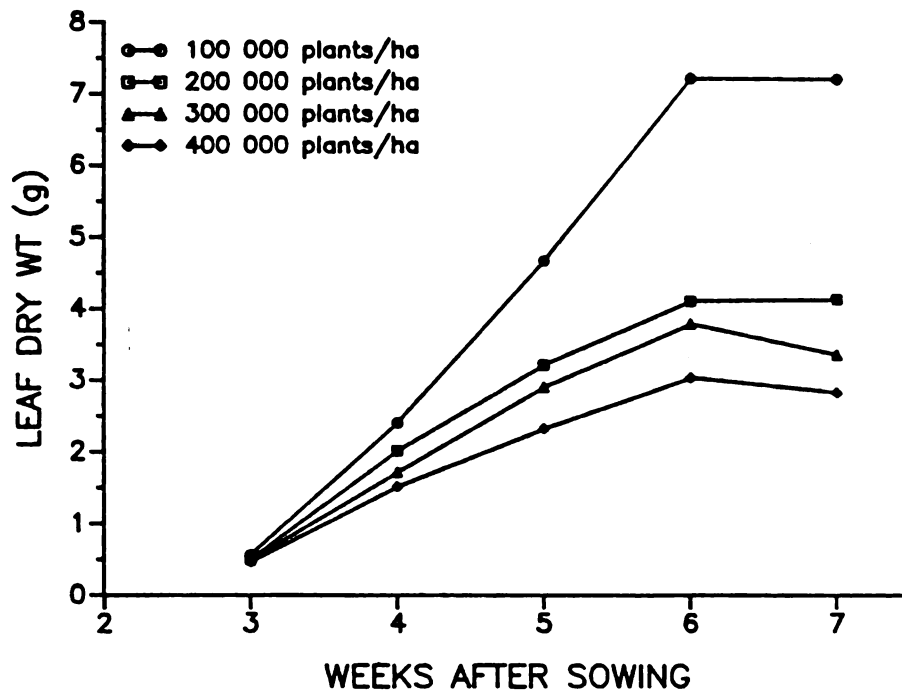


Figure 6. Effect of plant population on the number of nodes per plant in the main stem in 1986.

Figure 7. Effect of plant population on the number of lateral stems per plant in 1986.

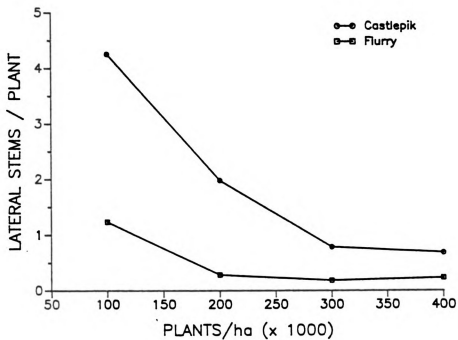
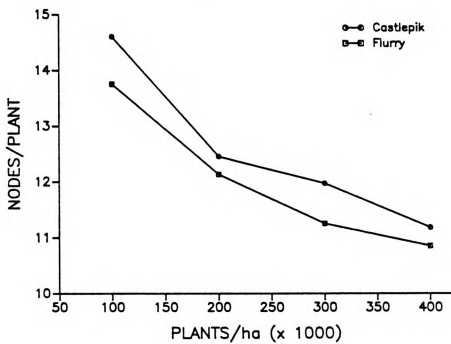


Figure 8. Linear relationship between fruit number and lateral stems per plant for cultivars Flurry and Castlepik in 1986. Each point is the mean of 4 replications.

