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Engineering and Horticultural Research on Improving the Mechanical Harvesting of Peppers

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A. ABSTRACT

In Israel, a new paprika cultivar ('Improved Shany') was selected which is far more adaptable to mechanical harvesting, due to improved plant architecture. Reducing in-row spacing is the best cultural practice for creating an optimal plant structure to facilitate mechanical harvesting. Principles and equipment were developed to remove attached paprika pods from broken plant branches, remove small trash and glean lost pods from the ground improving recovery, detachment and cleanliness.

In Penn., there was no significant change in plant structure (height, width or height to 1st branch) from irrigating peppers or splitting the nitrogen application between broadcasting and/or sidedressing. Hot cultivar plant structures lend themselves easier to mechanical harvesting than sweet cultivars.

In Mich., transplant type had little influence on yield or harvestability of four pepper types evaluated. Speedling transplants produced branches closer to the soil surface than other types. Yield of all cultivars increased with increased plant density, however, there was a decrease in fruit size and number of fruit per plant. Conical helical lifters improved gathering of bushy plants. Pepper damage was more related to peripheral helix speed than to impacts per plant. An air conveyor was developed. Differential speed combing belts improved subsequent operation of trash removal beds.

B. TECHNICAL REPORT

Nearly 75 million t of peppers (Capsicum sp.) are grown on 1 million ha in the world (F.A.O. 1982)^{1/}. The mechanization of pepper harvesting has been the subject of considerable research for the past 2 decades in Bulgaria, Hungary, Israel, Italy, USA and USSR. Renewed interest has resulted in further accomplishments (Marshall 1984a). Up until the late 1970's the main emphasis was on equipment design and little on cultural techniques that might modify the plant structure. This joint cooperative project was initiated to advance the horticultural and agricultural engineering research aspects as well as to cooperatively join the two disciplines.

B-1. Horticultural Research

- a. Medicinal and Spice Crops Institute (Israel): Dan Palevitch,
A. Levy, N. El Basal and Chen Shifriss

Abstract

The effect of cultivar and certain cultural practices on the implementation of mechanical harvesting of paprika has been studied.

A new cultivar named 'Improved Shany' was selected during the course of this study. This new cultivar exhibits better adaptability to mechanical harvesting in terms of plant architecture. It has a reduced number of lateral shoots below the main branching point, with a long stem from the soil surface to the branching point.

^{1/} Since many of the references cited in the individual sections are cited in some of the other sections, all report bibliographic references will be found in Section C. "PUBLICATIONS CITED".

In-row plant spacing proved to be the best means for establishing an optimal plant structure for efficient mechanical harvesting. Planting ten plants per meter resulted in a plant that has fewer side shoots near the soil surface as compared to four plants per meter, without affecting the yield of the red fruits. All the other cultural practices were less effective in affecting plant structure, and caused a decrease in fruit yield.

From the results gathered in the present study, it is apparent that growing suitable cultivars is the best way to increase the efficiency of the harvester. The optimal plant architecture of these cultivars is a plant with a small number of side shoots near the soil surface and a long stem below the main branching point. In case that no suitable cultivar is available, reducing in-row spacing seems to be a simple means for creating a more suitable plant structure for mechanical harvesting.

Introduction

Sweet paprika is one of the major spice commodities, worldwide. The international trade in sweet paprika is on the order of 30,000-35,000 tons per annum. The main producers are Hungary, Spain and recently also the U.S. (Smith 1982).

The main paprika product is the dried ground powder, mainly used in the food industry, as well as in households and as a coloring agent. To a lesser extent the oleoresin product is used as a natural coloring agent mainly in the meat industry.

In all the producing countries the fruits are picked by hand based on inexpensive labor. To the best of our knowledge there is no commercial use of mechanical harvesting of paprika in the producing countries. Since labor is scarce and costly in Israel, efforts were made to establish a once-over harvesting procedure in order to decrease the manpower needs in harvesting paprika (Palevitch et al. 1975, 1984).

The practice of once-over harvest paved the way to the endeavor of appropriate mechanical harvesting.

Objective

The aim of the present research was to identify some horticultural cultural practices that would enable and facilitate mechanical harvesting of paprika peppers.

Materials and Methods

The field experiments were carried out in the years 1981-1983. Most of the experiments were conducted at the Central Experiment Station - Bet Dagan, located at the coastal part of Israel, near Tel Aviv. Additional field experiments were conducted in commercial fields at Kibbutz Be'eri and Kibbutz Lahav, both located in the Negev (in the southern part of Israel).

The cultural practices used were according to the method developed by Palevitch et al. (1975), namely, once-over harvest of dried fruits after a long duration without irrigation. These methods are prerequisite for the implementation of mechanical harvesting.

The standard cultivar used was 'Shany' which is a sweet paprika cultivar we selected from a genetical line originally from California. The experimental design was generally based on random blocks replicated 5 to 6 times. The average area of each plot was 10m^2 . For more precise measurements, ten plants were randomly selected from each plot and each plant was analyzed individually. The statistical analysis was done according to a SAS program.

The determination of the dry matter content was based on drying samples of fruit (approx. 1/2 kg) in an oven at 50°C for 2 to 3 days until completely dry. Color intensity was measured according to standard ASTA procedure (ASTA 1968).

In Israel the climatic conditions permit sowing paprika seed from March to June. An experiment was set up to study the plant structure and yield potential of 4 sowing dates.

It is well documented that growth regulators affect plant structure. We studied the effect of certain growth regulators on pepper plants to evaluate if stimulating or retarding certain vegetative plant growth characteristics would improve their adaptability to mechanical harvesting.

Growth regulators were applied to the plants by hand spraying at the blooming stage.

In the nitrogen (N) fertilization experiment the fertilizer was dissolved in the irrigation water and was applied through the drip irrigation system. The N was applied twice a week proportionally to the irrigation rate. It was calculated on a basis of 90% of the daily

evaporation, approximately 7 m^3 per 1000 m^2 per day. The total amount of irrigation water applied was 480 m^3 per 1000 m^2 .

Results and Discussion

Selection of Cultivars

The standard cultivar used commercially in Israel is 'Shany' (a selection from genetical lines originally from California). 'Shany' is an outstanding cultivar in terms of suitability to once-over harvesting, and in its extremely high color intensity. However, its low branching of side shoots near the soil surface posed a problem for optimal mechanical harvesting. In order to overcome this negative trait, we started a program with special attention on selecting more suitable types of plants for mechanical harvesting, without altering the high quality of the 'Shany'. As a result of this selection of plants within the 'Shany' population we succeeded in establishing a new type of plant. These plants have a long stem from the soil surface to the first main branching of the plant, with few, if any side shoots below this main branching.

The most promising cultivar was line no. 446, which was named 'Improved Shany'. In Table 1 the new cultivar is compared to the old cultivar 'Shany'. In the first year at Bet Dagan (1982) the differences between the two cultivars were rather small. Even so, the average number of the side shoots under the main branching was significantly lower in the new cultivar: 4.4 side shoots per plant. However, in the experiment in the commercial field at Lahav the difference between the two cultivars was much greater in regards to plant architecture and yield potential.

In 1983 the new cultivar - 'Improved Shany' showed an extremely low number of side shoots below the main branching - an average of 0.8 per plant, while in 'Shany' the average number was 3.5. The new cultivar had bigger fruits and higher yield of red fruit. These promising results encouraged Israeli farmers to plan to sow at least 10% of their commercial fields in 1984 to this new cultivar.

It remains to be seen if a significant improvement in the mechanical harvesting operation will result from the replacement of 'Shany' by 'Improved Shany', which seems to be more suitable for the mechanical harvesting.

In-row Spacing

The results presented in Table 2, clearly reveal that by decreasing the plant spacing in the row, we can affect considerably the plant structure. It was found that by increasing plant density the stem length below the branching point was significantly greater than in plants which grew under wider spacing in the row.

It was quite evident that the number of side shoots below the branching point was profoundly affected by plant spacing. In both experiments the lower number of side shoots was exhibited in plants sown at higher plant densities. It was greatly pronounced in Be'eri where only 0.9 main shoots per plant developed under the highest density conditions, as compared to 6.1 branches at the widest spacing. This enabled better performance of the harvester. However, in the high density planting the yield of red fruit was significantly lower in the most dense treatment.

It remains to be seen if the easier operation of the harvester in the more dense plant population will compensate the lower yield potential under commercial conditions. By using less extreme distance between the plants in the rows, we could decrease the number of the side shoots, without causing a reduction in yield potential. Spacing of 10 cm between the plants in the row at the inter-row spacing employed in these experiments seems to be optimal for mechanical harvesting. At this spacing there were limited numbers of side-shoots and no reduction in the yield was observed.

Sowing Dates

In 1982 (Table 3) the plants that were sown on the earliest date were smaller in comparison to the later dates. The same is true regarding the stem length from the soil surface to the main first branching. It seems that it will be harder to get an optimal mechanical harvesting with small plants and with shorter stems. However, the number of side shoots below the main branching was significantly lower, thus helping an optimal harvesting. The main disadvantage of the early sowing date was the lower yields of both fresh and dry red fruits. The highest dry yields were achieved from the April 22 sowing date, the optimal date for commercial grower of paprika. But, on this sowing date the number of side shoots developing in the lower part were the highest.

From the results it is apparent that no concrete conclusion can be drawn in regard to what is the optimal date for ensuring the best plant structure adapted for mechanical harvesting.

Growth Regulators

The results presented in Table 4 showed the effect of 3 compounds on plant height, stem length and number of side shoots. All the compounds employed in this study showed an increase in the number of side shoots below the main branching, a negative character for improving optimal mechanical harvesting. Applying Ethrel, for example, resulted in a 3 fold increase in the number of lateral shoots in comparison to the control. This chemical also significantly decreased the yield.

From these results it is clear that the application of the growth regulators used in this study were not beneficial for our purpose and did not facilitate mechanical harvesting.

Nitrogen

Increasing the rate of N applied during plant development resulted in only a small alteration in the plant structure (Table 5). Applying 90 ppm significantly increased the plant height, but had no effect on the number of lateral shoots or stem length, compared to other N treatments. Plants which did not receive any N exhibited the shortest stem lengths. The dry red fruit yield was significantly different between the control and all N treatments. There was no significant difference in the yield between different rates of N. The N fertilization had no effect on fruit characteristics. From the results it seems likely that N fertilization is not a reliable means to change plant structure for better implementation of mechanical harvesting of paprika.

Conclusions

The effect of cultivar selection and certain cultural practices on the implementation of mechanical harvesting of paprika has been studied.

A new cultivar named 'Improved Shany' was selected during the course of this study. This new cultivar exhibits better adaptability to mechanical harvesting in terms of plant architecture. It has limited the number of lateral shoots below the main branching point, with a greater distance from the soil surface to the branching point.

In-row plant spacing proved to be the best means for stabilizing an optimal plant structure for a smooth mechanical harvesting. Increasing plant population to ten plants per meter resulted in a plant that had fewer side shoots near the soil surface as compared to four plants per meter without significantly affecting the yield of the red fruit. All other cultural practices evaluated were less effective in affecting plant structure, and caused a decrease in fruit yield.

From the results gathered in the present study, it is apparent that growing suitable improved cultivars is the best way to increase the efficiency of the harvester. The optimal plant architecture of these cultivars is a plant with a small number of side shoots near the soil surface and a long stem below the main branching point. In case a suitable cultivar is not available, reducing in-row spacing seems to be a simple means for creating a more suitable plant structure for mechanical harvesting.

Table 1. The new cultivar 'Improved Shany': Plant structure, fruit characters and yield potentiality, Bet Dagan, 1982, Lahav, 1983.

Cultivar	Plant structure		Fruit characters				Yield of red fruits (g/m ²)	
	Height	Stem length** (cm)	No. of side shoots**	Weight of dried fruit (g)	Pericarp (% of the whole fruit)	Dry matter (%)	Fresh	Dry
Bet Dagan 1982								
Shany	68a	20a	5.2a	6.2a	60a	49a	1208a	588a
Improved Shany (446)	65a	22a	4.4b	6.9a	65a	49a	1250a	608a
Kibbutz Lahav 1983								
Shany	88	29	3.5	4.2	59	32	2238	719
Improved Shany (446)	87	36	0.8	5.7	64	27	3264	878

(*) From soil surface to the main branching

(**) Below the main branching

Within columns figures, followed by different letters, differ significantly at p=0.05.

Table 2. Effect of in-row spacing on plant structure and yield of paprika pepper red fruits, Cultivar - 'Shany'

In-row spacing		Plant structure		Red fruits per plant	Yield of red fruits (g/m ²)		Fruit characters			
Plants per m spacing (mm)	In-row spacing (mm)	Height (cm)	Stem length* (cm)		Number of side shoots**	Fresh	Dry	Weight dry fruit (g)	Pericarp (% of whole fruit)	Dry matter (%)
<u>Kibbutz Be'eri</u>										
4.4	227	74a	22b	6.1a	27.9a	802a	560a	2.5a	59a	70ab
5.5	182	74a	23b	5.2b	21.4ab	743ab	479ab	2.6a	58a	64b
9.2	109	74a	25ab	3.5c	18.8bc	719ab	511ab	2.7a	61a	71a
15.8	63	80a	28a	0.9d	12.3c	615b	426b	2.3a	62a	69ab
<u>Bet Dagan</u>										
4.3	233	79a	20b	6.2a	24.8a	581a	400a	2.6a	59b	70a
6.8	147	85a	22b	4.8b	18.9ab	572a	427a	2.5a	64a	75a
8.2	122	81a	22b	3.7b	14.2b	517a	387a	2.7a	59b	74a
13.5	74	85a	28a	2.9c	16.6d	494a	358a	2.4a	61ab	75a

*From soil surface to the main branching

**Below the main branching

Within columns, figures followed by different letters, differ significantly at P=0.05

Table 3. Effect of sowing dates on plant structure, fruit characters and yield of paprika pepper red fruits,
Bet Dagan, 1982.

