Production & Marketing Reports

Harvest Mechanization for Deciduous Tree Fruits and Brambles

Donald L. Peterson

Summary. Hand-harvesting fruit crops is labor-intensive, and the supply of dependable, skilled labor is a concern of the fruit industry. Only a small portion of all fruit crops is harvested mechanically, primarily for processing. Public funding of mechanical harvesting research on fruit crops has reached a low level. However, there is renewed interest in mechanical harvesting research due to the potential scarcity of hand-harvest labor and new federal laws that may deplete further the labor pool. Much of the research expertise in mechanical harvesting of fruit crops has been lost, since most projects have been discontinued. Considerable lead time will be required to develop facilities, personnel, and projects if the decision is made to initiate publicly funded harvest mechanization research. More time will be required before commercially acceptable techniques and methods will be available. A majority of the research described in this paper was conducted outside the United States. The United States will not remain competitive in the world market for fruit crops with the present lack of mechanical harvesting research.

Appalachian Fruit Research Station, USDA/ARS, Kearneysville, WV 25430-9802.

Mention of a trademark, propriety product or vendor does not constitute a warranty of the product by the USDA and does not imply its approval to the exclusion of other products or vendors that may be suitable.

Fruit crops are an important component of the diets of consumers in the United States and other developed countries. Fruits in the diets of third-world countries will become more important as those countries' standard of living is raised. In all countries, as the standard of living increases, the demand for fresh fruits also increases. Fruit production is a costly and labor-intensive operation. Harvest labor alone can account for up to 50% of the labor required for fruit production (Brown et al., 1983b).

The availability and quality of a sufficient labor force to hand-harvest fruit crops has been a concern of growers for most of this century (Torres, 1988). As early as 1917, the U.S. Congress enacted "Guest Worker Programs" to permit farm laborers to be brought into the United States for temporary migrant work. In 1942, a "Bracero Program" was enacted by Congress to relieve labor shortages, and it operated formally and informally until Dec. 1964. Since that time, many foreign workers (mainly from Mexico) have continued to harvest fruit crops (Martin and Mines, 1983). Often the harvest labor force has consisted of > 50% undocumented workers (Martin, 1985; Mines and Martin, 1983). Large numbers ofundocumented workers in the United States have presented a major problem for the Immigration and Naturalization Service (INS). In 1983, 4 to 6 million foreign workers were reported to be living and working illegally in the United States, and the INS apprehended almost 1 million undocumented workers.

To solve the problems of illegal migration into the United States, Congress, in 1986, passed the Immigration Reform and Control Act (IRCA), which authorizes severe fines and potential jail terms for growers and other employers who knowingly hire undocumented workers. Reducing the number of undocumented workers in the United States was expected to decrease the labor supply for harvesting perishable fruit crops. However, Mines (1991) reported that there has been an adequate labor supply since the passage of IRCA. He indicated one of the reasons for the adequate supply of labor is continued migration from Mexico. These undocumented workers are circumventing the employer sanction of IRCA with fraudulent documentation. The 1990 National Agricultural Workers Survey (NAWS) (Mines et al., 1990) found that 25% of agricultural workers in the southeastern United States performing seasonal agricultural service (SAS) were unauthorized. The rest of the country averaged ≈ 10% unauthorized workers. NAWS also found that although 74% of SAS workers were willing to do more SAS work, only 41% were willing to migrate in search of additional work. One-half of all perishable-crop farm workers are migrants. NAWS also found that nearly half of all SAS workers earn income below the poverty level and work less than half the year. Even though, in general, there appears to be an adequate work force to perform SAS work in the United States, the above facts indicate instability and that labor shortages could occur in areas where perishable crops have to be harvested. Friedland et al. (1979) stated that uncertainty of labor supply is one of the greatest stimuli to increased mechanization. This prospect suggests that renewed interest in research on mechanical harvesting is warranted.

A CAST report (1983) on agricultural mechanization concluded that, in the long run, consumers are the principal beneficiaries of adoption of new agricultural technologies through increased product supply and lower or more stabilized prices. Other mechanization benefits cited were:

- Greater reliability in crop production
- Reduced human physical effort and drudgery
- Increased personal and family income
- Decreased labor-management problems and risks
- Applicability to large and small operations

- Performance of tasks in a more timely manner
- Increase in manufacturing jobs

CAST also concluded that future mechanization oflabor-intensive crops, such as fruits and vegetables, could be expected to produce only local and regional labor effects.

The remainder of this paper will discuss for deciduous tree fruits and brambles: 1) The labor situation for hand-harvesting; 2) current status of commercial mechanical harvesting and potential, and 3) recent and current research progress on mechanical harvesting.

Deciduous tree fruits

Labor situation. Hand-harvest labor for deciduous tree fruits comes from a number of sources as typified by the apple industry. In 1987, >42,000 workers were employed to harvest the apple crop in Washington (Stover, 1988). Forty percent of the workers were permanent local residents, and another 15% were state residents beyond daily commuting distances. Thirty-four percent were from other states in the United States, and 11% were foreign workers. In 1990, the Wage and Employment Survey, conducted by the U.S. Dept. of Labor (information gathered from ETA forms 223 and 232 required under federal law for state agencies engaged in recruitment of agricultural workers), showed similar employment patterns for the state of Washington; however, no foreign workers were employed.

Information from similar surveys conducted in 1990 in the northeastern apple-producing area (Pennsylvania, Virginia, West Virginia, and Maryland) showed a very sporadic pattern for the harvest labor source. In the northeast, harvest labor source was 0% to 100% local, 0% to 100% migrant, or 0% to 100% foreign workers, depending on location or state. The uncertainty of a stable available harvest labor supply can be a major frustration for orchardists. During the 1990 West Virginia Horticultural Society Meeting, C. Peters, orchardist and 1990 president of the Washington State Horticultural Assn., and S. Blizzard, Texas orchardist, stated that, during the 1990s, labor supply would be a significant problem for fruit growers. At a 1990 project review at the Appalachian Fruit Research Station, Kearneysville, W. Va., D. Derr, president of the International Apple Institute, emphasized the need for mechanical harvesting techniques to meet the industry's future labor shortages.