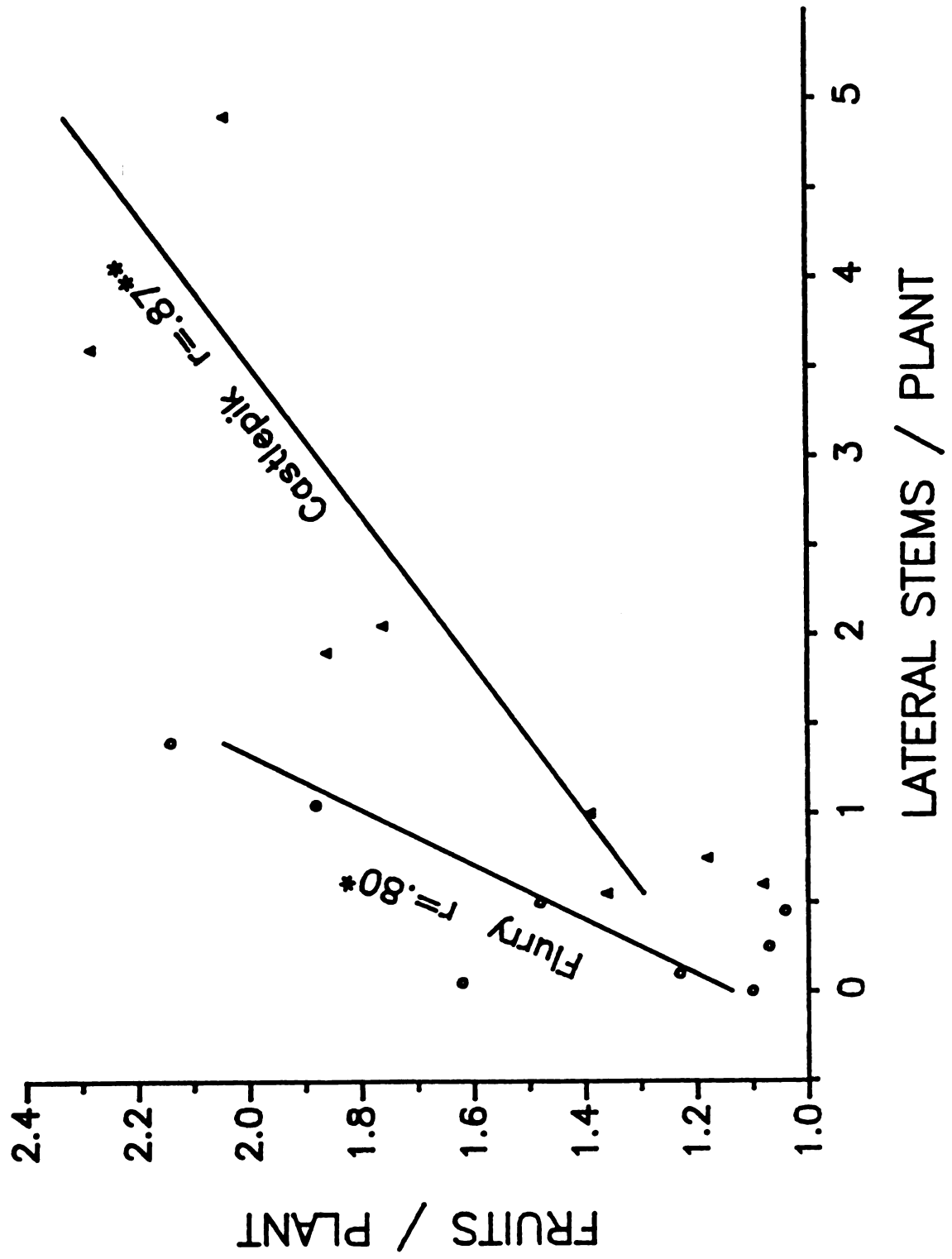
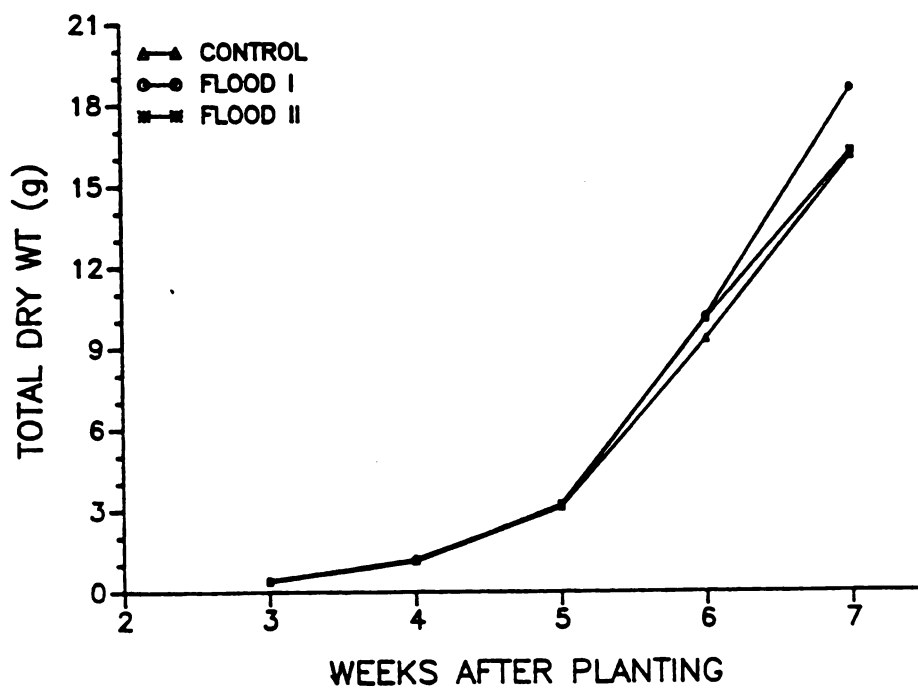