Sowing dates	Harvesting date	Plant structure			Yield of red fruits (g/m ²)		Red fruits characters		
		Height (cm)	Stem* length (cm)	Number of side shoots**	Fresh	Dry	Weight dry fruit (g)	Pericarp (% of the whole fruit)	Dry matter (%)
Mar 18	Oct 15	56b	16c	2.7b	751b	411b	2.8ab	58b	54a
Apr 22	Oct 18	68a	20b	5.2a	1197a	588a	2.8ab	61ab	45a
May 4	Oct 24	67a	19b	4.8a	882b	361bc	3.5a	62ab	54a
June 6	Oct 24	68a	24a	3.0b	1389a	296c	2.5b	68a	24b

*From soil surface to the main branching

**Below the main branching

Within columns figures followed by different letters differ significantly at p=0.05

Table 4. Effect of growth regulators on plant development, fruit characters and yield of paprika pepper red fruit, Bet Dagan, 1981. Sowing: April 14, Growth regulators spraying: July 1 & 8. Harvesting: November 3.

Compound	Plant structure			Yield of Red		Fruit characters	
	Height (cm)	Stem length* (cm)	Number of side shoots**	Fruit (g/m ²)		Weight (g) dry fruit	Pericarp (% of the whole fruit)
				Fresh	Dry		
Ethrel	59c	24a	9.8a	820a	370b	3.4a	54b
CCC	70b	24a	4.5c	694a	517a	3.1a	60a
Morphactin	59c	23a	6.0b	449b	374a	3.1a	67a
Control	81a	25a	3.3c	755a	557a	3.5a	65a

*From soil surface to the main branching

**Below the main branching

Within column figures followed by different letters differ significantly at $p=0.05$

Table 5 - Effect of nitrogen fertilization on plant structure, fruit characters and yield, Bet Dagan 1982.

<u>Nitrogen</u> (ppm)	<u>Plant structure</u>			<u>Yield of red fruits (g/m²)</u>		<u>Fruit characters</u>			
	Height (cm)	Stem length	Number of side shoots	Fresh	dry	Weight (dry) (gr)	Pentcarp (%)	Dry matter (%)	
0	63 b	17.4 b	6.2.a	646 b	252 b	2.1 a	59 a	39 a	
30	69 b	21.4 a	6.0 a	746 a	327 a	2.5 a	60 a	47 a	
60	66 b	20.0 a	6.3 a	677 b	310 a	2.3 a	59 a	46 a	
90	74 a	21.4 a	6.5 a	758 a	326 a	2.6 a	57 a	43 a	

* From soil surface to the main branching

** Below the main branching

Within columns figures followed by different letters differ significantly at $p = 0.05$.

b. Pennsylvania State University (Univ. of Delaware) (U.S.): Michael Orzolek

Abstract

Pepper irrigation, fertility and cultivar studies were conducted on a Norfolk sandy loam soil in 1981 and a Murrill silt loam soil in 1982 and 1983. Peppers were more responsive to drip irrigation on sandy soils than on silt loam soils. Irrigation significantly increased the yield of bell peppers, but had no significant effect on plant structure when grown on a sandy soil in 1981. There was no significant increase in yield or plant structure of bell peppers when grown on a silt loam in 1982 and 1983.

There was no significant increase in the yield or plant structure of bell peppers regardless of how 134 kg/ha of nitrogen was applied during the growing season. However, plants were more responsive to nitrogen on the sandy loam soils and less responsive on the silt loam soils. Applying half or all of the nitrogen broadcast, resulted in somewhat lower yields of marketable fruit and taller plants. When more than half or all of the nitrogen was sidedressed in single or sequential applications, yields were higher than the broadcast treatments and the plants were generally shorter.

During the three years that cultivar evaluation studies were conducted, it was observed that bell pepper types were more sensitive to extremes in environmental conditions (temperature, rainfall, and humidity) than the hot pepper types. The bell type cultivars would abort flowers and/or drop fruit in response to extremes in environmental conditions, resulting in a split set or very late maturity. The hot type cultivars generally did not drop fruit or abort flowers

and therefore had more uniform, earlier yields. Hence, the hot types were more adaptable to mechanical harvesting.

Introduction

Commercial production of peppers is an important industry in Pennsylvania and the United States. In 1976, national production of all pepper types amounted to 686,570 tons from 110,683 acres valued at nearly \$170,000,000 (Marshall 1979). Both production and value have risen since 1976 in Pennsylvania and the United States. Peppers have traditionally been harvested by hand. With the decline in available labor in recent years and a reduction in quality of southern grown transplants, new production techniques are necessary to reduce dependence of northern growers on southern grown transplants and to modify plant architecture which would facilitate the mechanical harvesting of peppers. Mechanization research was initiated by several U.S. Land Grant Universities in the late 1960's and early 1970's on the design of a pepper harvester (Marshall 1979). In 1977, harvesting research was begun by USDA-ARS. Up to this point in time, emphasis was on equipment design and very little on cultural techniques which might modify plant structure (height, branching angles, fruit set and the distance from the soil line to the initial branching of the plant).

The effect of nitrogen (N), phosphorous (P) and potassium (K) on the yield of peppers is well documented (Campbell and Swingle 1965, Cotter 1980, and Stroehlein and Oebker 1979). Campbell and Swingle (1965) reported that both N and K should be supplied at relatively high levels if peppers were grown on soils low in K. Ramachandran and Subbiah (1981) indicated that the highest yield of chili peppers

was obtained with 120 kg/ha of N at close spacings. Preplant-applied N, as high as 90 kg/ha, resulted in larger, darker colored plants of chili peppers compared to those receiving no preplant N (Cotter 1980). Stroehlein and Oebker (1979) reported that N rates between 100-150 kg/ha tended to produce a more desirable plant with the highest yield of bell peppers. Obviously, the amount of N, P, and K needed for optimum plant growth and production of peppers will vary with soil types and crop rotation schemes.

When climatic conditions are extremely dry, the single variable which will increase yield is water. When water was not supplied to chili plants to meet their transpirational needs, the plants adapted to their environment by reducing leaf area, number of leaves and general total growth (Horton et al. 1982). Few studies have dealt with the effect of fertility and irrigation on the architecture of pepper plants and its adaption to mechanical harvesting.

Objective

The objective of this research was to evaluate both fertilizer application methods and irrigation for changes in plant structure (plant height, width and distance from the soil line to the initial branching of the plant). In addition, pepper cultivar evaluation trials were conducted in hopes of identifying those cultivars which might be adaptable to the mechanization of pepper harvesting.

Methods and Materials

All 1981 field experiments were conducted at the University of Delaware Substation on a Norfolk sandy loam soil. In 1982 and 1983,

all field experiments were conducted at the Horticulture Research Farm, Rock Springs, Pa. on a Murrill silt loam soil. The same field design was used in both locations for the fertility and irrigation studies. All replicated studies were randomized complete block designs with 4 replications. Plot size for the irrigation study was three rows, 6 m x 2.7 m, with the data collected from the center row. Bell pepper transplants, 'Lady Bell' in 1981 and 'Yolo Wonder L.' in 1982 and 1983, were spaced 41 cm in the row. Drip irrigation lines were placed next to each row and plots were isolated from each other by 3 m on all sides. Irrigation treatments were based on field capacity of the respective soil types and depletion maximum. Hence, the treatments ranged from a high depletion maximum at 0.4 bar to a low depletion maximum of 1.0 bar. Irrigation applications were designed to begin when the soil was depleted a specific percentage (6.2 to 7.7) based on a dry weight basis.

Plot size for the fertility study was four rows, 6 m x 3.7 m, with data collected from the two inside rows. In 1981, the plots were gel seeded with 'Yolo Wonder L.' using a commercial push planter. Plants were thinned to a final stand after emergence to one plant every 41 cm. In 1982 and 1983 only potted transplants were used in the plots due to the cool, wet springs in both years. Plots were initially staked out prior to spreading the fertilizer by hand and incorporated with a disc. Ammonium nitrate was used as the N source. All plants received a starter fertilizer (16-32-16) at the rate of 6.2 g/l in the transplant water. A total of 134 kg/ha N was applied to all plots based on a review of the literature and personal experience.

In 1981, the treatments which included sidedressing applications were applied 3 weeks after transplanting and then at 2 week intervals.

Observational and replicated cultivar trials consisted of single row plots, 6 m long with 41 cm between plants. All cultivars were produced as transplants in the greenhouse at the research stations.

Results and Discussions

All depletion maximum treatments resulted in significantly larger fruit size and higher yields compared to the check in 1981 (Table 1). In 1982 and 1983, there were no significant differences in the fruit size and yield between the irrigation treatments and the check. Graifenberg and Bertolacci (1982) reported that bell peppers receiving irrigation had significantly higher yields than the check. The benefit from irrigation to peppers depends on soil type and amount of rainfall received during the growing period (Orzolek et al. 1979). Goldberg and Shmueli (1971) observed no significant difference in the yield of peppers regardless of the frequency of water application. There was no significant change in plant characteristic (plant height, plant width and height to 1st branch) between the irrigation treatments and the check (Table 2). There was little difference in fruit detachment force between irrigated and non-irrigated plots (Graifenberg and Bertolacci 1982). There was a significant increase in root growth of bell peppers when plants were irrigated compared to the non-irrigated check (Goldberg and Shmueli 1971). A larger root system would help anchor the plant and facilitate mechanical harvest of the fruit.

There was no significant difference in fruit size or yield of peppers between the N application treatments and the check (Table 3). Yields

were depressed in 1981 and 1983 because of dry, hot weather. There was a trend for larger yields when all of the N was sidedressed in sequential applications in comparison to part or all of the N broadcast prior to planting. Total yields of fresh long green chili fruit were not significantly increased by preplant N treatments as high as 90 kg/ha (Cotter 1980). Several workers have reported maximum yields of peppers by application of N in the range of 56 to 140 kg/ha (Campbell and Swingle 1965, Cotter 1980, Orzolek 1981, Ramachandran and Subbiah 1981 and Stroehlein and Oebker 1979). There was no significant difference in plant characteristics (plant height, plant width and height to 1st branch) between the N application treatments and the check (Table 4). There was a trend for larger plants (taller and wider) when all or part of the N was broadcast prior to planting compared with all or part of the N sidedressed. Cotter (1980) reported that chili pepper plants which did not receive any pre-plant N treatments were smaller and lighter in color compared to plants which recieved broadcast applications of N prior to planting (Cotter 1980). There was no significant difference in the yield between 'Yolo Wonder L.', 'Cherry Hot' and 'Hot Banana' grown in 1983 regardless of how the N was applied, broadcast or sidedressed (Table 5). The bell peppers generally yielded higher than the hot types at the standard plant population for bell peppers (26,670 plants/ha). The more erect, compact plant type of cherry and banana peppers does allow for higher plant populations compared to the standard population of bell peppers (Marshall 1979 and Orzolek 1981). There was no significant difference in plant characteristics between 'Yolo Wonder L.', 'Cherry Hot' and 'Hot Banana' grown in 1983 regardless of how

the N was applied, broadcast or sidedressed (Table 6). However, the hot cherry or hot banana type pepper plants were generally taller and fruit positioned higher from the soil than the bell type pepper plants.

Cultivar evaluation trial results (Tables 7, 8 and 9) have consistently demonstrated that overall, bell pepper types have shorter, fuller, and more prostrate plants compared to the hot types. In addition, due to the greater number of fruit produced on some hot pepper types, it is a necessity to consider mechanical harvesting of the plants instead of hand harvesting.

Conclusions

On light sandy soils during periods of dry weather or drought peppers are responsive to irrigation on a need basis in terms of increased fruit yield. On heavier soils or during periods of lower temperature extremes, peppers do not respond to irrigation.

Irrigation will not structurally modify a pepper plant to facilitate the mechanical harvesting of the fruit.

Peppers generally will not respond to N in excess of 140 kg/ha unless they are grown on a sandy soil with drip irrigation.

Broadcasting part or all of the N will increase plant height at the expense of fruit yield, while sidedressing part or all of the N will generally favor higher yields at the expense of plant height.

Bell cultivar types are more difficult to mechanically harvest because of their plant habit and position of the fruit on the plant.

Table 1. Effect of different irrigation rates on the yield and fruit size of peppers. Georgetown, Del., 1981 and Rock Springs, Pa., 1982 and 1983.

Depletion Maximum treatments	Marketable Yield ² (t/ha)				Average Fruit Mass (grams)			
	1981	1982	1983	Mean	1981	1982	1983	Mean
Check	9.5c	20.8	8.5	12.9	70b	132	134	112
0.4 bar	26.1b	23.3	5.8	18.4	95a	137	126	119
0.7 bar	34.9a	23.1	7.6	21.9	106a	137	120	121
1.0 bar	27.3Ab	19.3	7.6	18.1	104a	146	120	123
		NS	NS			NS	NS	

²Mean separation within rows by Duncan's multiple range test at the 5% level.