At the same review, R. Slonaker, orchardist and 1990 president of the West Virginia Horticultural Society, stated that fruit growers are too dependent on an unreliable supply of hand labor. He emphasized the need for tree designs for mechanical harvesting, and improved methods and equipment for mechanical harvesting. In addition to insufficient harvest labor during the short harvest season, growers face other risks while using hand harvesting, such as strikes by harvest workers, unionization, inadequate supervision, inadequate worker housing, and court settlements brought against the grower by the worker or tines for not meeting legal requirements relative to hired harvest workers (Ricks and O'Brien, 1983).

Commercial mechanical harvesting status. With the end of the Bracero Program, two fruit crops that have very high hand-labor requirements, tart cherries and prunes, went from < 10% mechanical harvesting to >80% mechanical harvesting in 6 to 8 years (Brown et al., 1983a). Without mechanization or an adequate harvest labor supply, the survival of those industries may have been questionable. Harvest costs might have risen to a point where hand harvesting was no longer economically feasible. Mechanical harvesting was at least 10 times more labor-efficient than hand harvesting.

Brown (1985) and Brown et al. (1983b) summarized the status of commercial mechanical harvesting of horticultural crops. The status has not changed significantly in the interim years. Less than 5% of the apple crop is harvested mechanically, and all of that is for processing. Excessive damage inflicted by commercial shake-catch harvesters prevents wider acceptance for the processing industry and does not meet the higher standards ofquality required by the fresh-market industry.

A small percentage of cling peaches for processing in California is harvested mechanically with shake-catch systems, but lack of uniform maturity is a major drawback to increased adoption of mechanized harvest for processing and fresh market. Damage inflicted during machine-harvesting is not a major deterrent to mechanical harvesting of fresh-market quality peaches, since damage levels are comparable to those for hand-harvesting. Plums for the fresh market are hand harvested selectively as they ripen and are not likely to be mechanically harvested commercially in

Table 1. ***Engineers conducting deciduous tree fruit harvest mechanization research in the United States.***[z]

Project location	Crop	No. research engineers[y] 1971	1981	1991
State				
Davis, Calif.	Peach, prunes	3	2	1
Athens, Ga.	Peach	1	---	---
Ithaca, N.Y.	Apple	2	1	---
Corvallis, Ore.	Apple, cherry	1	2	---
Amherst, Mass.	Apple	1	---	---
E. Lansing, Mich.	Apple, cherry	1	1	1
State College, Pa.	Apple	1	---	---
Clemson, S.C.	Peach	2	2	---
College Station, Texas	Peach	2	---	---
Morgantown, W.Va.	Apple, peach	1	1	---
Madison, Wis.	Cherry	1	---	---
Total		16	9	1
USDA, ARS				
Davis, Calif.	Peach, prune	1	---	---
Byron, Ga.	Peach	2	---	---
E. Lansing, Mich.	Apple, cherry	2	2	---
Kearneysville, W.Va.	Apple, peach	---	1	1
Wenatchee, Wash.	Apple	2	1	---
Totals		7	4	1

[z]*Data compiled from author's experience and survey of* past *fruit mechanization researchers.*
[y]*May not be full time SYs in fruit harvest mechanization.*

the near future. Sweet cherries destined for the fresh market suffer excessive damage when harvested with present commercial shake-catch systems, preventing acceptance at this time. Both fresh-market and processed pears are picked almost exclusively by hand, since damage levels are excessive when commercial shake-catch harvesting equipment is used. Depending on the crop, labor productivity can be improved by a factor of 5 to 15 by using mechanical harvesting.

Research effort. Public support for research on mechanized harvest of deciduous tree fruits peaked in the 1960s and '70s and then declined (Table 1). Some of that decline can be attributed to acceptance of commercial mechanical harvesting for prunes and tart cherries. Publicly funded research into mechanical harvesting of these two crops (Adrian and Fridley, 1969; Levin et al., 1969) greatly assisted in their successful commercialization.

A significant factor in the decline in publicly funded research in mechanization is the strong antimechanization movement given encouragement by a lawsuit against the Univ. of California for using public funds to support mechanization research (The Grower, 1979) and from political policy during President Jimmy Carter's administration. When asked to to comment on the California lawsuit, then Secretary of Agriculture R Bergland responded by saying, "I will not put federal money into any project that results in savings on farm labor" (Best, 1980). Secretary Bergland later clarified his comments by stating that research on mechanization may be appropriate if it eases the drudgery of work, or when an adequate and willing work force is not available (Bergland, 1980). The debate on what constitutes an adequate and willing work force is ongoing. In the 10 years following Bergland's statements, the USDA's Agricultural Research Service discontinued 75% of its research effort on mechanical harvesting of deciduous tree fruits (Table 1), their citrus harvesting project [2 significant years (SYs)], and their only vegetable mechanization project (2 SYs).

Despite substantial past efforts on mechanical harvest of tree fruits, damage inflicted on the fruit during the harvesting process is still a major obstacle to commercial adoption. Recent research and present efforts place emphasis on adapting the tree design and machine component design to be compatible. The majority of this work is outside the United States.

Peterson (1985) summarized cultural modifications necessary for mechanical harvesting of tree fruits. The Tatura Trellis training system combined a narrow fruiting canopy (Chalmers et al., 1978) with a mating incline catching surface and customized detachment principles (Gould et al., 1986) in an attempt to minimize damage during peach harvest. Damage levels were very low, but still had the problem of nonuniform maturity. Colorio (1987) used a "multiple basket" position under a "V" trellis with a series of above-limb impacters to harvest apples. Initial results look promising in reducing bruise damage.

The Lincoln Canopy System (Dunn and Stolp, 1980) used a "T"-shaped trellis for apples to present a single horizontal tier for mechanical harvesting. Dunn and Stolp (1980) and Domigan et al. (1988) used an under-limb impacter and catching surface positioned under the trellis to effect mechanical harvesting. Land (1989) used a rotating drum shaker to remove apples from the Lincoln Canopy. Peterson and Miller (1988) used their over-the-row continuously moving shake-catch harvester with specialized catching surfaces and trunk impacter to remove fruit from the Lincoln Canopy. A rod press harvester (Peterson and Miller, 1988) was designed to push fruit off the Lincoln Canopy, and I.R Domigan (personal communication) is studying an above-canopy limb shaker to effect fruit removal. All types of harvesting systems have potential but have not reached the commercialization stage.

