9. Levin, J. H., H. P. Gaston, S. L. Hedden and R. T. Whittenberger. 1960. Mechanizing the harvest of Red Tart cherries. *Quarterly Bulletin*, Mich. State Univ. 42(4) :32 pages.
10. Markwardt, E. D., R. W. Guest, J. C. Cain and R. L. Labelle. 1962. Mechanical cherry harvesting as related to costs, product quality and cultural practices. *Proc. Amer. Soc. Agr. Eng.* 1962. Paper No. 62-156.
11. Mohsenin, N., H. Goehlich, and L. D. Tukey. 1962. Mechanical behavior of apple fruits as related to bruising. *Proc. Amer. Soc. Hort. Sci.* 81:67-77.
12. Norton, R. A., L. L. Claypool, S. J. Leonard, P. A. Adrian, R. B. Fridley and F. M. Charles. 1962. Mechanical harvesting of sweet cherries. *Calif. Agr.* 16(5):8-10.
13. O'Brien, Michael. 1960. Design for bulk fruit bins. Univ. of Calif., Div. of Agr. Sci. Circular 490.
14. Schertz, C. E. 1963. Citrus mechanical harvesting research. *Calif. Citrograph* pp. 458-460, October, 1963.
15. Whitney, J. D., N. Mohsenin and L. D. Tukey. 1963. An elevating mechanical harvester for apple trees trained to the plateau system. *Proc. Amer. Soc. Hort. Sci.* 83:175-184.
16. Whittenberger, R. T., H. P. Gaston, S. L. Hedden and J. H. Levin. 1962. Processing mechanically harvested cherries in 1962, quality and cost comparisons. Great Lakes Cherry Producers Marketing Cooperative, Inc., *Annual Report for 1962* (10 pages).

Maximum Yields of Processing Vegetables

By M. T. Vittum, *New York State Agricultural Experiment Station, Geneva, New York*

Intense competition in the fruit and vegetable processing industry rapidly eliminates the inefficient operator. Thus, in a free economy, only the most efficient growers survive. These are the growers who have the ability to manage their soils and crops in such a way as to produce large yields of high quality at low cost per unit of production.

Since large yields are usually a key factor in efficient production, it would be interesting to know the maximum yields that have been, or can be, produced by good growers. Thus, in the fall of 1964, a questionnaire was distributed to various processors, seedsmen, commercial agronomists, and land grant college research and extension personnel throughout the United States. Information was requested on the best commercial or field yields, and on the highest yield ever obtained in small research or extension plots, for 10 different processing vegetables. Response to the questionnaire was quite heartening. Processors, however, were considerably more cooperative than professors in supplying information. Thus, the maximum yields from small research trials reported herein for several crops represent a much smaller "sample" of response than that for comercial fields.

Top yields reported for each crop are summarized in Table 1. In studying these data, keep in mind the obvious limitations in this type of information. Most processing vegetables, for example, do not have definite maturity dates. They are harvested according to the type of pack each processor is putting up. The questionnaire requested information on crops of "acceptable processing quality." This could vary considerably from one processor to another.

In most cases the actual pounds or tons which are removed from a field are measured quite acurately, using scales which are checked by local inspectors. Acreage data, on the other hand, are much less accurate. Although most good growers know the approximate size of each individual field, they sometimes contract for either a larger or smaller acreage. Unpublished work in New York State indicates that the grower's and/or fieldmen's estimate of acreage can vary as much as 20 percent from the actual measured acreage of any given field.

Yields for small research plots are usually higher than for commercial fields because of better control of such factors as plant population, fertilizer, weeds, insects, and diseases. Thus it is interesting to compare maximum yields from small experimental plots with those from commercial fields (Table 1).

Results for the different crops are summarized in Table 1, and the survey data are compared with state average yields and with potential or theoretical yields in Table 2.

Bush Beans: Average yield of the top 7 commercial fields was 5.6 tons per acre. Five experimental plots averaged double this yield, or 11.2 tons per acre (Table 1). All results are for a once-over harvest with a mechanical bean picker for commercial fields, and for a single hand picking for small plots. The best commercial field was a 20-acre field in Oregon which averaged 9.4 tons per acre. Rows were 30 inches apart with 7.5 plants per foot of row, or 131,000 plants per acre. Moisture was adequate throughout the season, and success of this crop was attributed to "total absence of stress—water, nutrients, temperature, wind, insects, diseases, etc."