Table 2. Effect of different irrigation rates on the plant characteristics of peppers. Georgetown, Del., 1981 and Rock Springs, Pa., 1982 and 1983.

Depletion Maximum Treatments	Plant Height (cm)				Plant Width (cm)				Stem Height from soil to 1st branching 1982
	1981	1982	1983	Mean	1981	1982	1983	Mean	
Check	32.5	39.1	--	35.8	31.5	44.2	--	37.9	11.4
0.4 bar	32.0	39.6	--	35.8	30.5	46.2	--	38.4	12.4
0.7 bar	30.7	42.9	--	36.8	30.0	45.0	--	37.5	11.7
1.0 bar	30.2	37.8	--	34.0	29.5	42.9	--	36.2	11.9
	NS	NS			NS	NS			NS

Table 3. The effect of 134 kg/ha nitrogen applied as broadcast or sidedress treatments on the average pepper yield and fruit mass. Georgetown, Del., 1981 and Rock Springs, PA., 1982 and 1983.

Treatments (kg N ₂ /ha)		Marketable Fruit (t/ha)				Average Fruit Mass (grams)			
Broadcast	Sidedressed	1981	1982	1983	Mean	1981	1982	1983	Mean
134	0	3.5	17.2	4.7	8.5	--	134	98	116
67	67	4.7	16.6	4.5	8.6	--	126	98	112
67	34 + 34	3.7	20.4	3.3	9.1	--	140	98	119
0	134	3.5	21.0	4.2	9.6	--	148	73	111
0	67 + 67	4.8	17.9	5.0	9.2	--	132	87	110
0	45 + 45 + 45	5.6	21.7	4.2	10.5	--	143	87	115
Check		2.2	20.6	3.9	8.9	--	146	106	126
		NS	NS	NS			NS	NS	

Table 4. The effect of 134 kg/ha nitrogen applied as broadcast or sidedress treatments on average plant characteristics of peppers. Georgetown, Del., 1981 and Rock Springs, Pa., 1982 and 1983.

Treatment (kg N ₂ /ha)	Plant Height (cm)				Plant Width (cm)				Stem Height From Soil to First Branching				
	1981	1982	1983	Mean	1981	1982	1983	Mean	1981	1982	1983	Mean	
Broadcast													
Sidedressed													
134	0	31.8	46.7	22.6	33.7	33.8	42.4	16.8	31.0	--	10.9	2.4	6.65
67	67	32.8	44.5	22.9	33.4	33.3	45.0	15.8	31.4	--	10.9	3.5	7.20
67	34 + 34	30.2	41.4	22.4	31.3	31.8	41.7	14.0	29.2	--	9.1	4.8	6.95
0	134	31.2	41.4	24.4	32.3	28.7	40.9	17.1	28.9	--	9.9	2.9	6.40
0	67 + 67	32.0	41.4	26.4	33.3	27.9	40.9	17.1	28.6	--	11.2	5.7	8.45
0	45 + 45 + 45	30.0	42.7	23.6	32.1	31.2	38.6	15.6	28.5	--	10.2	3.6	6.90
Check		26.7	43.9	23.3	31.3	28.2	40.9	17.8	29.0	--	9.9	5.9	7.90
		NS	NS	NS		NS	NS	NS			NS	NS	

Table 5. The effect of 134 kg/ha nitrogen applied as broadcast or sidedress treatments on the yield of Yolo Wonder L. (YW), Cherry Hot (CH), and Hot Banana (HB) peppers. Rock Springs, Pa., 1983.

Treatment (kg N ₂ /ha)		Marketable Yield (t/ha)			
Broadcast	Sidedressed	YW	CH	HB	Mean
134	0	4.7	3.1	4.2	4.0
67	67	4.5	3.2	2.0	3.2
67	34 + 34	3.3	2.2	1.7	2.4
0	134	4.2	3.5	2.9	3.5
0	67 + 67	5.0	2.7	2.4	3.4
0	45 + 45 + 45	4.2	3.1	3.6	3.6
Check		3.9	3.2	3.8	3.6
	Mean	4.3	3.0	2.9	
		NS	NS	NS	

Table 6. The effect of 134 kg/ha nitrogen applied as broadcast or sidedress treatments on the plant characteristics of Yolo Wonder L (YW), Cherry Hot (CH), and Hot Banana (HB) peppers. Rock Springs, Pa. 1983.

Treatment (kg N ₂ /ha)		Plant Height (cm)				Plant Width (cm)				Stem Height (cm)			
		YW	CH	HB	Mean	YW	CH	HB	Mean	YW	CH	HB	Mean
134	0	22.6	34.7	30.5	29.3	16.8	19.9	21.1	19.3	2.4	10.7	8.6	9.2
67	67	22.9	36.1	30.1	29.7	15.8	22.4	19.0	19.1	3.5	10.4	11.9	8.6
67	34 + 34	22.4	32.3	27.3	27.3	14.0	17.6	14.2	15.3	4.8	11.1	10.2	8.7
0	134	24.4	38.3	28.5	29.7	17.1	24.1	16.5	19.2	2.9	13.1	8.7	8.2
0	67 + 67	26.4	37.3	31.2	31.6	17.1	19.0	16.6	17.6	5.7	12.0	9.7	9.1
0	45 + 45 + 45	23.6	35.3	27.8	28.9	15.6	20.4	17.8	17.9	3.6	10.7	7.9	7.4
Check		23.3	34.7	28.0	28.7	17.8	20.1	16.6	18.2	5.9	10.6	9.5	8.7
	Mean	23.7	35.5	29.1		16.3	20.5	17.4		4.1	11.2	9.5	
		NS	NS	NS		NS	NS	NS		NS	NS	NS	

Table 7. Results of pepper cultivar evaluation trial, Georgetown, Del., 1981.

Cultivar	Marketable Yield			Unmarketable Fruit (%)	Plant Structure		
	No of Fruit/ Plot	Wt of Fruit/Plot (kg)	Avg Mass (grams)		Height (mm)	Width (mm)	H/W Ratio
PIP	61	13.3	131.6	31.4	300	375	0.80
Delray Belle	70	10.9	95.2	50.7	250	325	0.77
Big Belle H ₁	59	9.4	95.2	59.3	363	400	0.91
Calif. Wonder 300 TBR	31	6.0	109.2	62.7	375	350	1.07
Keystone Res. Giant #3	73	12.6	103.6	33.0	275	400	0.69
Sweet Belle H ₁	91	15.7	103.6	36.4	350	425	0.82
Yolo Wonder A ₁	81	15.4	114.8	15.6	300	375	0.80
Yolo Wonder L	103	16.4	98.0	22.6	325	450	0.72
Yolo Wonder 43	90	14.4	98.0	28.0	275	350	0.79
Pimiento Perfection	215	13.8	39.2	14.7	425	325	1.31
Hungarian Yellow Wax	313	20.8	30.8	1.3	350	450	0.78
Long Sweet Yellow	117	9.5	50.4	39.1	275	325	0.85
Cubanelle	107	8.9	50.4	56.7	250	300	0.83
Large Red Cherry	146	7.3	30.8	16.6	350	350	1.00
Hot Large Red Cherry #265	193	7.4	22.4	6.3	350	475	0.82
Penn Red Hot Cherry	191	9.6	30.8	7.3	325	375	0.87
Hot Cherry P-234	256	4.6	11.2	0.8	350	325	1.08
P-9620	252	7.7	19.6	6.3	375	350	1.07
Sweet Banana	183	7.3	25.2	45.9	375	325	1.15
Cascabella	250	2.3	5.6	0.0	350	450	0.78
Early Jalapeno	229	8.8	22.4	0.0	225	275	0.82
Jalapeno M	165	4.3	16.8	1.8	375	375	1.00
Floral Gem	193	5.9	11.2	2.0	250	325	0.77
Sante Fe Grande	334	10.0	19.6	2.3	225	450	0.50
New Mexico #6	148	10.6	44.8	11.4	425	500	0.85
Anaheim TMR23	174	8.9	30.8	20.9	450	400	1.13

Table 8. Results of the pepper cultivar evaluation trial, Rock Springs, Pa., 1982.

Cultivar or Selection	Seed ^{y/} source	Avg Mass (g)	Mass (t/ha)	Culls (t/ha)	Characteristics								
					Fruit Yield		Fruit			Detachment		Plant	
					U.S. No. 1		Height (mm)	Diameter (mm)	No. of lobes	Rating z/	Height (mm)	Width (mm)	Height from soil to 1st branching (mm)
Large Red Cherry-Hot Sweet Banana	1 1	24* 31	7.8 23.1	0 1.1	-- Very long cylindrical, pale yellow	-- 80	-- 78	-- 3 to 4	2.0 2.5	495 535	445 425	145 170	
Hungarian Hot Wax	1	27	23.9	1.2	Yellow, cylindrical	75	60	3	3.5	395	458	65	
Lady Bell	1	128	16.6	5.5					4.5	405	458	120	
Gypsy	1	78	20.1	1.5	Blunt shape, yellow pimiento type				2.0	510	435	100	
NCX-4012	1	204	14.3	4.6		80	78	3 to 4	3.0	420	495	150	
NCX-4014	1	125	19.9	5.2		88	55	3	1.5	398	450	123	
NCX-4018	1	129*	5.4	3.6		68	63	4	2.0	320	400	63	
#203 Sweet Cherry	2	14	9.9	0		--	--	--	1.5	575	460	145	
#306 Sweet Cherry	2	13	14.4	0			Look good		5.0	610	445	160	
#307 Small Hot Cherry	2	12	14.5	1.2			Large percentage red fruit		5.0	673	695	208	
#801 Small Hot Cherry	2	17	16.9	0			Small round cherry		4.0	650	460	210	
Surefire	3	28	29.9	1.2			Hot yellow banana type		1.5	565	470	40	
Super Set	4	110	29.7	7.4		93	68	3	6.0	460	440	123	
Pick A Peck	4	93	20.4	8.4		75	65	1 to 4	3.5	458	480	143	
Canape	4	98	20.9	10.9		75	55	1 to 3	2.0	525	450	180	
Early Bountiful	4	82	10.1	6.7		70	58	3	6.0	325	365	18	
Cadice	5	142	19.3	7.5		98	63	2 to 4	6.0	438	475	105	
Slam Chili	5	29	21.9	0			Long slender chili type		3.0	545	405	160	
Wonder Bell	5	127	13.4	17.4		73	65	4	2.0	510	515	123	
Big Belle	5	126	13.6	3.9		75	68	3	1.5	420	455	125	
Peter Piper	6	138	17.5	8.9		93	63	2 to 4	2.0	450	490	130	
Big Stuffer	6	138	14.4	6.7		118	98	3 to 4	1.5	420	468	170	
Bell Boy	6	130	25.3	9.5		68	68	3	3.0	470	460	15	
Large Hot Cherry	7	7	9.1	0			Smaller than #801-1		1.0	680	505	205	

(Cont'd)

Table 8. (Continued)

Variety or Selection	Seed source	Avg Mass (g)	Mass (t/ha)	Culls (t/ha)	Height (mm)	Diameter (mm)	No. of lobes	Characteristics					
								Fruit	Detachment Rating z/	Height (mm)	Width (mm)		
												Plant	Height from soil to 1st branching (mm)
Valley Giant	7	143	15.9	6.9	88	70	3	2.5	408	400	98		
Big Bertha	7	153	19.8	7.2	123	70	3 to 4	2.0	505	435	163		
Green Belle	7	112	15.1	8.8	95	83	3 to 4	2.0	313	403	105		
Hungarian Hot Wax	7	27*	18.1	--			Yellow, cylindrical	3.5	425	375	73		
Keystone Resistant Giant	7	182	19.7	2.4	105	68	1 to 4	2.0	525	470	145		
P-705	8	140	20.2	5.4	100	75	3 to 4	1.5	425	410	115		
Blue Star	9	141	18.6	4.2	113	58	4	2.0	445	425	53		
Marengo	9	152	23.7	2.5	90	70	1 to 5	8.0	375	415	65		
Melody	9	179	19.4	4.5	108	73	2 to 4	3.0	490	480	115		
Shamrock	9	159	32.3	4.3	75	70	4	6.0	490	510	110		
AVX 6700	10	160	18.6	8.4	75	68	3 to 4	2.0	450	435	110		
AVX 9370	10	6	21.5	--			Resembles pepperoncini	2.0	695	740	13		

^ySeed Source 1 - Harris Seeds

2 - Dr. Jo' Muehmer, Ridgeway College of Agricultural

3 - Agway, Inc. Technology, Ontario, Canada

4 - T. Sakata and Company

5 - Gloechner Seed

6 - Herbst Seed

7 - Abbott and Cobb

8 - Sluis and Groot

9 - Asgrow Seed

10 - Sun Seed

^zDetachment Rating Scale: 1 - very easy
10 - very difficult

*Low yields due to poor stand

Table 9. Results of the pepper cultivar evaluation trial, Rock Springs, Pa., 1983.