Bennedsen (1986) described a series of foam Xs and Ls that have special pivoting components to enable them to decelerate and transfer fruit. These systems were effective in reducing damage to free-falling apples, but required specialized construction techniques and have not been commercialized. Peterson (1991) developed a specialized catching surface using counter-rotating foam cylinders to decelerate and then transfer free-falling fruit to a conveying system. This catching surface is being evaluated on his experimental over-the-row continuously moving shake-catch harvester. Grand d'esnon et al. (1987) have developed a self-propelled robot harvester to pick apples. The unit is functional, but field losses are high and development is continuing.

Brambles

Labor situation. Barton (1991) indicated that labor to harvest fresh market- quality brambles, a very labor-intensive operation, is becoming more difficult for growers to obtain. Hand-picking brambles requires 600 to 1000 $h \cdot ha^{-1}$. Brambles need to be picked three to four times per week for 3 to 8 weeks, depending on cultivar. The fruit is small and delicate, and often the bramble plant is thorny. Availability of hand-harvest labor for brambles is probably more uncertain than it is for. tree fruits.

Commercial mechanical barvesting status. Reviews by Booster (1983), Brown et al. (1983b), and Martin (1985) concluded that mechanical harvesting of certain cultivars of raspberries and blackberries was a commercial reality in many parts of the United States. Labor productivity improved by a factor of 12 to 20 with mechanical harvesting. Nearly all the mechanical harvesting is for the processing industry.

Selective mechanical harvesting of brambles is possible since the detachment force decreases as the fruits mature. Commercial mechanical bramble harvesters employ two types of shaking mechanisms. The first consists of one or more pairs of oscillating horizontal or nearly horizontal beater bars (Littau Harvester, Stayton, Ore.; Korvan Industries, Lynden, Wash.; BEI, South Haven, Mich.). The second principle uses a vertically oriented spiked-drum shaker that is oscillated in a horizontal plane relative to the rotation of the drum. The spiked-drum shaker is activated by either an inertia drive (Weygandt, Canby, Ore.) or an eccentric cam mechanism (BEI).

Research effort. The shortage of harvest labor has prompted equipment manufacturers to look more closely at their harvesters to minimize damage for the more stringent fresh-market quality requirements, and may stimulate public funding for renewed bramble harvest mechanization research. Peterson et al. (1989) are developing a mechanical harvester for Eastern thornless blackberries. A unique shaking mechanism that provides uniform acceleration and displacement within the fruiting canopy shows promise for reducing berry damage. Similar shaker designs, emphasis on improved catching surfaces and conveying systems, and innovative trellis training systems may make mechanical harvest of delicate brambles for fresh-market quality feasible.

Literature Cited

Adrian, P.A. and R.B. Fridley. 1969. Mechanization and handling of deciduous fruits by the shake-catch method, p. 677-686. In: B.F. Cargill and G.E. Rossmiller (eds.). Fruit and vegetable harvest mechanization—Technological implications. Rural Manpower Ctr. Rpt. X16, Michigan State Univ., East Lansing.

Barton, K. *1991.* Reaping greater profits. The Grower 17-22.

Bennedsen, B. 1988. Study of mechanical apple harvesting methods. Meddeleise, Jordbruksteknisd Inbstut SP:73.

Bergland, B. 1980. The federal role in agricultural research. Agr. Eng. April:32-33.

Best, A.M. 1980. An explanation please! Agr. Eng. April:30-31.

Booster, D.E. 1983. Berry harvesting III. Cane and bush berries, p. 503-519. In: O'Brien, Cargill, and Fridley (eds.). Principles and practices for harvesting and handling fruits and nuts., AVI, Westport, Conn.

Brown, G.K. 1985. Fruit and vegetables mechanization, p. 1-5. In: P.L. Martin (ed.). Migrant labor in agriculture, an international comparison. Giannini Foundation of Agricultural Economics and the German Marshall Fund of the United States, Washington, D.C.

Brown, G.K., D.L. Peterson, J.H. Levin. 1983a. Tree fruit harvesting systems: I. Individual trees, p. 575-587. In: O'Brien, Cargill, and Fridley (eds.). Principles and practices for harvesting and handling fruits and nuts. AVI, Westport, Conn.

Brown, G.K., D.E. Marshall, B.R. Tennes, D.E. Booster, P. Chen, R.E. Garrett, M. O'Brien, H.E. Studer, R.A. Kepner, S.L. Hedden, C.E. Hood, D.H. Lernker, W.F. Millier, G.E. Rehkugler, D.L. Peterson, and L. N. Shaw. 1983b. Status of harvest mechanization ofhorticultural crops. Amer. Soc. Agr. Eng., Spec. Publ. 3-83.

CAST. 1983. Agricultural mechanization: physical and societal effects, and implications for policy development. Rpt. no. 96, ISSN 0194-4088, Council Agr. Sci. and Technol., Ames, Iowa.

Chalmers, D., B. van den Ende, and L. van Heek. 1978. Productivity and mechanization of the Tatura trellis orchard. HortScience 15:517-521.

Colorio, G. 1987. "Multibasker": a non-stop self-propelled harvesting machine for fruit trees growing on inclined surface. Annali dell'Instituto Sperimentale per la Frutticoltura, XVIII:3-14.

Domigan, I.R., R.G. Diener, K.C. Elliott, S.H. Blizzard, P.E. Nesselroad, S. Singha, and M. Ingle. 1988. A fresh fruit harvester for apples trained on horizontal trellises. J. Agr. Eng. Res. 41:329-349.

Dunn, J. W. and M. Stolp. 1980. Mechanical harvesting apples and raspberries grown on the Lincoln Canopy system. Acta Hort. 114:261-268.

Friedland, W.H., A.E. Barton, and R.J. Thomas. 1979. Conditions and consequences of lettuce harvest mechanization. HortScience 14:110-113.