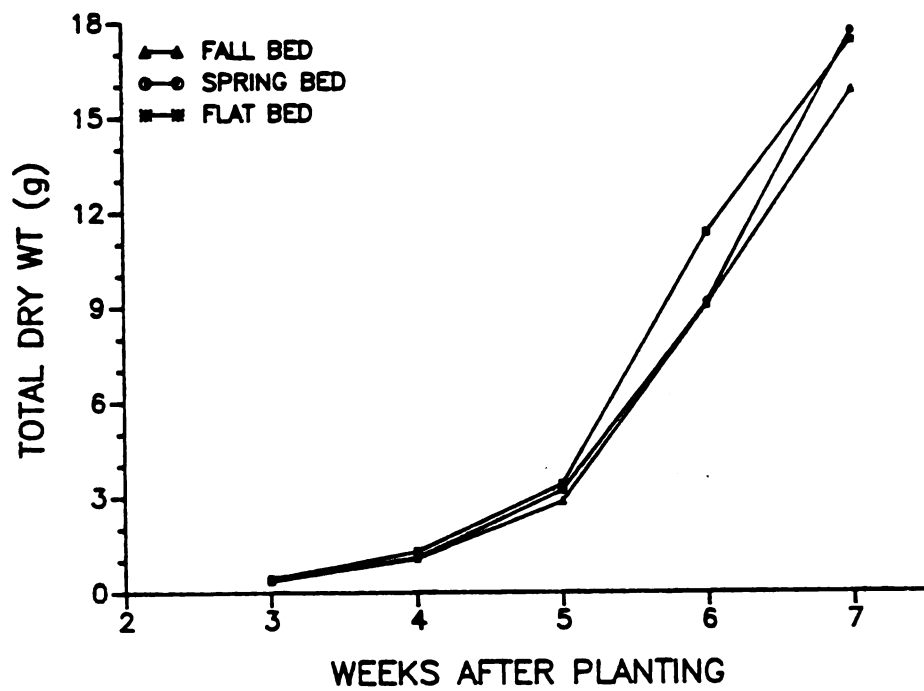