Cultivar or Selection	Seed ^{2/} Source	Yield-U.S. No. 1		Plant Characteristics		
		Mass (t/ha)	Avg Mass (g)	Height (mm)	Width (mm)	Height from soil to 1st branching
<u>Sweet Types</u>						
Liberty Bell	1	16.6	95	400	338	40
Big Stuffer	4	3.8	129	365	198	158
Bell Boy	4	16.6	120	333	240	43
Peto Wonder	6	10.3	126	270	200	30
Citadel	6	3.6	95	275	208	38
Green Boy	2	13.7	129	340	263	48
XPO31	2	18.4	179	325	225	53
Gator Belle	1	20.4	112	295	260	23
Ma Belle	1	8.5	109	318	208	35
Greene Belle	1	12.3	112	365	265	40
Big Bertha	1	10.1	98	290	208	33
Valley Giant	1	11.6	120	290	205	50
Lady Bell	5	14.6	98	308	225	35
P-705	7	13.4	160	350	190	95
Cadice	7	5.6	84	373	205	105
P-7118	7	11.6	112	335	150	73
Espadon	7	11.0	81	335	218	83
Sharina	3	17.2	98	308	193	48
Melody	3	14.1	87	293	210	110
Marengo	3	14.6	98	290	198	150
Shamrock	3	12.1	92	350	165	148
Blue Star	3	12.3	109	330	223	143
119	9	12.1	64	335	42	140
124	9	7.4	56	328	235	115
126	9	6.9	95	358	195	148
127	9	9.4	73	290	210	60
131	9	2.2	112	295	185	98
132	9	2.9	102	243	180	70
133	9	4.5	126	263	178	110
134	9	4.7	84	303	175	170
135	9	4.3	112	335	185	153
136	9	4.5	106	223	138	98
137	9	3.8	84	328	200	85
138	9	4.0	115	300	183	60
140	9	6.5	98	255	180	50
208	9	6.5	115	290	178	55
82	9	2.5	17	405	193	155
102	9	2.7	17	395	230	145
106	9	2.0	17	405	210	150
206	9	1.1	20	400	185	135
306	9	2.0	17	503	240	210
311	9	2.5	17	495	238	170
912	9	2.5	17	410	225	168

(Cont'd)

Table 9. (Continued)

Variety or Selection	Seed Source	Yield-U.S. No. 1		Plant Characteristics		
		Mass (t/ha)	Avg Mass (g)	Height (mm)	Width (mm)	Height from soil to 1st branching (mm)
<u>Hot Types</u>						
Small Red V. Hot	8	6.9	11	428	428	85
Serranno	4	17.0	14	248	148	15
Jalapeno	4	8.7	17	415	280	20
Romanian Hot	4	4.5	3	488	418	18
Fresno Chili Grande	6	14.8	14	298	270	63
Large Red Cayene	6	11.2	20	423	308	110
Coronado	6	18.4	28	345	135	68
Anaheim TMR23	6	27.8	53	303	300	73
Serrano	6	10.1	22	503	273	95
Sante Fe Grande	6	4.3	8	430	318	98
Surefire	2	3.4	70	545	448	15
Eastern Rocket	2	3.4	14	288	248	18
Large Hot Cherry	1	13.9	22	530	410	68
Hot Portugal	5	5.2	31	545	303	213
114	9	6.3	11	375	270	143
116	9	6.9	11	500	353	163
117	9	6.3	14	533	343	215
307	9	8.5	11	435	308	158
VFI 200	10	10.3	17	353	227	70
VFI 250	10	9.9	22	390	218	160
VFI 300	10	10.1	25	353	248	43
VFI 350	10	11.5	22	355	195	58

^z - Seed sources: 1-Abbott & Cobb, 2-Agway, 3-Asgrow, 4-Herbst, 5-Harris, 6-Peto, 7-Sluis & Groot, 8-Dr. Ernest Bergman, Dept. of Horticulture, Penn State Univ. 9-Jo' Muehmer, Ridgetown College of Agricultural Technology, Ontario, and 10-Dr. Greg Tolla, Campbell Research Institute.

c. Michigan State University (U.S.): Hugh Price

Abstract

The yield of four pepper cultivars, representing four distinct fruit types, was unaffected by the type of transplant utilized. Bare root transplants tend to mature later than the plants grown in Speedling flats, multipot or soil block, but there was no difference in total yield. Plants grown in Speedling flats had branches closer to the soil surface than other types of transplants, but the plants were still harvestable.

Plant spacing had little influence on how close to the surface of the soil the plants branched, but influenced the distribution and number of fruit on the plant. All cultivars had a reduced number of fruit per plant at increased plant densities. The size of fruit was also directly related to spacing such that close spacing significantly reduced fruit size. The distribution of fruit on the cherry type peppers was more diverse at spacings of 200 mm and closer which greatly facilitated the mechanized harvest.

Total yield of all cultivars increased with increased plant density. The increase in yield at spacings closer than 200 mm probably does not justify the increased cost of transplants and transplanting labor. In areas where direct seeding is feasible, spacings as close as 100 mm may be advantageous.

Introduction

Peppers (Capsicum sp.) having various fruit types and pungencies are utilized by the pickling, dehydration, and extracting industries.

These specialty crops are produced over a wide range of latitudes, but are generally restricted to regions having at least 120 frost-free days. Considerable variability exists in cultural practices, irrigation methods and stage of maturity for harvest depending on the production area and end use. Regardless of the type of pepper product, harvesting is a major cost and often limiting factor in the production of peppers for processing. The small fruit size and low growing plant structure contribute to disagreeable hand harvesting and often inability to obtain labor at a reasonable price to harvest the crop.

The need for mechanical harvest of the crop has been long recognized, and several engineering projects have contributed to the development of technology to this end (Fullilove et al. 1970, Lenker et al. 1980, Marshall 1979, Shaw et al. 1979). Marshall (1984a) and Esch et al. (1983) have successfully incorporated much of the available technology into a machine that has been demonstrated to harvest several types of peppers. This machine, which utilizes the double open helix stripping mechanism, operates at highest efficiency when certain plant requirements are met. First, the root system must be sufficiently developed to hold the plant securely in the soil during the stripping action. Second, the fruit should be sufficiently off the surface of the soil to allow the stripping mechanism to get beneath the fruit. Third, the fruit load should not be concentrated at a particular location on the plant or the stripping action is inhibited. Fourth, the maturity of the fruit should be uniform.

Previous studies (Batal et al. 1981, Ramachandran et al. 1981, and Kemp et al. 1972) have demonstrated an increase in total yield as plant density increases. The increase in total fruit is generally accompanied with a decrease in plant size (Dempsey 1970) and decrease in number of fruit per plant (Ramachandran et al. 1981).

Objectives

This study was initiated to evaluate the type of transplant and plant spacing on the harvestable yield of four types of peppers. Although considerable research has been conducted on the influence of plant density on yield little attention has been devoted to observation of plant morphology and yield from a once over destructive harvest.

Materials and Methods

Spacing trials 1981 and 1982

There were four pepper cultivars representing distinct fruit types selected for these studies: hot cherry - 'Large Red Cherry', small yellow - 'Sante Fe Grande', bell - 'Yolo Wonder L' and hot banana - 'Hungarian Yellow Wax'. These were all open pollinated cultivars obtained from commercial seed companies. The seed was stored at 12°C at low relative humidity during the course of these investigations and maintained a germination in excess of 90%.

Seed for all transplant production was sown on a hydrocolloid gel (1.5%), Viterra II, in petri dishes and held at room temperature until the radicles emerged. The germinated seed was then placed in cell packs filled with synthetic soil mix and placed in the green-

house. Transplants of sufficient size for planting into the field were ready five weeks after sowing the seed. The plants for all plant spacing studies were grown in cell packs containing 72 cells (30 mm x 30 mm) per flat. The flats were watered from overhead and a complete soluble fertilizer was added once per week.

Planting dates for the 1981 and 1982 trials were June 3 and May 20, respectively. Preplant applications of phosphate (P) and potassium (K) were applied as per soil test. Nitrogen (N) was broadcast (84 kg/ha ammonium nitrate form) and disked in along with the P and K. An additional 56 kg/ha N was sidedressed 3-4 weeks after transplanting. The herbicide, trifluralin (α, α, α -trifluoro-2,6-dinitro-N, N, dipropyl-p-toluidine) was applied at 0.56 kg/ha and preplant incorporated to a depth of approximately 50 mm.

The transplants were set by hand in the furrow bottom with a starter solution (10-52-17) at the rate of 7.4 g/l in the transplant water at 750 ml/m of row. The between row spacing was constant at 1.2 m, and the within row spacings were established at 50, 100, 200 and 400 mm (200,000, 100,000, 50,000 and 25,000 plants/ha, respectively). The plots were 4.8 m long. All plots received routine maintenance sprays for the control of insects and diseases. Natural rainfall was supplemented with sprinkler irrigation to insure 25 mm of precipitation per week until the fruit began to mature.

Twice during the growing season the height of the plants and the distance from the soil surface to the first branch was measured. Only the data from the second measurement, taken just prior to harvest, are presented.

The cherry pepper type was harvested in a simulated machine harvest when approximately 50% of the fruit were red. The fruit were graded into four diameter sizes. The weight of each size grade was recorded. The 'Santa Fe Grande' harvests were handled similarly, except the fruit were harvested when the majority had turned yellow. The hot banana type was harvested when the majority of the fruit were yellow and 10-15% were red. This cultivar was not graded for size, but was sorted into various maturity groups: mature-red, mature-yellow and immature-green. The bell pepper type was harvested three times, and only fully formed green fruit were harvested. The fruit were counted and weighed so that fruit size (g/fruit) could be determined.

Type of transplant trial - 1981

The same cultivars and seed germination techniques as previously described were utilized for this trial. The four types of transplants were: 1) bare root, 2) Speedling 125, 3) Multipot 96 and 4) 50 mm square soil blocks. The germinated seeds for the bare root transplants were sown in plastic flats 26 cm x 52 cm filled with synthetic soil mix. There were 100 plants per flat, thus 13 cm^2 per plant. The Speedling flats were made of styrofoam, and there was 10 cm^2 per plant. The multipot trays were plastic and had cylindrical cavities which allowed 11.2 cm^2 per plant. The soil blocks were 50 mm square, thus allowing 25 cm^2 per plant.

The field plot was established on June 3 in rows 1.2 m apart and 400 mm between plants within the row. All other cultural practices were as described previously for the plant spacing trial.

Mechanical harvest trial - 1983

Transplants of 18 pepper cultivars representing four fruit types (banana, cherry, 'Jalapeno', and bell) were produced in cell packs (72/flat) from germinated seed as described previously. On June 3 the plants were transplanted into the field. The rows were 1 m apart, and there were 2 within row spacings, 200 mm and 400 mm. The plots were 8 m long.

All plots were harvested with the USDA-ARS experimental pepper harvester. Sorters on the machine removed all broken or damage fruit which were weighed separately from the harvested undamaged fruit. In addition, all losses were separated into those which were on the ground and those which were attached to the plant. This assisted in determining the recovery percentage for the various pepper types.

Results

Plant spacing

All four cultivars, 'Large Red Cherry', 'Sante Fe Grande', 'Yolo Wonder L' and 'Hungarian Yellow Wax', showed a linear increase in plant height as the distance between plants decreased (Table 1). Similarly, the distance from the soil to the first branch was inversely related to the spacing between plants (Table 2). Although the increase in height of branching in response to plant spacing was statistically significant the actual increase is so small that it will provide little benefit to the harvesting operation.

The total yield of bell peppers was not influenced by plant spacing in either 1981 (Table 3) or 1982 (Fig. 1). Through the first 3 harvests in 1982, however, there was a significant quadratic response of pepper yield to plant spacing. Highest yields were achieved at the 200 mm spacing and less at either closer or wider spacing. By the fourth harvest, however, there was no difference in yield between the 4 plant spacings (Fig. 1). The number of fruit per plant decreased as the plant density increased (Table 3). In 1981 there was no significant decrease in fruit size with increased plant density, however, in 1982 the decrease in fruit size was very significant (Fig. 2).

The total yield of 'Sante Fe Grande' was not influenced by plant density in 1981 (Table 4), however, there was a positive linear relationship between yield and plant density in 1982 (Fig. 3). A significant quantity of the increased yield at the highest population was the small size fruit (35 mm dia. and smaller) (Fig. 3).

In 1981 and 1982 there was no significant difference in total yield of cherry peppers at the 4 plant densities (Table 5 and Fig. 4). There was, however, a significant increase in yield of the smaller sized fruit with the increased plant density. Fruit larger than 44 mm dia. were produced in greatest quantity at the 200 mm spacing (Fig. 4), thus demonstrating the profound influence of plant spacing on fruit size.

The yield of hot banana peppers, 'Hungarian Yellow Wax', demonstrated a quadratic response to yield in 1981 and a similar trend in 1982 (Table 6 and Fig. 5). Particularly, the yellow mature fruit had highest yield at the 100 and 200 mm spacing with reduced yield at

both 50 and 400 mm (Table 6). Maturity tends to be hastened at the highest plant populations as is evidenced by the linear increase in red fruit with the increased population (Table 6).

Type of transplant - 1981

The height of plants grown in soil blocks was greater than any of the other transplant types (Table 7), and there was no significant interaction with cultivar. 'Large red Cherry' were the tallest plants followed by 'Hungarian Yellow Wax', 'Sante Fe Grande' and 'Yolo Wonder L'. Similarly, the distance from the soil to the first branch was greatest with the soil block (Table 8), but followed closely by the bare root and multipot transplants. The plants grown in Speedling flats significantly reduced the distance from the soil to the first branch (Table 8). This was consistent with all cultivars, thus the interaction F ratio was not significant.