Gould, I.V., G.S. Young, and *G.L. Godley. 1986.* Mechanized fruit harvesting from the Tatura Trellis. Amer. Soc. Agr. Eng. paper 386-1070.

Grand d'esnon, A., G. Rabatel, R. Pellenc, A. Journeau, and M.J. Aldon. 1987. Magali—a self propelled robot to pick apples. Amer. Soc. Agr. Eng. paper 87-1037.

Land, Z. 1989. Lincoln canopy apple harvester using a continuous horizontal shaking method. J. Agr. Eng. Res. 44:267-273.

Levin, J.H., H.D. Bruhn, and E.D. Markwardt. 1969. Mechanical harvesting and handling of cherries, p. 677-686. In: B.F. Cargill and G.E. Rossmiller (eds.). Fruit and vegetable harvest mechanization—technological implications. Rural Manpower Ctr. Rpt. no. 16, Michigan State Univ., East Lansing.

Martin, L. W. 1985. Cultural modifications for improving mechanical harvesting of red raspberries and blackberries. HortScience 20:1014-1015.

Martin, P.L. 1985. Introduction, p. l-5. In: P.L. Martin (ed.). Migrant labor in agriculture, an international comparison. Giannini Foundation of Agricultural Economics and the German Marshall Fund of the United States, Washington, D.C.

Martin, P.L. and R. Mines. 1983. Immigration reform and California agriculture, California Agr., Jan.-Feb. 37(1&2):14-15.

Mines, R. and P.L. Martin. 1983. Foreign workers in selected California crops. California Agr., Mar.-Apr. 37(3&4):6-8.

Mines, R.S. Gabbard, and B. Boccalandro. 1990. Findings from the National Agricultural Workers Survey (NAWS) 1990. Res. Rpt. no. 1, Office of Program Economics, U.S. Dept. Labor.

Mines, R. 1991. The future of farm labor in the 1990s, the horticultural, fruit and vegetable industries. Labor Outlook and Mechanization Research Void, ASHS Wrkshp., Pennsylvania State Univ., State College, 22 July 1991.

Peterson, D.L. 1985. Cultural modifications of deciduous tree fruits for mechanized production. HortScience 20(6):1015-1018.

Peterson, D.L., F. Takeda, and T.S. Kornecki. 1989. New shaking concepts for brambles. Trans. Amer Soc. Agr. Eng. 32(4):1165-1168.

Peterson, D.L. and S.S. Miller. 1988. Advances in mechanical harvesting of fresh market quality apples. J. Agr. Eng. Res. 42: 43-50.

Peterson, D.L. 1991. Fruit decelerator, U.S. Patent no. 4,999,986, 19 Mar. 1991.

Ricks, D.J. and M. O'Brien. 1983. Economic aspects of fruit industry, p. 47-72. In: O'Brien, Cargill, and Fridley (eds.). Principles and practices for harvesting and handling fruits and nuts. AVI, Westport, Conn.

Stover, E. 1988. Apple pickers earned over $8/hour state, survey shows. The Goodfruit Grower 39(9):15.

The Grower. 1979. The Grower interviews: Roger Garrett. The Grower, Aug. 6C-9C.

Torres, A. 1988. Impact of the immigration reform and control act of the 1986 on California agriculture. Rpt. Joint Comm. Refugee Resettlement, Intl. Migration and Coop. Dev.

Forecasting Annual Vegetable Plantings

Joseph F. Guenthner[1]

Additional index words. potato, *Solanum tuberosum,* onion, *Allium cepa,* acreage response, alternate crops

Summary. Vegetable producers and marketers make business decisions based on supply estimates. The U.S. Dept. of Agriculture provides estimates of planting intentions for field crops but not for most vegetable crops. This study developed models that can be used to forecast vegetable crop plantings. Multiple linear regression analysis was used to determine the factors that influence plantings of potatoes and onions. Field crop planting intentions, industry structure, lagged values of plantings, prices received, price volatility, and the price of sugar beets were found to be significant factors. The models and/or methods used in this study should be useful to those interested in forecasting vegetable plantings.

Changes in the supply of vegetable crops can cause relatively large price changes. Accurate forecasts of supplies can enable growers, shippers, processors, and supply firms to make more profitable decisions regarding production, contracts, storage, and timing of sales. The U.S. Dept. of Agriculture (USDA) provides estimates of planted areas for most of the major crops grown in the United States. For the main field crops, USDA not only estimates hectares *after* planting but also provides an estimate ofplanting intentions *before* the crop is planted. For mostvegetable crops only the after-planting estimate is done. Exceptions are onions and processor contract intentions for green peas, snap beans, sweet corn, and tomatoes. Those interested in earlier estimates must rely on other sources of information, some of which may be inaccurate.

[1]*Extension Horticultural Economist.*

Department** of Agricultural **Economics; University of Idaho; Moscow, ID 83843; phone (208)882-0874; fax (208)885-5759

The objective of this study was to develop models for forecasting vegetable plantings using field crop planting intentions and other relevant data. Due to differences in alternative crops and other factors that affect plantings, the focus was on state rather than national models. The initial models in this study were estimated for Idaho onions (15% of U.S. crop) and Idaho potatoes (28% of U.S. crop). Idaho onions are grown in the Treasure Valley area, the nation's largest fresh-onion production region. Idaho is also the largest potato-producing state.

Methods

According to Tomek and Robinson (1990), the supply of an agricultural commodity depends on the price of the commodity, input prices, returns of alternative crops, technology, risk, and government programs. Due to the amount of time required to plant, grow, and harvest a crop, Nerlove (1956) verified a time lag between output and prices.

Vegetable planting models have been developed by Hammig (1978), Estes et al. (1982), and Love and Willett (1990) using lagged price relationships. Guenthner and Folwell (1989) built a similar model based on a survey of growers. All these models used lagged prices to handle the alternative crops issue. The model in this study instead uses USDA planting intentions as the alternative crops explanatory variable. This may provide a more reliable variable by capturing actual grower intentions rather than their expected response to prices.

The forecasting equations were estimated by multiple linear regression. The potato model consists of two equations representing the two parts of Idaho for which USDA reports potato plantings: 1) the 10 southwestern counties and 2) all other counties. The southwestern counties are also the primary onion-producing counties in the state.