Figure 9. Effect of bed type on shoot biomass accumulation per plant throughout the growing period in 1987.

Figure 10. Effect of moisture levels on shoot biomass accumulation per plant throughout the growing period in 1987.



moisture treatments (Figures 9 and 10). However, the short period of waterlogging at the early stage of growth affected yield by reducing the number of marketable fruit, and increasing the number of nubs/crooks, as discussed earlier (Table 8).

Root distribution, and soil parameters.

There were no effects of bed types on root number (data not presented) or root distribution (Figures 11 and 12) in 1986. The transition zone between the A and B horizons was located at a depth of 25 and 30 cm for flat and raised beds respectively. More than 80% of the root system developed in the top 20 cm of the A horizon. This pattern of distribution was similar for both cultivars.

Although cucumber is considered a shallow rooted plant, the high bulk density found within the A horizon (Figure 13) may have affected root penetration and distribution. Below the top 8 cm of the soil profile, the bulk density significantly increased.

In 1986, the soil bulk density of the raised beds was lower than that of the flat beds at the 0-7.6 cm depth, however there was no difference for the subsequent depths (Figure 13).

The data indicate that once the raised beds had been settled throughout the growing period, only the top 8 cm of soil remained with high pore space. Below this layer, the increase in density was more severe for raised beds than for flat beds.

Without the help of supplemental irrigation in 1986, the higher pore space present in the top soil of the raised beds enhanced the loss of moisture faster than in flat beds. This moisture stress may have negatively affected marketable yield, as was discussed earlier.

In 1987 bulk density was not influenced by the bed treatments or depth of sampling within the A horizon of the profile (Figure 14). It is important to note that for the 1987 season, the number of passes with heavy equipment in the field were significantly less than for the previous year. It is hypothesized that this difference in traffic pattern was reflected on soil porosity, and influenced the mean value of bulk density for each year: 1.56 gr/cm³ in 1986 vs 1.43 gr/cm³ in 1987.

The soil moisture release curve, at a sampling depth of 0-7.6 cm, was only influenced by bed types at the lower range of matric potential. There was a higher value for spring beds than for fall or flat beds (Figure 15).

Spring beds had higher total porosity than the other bed types (total porosity is equivalent to the volumetric moisture content at the saturation level, Figure 15). This difference in total porosity may be attributable primarily to large size pores. After a soil becomes saturated, the amount of water released depends primarily upon the pore-size distribution (Hillel, 1982). The higher percent of large pores suggests that the initial release of water with the application of low suctions may be higher for spring

Figure 11. Influence of bed type on root distribution in the soil profile in 1986 (cv Flurry). The transition between the A and B horizons was located at a depth of 25 and 30 cm for flat and raised beds respectively.

Figure 12. Influence of bed type on root distribution in the soil profile in 1986 (cv Castlepik). The transition between the A and B horizons was located at a depth of 25 and 30 cm for flat and raised beds respectively.

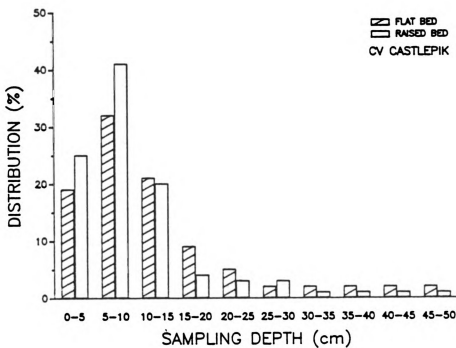
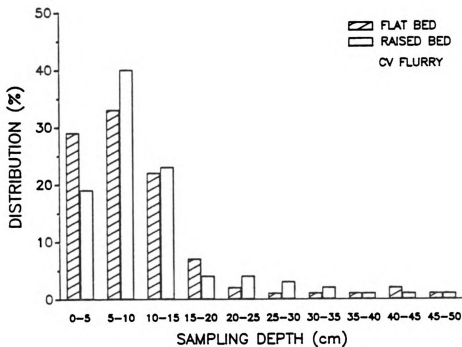


Figure 13. Effect of bed type on bulk density at different depths within the A horizon of the soil profile in 1986. The interaction bed x depth was significant at the .01 level of probability.