The type of transplant had no influence on yield of any of the cultivars investigated (Tables 9, 10, 11, 12). The bell cultivar showed no effect of transplant type on fruit per plant or fruit size (Table 9). Similarly, the size distribution and maturity of the other cultivars were not influenced (Table 10, 11, 12).

Mechanical harvest trial - 1983

With the exception of 'Yolo Wonder L' the harvested yield of undamaged fruit was greatest at the 200 mm spacing (Table 13). The banana and bell types also showed increased damage at the higher plant population. Damage to cherry, 'Jalapeno', 'Serrano chili' and 'Casabella' cultivars was minimal, and there was no association with plant

spacing (Table 13). The yield of both undamaged and damaged fruit of all cultivars on a per plant basis was less at the 200 mm spacing than at the 400 mm spacing (Table 14). There were however, differences between cultivars in the percentage of the yield per plant that was damaged in the harvesting operation (Table 15). The banana and bell were the types most subject to damage.

Discussion

The correlation between plant spacing and height of all cultivars was highly significant, however, its influence on raising the fruit set above the surface of the soil was minimal. Particularly, the banana type peppers tended to have fruit touching the soil regardless of the plant spacing. Modification of the plant intake portion of the harvester was, however, able to handle this fruit set close to the soil with a minimum of loss. One of the greatest benefits of closer spacing was with cherry type peppers. At the 400 mm spacing fruit set tended to be very concentrated in the center of the plant. This clustering of fruit often caused resistance to the stripping action of the harvester, and the plant was uprooted. Closer spacing caused the fruit set of cherry peppers to be more uniformly spread from the bottom to the top with no area of concentration. The latter configuration of fruit set allowed efficient stripping, and thus the excellent recoveries at the 200 mm spacing.

The yield data from a simulated once over mechanical harvest generally support the finding of other researchers using multiple hand harvesting techniques. There is a linear increase in yield with an increase in plant population, however, there is a decrease in fruit

size. With cherry, banana and 'Jalapeno' types, this may not be undesirable, but with bell peppers it would be a major detriment. Although the trend was for increased yields of all types, with spacings closer than 200 mm the increased cost of plants and labor of transplanting may not justify going to 100 mm or 50 mm spacings. In areas where direct seeding is feasible, such spacings may be a viable option, but not in northern latitudes where the duration of the growing season does not allow for direct seeding techniques.

A tendency for lodging was observed with some cultivars at spacings closer than 200 mm. Lodging was never a major factor in these trials, however, excessive N nutrition or a severe wind at a critical time after fruit set may have been very detrimental. Willowy cultivars such as 'Serrano chili' and 'Cascabella' appear to be more susceptible to lodging. In this trial, however, the harvester was able to handle them very well.

The type of transplant, i.e. bare root or container, did not influence yield or harvestability. It is imperative to have a well developed root system so that the plant is not pulled from the soil during the harvesting operation. It was evident that Speedling transplants branch closer to the soil than other types, but this did not appear to be a limiting factor to the harvester. The advantage of having a direct seeded pepper plant with an intact tap root is very evident, however, as pointed out previously, this is quite difficult to achieve in our location.

Conclusions

Plant height was directly related to plant density, however, the influence of increasing the height of plant branching above the soil surface was minimal.

Plant spacings 200 mm apart or closer effectively spread the distribution of fruit set on cherry pepper plants, thus providing a fruit distribution more conducive to mechanical harvest.

The yield of most pepper cultivars was increased as plant density increased. The yield per plant and fruit size were inversely related to plant density.

The type of transplant had little influence on the yield or harvestability of the pepper cultivars evaluated.

Table 1. Plant height of 4 pepper cultivars grown from transplants at 4 spacings, Michigan, 1981.

Cultivar	Plant Height (mm) 1/ Spacing between plants (mm)				Mean 2/
	400	200	100	50	
Large Red Cherry	492	497	556	593	534a
Sante Fe Grande	402	463	565	587	504ab
Yolo Wonder L	403	427	507	549	471 bc
Hungarian Yellow Wax	406	435	479	473	448 c
Mean 1/ 2/ 3/	426x	455x	526y	551y	

1/ The cultivar x spacing interaction was NS at the .05 level.

2/ Means followed by the same letter are not significantly different at the .05 level.

3/ The linear regression is significant at the .05 level:
 $r = .94$, $y = 55.6 - .35x$.

Table 2. Distance from the soil to the first branch of 4 pepper cultivars grown from transplants at 4 spacings, Michigan, 1981.

Cultivar	Height from soil to first branch (mm) 1/ Spacing between plants (mm)				Mean 2/
	400	200	100	50	
Large Red Cherry	154	150	171	174	162
Sante Fe Grande	150	150	161	175	159
Yolo Wonder L	166	152	167	189	168
Hungarian Yellow Wax	157	159	160	166	160
Mean 1/ 2/ 3/	157x	153x	165x,y	176y	

1/ The cultivar x spacing interaction was NS at the .05 level.

2/ Means followed by the same letter are not significantly different at the .05 level.

3/ The linear correlation of spacing and height to the first branch was significant at the .05 level: $r = .71$, $y = 17.2 - .046x$.

Table 3. Yield of bell peppers 'Yolo Wonder L' grown at 4 plant spacings, Michigan, 1981.

Plant spacing (mm)	Marketable Yield		g/fruit
	t/ha	Fruit/ plant	
400	14.7	4.6	159
200	21.1	3.0	167
100	14.7	1.2	154
50	18.8	1.0	127
LSD .05	NS		NS

Table 4. Yield of 'Sante Fe Grande' peppers grown at 4 plant spacings, Michigan, 1981.

Plant spacing (mm)	Yield (t/ha)				Total
	Fruit diameter (mm)				
	<27	27-35 1/	35-44	44-51	
400	2.1	6.0	3.6	0.4	12.1
200	1.7	8.2	4.9	0.2	15.0
100	1.5	9.4	5.5	0.6	17.0
50	2.6	8.6	3.2	0.2	14.5
LSD .05	NS	1.5	NS	NS	NS

^{1/} The linear regression is significant at the .01 level: $r = .93$, $y = 9.69 - .086x$.

Table 5. Yield of 'Large Red Cherry' peppers grown at 4 spacings, Michigan, 1981.

Plant spacing (mm)	Yield (t/ha)					Total
	Fruit diameter (mm)					
	27 1/	27-35 2/	35-44 3/	44-51	51	
400	0.1	1.2	2.7	5.0	0.1	9.0
200-	0.4	1.4	3.5	6.8	0.0	12.1
100	0.2	1.4	3.6	6.3	0.0	11.4
50	0.7	1.9	4.1	3.6	0.0	10.3
LSD .05	NS	NS	NS	NS	NS	NS

1/ The linear regression is significant at the .05 level: $r = .69$,
 $y = .546 - .011x$.

2/ The linear regression is significant at the .05 level: $r = .80$,
 $y = 1.75 - .015x$.

3/ The linear regression is significant at the .05 level: $r = .97$,
 $y = 4.13 - .036x$.

Table 6. Yield of 'Hungarian Yellow Wax' peppers grown at 4 plant spacings, Michigan, 1981.

Plant spacing (mm)	Marketable Yield (t/ha)			
	Yellow mature <u>1/</u>	Red mature <u>2/</u>	Immature	Total <u>1/</u>
400	7.8	1.3	2.5	11.6
200	14.0	2.4	1.5	17.8
100	10.5	3.9	2.3	16.7
50	7.8	3.5	2.8	14.1
LSD .05	4.5	0.9	NS	NS

1/ The quadratic function is significant at the .05 level.

2/ The linear regression is significant at the .05 level:
 $r = .95$, $y = 4.1 - .07x$.

Table 7. Plant height of 4 pepper cultivars grown from 4 types of transplants, Michigan, 1981.

Cultivar	Plant height (mm)				Mean <u>1/</u>
	Bare root	Seedling	Multipot	Soil block	
Large Red Cherry	448	470	484	500	475a
Sante Fe Grande	451	395	373	406	397 c
Yolo Wonder L	386	350	378	415	382 c
Hungarian Yellow Wax	380	450	432	442	426 b
Mean <u>1/</u>	407y	416y	417y	440x	

1/ Means followed by the same letter are not significantly different at the .05 level.

Table 8. Distance from the soil to the first branch of 4 pepper cultivars grown from 4 types of transplants, Michigan, 1981.

Cultivar	Height to first branch (mm)				Mean <u>1/</u>
	Bare root	Seedling	Multipot	Soil block	
Large Red Cherry	172	127	150	177	156ab
Sante Fe Grande	161	101	131	127	130 c
Yolo Wonder L	170	134	154	191	132a
Hungarian Yellow Wax	145	137	147	165	148 b
Mean <u>1/</u>	162x	124z	145y	165x	

1/ Means followed by the same letter are not significantly different at the .05 level.

Table 9. Yield of bell peppers 'Yolo Wonder L' grown with 4 types of transplants, Michigan, 1981.

Transplant type	Marketable Yield		g/fruit
	kg/ha	Fruit/plant	
Bare root	17.4	5.5	156
Speedling	18.7	6.0	154
Multipot	16.8	5.2	161
Soil block	18.4	6.3	145
LSD .05	NS	NS	NS

Table 10. Yield of 'Sante Fe Grande' peppers grown with 4 types of transplants, Michigan, 1981.

Transplant type	Marketable Yield (t/ha)				Total
	Fruit diameter (mm)				
	<27	27-35	35-44	44-51	
Bare root	1.7	7.6	3.3	0.1	12.7
Speedling	0.7	7.3	4.8	0.4	13.2
Multipot	1.4	7.2	5.1	0.5	14.1
Soil block	2.3	6.5	1.6	0.1	10.5
LSD .05	0.9	NS	NS	0.3	NS

Table 11. Yield of 'Large Red Cherry' peppers grown with 4 types transplants, Michigan, 1981.

Transplant type	Marketable Yield (t/ha)					Total
	Fruit diameter (mm)					
	<27	27-35	35-44	44-51	>51	
Bare root	0.1	0.8	3.3	7.9	0.0	12.1
Speedling	0.0	1.1	3.5	9.0	0.1	13.7
Multipot	0.1	0.9	3.6	9.0	0.2	13.7
Soil block	0.1	1.0	3.6	7.9	0.1	12.6
LSD .05	NS	NS	NS	NS	NS	NS

Table 12. Yield of 'Hungarian Yellow Wax' peppers grown with 4 types of transplants, Michigan, 1981.

Transplant type	Marketable Yield (t/ha)			Total
	Yellow mature	Red mature	Immature	
Bare root	10.6	1.0	1.0	12.6
Speedling	18.0	1.4	1.0	20.4
Multipot	16.0	1.8	0.7	18.8
Soil block	13.0	1.5	1.4	15.9
LSD .05	NS	NS	NS	NS

Table 13. Yield of 18 pepper cultivars grown at 2 within row spacings for mechanical harvest with the USDA harvester, Michigan, 1983.

Cultivar	Recovered pepper yield (t/ha) 1/ 2/			
	Undamaged		Damaged	
	200 mm	400 mm	200 mm	400 mm
Hungarian Yellow Hot	22.3 1/	15.2	4.8	3.9
Hungarian Wax Hot	18.6	10.5	3.6	2.1
VFI 200	21.0	15.9	6.8	3.7
VFI 250	19.6	15.8	6.7	3.3
VFI 300	21.8	16.2	5.1	3.7
VFI 350	21.9	14.9	4.8	3.0
Sweet Banana	24.6	15.2	6.9	5.5
Sweet Banana Sweet	18.8	12.7	10.3	7.4
Yolo Wonder L	15.6	17.1	6.1	2.7
KRG 3	21.2	15.2	3.3	1.8
Cascabella	7.5	6.4	.6	.7
Large Red Cherry Hot	19.7	15.0	1.2	.9
RCAT 116 Hot Cherry	12.6	11.2	.1	.1
Sweet Cherry	16.3	11.8	.7	.3
RCAT 102 Sweet Cherry	16.5	11.2	.2	.3
Serrano Chili	14.5	8.1	.4	.4
Early Jalapeno	20.6	12.6	1.3	.6
Jalapeno M	26.8	16.0	1.5	.7
LSD .01 4.6 LSD .05 1.6				

1/ Each value is the mean of 2 replications.

2/ Yield is of those peppers recovered (not including peppers lost on the ground or remaining on plants).

Table 14. Influence of plant spacing on the yield per plant of peppers harvested with the USDA harvester, Michigan, 1983.

Spacing (mm)	Recovered pepper yield <u>1/</u> (g/plant)		Percent damage
	Undamaged	Damaged	
200	378	72	16
400	535	92	14
LSD .01	39	16	

1/ Each value is the mean of 18 cultivars x 2 replications

Table 15. Yield per plant of pepper cultivars harvested with the USDA harvester, Michigan, 1983.

Cultivar	Recovered pepper yield (g/plant) ^{1/}	
	Undamaged	Damaged
Hungarian Yellow Hot	527	126
Hungarian Wax Hot	397	79
VFI 200	528	142
VFI 250	511	134
VFI 300	542	126
VFI 350	517	108
Sweet Banana	551	179
Sweet Banana Sweet	442	251
Yolo Wonder L	497	115
KRG 3	515	69
Cascabella	204	20
Large Red Cherry Hot	497	31
RCAT 116 Sweet Cherry	350	4
Sweet Cherry	400	13
RCAT 102 Sweet Cherry	388	9
Serrano Chili	306	11
Early Jalapeno	458	24
Jalapeno M	587	29
LSD .01	116	48

^{1/} Each value is the mean of 2 spacings x 2 replications.