The potato equations were estimated using USDA-published annual data for the 1978-90 period. While a larger sample size could improve statistical properties, a longer time period was not selected because of changes in industry structure. Earlier data were not used because of the prior collapse of the eastern Idaho sugar beet industry, which changed crop alternatives. The onion equation was estimated from annual data for the 1973-90 period.

Results

The estimated equations are in Table 1. There are five categories of explanatory variables: 1) hectares planted the previous year; 2) price of the previous crop; 3) price risk; 4) alternate crops prospects; and 5) changes in market structure. All explanatory variables were designed so that forecasts could be made from their current values.

The lagged hectares variable represents "asset fixity." Growing vegetables in the United States requires large investments in specialized equipment, including planters, harvesters, and storage facilities. Once growers. invest in these factors of production they are likely to continue to grow the vegetable crop. The lagged hectares variable can be viewed as a proxy for current investment in vegetable production assets.

Lagged price (¢/kg) also was included because some growers develop their price expectations for the next crop based on the price for the previous crop. The sign of this variable is positive; as prices increase growers respond by planting more hectares.

The third type of variable, price risk, is the difference in price (e/kg) between the previous 2 years. The negative coefficient in the "other" Idaho potato equation indicates that those growers are risk- averse; increased price volatility causes a reduction in potato plantings. The positive coefficient in the other two equations indicates that southwestern Idaho growers are risk-takers.

One reason for the difference in risk preference is that there are dozens of alternative crops in southwestern Idaho, but relatively few in the rest of the state. Increased price volatility may be seen by southwestern Idaho growers as an opportunity to make money on one of their many crops, but growers in the rest of Idaho may see it as a possibility of losing money on their main crop. Another reason is that many southwestern Idaho growers contract with potato processors, while eastern Idaho is primarily an open market. With the security of contracts, southwestern Idaho growers can afford to take on more risk for the portion of their crop that is not contracted.

Alternative crop prospects are

represented by two different types of variables. First, the lagged sugar beet price ($/mg) is used because USDA no longer estimates planting intentions for that crop. Second, the planting intentions variable represents the USDA estimate for the relevant field crops that are grown in the area. For the onion equation, this variable is total Idaho planting intentions for wheat, barley, and hay. The selection of these field crops is supported by Greene's (1991) survey of onion growers' alternate crop enterprises. Wheat and barley make up the intentions variable for the other Idaho potato equation; corn, beans, and hay are used for the southwestern Idaho potato equation.

The dummy variables in two of the equations represent changes in the structure of the industry. The variable has a value of 1 after the change and 0 before the change. In the onion equation, the dummy variable represents expansion of onion processing and fresh-pack facilities in 1985. In the southwestem Idaho potato equation, the dummy variable represents a contraction of the industry due to a potato quality problem. Beginning in 1986, potato processors reduced the amount of hectares contracted in the region because of concerns about sugar ends. Potato plantings dropped from 12,150 hectares in 1985 to 6885 hectares in 1986.

Discussion

The R^2 values in Table 1 indicate that more than 90% of the variation in hectares is explained by the equations. The accuracy of the onion model can be compared to the USDA intentions reports (Table 2). The comparison is not direct because the USDA estimate is for the Treasure Valley, which includes southwestern Idaho as well as eastern Oregon—a separate intentions report for Idaho was not done. The root mean square error (RMSE) at the bottom of Table 2 indicates that the forecasting equation was a more accurate predictor than the planting intentions report. Out-of-sample forecasts for 1991 gave errors ranging from –3.5% for onions to 4.0% for potatoes in southwestern Idaho, to 6.4% for potatoes in the rest of the state.

The forecasting models developed in this study may provide more reliable forecasts than the USDA planting intentions reports; one reason is that growers may change their planting plans after they read the planting intentions reports. In a recent survey (Guenthner and Folwell, 1989), growers rated planting projections as the third most important factor they consider when deciding how much to plant. The models developed in this study avoid the problem of grower response to USDA preplaming estimates.

The models fit the data well, and if grower behavior does not change, they could provide reliable forecasts of hectares planted in the future. Grow-

Table 1. ***Estimated equations for potato and onion hectares planted in Idaho.***

Explanatory variables	Dependent variables (ha planted)[z] Onions	Potatoes, southwest (1000 ha)	Potatoes, other (1000 ha)
Constant	2260.0	31.9	54.4
Hectares lagged	0.17	0.90	0.66
	(1.7)	(4.7)	(4.5)
Price lagged (¢/kg)	5.6	0.32	3.0
	(1.6)	(3.6)	(6.9)
Price risk (¢/kg)[y]	5.7	0.42	–2.2
	(1.4)	(2.2)	(2.8)
Sugar beet price lagged ($/mg)	–7.2	–0.08	
	(2.3)	(2.1)	
Planting intentions[x] (1000 ha)	–0.44	–0.05	–0.05
	(1.6)	(4.7)	(3.9)
Dummy variable[w]	932.0	–5.2	
	(9.7)	(8.3)	
R^2	0.98	0.98	0.92

[z]*Values in parentheses are t ratios.*
[y]*The price risk variable is the absolute difference in price the previous two seasons.*
[x]*Planting intentions are for corn, beans, and bay in the onion and southwest potato equations, and for wheat and barley in the otherpotato equation.*
[w]*Dummy variables represent expansion of processing facilities in the onion equation and the potato sugar end problem in the southwest potato equation.*

Table 2. ***USDA intentions reports.***

Year	Forecasted, Idaho Actual	Predicted	Error	Intentions, Treasure Valley Actual	Predicted	Error
1990	3159	3071	–88	7290	7128	–162
1989	3078	3086	8	7128	7128	0
1988	3118	3130	12	7290	7087	–203
1987	3159	3151	–8	6925	6885	–40
1986	2875	2969	94	6358	6480	122
1985	2875	2856	–19	6885	6075	–810
1984	1903	2078	175	5670	5467	–203
1983	2025	1969	–56	5265	5062	–203
1982	2025	1982	–43	5062	4860	–202
1981	2065	1990	–75	4698	---[z]	---
1980	1863	1831	–32	4455	4414	–41
1979	1863	1957	94	4779	5508	729
1978	2146	2050	–96	5103	5022	–81
1977	2187	2121	–66	5022	4536	–486
1976	2187	2081	–106	4657	4455	–202
1975	1863	1858	–5	4131	4131	0
1974	1863	1979	116	4131	4252	121
1973	2025	2114	89	4333	4009	–324
Root mean square error			0.78			1.43

[z]***Not available.***

ers, processors, and university specialists might adopt this framework to forecast vegetable plantings in other states. Analysts should account for alternate crops specific to the area and changes in industry structure. The main limitation of the models is that growers do not always behave according to model expectations.