Figure 14. Effect of bed type on bulk density at different depths within the A horizon of the soil profile in 1987. There were no significant differences.

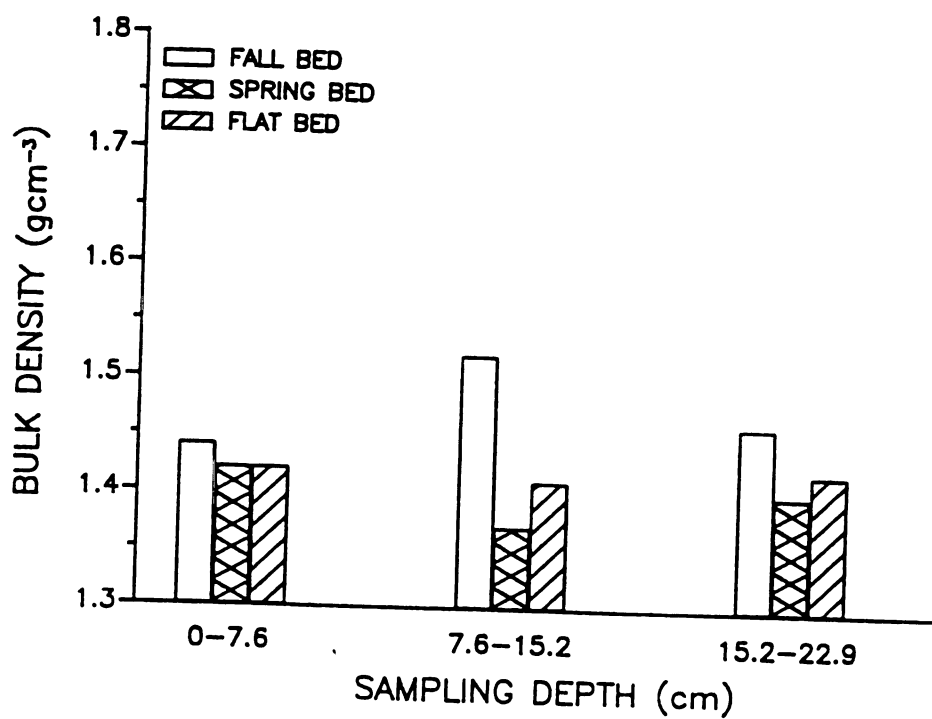
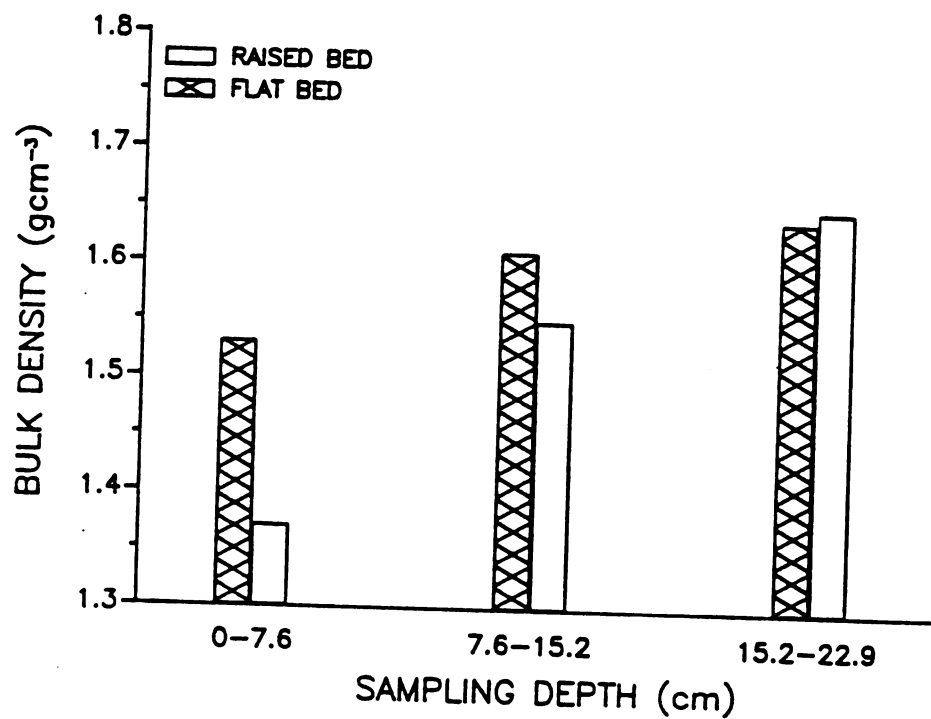