Figure 1. Accumulative yield of bell peppers 'Yolo Wonder L' grown at 4 plant spacings. QUAD above harvests 1, 2 and 3 indicates a significant quadratic trend at the .05 level, Michigan, 1982.

Figure 2. Influence of plant spacing on fruit mass (g/fruit) of bell peppers 'Yolo Wonder L', Michigan. 1982.

Figure 3. Yield of 'Sante Fe Grande' peppers grown at 4 plant spacings. Fruit size 1B = <27 mm dia., 2A = 27-35 mm dia. and 2B = 35-44 mm dia. The LIN above sizes designates a significant linear trend at the .05 level, Michigan, 1982.

Figure 4. Yield of 'Large Red Cherry' peppers grown at 4 plant spacings. Fruit size 1B = <27 mm dia., 2A = 27-35 mm dia., 2B = 35-44 mm dia. and 3 = 44-51 mm dia. The LIN above sizes designates a significant linear trend and QUAD designates a quadratic trend at the .05 level, Michigan, 1982.

Figure 5. Yield of 'Hungarian Yellow Wax' peppers grown at 4 plant spacings, Michigan, 1982.

B-2. Agricultural Engineering Research

a. Agricultural Engineering Institute, ARO (Israel): Itzhak Wolf
and Yekutieli Alper

Abstract

This research concerned the development of devices and implements to improve the performance of a mechanical system for harvesting paprika peppers and to improve fruit recovery and product cleanliness. Three variations of the double open helix harvesting elements were constructed and compared for fruit losses on the plants and trash content of the product.

A device was developed to remove paprika pods from loose branches and was installed on a harvester and in the processing plants. It consisted of a pair of spring-loaded slowly revolving rollers which fed branches between fast counter-rotating stripping elements. A sifting unit for small trash was developed and installed on a harvester, in the processing plants and on the paprika gleaning machine. It consisted of a series of unidirectionally revolving shafts with eight-fingered rubber starwheels.

A 10 m³ tipping storage basket system was installed on a pull type harvester. A special rotating disc spreading device was mounted in the basket for better utilization of the storage space.

A paprika gleaner, employing a sweeping system used for pecan harvesting, was developed to complete the paprika harvest mechanization by retrieving the lost fruit from the ground.

Introduction

Mechanical harvesting of sweet paprika has been practiced in Israel since 1980 and has led to considerable expansion of the crop. Two three-row harvesters (a self propelled and a pull type) were developed for local conditions (Wolf and Alper 1984). They employ counter-rotating double open helixes, which strip the pods from the standing plants, originally developed in Georgia, U.S. (Fullilove and Futral 1968, 1970, 1972a, 1972b).

Depending to a great extent on the field conditions the harvested product contained a certain amount of branches with fruit attached, which were broken off from the plants by the stripping action. These fruit have to be detached, preferably by mechanical means before discarding the branches. Any other plant material picked up by the harvester also has to be eliminated. Fruit detachment efficiency and the amount of trash in the product are also affected by the aggressiveness of the stripping action applied to harvest the fruit. Growers want to recover as many pods as possible even if it means picking up more trash. The stripping aggressiveness of the picking elements is affected by helix rpm, spacing and the harvester ground speed.

Helix angle (and pitch) and helix rod dia., was also thought worthwhile to investigate as affecting detachment efficiency and trash content in the harvested product.

Paprika fruit are dried on the plants in Israel saving dehydration energy and improving pod color. However, in some cases, pre-harvest fruit drop occurs. Additional fruit may be dropped onto the ground dur-

ing harvesting, especially if plants have been bent over by wind or other elements.

Paprika peppers left on the ground after harvesting are generally of good quality and would have a market value if collected. Hand gleaning was practiced by some growers. However, this does not fit in with mechanized harvesting, especially in larger fields. Therefore, attempts were made to mechanize the gleaning in order to complete the harvest mechanization.

Methods and Materials

Helix Pitch and Bar Dia. Variations

Two variations in harvesting elements were tested: Pitch of the helixes and dia. of the helix bars. The helix pitch angles tested were 30° and 45° (included angle from the helix bar to the helix axis). The 45° wound-helix reduces the aggressiveness by reducing the cylindrical "open" area. The other variation tested the regularly-used 1/2 in. water pipe (21.3 mm dia.) against 1/4 in. water pipe (13.7 mm dia.) in order to obtain a more aggressive stripping action with thinner (or sharper) helix bars.

The original 30° , 21.3 mm dia. helix bars (with about 100 mm dia. helixes) and the two variations of the picking elements (45° helixes made from 21.3 and 13.7 mm dia. pipe) were tested simultaneously on a three-row harvester for fruit recovery and trash content (Wolf and Alper 1984).

Harvester Storage Bin

In the first year of operation (1980) the harvested product was transferred from the pull type harvester to a trailer driven alongside.

In order to increase the efficiency of the harvest operation an on-board storage system was designed, consisting of an elevator, a cross conveyor and a tipping 10 m^3 capacity basket. A special rotating-disk device was developed and installed in the basket to spread the product, in order to make better use of the available storage space.

A fool-proof sequencing mechanism for shifting the elevating conveyor prior to the tipping of the basket was also designed and installed on the harvester.

Trash Removal

Equipment to Remove Attached Paprika Pods

During mechanical harvesting some branches are removed with paprika pods still attached. Several methods have been tried to detach or remove pods from loose branches. Among those tested were: 1) feeding the branches between two bar-conveyors mounted above each other with the lower one having also a reciprocating motion. This system detached only a small portion of the pods. 2) A small dia. roller (19 mm) cleaning bed for flower bulbs caused extreme damage to the pods that squeezed between the rollers, when tried on paprika. However, applying a similar system to remove attached paprika pods yielded better results. The branches were fed by a pair of slowly-revolving spring-loaded rollers, in between two pairs of faster rotating stripping elements (Wolf and Alper 1984). These units were installed in the conveying system of the pull-type harvester and at the processing plants.

Tests to investigate the efficiency of detachment were conducted with the unit operating on the harvester by comparing the amount of pods attached to the loose branches before and after the treatment (Wolf and Alper 1984).

Removal of Small or Fine Trash

A trash removal or cleaning unit was constructed to remove small, fine trash (leaves, small branch pieces or undersized fruit). It was made from unidirectional rotating, eight-fingered, 150 mm dia. rubber starwheels used for cleaning flower bulbs.

A small unit consisting of 4 shafts of starwheels was integrated in the pull-type harvester. This was tested for separation efficiency by comparing the amount of trash sifted out of the product to that remaining after the treatment. The results of this test were subsequently incorporated in the design of the gleaning machine for paprika where a nine-shaft cleaning table was installed (Wolf and Alper 1984).

Paprika Gleaning

A mechanical gleaning system was first developed in the United States and incorporated in a harvester for chili peppers. Belts with rubber fingers were used to pick up pods from the irrigation furrows after being swept there by a small side delivery rake (Lenker and Nascimento 1980).

Several methods to pick up paprika pods from the ground were tried in Israel in 1981. Among them, a suction device was too slow, and a flail-type forage harvester was too rough. A pecan harvester developed

by the Agricultural Engineering Institute (Sarig et al. 1982) was also tried and showed good potential. This led to the design and construction in 1982 of a special experimental gleaner-sweeper for paprika peppers (Wolf and Alper 1984). The gleaning machine consists of three major components: a pick-up unit, pod and trash separator and a conveying and storage system. It was first necessary to shred the plants down to about 150 mm from the ground prior to operating the gleaner.

Peppers lost in the wheel tracks were first moved or thrown onto the bed by a pair of rotating rubber-fingered sweeping reels. The pepper pods were picked up by a main sweeping reel and an inclined "Rubber chain" (Broekema) bar elevator, both 1.2 m wide. The elevator was mounted with the lower part at the rear of the machine. The bottom side of the elevator was "laid down" or operated at ground speed without upsetting the surface of the beds. The sweeping reel had 300 mm long rubber fingers, which lifted all loose material from the bed surface onto the elevator. The material was conveyed to an eight-shafted cleaning table made of unidirectional-rotating shafts with rubber fingered starwheels (described above) and one final shaft with square rubber discs (to prevent "carry around") to sift out the small trash. The trash was conveyed to the side of the bed so that it would not be picked up again. The pods and the larger plant material were blown into the storage basket mounted on the machine. Field capacity was between 0.3 to 0.4 ha/h.

Results and Discussion

No significant difference was found in the tests between the performance of the three variations of helixes regarding branch material found in

the harvested product and fruit left on the plants (Wölf and Alper 1984). However, it was noticed from observation throughout the entire 1982 season, that the denser 45° helixes broke off more plant material. For the 1983 season they were replaced by the original 30° units. Helixes larger than 100 mm dia. (which were less dense) were not tried because they would not fit into the space available on the harvesters.

Performance tests of the device to remove pods attached to foliage showed a 50% reduction in attached pods from about 30% down to 15% of the harvested product (Wolf and Alper 1984). Part of the remaining attached pods were connected to small, short branches which fell short of the device's feed roller, and were thus not treated while the rest sustained the more aggressive stripping action. Although the device did not eliminate the cleaned branches, they were much easier to manually sort out without having to pick the pods from them first.

The performance test of the four-shafted starwheel cleaning table in operation on the pull type harvester showed that 42% of the small trash was sifted out, while losing only about 0.25% of the pepper pods. The performance of the cleaner, which has only three working gaps (between the four shafts) could be improved considerably by doubling the number of starwheel shafts.

The elevator, product spreading disk and overhead storage basket worked very well. It saved cost, time and effort by eliminating the need for a trailer and tractor driver.

The gleaner, after a short period of experimenting and minor modifications became commercially operational. It gleaned about 25 ha during

the 1982 season and about 40 ha in the 1983 season. The width of the main pick-up sweeping reel and elevator should have been built 100 to 200mm wider than the 1.2 m width design used on beds spaced 1.0 m between the outer plant rows. However, this problem was overcome by proper adjustment of the secondary reels which swept the fruit from the wheel track onto the beds. No recovery tests were conducted but observations showed that most ground losses were picked up both from the beds and the wheel track leaving the field virtually clean after gleaning. An economic study has not been conducted to indicate the recovery, etc. required for a detailed break-even analysis.

Conclusions

No significant differences were found in recovery nor trash content in tests comparing shorter pitch, more dense 45° helixes and smaller dia. (13.7 mm) helix bars to the standard 30° pitch angle and 21.3 mm dia. helix bars.

Equipment designed to remove attached paprika pods from loose branches from broken plants was installed on a harvester and in processing plants, considerably reducing the hand labor required for this job. Further, labor reduction could be achieved by increasing the detachment efficiency of the devices through minor modifications.

A nine-shaft starwheel cleaning bed was found to separate most of the small, fine trash from the harvested product.

An on-board conveyor-storage basket system operated well on a pull type harvester providing considerable savings by reducing labor and equipment requirements.

The gleaning machine retrieved most of the paprika pods lost on the ground from the beds and from the wheel track, operating at a rate of 0.3 to 0.4 ha/h. The gleaner was successfully operated during the 1983 season in most of the mechanically harvested paprika fields.

b. U.S. Dept. of Agriculture, ARS (U.S.): Dale Marshall

Abstract

A self-propelled all-hydraulic experimental mechanical pepper harvester was constructed utilizing the open-helix harvesting principle first tested by Fullilove and Futral (1972). Average pepper damage ranged from 3% to 32%. A conveyor utilizing air with 10 mm slots was effective in conveying even the largest pepper type (bell) with air slot velocities of 38.3 m/s and 5.8 kW power consumption. Four experimental trash removal devices were evaluated for their ability to remove attached leaves and plant parts. Air was used to aid separation of detached leaves and trash. Depending upon pepper type, average recovery ranged from 84% to 98%. Differential-speed, rubber-pegged, double comber belts in combination with a helical-wound counter-rotating cleaning bed were found to singulate over 90% of the attached cherry peppers going through the system.

Whereas a single harvesting concept, such as the open-helix, may have application to a number of pepper types regardless of fruit diameter or shape, successful trash removal will require a number of different designs (or cleaning bed diameters) since trash removal is dependent on the relative difference between trash and fruit diameter.

Introduction

Considerable pepper harvest mechanization research has been conducted over the last 20 years (Marshall 1984a). Limited emphasis was placed on cultural practices and selection of pepper types or cultivars suited for mechanization until the late 1970's (Marshall 1984b). This cooperative

project was undertaken to advance the horticultural and engineering technology required to successfully mechanize the harvest of Capsicum annuum L. peppers.

Objectives

Build an improved technology experimental mechanical pepper harvester utilizing the open-helix principle. Determine field capacity and effect of helix rpm, helix diameter, and forward travel speed on pepper removal, recovery and damage. Evaluate decreased within row plant spacings. Build and evaluate 1 or more cleaning beds for effectiveness in removal of plant trash (leaves and branches). Evaluate new collecting, transfer and conveying systems. Determine hand and mechanical harvest labor productivity.

Methods and Materials

Tapered Helical Lifters

The recovery of peppers in the lower 150 mm of the pepper plant has been a problem where the lower ends of the helixes cannot touch the fruit. Further, with aggressive open helix lifters fruit were being removed prematurely and were not being recovered by the harvester conveyors. Tapered conical lifters (380 mm long) were wound with a single 10 mm dia. tubing helix. The rear end of the cone was 135 mm dia.