Literature Cited

Estes, E., L. Blakeslee, *and R.C. Mittle*hammer. 1982. Regional and national impacts ofexpanded Pacific Northwest potato production. Western J. Agr. Econ. 7:l.

Greene, C. 1991. Characteristics of onion growers and farms in six major onion states. Vegetables and Specialties Situation and Outlook, U.S. Dept. Agr. ERS, April.

Guenther, J.F. and R.. Folwell. 1989. Forecasting potato acreage. Proc. Idaho Potato School, Pocatello, 24-27 Jan.

Hammig, M.D. 1978. Supply response and simulation of supply and demand for the Unites States fresh vegetable industry. PhD Diss., Washington State Univ., Pullman.

Love, J.M. and L.S. Willett. 1990. Modelling the U.S. potato industry. Vegetables and Specialties Situation and Outlook, U.S. Dept. Agr. ERS, March.

Nerlove, M. 1956. Estimates of the elasticities of supply of selected agricultural commodities. J. Farm. Econ. 38:496-509.

Tomek, W.G. and K.L. Robinson. 1990. Agricultural product prices. 3rd ed. Cornell Univ. Press, Ithaca, N.Y.

A Comparative cost Analysis of Vegetable Irrigation Systems

J.W. Prevatt[1], G.A. Clark[2], and C.D. Stanley[3]

Additional index words. farm management, economics, decision-making.

Summary. Three vegetable irrigation systems, semi-closed subirrigation (seepage), fully enclosed subirrigation (seepage), and drip irrigation, were evaluated for use on sandy soils with naturally high water tables to determine comparative irrigation costs for tomato production. Investment, fixed (ownership), and variable (operating) costs were estimated for each irrigation system. The investment costs of the drip irrigation system were significantly greater than those for the semi-closed and fully enclosed irrigation systems. The variable costs, however, for the semi-closed system were considerably less than those for the fully enclosed and drip irrigation systems. The semi-closed irrigation system, therefore, was determined to be the least-cost tomato irrigation system under present fuel cost and nonlimiting water supply conditions.

Irrigation is an essential production input for the majority of Florida vegetable growers to achieve adequate yields and suitable crop quality. A large percentage of vegetable production and farm income would not be realized without the aid of irrigation (Sammis, 1980). Therefore, because of the important contribution of irrigation to vegetable production and farm incomes, any major adjustment in irrigation system design, management practices, or use could have a large impact on vegetable profits.

Irrigation is a major cost component of any vegetable enterprise. Irrigation costs of vegetable crops have increased significantly during the past 3 decades, primarily as a result of rising energy costs, higher interest rates, and inflation. In many areas water has become a limited resource due to increased competition among agricultural and nonagricultural users, thus resulting in tighter restrictions on its use by regulatory agencies.

As a result of recent increases in irrigation costs, limited water supplies, and new vegetable irrigation technology, many vegetable growers are considering alternative irrigation systems for new installations and/or the replacement of traditional irrigation systems as they either wear out or become cost-prohibitive. The selection of a vegetable irrigation system is influenced by economic, biological/physical, and institutional/regulatory considerations.

Specifically, this paper evaluates the economics of owning and operating three different irrigation systems for the production of fresh-market vegetables on sandy soils with naturally high water tables in Florida. While changes in irrigation system design and management may affect crop yields, this analysis assumes that recommended management practices are followed for each system design such that yields would not be affected. This assumption is supported by previous studies comparing yields of drip and subirrigated fresh-market tomatoes in Florida (Pitts et al., 1988; Pitts and Clark, 1990; Clark et al., unpublished data).

Two of the irrigation systems (fully enclosed and drip) have been shown to have higher water application efficiencies than the most common irrigation system (semi-closed). The fully enclosed subirrigation system, which achieves water-table control using drip tubing to apply water instead of lateral ditches (which is the case with semi-closed), was developed to improve water conservation while still using subirrigation. In contrast, drip irrigation is a technologically advanced system that requires a commitment to intense management to achieve a higher level of water conservation (application efficiency) and does not use water-table control.

[1]*Associate professor, Dept. of Agricultural Economics and Rural Sociology, Auburn Univ., Ala.*

[2]*Associate* ***professor.***

[3]***Assistant professor.***

Gulf Coast Research and Education Center–Bradenton, Institute for Food and Agricultural Sciences, University of Florida, Bradenton, FL 34203.

Cost analysis

This study evaluated the initial investment, annual fixed costs, and variable costs of three vegetable irrigation systems common to southwestern Florida. The evaluation of these irrigation systems was based on installation, operation, andmaintenance costs with respect to fresh-market tomato production on plastic-mulched raised beds. A hypothetical 100-acre (40.5 ha) site measuring 1320 × 3300 ft (402.4 x 1006.1 m) was used to design the irrigation systems and field layout. Perimeter roads, swale ditches, and the well site were included in the layout. Bed rows were constructed on 6-ft (1.83-m) centers with a 13-ft (3.96-m) spray and harvest aisle every three beds, as shown in Fig. 1. Irrigation/drainage ditches were designed in the spray and harvest aisle and spaced every 25 ft (7.62 m). Disposable drip tubing was selected to be used in the fully enclosed and drip irrigation systems (i.e., variable costs).