Figure 15. Effect of bed type on the soil moisture release curve at a sampling depth of 0-7.6 cm in 1987.

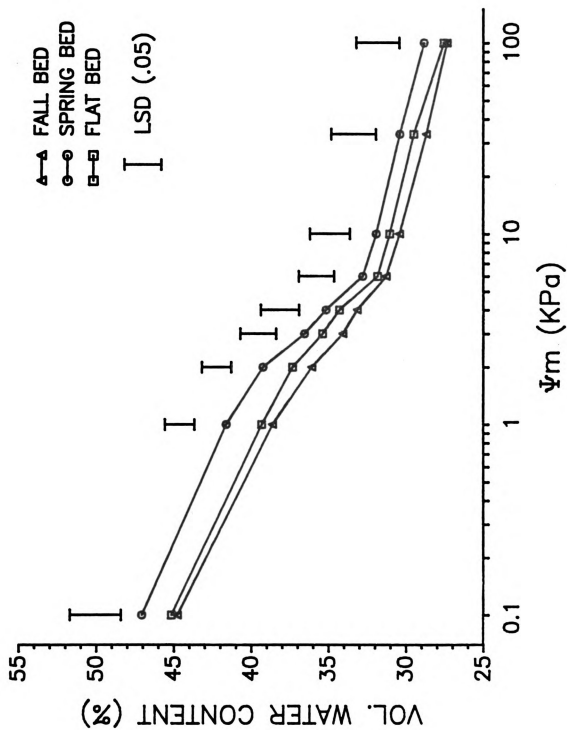
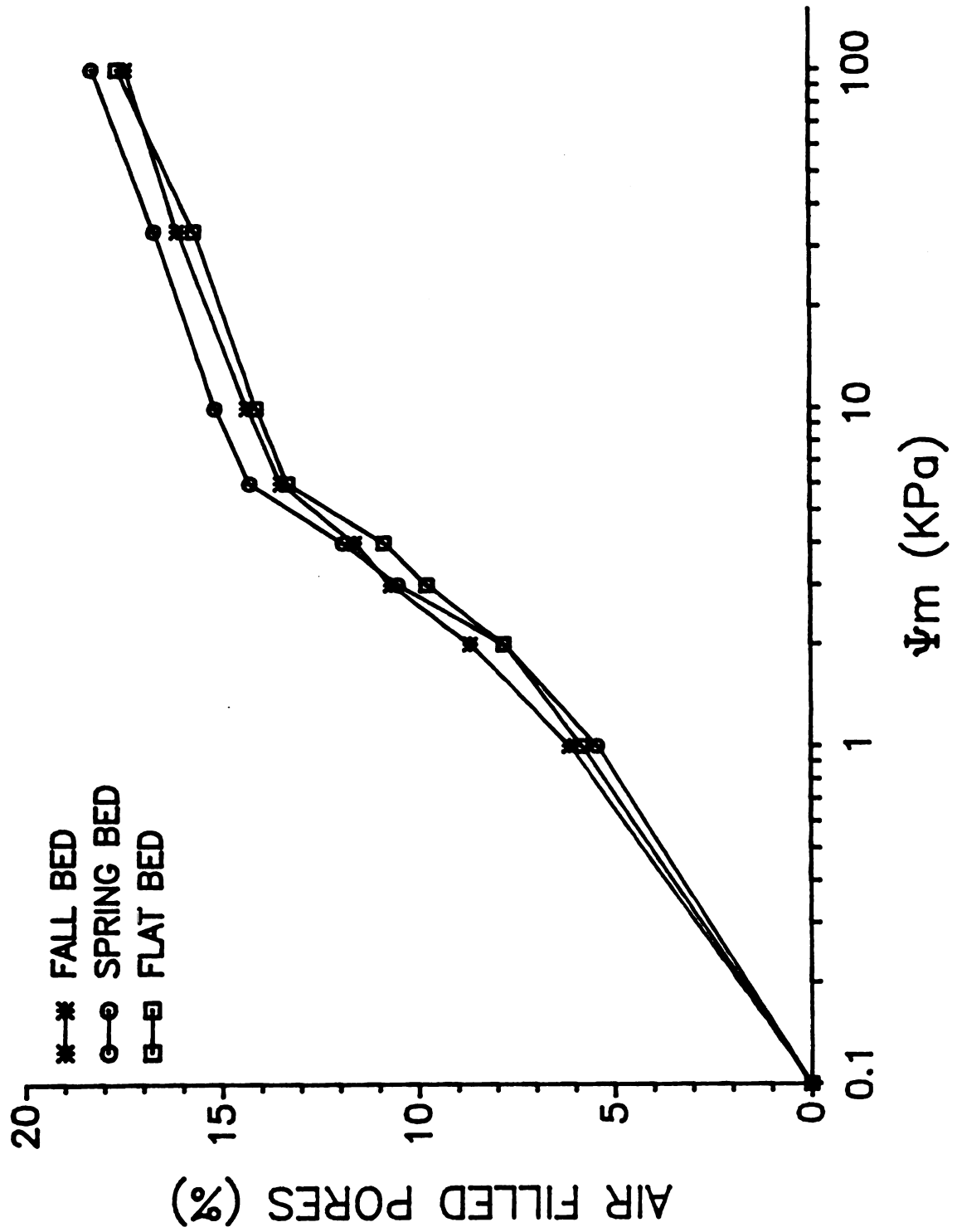