Comparison of 2 bar vs 3 bar and 155 mm vs 210 mm dia. Helixes

The effectiveness of pepper harvesting systems have been gauged by recovery and damage. No known research has evaluated which is more detrimental to pepper damage: peripheral speed of the helix or the

number of Beats (impacts) Per Meter of plant Height (BPMH). A series of rotational speeds for 210 mm dia. 2 bar and 3 bar (14 mm dia. pipe) helixes and 155 mm and 210 mm dia. 2 bar helixes were selected for evaluation at identical rpm or BPMH. The helixes were constructed with a pitch equal to twice the helix dia., which results in a helix angle of about 45° . If the number of helix bars were changed from 2 to 3 and the BPMH held constant, the peripheral velocity of the helix bars impacting the peppers would be reduced by $1/3$, and the kinetic energy absorbed by the peppers reduced by 55%.

Air Conveyor

Based on previous research a larger air conveyor, over 2.5 m long, was constructed which had variable width features to permit conveyance of peppers recovered ahead of the open helixes. An air gap of 10 mm and slot overlap of 20 mm provided a suitable air outlet.

Trash Removal

Four devices were evaluated for their ability to remove trash (extraneous leaves and plant branches). A differential speed, rubber-pegged, double combing belt device was constructed to singulate medium sized, spherical shaped peppers such as cherries and 'Jalapeno'. Two sizes (25.4 mm and 102 mm dia.) of counter-rotating roll cleaning roll beds and an 8-fingered, 150 mm dia. rubber rotating starwheel cleaning bed was constructed (Esch and Marshall 1983). The starwheels were identical to those used on the Israeli paprika harvester and gleaner cleaning beds.

In-row Spacings

In 1983 eighteen plots (10 pepper types) were grown at the MSU Horticulture Farm at 200 and 400 mm in row spacings and 1 m between rows. Recovery, damage and yield data were recorded for 2 replications per plot per spacing. To assess the relative brittleness or tendency for different cultivars to break up during mechanical harvesting, a new term, "breakability", was defined as the weight of the trash (leaves and branches) that went through the 25.4 mm cleaning bed divided by the weight of the peppers (recovered, lost on ground and lost on plant) plus the trash.

Results and Discussion

The USDA-ARS pepper harvester conical lifters worked very well and recovered the majority of the peppers 50 to 75 mm or higher above the soil surface. The 10 mm dia. tubing provided just enough aggressiveness to gently but firmly lift the lower plant branches and straighten up lodged plants and feed them into the open helixes. A conveyor utilizing air was used to convey mechanically harvested peppers rearward a distance of 2.5 m and up 0.6 m. In tests on 3 pepper types ('Jalapeno', hot banana, and green bell) the static pressure required within the plenum chamber for continuous conveyance of peppers ranged from a minimum of 102 mm water and an air velocity at the slot opening of 29.7 m/s for the 'Jalapeno' to a maximum of 127 mm of water and 38.3 m/s for the green bell (Marshall et al. 1982). Power required to continuously convey peppers ranged from 4.4 kW for 'Jalapeno' to 5.8 kW for the bells.

For 14 pepper types evaluated no physical property (length, diameter, L/D ratio, mass, cross-sectional area and specific gravity) consistently correlated with terminal velocity. One cultivar however, 'Jalapeno', did have high coefficient of correlations, .79, -.76 and .73 for diameter, L/D ratio and cross-sectional area, respectively, with respect to terminal velocity. The air conveyor provided variable width design so a catching conveyor could be built alongside the lifter cones to recovery any fruit removed prior to contact with the helixes. No clogging problems were encountered from the air conveyor. Occasional clogging did occur because of interference with large branches or uprooted plants at the bearing supports at the rear of the helixes (Marshall et al. 1982).

Fig. 1 shows the results of comparing 2 bar, 155 mm dia. helixes to 2 bar, 210 mm dia. helixes. This graph shows that the rate of increase of damage by 210 mm dia. helixes to hot banana peppers is about double of that induced by the 155 mm dia. helixes. When evaluated at identical rpm, comparing identical impact velocities (numbers by the data points on Fig. 1), the 210 mm dia. helixes also induced much greater damage than the 155 mm dia. helixes. This means that damage is more directly related to peripheral helix speed or rotational speed than to number of impacts sustained.

Fig. 2 shows the results of comparing 2 bar to 3 bar helixes (210 mm dia.). The graph shows that the rate of increase of damage by the 2 bar helixes (with 50% greater peripheral impact velocities) is about double that induced by the 3 bar helixes to hot banana peppers. However, little differences exist in the 100 to 200 BPMH area of the graph where most harvesting occurs. Also, in the 3 bar design, the open cylindrical area between bars for peppers to enter the helix prior to detachment is

reduced compared to the 2 bar. A 155 mm dia. 3 bar helix was not tested because it would have had even less open cylindrical area. A minimum or threshold level of helix speed is necessary for optimum recovery and minimal damage. Therefore, from the results of these 2 figures, the recommended helixes to use for hot banana peppers are 2 bar, 155 mm dia. helixes. The effective field capacity of the one row USDA-ARS harvester was about .08 ha/h when operated at 1 km/h.

The performance of the 25.4 mm and 102 mm counter-rotating roll beds was significantly improved by first feeding mechanically harvested peppers through a differential speed (5:1 to 10:1) rubber-pegged, double combing belt. There was no significant difference in trash removal between the counter-rotating roll units nor with respect to roll speeds with either. Damage resulting from the double comber - 25.4 mm roll combination was 1% and 4% for sweet and hot cherry peppers, respectively. It was slightly higher for the 102 mm roll bed and for hot banana peppers. Typically, less than 40% of the mechanically harvested peppers still had trash attached. Over 90% of those cherry peppers with trash attached were singulated after passing once through the comber belts and over either roll bed. The 25.4 mm cleaning bed is recommended because it has higher throughput capacity (about 3 t/h per m of bed width for cherry peppers), better effectiveness, safety, and ease of operation, and reduced size and weight compared to the 102 mm unit (Esch 1983 and Esch and Marshall 1983).

The starwheel cleaning bed was ineffective in removing attached trash but was found effective in removing fine, light trash that could also be removed with a fan and to have potential as a diameter grader for

spherical-shaped peppers. In cherry and 'Jalapeno' peppers its throughput capacity was about 2.5 t/hr per m of bed width. Grading efficiency was affected by starwheel spacing, rotational speed, pepper shape and average diameter, and location of cross conveyor(s) under the bed.

Every type of pepper grown commercially in the U.S. can be mechanically harvested with the open-helix concept (Marshall 1979). It is critical that the helixes be operated out-of-phase. Recovery of banana, bell, and cherry peppers generally increased with increased open-helix rotational speeds and decreased with increased harvester ground speeds. There was no consistency in the relationship of damage for these varieties relative to helix rpm. However, damage generally decreased as forward ground speed increased (Marshall 1981).

The open-helix concept has excellent potential for effectively mechanically harvesting 80% to 90% of the peppers from all pepper types grown commercially in the U.S. Removal of trash from these same peppers, however, will take a number of different trash removal beds since removal of trash is dependent on the relative size of the trash to the pepper. Therefore, successful mechanical harvesting may be accomplished with one size open-helix harvesting element but may require 3 or more sizes of trash removal systems. As an example, the 25 mm dia. counter-rotating bed is marginal for use in bell peppers and a 50 mm or larger size is better. The 25 mm bed is fine for sweet and hot cherries, 'Jalapenos', and is generally satisfactory for the hot and sweet bananas, however, the tips of some of the more tapered banana peppers may be damaged. Smaller peppers such as the 'Cascabella, or 'Chili serrano' type generally are too small in diameter and are likely to be severely damaged

by the 25 mm bed. Suitable air flow required to move the product up the air conveyor is generally sufficient to blow the light trash from the mechanically harvested peppers at one or more transfer points.

Experience has shown that double to triple the normal plant population causes the plants to grow taller, with fewer upright branches, narrower crotch angles and higher fruit placement, and allows for easier mechanical harvesting (Marshall 1984b). In 1982 increases in yield/ha and decreases in yield/plant for 200 mm in-row-spacings compared to 400 mm spacings were, respectively: 2% and 89% for bell, 29% and 84% for hot cherry, 50% and 81% for Santa Fe Grande, and 75% and 78% for hot banana peppers. Similar results were found by Marshall (1981) in 1980. In 1983 an average 27% reduction in yield/plant was offset by a 47% increase in yield/ha at higher plant populations (Table 1).

Table 1 shows the 1983 results for 8 pepper types grown at 2 in-row spacings. There was no significant difference in average recovery or average damage for the 2 spacings. The ground loss was slightly less for the more dense plant population. This may be explained by the fact that with the denser higher plant population detached peppers that might otherwise fly forward or fall directly onto the ground are caught or have their fall retarded by the closer plant locations. Also, there was slightly less plant branch breakage.

Table 2 shows average hand harvest costs, harvest rates and labor requirements for the USDA-ARS experimental harvester. The cost of harvesting peppers by hand ranged from 20.1% to 47.6% of the product value.

An estimated 468% worker productivity increase was achieved in 1983 in sweet cherry peppers.

Considerable mechanical harvesting research effort has been expended over the past 2 decades. Over 130 experimental harvesters have been built by at least 59 different research groups around the world (state or federal researchers, private inventors, consultants, processors or manufacturers) based on over a dozen different harvesting concepts. Mechanical pepper harvesting is a viable alternative to hand harvesting for certain pepper types when the plant culture, field conditions, etc. are suitable. This research has been conducted in Bulgaria, Hungary, Israel, Italy, U.S. and USSR (Marshall 1984a). Interest in mechanical pepper harvesting in the U.S. has leveled off in recent years because of the economic recession and the availability and willingness of field laborers to hand harvest the crop.

Conclusions

Mechanical pepper harvesting is a viable alternative to hand harvesting for certain pepper types when the plant culture, field conditions, etc. are suitable. The open-helix concept has excellent potential for successful pepper harvesting, and has been used in commercial prototypes in recent years. Use of the USDA-ARS experimental harvester in 1983 showed a 468% increased worker productivity in sweet cherry peppers.

Conical-shaped, helical-wrapped lifters greatly improved the harvester's ability to lift and gather low lying plant branches or lodged plants and feed them into the open helix harvesting elements. It is essential that the helixes be operated out-of-phase.

Pepper recovery and damage was generally directly related to helix rotational speed and inversely related to harvester ground speed. Of four different helix diameters tested, the 155 mm dia. 2 bar open-helix was the most successful. A minimum or threshold level of helix peripheral speed and beats sustained by the pepper plant is required for optimum recovery and minimal damage. Damage is more directly related to peripheral helix speed (rotational speed) than to number of impacts sustained.

A conveyor utilizing air was refined to convey a range of type of mechanically harvested peppers. It provided variable-width design and conveyed peppers 2.5 m rearward and elevated them 0.6 m at outlet gap air velocities of 30 to 40 m/s at a power requirement of 4.4 to 5.8 kW. The conveyor experienced minimal problems of clogging from trash or uprooted plants.

Experimental trash removal techniques have been shown to be viable for many of the pepper types grown in the U.S. The best overall trash removal for banana or cherry peppers was obtained with a combination of the double combing belt used ahead of a counter-rotating 25.4 mm dia. smooth rubber and spirally-wound steel roller cleaning bed. Of those fruit still attached to foliage after mechanical harvest, over 90% of sweet and hot cherry peppers were singulated and had 4.1% or less damage. Since some of the larger plant stems or branches may remain, provision was made for hand sorting on a side conveyor.

Whereas a single harvesting concept, such as the open-helix, has application to a number of pepper types regardless of fruit diameter or

shape, successful trash removal will require a number of different designs (or cleaning bed diameters) since trash removal is dependent on the relative difference between trash and fruit diameter.

Interest in mechanical pepper harvesting in the U.S. has leveled off in recent years because of the economic recession and the availability and willingness of field laborers to hand harvest the crop.

Fig. 1. Average damage and least squares regression line equations for hot banana peppers harvested at 1.5 km/h by 155 mm dia. and 210 mm dia. open helixes constructed with 2 bars per helix. Helix rpm equals 2.27 times the beats per meter of plant height. Numbers by data points are the peripheral helix bar impact velocities (m/s), 6 reps each, Michigan, 1982.

Fig. 2. Average damage and least squares regression line equations for hot banana peppers harvested at 1.5 km/h by 210 mm dia. open helixes constructed with 2 and 3 bars per helix. Rpm of 2 and 3 bar helixes equals 2.27 and 1.51 times the beats per meter of plant height, respectively. Numbers by data points are the peripheral helix bar impact velocities (m/s), 6 reps each, Michigan, 1982.

Table 1. Average recovery, damage, breakability and yield of 8 types (18 cultivars) of peppers grown at 200 and 400 mm in-row-spacings at the M.S.U. Horticultural Farm, Michigan, 1983.