It is interesting to calculate the potential yield that could be obtained if certain assumptions are made. If there are 174,000 plants per acre (1″ apart in 36″ rows, 1.5″ apart in 24″ rows, 3″ apart in 12″ rows, or 6″ apart in 6″ rows), and if each plant produces 10 sieve-size 4 pods and these pods average 7 grams each (or 65 pods per pound), the potential yield is 13.4 tons per acre (Table 2). Think of the potential yield if each plant produced 12, 15, or even 20 pods! Individual bush bean plants under ideal conditions can produce as many as 50 pods.

Pole Beans: Average yield of the top 6 commercial fields was 13.7 tons per acre; for 3 research plots 20.2 tons (Table 1). All of these yields were from the West Coast, where each field is irrigated and is picked 5 to 8 times by hand.

With 43,560 plants per acre (5 plants per foot in rows 5′ apart, or 4 plants per foot in rows 4′ apart), and with 1 pound of pods per plant, a yield of 21.8 tons should not be unreasonable (Table 2).

Green Lima Beans: Because of much smaller acreage, data on lima beans are not nearly so voluminous as for snap beans. Average yield of the 6 top commercial fields was 2.6 tons per acre, as compared with 3.5 tons for the top 5 experimental plots (Table 1). With a population of 87,100 plants per acre (2″ apart in 36″ rows), each plant would have to produce only 0.10 pounds of beans to obtain a theoretical yield of 4.4 tons (Table 2).

Beets: Only a small acreage of table beets is grown for processing in the United States, but this is an important crop in parts of New York, Wisconsin, Oregon, and Texas. Average yield of the 4 top commercial fields was 34.0 tons per acre, considerably higher than the 21.5 tons averaged in the top 4 research trials (Table 1). This crop is difficult to evaluate in this type of a survey. Small beets 1 to 1¾″ in diameter are worth 30 to 35 dollars per ton, whereas large beets, greater than 3 or

4″ in diameter, are usually worthless. Size of beets is controlled by plant population, soil fertility, and irrigation, whereas total yield is determined by the length of time the beets are permitted to grow and enlarge. For the valuable small sized beets, a population of 871,000 plants per acre (30 beets per foot in rows 18″ wide) will yield 43.6 tons per acre if individual beets average 45 grams, or 10 per pound (Table 2).

Cabbage for Kraut: This crop is also of limited interest for processing, except in parts of New York, Ohio, and Wisconsin. Average yield of the 6 best commercial fields was 40 tons per acre, as compared with only 34.8 for research plots (Table 1). At 14,520 plants per acre (12″ apart in 36″ rows, 14.4″ apart in 30″ rows, or 18″ apart in 24″ rows), 7 pound heads would produce 50.8 tons (Table 2).

Sweet Corn: After studying the returns, it was decided to separate the data into two geographical areas: The Pacific Northwest, and the Midwest and/or East. The top 6 commercial fields in the Northwest averaged 13.2 tons per acre, whereas the top 6 fields in the Midwest and East averaged only 8.5 tons (Table 1). This difference is probably due to the higher light intensity, warmer days, and cooler nights in the Northwest. Potential yields, with populations of 17,400 plants per acre (10″ apart in 36″ rows, 12″ apart in 30″ rows, 15″ apart in 24″ rows), and each plant producing two 1-pound ears, would be 17.4 tons (Table 2).

Cucumbers for pickles: Average yields of the 4 top commercial fields was 19.8 tons per acre, whereas for 3 experimental plots it was 18.4 tons (Table 1). Normal cucumber vines have a tremendous potential if each female flower sets a fruit. Recent trends toward mechanical harvesting suggest that in the future, dwarf varieties producing only 1 or 2 fruit per plant but planted close together may be harvested in a once-over operation. With 174,000 plants per acre (6″ apart in 6″ rows, or 3″ apart in 12″ rows), each plant would have to produce only 2 fruit, averaging 57 grams each (8 per pound), to give a yield of 21.8 tons (Table 2).

Peas: Peas are similar to snap beans. Hundreds of thousands of acres of each are grown for processing and both are legumes which normally produce a succession of flowers and pods. Average yield of the top 6 commercial fields, all in the Pacific Northwest, was 8,500 pounds per acre compared with 10,220 pounds for the 5 top research trials (Table 1).