Figure 16. Effect of bed type on air filled pores at a sampling depth of 0-7.6 cm in 1987.



beds than for fall or flat beds. However, the percent of air filled pores at different suctions (Figure 16) was similar for all bed types.

It is important to note that porosity is a dynamic soil characteristic that changes with time. In 1987, the samples were taken at the end of the growing period, once the beds had been settled to some extent, therefore, the data showed the porosity of the soil at that particular time.

CONCLUSIONS

In 1986, without supplemental irrigation, and with several periods of moisture deficit, raised-bed culture on a Riddles sandy loam soil, did not provide any advantage over flat-bed culture. Under these conditions, plants grown on raised beds had lower marketable yields as well as higher yields of nubs/crooks than plants grown on flat beds.

In 1987, with supplemental irrigation provided, no differences in yield were found between raised and flat beds, thus, the effect of raised-bed culture on yield is influenced by soil moisture levels.

Castlepek produced significantly higher yields with fewer nubs/crooks than Flurry. Both cultivars increased yields as population increased to 200,000 plants per ha.,

however, the yields of Flurry decreased at higher densities while Castlepik maintained the same yields. Earliness was delayed by increasing plant population.

The results suggest that cultivars with determinant growth habits, such as Castlepik, provided with adequate moisture and nutrients, may withstand high population pressures and produce larger yields for once-over mechanical harvest.

Cucumber plants were more susceptible to flooding at the early stage of development. However, the effects of waterlogging are influenced by certain soil characteristics such as texture, degree of compaction, structure, porosity and drainage; and by environmental conditions such as light intensity, relative humidity and temperature during the time of the stress.

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