Cultivar	Recovery (%)		Damage (%)		Ground Loss (%)		Breakability (%)		Total Yield (g/plant)		Total Yield (t/ha)		Yield change relative to 400 mm spacing	
	200	400	200	400	200	400	200	400	200	400	200	400	Decrease g/plt (%)	Increase t/ha (%)
Banana, hot (P)	89.1	89.8	17.5	20.3	5.9	7.7	17.5	18.0	447	606	30.7	21.5	26	43
(Erect) (H)	89.0	85.7	21.3	17.5	4.4	7.4	5.0	4.4	373	422	25.7	14.9	12	72
Average	89.1	87.8	19.4	18.9	5.2	7.6	11.3	11.1	410	514	28.2	18.2	19.0	57.5
Banana, hot #200 (Pendant) #250 (V)	96.7	97.1	24.2	19.0	2.6	2.3	20.4	20.1	421	634	29.0	20.4	34	42
#300	98.2	98.2	25.7	18.0	0.9	1.3	17.7	17.5	392	630	27.1	19.6	38	38
#350	96.1	97.4	19.0	18.4	2.5	2.1	17.9	16.9	435	648	28.2	20.7	33	36
Average	97.0	97.4	17.9	17.4	1.3	1.8	17.8	17.1	376	595	27.8	18.6	37	49
	97.0	97.5	21.7	18.2	1.8	1.9	18.5	17.9	406	627	28.0	19.8	35.5	41.3
Banana, sweet (P)	98.8	96.3	22.0	26.7	1.0	2.6	18.0	21.1	493	610	32.2	21.7	19	48
(H)	93.3	95.6	35.4	36.9	4.4	2.3	10.8	13.6	377	508	31.5	21.2	26	49
Average	96.1	96.0	28.7	31.8	2.7	2.5	14.4	17.4	435	559	31.9	21.5	22.5	48.5
Bell, Yolo W. (P)	88.3	88.8	13.4	10.6	8.0	10.8	14.6	18.6	312	682	28.0	19.4	54	44
KRG 3 (P)	96.0	93.2	28.2	13.5	3.5	6.0	12.9	15.5	424	607	22.8	21.4	30	7
Average	92.2	91.0	20.8	12.1	5.8	8.4	13.8	17.1	368	645	25.4	20.4	42.0	25.5
Cascabella (P)	84.9	90.9	7.2	9.6	6.9	5.3	53.3	50.6	151	257	9.7	7.9	41	23
Cherry, hot (P)	92.6	95.0	5.8	5.7	4.3	4.3	20.8	26.8	393	600	22.8	17.0	35	34
(R)	74.9	87.9	1.1	1.3	14.4	8.9	28.3	28.0	253	448	17.2	13.0	44	32
Average	83.8	91.5	3.5	3.5	7.4	6.6	24.6	27.4	323	524	20.0	15.0	39.5	33.0
Cherry, sweet (P)	95.4	96.1	4.3	2.2	3.7	2.6	26.1	26.5	326	473	18.0	12.7	31	42
(R)	91.6	92.0	1.1	2.9	7.1	5.9	25.0	25.8	330	446	18.5	12.6	26	47
Average	93.5	94.1	2.7	2.6	5.4	4.3	25.6	26.2	328	460	18.3	12.7	28.5	44.5
Chili Serrano (P)	93.3	86.2	2.8	4.2	6.0	12.5	29.4	34.6	289	323	16.1	9.9	11	63
Jalapeno, early (P)	92.5	94.0	5.7	4.3	6.0	5.5	14.1	21.8	412	503	23.9	14.1	18	70
Jalapeno M (P)	91.8	93.1	5.4	4.1	7.0	5.8	18.2	18.2	535	639	31.1	19.4	16	60
Grand Average	91.4	92.2	11.8	10.9	5.4	6.0	22.3	24.2	365.7	505.1	23.3	16.0	27.3	46.6

Table 2. Typical average hand harvest rates and costs, product value, labor requirements and productivity with the experimental USDA ARS mechanical pepper harvester, Michigan, 1983.

Cultivar	Hand harvest (c/kg) 1/	Product value (c kg)	Hand harvest labor as % of value	Hand harvest rate		Hand harvest labor req't (man-h/ha)	Typical yield (kg/ha) 2/	With mechanical harvester		
				typical (kg/h)	fastest (kg/h)			Labor req't 3/	(man-h/ha) 4/	Productivity increase (%) 5/
Banana, Hot	1.37	5.67	24.2	413	604	210	87125	5	75.4	179
Banana, Sweet	1.61	5.67	28.4	402	579	203	81679	5	75.4	169
Bell, Green	1.04	5.17	20.1	621	941	123	76234	NA	NA	NA
Cascabella	9.07	19.05	47.6	55	110	NA	NA	NA	NA	NA
Cherry, Hot	2.18	6.53	33.4	203	400	268	54453	5	75.4	255
Cherry, Sweet	3.08	7.89	39.0	127	255	428	54453	5	75.4	468
Jalapeno	3.00	8.30	36.1	181	271	241	43562	4	60.6	298

1/ Includes fringe benefits.

2/ Typical average yields for mid-Michigan.

3/ Assuming 1 harvester driver, 1 chase wagon tractor driver and hand sorters.

4/ Assuming labor requirements for typical worker shown and 87.5% efficiency.

5/ Assuming typical yields and labor requirements shown with a 1-row harvester operating at 1 km/h, and 914.4 mm row spacing.

6/ NA = not available.

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ORIGINAL RESEARCH PROPOSAL

D-1. Horticultural Research

a. Medicinal and Spice Crops Institute (Israel): Dan Palevitch,

A. Levy, N. El Basal and Chen Shifriss

All the objectives proposed in the research plan were carried out during the course of this research time span, except defoliation. Defoliation of paprika prior to harvest is common practice now in Israel. The technique was adopted from cotton defoliation procedure. All other cultural practices were thoroughly studies in the present research.

Selection towards more suitable cultivars for mechanical harvesting was fully infestigated and resulted in a new cultivar 'Improved Shany'.

b. Pennsylvania State University (Univ. of Delaware) (U.S.): Michael Orzolek

We have known for many years that increasing the nitrogen rate and applying irrigation to peppers will, under certain conditions, increase the yield of peppers. What has not been known about application of additional nitrogen and irrigation to peppers was their effect on the plant structure of peppers. Results of this research have indicated that irrigation had no significant effect on the plant and/or stem height of peppers. There was also no significant effect on plant and/or stem height of pepper when nitrogen was either broadcasted or sidedressed prior to or after planting. The protocol for this study paralleled the objectives of the original proposal. The only significant departure from the original proposal was made in the evaluation of plant populations. Instead, emphasis was placed on the evaluation of new cultivars and breeding lines which were adaptable to mechanical harvesting. The departure in objectives from the original proposal was made because of the much larger pool of plant and stem heights variation among cultivars compared to the height adjustments possible with higher plant populations.

c. Michigan State University (U.S.): Hugh Price

The influence of plant spacing on the yield and harvestability of 4 types of peppers was investigated as outlined in the original proposal. Distinct differences between pepper types were identified which will assist further efforts toward mechanization.

One aspect of transplant establishment which had to be eliminated was the influence of storage on Georgia grown transplants. The cooperator in Georgia became ill and thus I was unable to obtain the precise plants (from the same seed lots of Michigan grown plants) required for the experiment.

D-2. Agricultural Engineering Research

a. Agricultural Engineering Institute, ARO (Israel): Itzhak Wolf and Yekutieli Alper

In general, the research was conducted according to the original proposed plan.

b. U.S. Dept. of Agriculture, ARS (U.S.): Dale Marshall

The major departure from the proposed plan was the inability to test helix angles other than 20° . This was because of lack of time and from unfavorable experiences in previous years with larger angles.

E. DESCRIPTION AND RESULTS OF COOPERATION

E-1. Horticultural Research

a. Medicinal and Spice Crops Institute, ARO (Israel):

Dan Palevitch, A. Levy, N. El Basal and Chen Shifriss

Cooperation between the scientists involved in the study was essential for the success of the research project. As far as horticulture is concerned, a visit in the specific fields in both countries was by far indispensable. One of us (D.P.), visited the U.S. before launching the studies in Israel. He visited research centers, commercial fields and industrial plants in some states, namely Michigan, California, Arizona and New Mexico. Discussions with the U.S. counterparts in Michigan, Dale Marshall and Hugh Price, were highly fruitful. Exchange of genetical material was also most beneficial for the breeding and selection project. The U.S. Principal Investigator, Dale Marshall, was very keen in enabling the cooperation by keeping track with all investigators and by providing most useful up-to-date scientific information.

We would like to express our thanks to E. Menagem, Michal Barzelai, Esther Aloni, M. Dachbash from the Dept. of Medicinal and Spice Crops for their skilful technical aid. Also to Mr. E. Admati from the Extension Service of the Ministry of Agriculture for his help in the Be'eri experiment, and Dan Omri from Kibbutz Lahav for his most helpful assistance in the experiment conducted in the commercial field in his kibbutz.

b. Pennsylvania State University (Univ. of Delaware) (U.S.):

Michael Orzolek

Cooperation has been excellent between the cooperating institutions in both the United States and Israel. Exchange of information and plant material has been very useful and important to the successful completion of this project.

c. Michigan State University (U.S.):

Hugh Price

The MSU and USDA portions of this project shared greatly in all phases of the projects. The horticultural and engineering inputs complemented each other.

E-2. Agricultural Engineering Research

a. Agricultural Engineering Institute, ARO (Israel):

Itzhak Wolf and Yekutiel Alper

The cooperation permitted the dividing of the effort invested in research and development between the partners, mainly as far as types of peppers are concerned, the results of which are exchangeable and applicable in both countries. We wish to stress that the cooperation with the research in the U.S. in this specific BARD project developed into extensive cooperation and wide exchange of ideas and information in other branches and scopes of mutual interest to the benefit of all concerned.

b. U.S. Dept. of Agriculture, ARS (U.S.):

Dale Marshall

Horticultural greenhouse transplant growing space, test plot land area and maintenance, and mechanical harvest evaluation labor was provided by Hugh Price, MSU Horticultural Dept. Grower test fields and abandoned fruit were provided by at least a dozen Michigan, Indiana and Ohio pepper producers. Pickle Packers Int'l, Inc. and many processors and their fieldmen assisted our project including Aunt Jane Foods, Central Michigan Packaging Co., Green Bay Foods, H. J. Heinz, Pilgrim Farms and Vlasic Foods Div. of Campbell Soup Co. At least two seedsmen provided pepper seed for observation and evaluation trials.

F. BENEFIT TO AGRICULTURE

F-1. Horticultural Research

a. Medicinal and Spice Crops Institute, ARO (Israel):

Dan Palevitch, A. Levy, N. El Basal and Chen Shifriss

Due to the cooperation with Israeli Agr'l Engineering crews, an improved harvester was operated in all commercial paprika fields in Israel. To the best of our knowledge Israel is the only country in the world using a mechanical harvester for the commercial harvest of paprika.

The new cultivar 'Improved Shany' is more prolific in terms of yield and in 1984 10% of all commercial fields are projected to be sown with this new cultivar developed during the present study.

b. Pennsylvania State University (Univ. of Delaware) (U.S.):

Michael Orzolek

Because of the result of this project, there will be a substantial increase in processing pepper acreage in Pennsylvania in 1984. A minimum of 2000 ha of processing peppers will be planted compared to only 250 ha grown for the last 3 years. Planting estimates are based on personal communication from the processor's fieldman. In addition, sidedressing peppers with no more than 134 kg/ha will allow both growers and processors to reduce production costs by the savings in nitrogen fertilizer. Finally, new cultivars have been identified which are adaptable to mechanical harvesting, have high yields, and acceptable as processed products.

c. Michigan State University (U.S.):

Hugh Price

A system for efficient growing and harvesting of peppers for processing was developed. The feasibility of mechanically harvesting a crop which in the past required many hours of tedious labor was demonstrated.

F-2. Agricultural Engineering Research

a. Agricultural Engineering Institute, ARO (Israel):

Itzhak Wolf and Yekutieli Alper

The harvest mechanization system for paprika which was completed with the aid of the BARD project enabled farmers to start this new and profitable branch of paprika growing for dehydration which

without mechaization would be unable to harvest. The mechanization reduced the labor requirement for harvesting, from about 25 work days per ton (of dry product) to about one half of a work day per ton. The BARD project included the development of cleaning devices for the produce and a machine to retrieve field lost paprika fruit prior and during the harvest by machine.

b. U.S. Dept. of Agriculture, ARS (U.S.): Dale Marshall

The open helix concept has been shown to be a viable harvesting method. Trash removal methods have been shown to be suitable to certain pepper types. A conveyor utilizing air has shown to be suitable for transporting mechanically harvested peppers. The system has shown that up to 468% increase in worker productivity can be achieved by use of the USDA-ARS experimental pepper harvester.

G. INVENTIONS

None

H. PUBLICATIONS RESULTING FROM THIS RESEARCH PROJECT

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Great Lakes Vegetable Growers News. 1983. New frontier opened in mechanical vegetable harvesting. Great Lakes Vegetable Growers News 17(12):1, 4.

Kovalchuk, S. 1983. A mechanical pepper harvester. American Vegetable Grower 31(5):8-9, 22.

I. TECHNICAL PAPERS, THESIS, OR MANUSCRIPTS SUBMITTED FOR PUBLICATION RESULTING FROM THIS RESEARCH PROJECT

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Esch, T. A. and D. E. Marshall. 1983. Trash removal from mechanically harvested peppers. ASAE Paper No. 83-1072. Am. Soc. of Agr. Eng., St. Joseph, MI 49085. 23 p.

Marshall, D. E., M. G. Pickett, and T. A. Esch. 1982. Using air to convey mechanically harvested peppers. ASAE Paper No. 82-1063. Am. Soc. of Agr. Eng., St. Joseph, MI 49085. 13 p.