Table 1. Maximum Yields of Processing Vegetables

Commercial Fields Tons/Acre	Location	Experimental Plots Tons/Acre	Location
Bush Beans (Single Mechanical Harvest)			
9.4	Oregon	12.4	Oregon
6.0	California	12.0	——
5.3	California	11.2	Oregon
5.0	——	10.4	Washington
4.8	New York	10.0	New York
4.5	Oregon	11.2	Average
4.5	Maryland		
5.6	Average		
Pole Beans (Multiple Hand Harvest)			
15.0	Oregon	30.0	California
13.7	California	16.1	Oregon
13.7	Washington	14.6	Oregon
13.7	Oregon	20.2	Average
13.0	Washington		
13.0	Oregon		
13.7	Average		
Green Lima Beans			
3.0	California	4.5	Wisconsin
2.63	Wisconsin	4.0	California
2.6	Oregon	3.4	Washington
2.6	Washington	2.9	Oregon
2.6	California	2.5	Oregon
2.4	New York	3.5	Average
2.6	Average		
Beets			
40.0	Oregon	24.8	Oregon
35.0	Oregon	23.0	New York
31.0	New York	21.4	Oregon
30.0	New York	16.8	Wisconsin
34.0	Average	21.5	Average
Cabbage			
55.0	New York	40.0	Alaska
40.0	New York	40.0	California
38.0	Washington	36.0	Washington
37.0	Washington	30.0	California
35.0	Washington	27.8	Wisconsin
35.0	Oregon	34.8	Average
40.0	Average		
Sweet Corn (Pacific Northwest)			
14.6	Washington	12.2	Washington
14.0	Oregon	10.8	Washington
13.6	Washington	10.8	Oregon
13.0	Idaho	10.7	Washington
12.1	Oregon	10.2	Washington
12.0	Washington	10.9	Average
13.2	Average		

Commercial Fields Tons/Acre	Location	Experimental Plots Tons/Acre	Location
Sweet Corn (Midwest & East)			
9.7	Minnesota	11.5	Wisconsin
9.0	Pennsylvania	11.3	Wisconsin
8.2	New York	10.5	Wisconsin
8.2	Ontario	8.4	Wisconsin
8.1	Wisconsin	10.4	Average
8.0	Illinois		
8.5	Average		
Cucumbers			
26	Washington	21.6	Wisconsin
20	Washington	20.0	California
18	California	13.7	Washington
15	——	18.4	Average
19.8	Average		
Peas			
(lbs.)		(lbs.)	
9,400	Oregon	14,200	Wisconsin
9,030	Oregon	9,800	Washington
8,740	Oregon	9,200	Washington
8,000	Washington	9,100	Washington
8,000	Washington	8,780	Wisconsin
7,850	Oregon	10,220	Average
8,500	Average		
Spinach			
18.0	Washington	16.0	Washington
14.0	California	10.0	California
14.0	Washington	10.0	Washington
11.6	California	12.0	Average
10.9	California		
13.7	Average		
Tomatoes			
52.3	California	65.0	California
52.0	California	57.7	California
46.0	Pennsylvania	52.0	Michigan
41.0	Ohio	51.3	New York
40.9	Ohio	50.0	Indiana
40.4	California	50.0	Idaho
40.3	Ohio	54.3	Average
44.7	Average		

If we assume a population of 448,000 plants per acre (2″ apart in 7″ rows), 5 pods per plant, 5 peas per pod, and 0.5 grams per pea, the potential yield is 12,350 pounds or 6.2 tons (Table 2). New high-ovule breeding lines contain 8 to 10 peas per pod, and individual plants can produce as many as 15 or 20 pods under certain conditions. Potential yields of peas are far greater than those presently obtained (Fig. 1).

Spinach: Spinach averaged 13.7 tons per acre from the 5 top commercial fields and 12.0 tons in 3 research trials (Table 1). With a population of 653,400 plants per acre (15 plants per foot in 12″ rows, or 7.5 plants per foot in 6″ rows), an average plant weight of 25 grams (18 plants per pound) would produce a yield of 21.8 tons (Table 2).

Tomatoes: Average yield of the top 7 commercial fields was 44.7 tons per

Table 2. Comparison of selected state average yield with the best commercial yield, the best experimental plot yield, and a theoretical or potential yield.