Description of irrigation systems

The semi-closedirrigation system uses PVC pipe to deliver irrigation water from the pump to the field lateral ditches. Water is applied into lateral ditches that may be spaced from 20 to 30 ft (6.1 to 9.2 m) apart, which are used to maintain a water table at 16 to 20 inches (40.64 to 50.8 cm) below the soil surface [naturally high water table is at 36 to 48 inches (90 to 120 cm) below soil surface]. Peak daily application amounts average 12,000 to 15,000 gal (45,360 to 56,700 liters)/acre (0.405 ha). Extensive water losses are due to runoff, nonuniformity of application, evaporation, and subsurface runoff, resulting in water application efficiencies of 30% to 70% (Smajstrla et al., 1988).

The fully enclosed irrigation system differs from the semi-closed system in that water is applied in the field by a pressurized plastic drip tube (10 mil, 12-inch emitter spacing) buried from 1 to 16 inches (2.5 to 40.64 cm) below the soil surface (Clark et al., 1990). Drip tubes are spaced 20 to 30 ft (6.1 to 9.2 m) apart and operated to maintain a water table at 16 to 20 inches (40.64 to 50.8 cm) below the soil surface. Peak daily application amounts average 7000 to 9000 gal (26,460 to 34,020 liters)/acre (0.405 ha), depending on field conditions and evaporative demand. Water loss is primarily due to evaporation and subsurface runoff, resulting in a higher application efficiency than the semi-closed irrigation system (Stanley and Clark, unpublished data).

The drip irrigation system uses buried PVC pipes to deliver irrigation water to the field (Clark et al., 1988). In the field, water is distributed to plants via a plastic drip tube (15 mil, 24-inch emitter spacing) placed in each plant bed. Irrigations are scheduled to meet crop water requirements with peak daily application amounts averaging 5000 to 7000 gal (18,900 to 26,460 liters)/acre (0.405 ha).

Investment, fixed, and variable costs

Making the correct irrigation system selection based on costs requires an understanding of how different types of costs affect total irrigation costs. The information needed to develop a cost analysis includes investment, fixed, and variable costs (Osburn and Schneeberger, 1978). Investment cost may be interpreted as the amount of capital necessary to purchase the irrigation system ready for operation. Fixed costs are unrelated to output and do not vary during the production period. The fixed costs considered include depreciation, interest, repairs, taxes, and insurance. Variable costs are those that vary with output during the production period. These costs were determined by the price and quantity of inputs such as fuel, labor, chemicals, drip tube, etc.

The investment costs of the irrigation systems were based on a 100-acre (40.5-ha) site. The basic components of each system included a well, pump, power unit, and distribution system. Agribusiness representatives and university research and extension personnel furnished price and quantity estimates for the design, materials, and installation of the irrigation systems.

The fixed costs of depreciation, interest, repairs, taxes, and insurance were calculated for each irrigation system to determine the annual fixed costs (Osburn and Schneeberger, 1978). The investment cost, salvage value, and useful life (years) of the many different inputs of an irrigation system determine the level of depreciation. Depreciation (a non-cash expense) simply allocated the loss in value over the life of the irrigation system to particular time periods. Annual depreciation was calculated with a straight-line depreciation schedule (investments cost minus salvage value divided by the asset's useful life). Interest costs were calculated at 12% of the average of investment cost and salvage value for each item. Repairs, taxes, and insurance costs were estimated at 4.0%, 1.6%, and 0.6% of the investment costs, respectively.

The variable costs of pumping fuel, labor, drip tubing, and chemicals were calculated from operation and maintenance specifications and production requirements. The pumping variable costs were estimated based on supplying 66, 46, or 24 inches of water for the semi-closed, fully enclosed, and drip irrigation systems, respectively (Harrison and Choate, 1969). Labor costs were estimated for the three irrigation systems from time requirement information furnished by growers and university personnel. Drip tube and chemical treatment costs were obtained form agribusiness representatives. The opportunity cost of operating capital was assumed to be 10% annually for 6 months.

Table 1. ***Investment costs of vegetable irrigation systems, 1991.***[z]

Item	Semi-closed	Fully enclosed	Drip irrigation
Investment costs[y]	$61,820	$65,846	$84,355
Investment costs/acre[x]	$1,005	$1,071	$1,372
Investment costs/TLBF[w]	$138	$148	$189

[z]*The basic components of each irrigation system include a well, pump, power unit, and distribution system. Drip tubing costs were not included in the investment cost estimates since its useful life was consider to be 1 year or less. Drip tubing costs were assumed to be variable costs as shown in Tables 4 and 5.*

[y]*Investment costs of each irrigation system are based on a 100-acre (40.5-ha) site.*

[x]*An acre (0.45 ha) is 7260 linear bed feet (2213 linear bed m).*

[w]*TLBF denotes thousand linear bed ft (304.9 linear bed m).*

Results and discussion

The initial investment costs for the three irrigation systems are shown in Table 1. The drip irrigation system was the most expensive at $84,355 for the 100-acre (40.5-ha) site. The investment costs for the semi-closed and fully enclosed systems were $61,820 and $65,846, respectively. Investment costs per acre (7260 linear bed ft or 2213 linear bed m) and investment costs per thousand linear bed ft (TLBF or 304.9 linear bed m) also are provided in Table 1.

The annual fixed costs of the three irrigation systems are reported in Table 2. The drip irrigation system had the highest annual fixed costs ($15,926), while fixed costs for the semi-closed and fully enclosed systems were $11,257 and $12,117, respectively.

The variable costs of the drip, semi-closed, and fully enclosed irrigation systems are shown in Table 3. The drip irrigation system had the highest variable costs at $20,148, followed by the fully enclosed ($15,237) and the semi-closed ($9255) systems. The variable costs of the fully enclosed and drip irrigation systems were larger than those for the semi-closed primarily due to the cost of the drip tubing. The chemical variable cost associated with drip tube maintenance (to prevent clogging) is influenced by operation time and system flow rate. Hence, the fully enclosed system, which used less drip tubing, incurred a chemical variable cost similar to the drip irrigation system due to the increased quantity of water used for irrigation.

The total cost of the irrigation system is simply the sum of the fixed and variable costs associated with each irrigation system, as shown in Table 4. The semi-closed system had the lowest total cost at $20,512 for the 100-acre (40.5-ha) site, while total cost for the fully enclosed and drip irrigation systems were $27,354 and $36,064, respectively.

The results of this analysis clearly indicate the semi-closed irrigation system would be the least-cost choice for a new installation. Therefore, assuming all other parameters (interest rates, energy costs, water permits, yield, quality, etc.) are held constant among irrigation systems, growers will choose the irrigation system with the lowest total costs.

The information developed here represents the estimated average annual total costs of the new systems. You should be aware that the actual costs incurred by the grower over time (yearly) will most likely be different. However, the estimated average annual total costs described here should approximate the weighted average of the actual costs incurred by the grower.

Table 2. ***Annual fixed costs of vegetable irrigation systems, 1991.***

Item	Semi-closed	Fully enclosed	Drip irrigation
Annual fixed costs			
Depreciation	$3,715	$4,084	$5,634
Interest	$3,709	$3,951	$5,061
Repairs	$2,473	$2,634	$3,374
Taxes	$989	$1,054	$1,350
Insurance	$371	$395	$506
Total annual fixed costsz	$11,257	$12,117	$15,926
Total annual fixed costs/acre[y]	$183	$197	$259
Total annual fixed costs/TLBF[x]	$25	$27	$36

[z]*Annual fixed costs of each irrigation system are based on a 100-acre (40.5-ha) site.*
[y]*An acre (0.45 ha) is 7260 linear bed ft (2213 linear bed m).*
[x]*TLBF denotes thousand linear bed ft (304.9 linear bed m).*

Table 3. ***Variable costs of three irrigation systems, 1991.***

Item	Semi-closed	Fully enclosed	Drip irrigation
Variable costs			
Chemical treatment	NA	$1,476	$1,476
Drip tube	NA	$3,864	$10,500
Drip trube installation	NA	$404	$716
Irrigation maintenance labor	$1,120	$560	$1,120
Irrigation manager (acres/day)	$371	$395	$506
Pumping (diesel fuel)	$7,135	$7,088	$2,247
Operating interest	$441	$726	$959
Total variable costs/season[z]	$9,255	$15,237	$20,148
Total variable costs/season/acre[y]	$151	$248	$328
Total variable costs/season/TLBF[x]	$21	$34	$45

[z]***Annual fixed costs of each irrigation system*** are ***based on a 100-acre*** (40.5-ha) site.
[y]*An acre (0.45* ha) is 7260 *linear bed ft (2213 linear bed* ***m).***
xTLBF denotes thousand linear bed ft (304.9 linear bed m).

Table 4. ***Total costs of three vegetable irrigation systems, 1991.***

Item	Semi-closed	Fully enclosed	Drip irrigation
Total annual fixed costs	$11,257	$12,117	$15,926
Total variable costs/season	$9,255	$15,237	$20,138
Total irrigation costs[z]	$20,512	$27,354	$36,064
Total irrigation costs/acre[y]	$334	$445	$587
Total irrigation costs/TBLF[x]	$46	$61	$81

[z]*Total irrigation costs are based on a 100-acre (40.5-ha) site.*
[y]*An acre (0.45 ha) is 7260 linear bed ft (2213 linear bed m).*
[x]*TLBF denotes thousand linear bed ft (304.9 linear bed m).*

Other factors affecting irrigation system selection

Frequently, other economic, biological/physical, and institutional/regulatory variables also affect the irrigation selection decision. The semi-closed irrigation system was found to be the least-cost irrigation system while other variables were held constant. However, should changes in these variables occur, growers should examine irrigation cost per unit of output. Small changes in some of the variables may result in dramatic adjustments in the total cost relationships of the irrigation systems. Some of these variables include crop yield, product quality, level of water use, efficiency, etc. For instance, the expanded use of the water resource may allow an individual to farm more acres due to the use of a water-conserving irrigation system or to use an irrigation system more intensely in a multiple-cropping program, thereby distributing costs over multiple crops.

In addition, a grower may want to consider options other than a new installation. The modification of an existing irrigation system may be a desirable alternative to a new installation. This evaluation and the replacement decision of an existing system with a new installation require a time-value analysis of costs.

Traditionally, growers have adopted those irrigation systems that are easily combined in their production system and that produce favorable returns over costs. Given the results of this study under the prevailing conditions (holding all others factors constant) and assuming no yield difference between systems, the well-informed producer would choose the semi-closed system for a new installation.

The use of water for irrigating vegetable crops certainly will continue to be a major input in any vegetable production system. Therefore, growers who understand clearly the factors affecting irrigation costs will likely plan an economical irrigation system.

Literature Cited

Clark, G.A., C.D. Stanley, and P.R. Gilreath. 1990. Fully enclosed subsurface irrigation for water table management. Proc. Fla. Tomato Inst. Fla. Coop. Ext. Serv. Spec. Ser. Rpt. SS-VEC-001. Univ. of Florida, Gainesville. p. 19-30.

Clark, G.A., C.D. Stanley, and A.G. Smajstrla. 1988. Drip irrigation on mulched bed systems: Components, system capacities, and management. Fla. Coop. Ext. Serv. Bul. 245. Univ. of Florida, Gainesville.

Harrison, D.S. and R.E. Choate. 1969. Selection of pump and power units for irrigation systems in Florida. Fla. Coop. Ext. Serv. Circ. 330. Univ. of Fla., Gainesville..

Osburn, D.D., and K. C. Schneeberger. 1978. Modern agricultural management, Reston Publishing, Reston Va. p. 61-70.

Pitts, D.J, G.A. Clark, J. Alvarez, P.H. Everett, and J.M. Grimm. 1988. A comparison of micro to subsurface irrigation of tomatoes. Proc. Fla. State Hort. Soc. 101:393-397.

Pitts, D,J. and G.A. Clark. 1990. Comparison of drip irrigation to subirrigation for tomato production in southwest Florida. Applied Eng. 6(6):725-732.

Sammis, T. W. 1980. Comparison of sprinkler, trickle, subsurface and furrow irrigation methods for row crops. Agron. J. 72:701-704.

Smajstrla, A.G., B.J. Boman, G.A. Clark, D.Z. Haman, D.S. Harrison, F.T. Izuno, and F.S. Zazueta. 1988. Efficiencies of Florida agricultural irrigation systems. Fla. Coop. Ext. Serv. Bul. 247. Univ. of Florida, Gainesville.