	1964 Average Yield		Average yields of best fields in survey (Tons/Acre)		Potential Yield		
Crop	State	Tons/ Acre	Com. Fields	Exp. Plots	Plants/ Acre	Lbs/ Plant	Tons/ Acre
Beans, Bush	New York	1.8	5.6	11.2	174,000	0.154	13.4
Beans, Pole	Oregon	5.8[1]	13.7	20.2	43,560	1.00	21.8
Beans, Green Lima	(United States)	1.0	2.6	3.5	87,100	0.10	4.4
Beets	New York	11.6	34.0	21.5	871,000	0.10	43.6
Cabbage	New York	17.0	40.0	34.8	14,520	7.00	50.8
Sweet Corn—Pacific Northwest	Idaho	6.0	13.2	10.9	17,400	2.00	17.4
Sweet Corn—Midwest & East	Illinois	4.4	8.5	10.4	17,400	2.00	17.4
Cucumbers	Michigan	5.0	19.8	18.4	174,000	0.25	21.8
Peas	New York	1.4	4.2	5.1	448,000	0.028	6.2
Spinach	California	9.3	13.7	12.0	653,400	0.067	21.8
Tomatoes	California	21.0	44.7	54.3	43,560	3.00	65.3

[1] Average of both bush and pole beans.

acre. The top 6 experimental plots averaged about 10 tons more per acre (Table 1). Tomato plants are extremely reactive to their environment. With a spacing of 1 square foot per plant (12″ apart in 1 foot rows, or 6″ apart in 2 foot rows), a yield of 3 pounds per plant (or 9 fruit at ⅓ pound each), is 65.3 tons per acre (Table 2). Even higher yields could be expected by putting the plants closer together, by harvesting more fruit per plant, or by increasing size of individual fruit.

Where do we go from here? Why don't commercial yields come closer to the theoretical? What can we do to help growers obtain better yields?

Technical knowledge already exists for producing yields close to the potentials shown in the last column of Table 2. These goals cannot be reached, however, until *all* growers combine the principles of good management and stewardship: soils selected or treated for good drainage and aeration; crop rotations and cover crops to discourage build-up of diseases and to maintain actively-decaying organic matter; good seed of adapted varieties; careful planting to ensure adequate stands; proper placement, rate, and ratio of fertilizer; tillage as needed but not in excess; adequate weed, insect, and disease control; and irrigation as needed.

Good management, as outlined here, can remove all limiting factors except those controlled by nature, such as solar radiation, air and soil temperature, wind, and vapor pressure deficit. With minor exceptions, growers must accept these as they occur. Thus, our best hope for even higher yields is that plant breeders develop varieties that are more efficient users of the energy they receive from the sun.

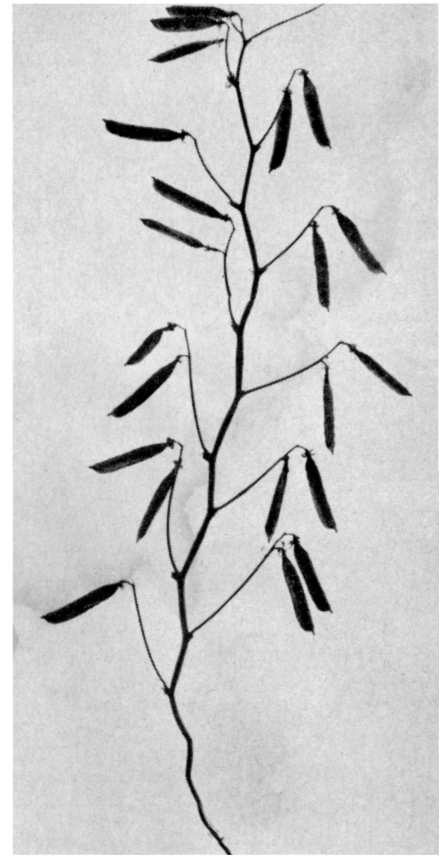

Fig. 1. Under ideal conditions, potential yield of an individual pea plant is quite amazing. If each of the 21 pods on this plant produces 6 peas, the original seed has been multiplied by a factor of 126. The normal factor is only 10 to 20!

We have already seen 300-bushel corn and 200-bushel wheat. Who will be the first to produce 100-ton tomatoes or 20-ton bush beans?