Apple Research: Present Efforts, Future Needs[1]

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Most of the important changes in the apple industry during the last century have resulted from State and Federal research. Methods have been developed for improvement of nutrition, protection from diseases and insects, extension of storage life, and long-distance shipment.

Research also has largely solved the problem of biennial bearing of trees and decreased markedly the use of hand labor. These developments have resulted in changes in the industry that have made it possible to decrease the acreage to about one-seventh of that in 1920 with little decrease in total production (9).

Difficult problems of national scope remain. Production costs of apples are high. Most existing orchards do not produce the quantity of quality fruit necessary for profitable operation. Orchards that produce less than about 600 bu/acre cannot survive. The fresh-fruit market demands very uniform, high quality apples. They must be appealing in shape, red or bright yellow in color, and completely blemish free. Apples must remain crisp even after extended storage. Consistently high yields of quality fruit, then, looms as the basic requirement of future apple production. Orchard management must also adjust to social changes and effectively utilize permanent labor. New types of high- or ultra-high-density orchards will be needed to meet these demands.

The apple industry again must depend on research for leadership and direction. Is present research developing the scientific basis for future changes? No one knows for sure. Traditionally, fruit research has been an individual effort with little coordination between regions, States, institutions, and individual workers. The direction of present efforts is, therefore, not easy to see at a glance. Future needs are difficult to survey. One needs the collective opinion of many people knowledgeable in the field. A survey of the present research efforts and a comparison of them with anticipated future needs seems necessary.

Definitions

Most agricultural scientists file project reports with the USDA's Current Research Information System (CRIS). We used these reports to survey current research. The CRIS reports reflected the status of research in 1971. Because a recent survey by Harris and Walker (3) is available on total research support, we concentrated on the projects themselves. Several research projects are conducted to discover basic physiological processes in a variety of crops, one of which is apples. We included these projects in the survey because they also contribute to the overall research conducted on apples. There are 302 research projects on apples filed with CRIS. Some of these list more than one line of work. We classified this on the basis of our knowledge of the major interests of the investigator into five major groups: *breeding and genetics, culture and physiology of the tree, postharvest handling, protection of trees and fruit,* and *economics of production.* In some cases we verified the classification by checking with the investigator himself.

Breeding and genetics

Usually 20-25 years are required from the time the original cross is made until a new apple seedling can be developed, evaluated, and introduced as a new cultivar. This timespan is excessive. Breeders usually recognize existing problems and develop new cultivars to answer these problems. Often, by the time the new cultivar is introduced, the need for producing such an apple has passed. In 1937, Magness (7) listed 62 cultivars that had been introduced from breeding programs before that time. Recently, Way (10) listed 37 additional cultivars not mentioned by Magness or which had been introduced since 1937. Few of these cultivars are familiar to horticulturists today, and only one of them has been planted extensively.

Present apple-breeding programs face similar discouraging prospects. Apple scab was an important problem in 1945. A group of outstanding breeders worked 25 years and named the first scab-resistant cultivar in 1970 (1). By this time scab could be completely controlled by sprays, and the need for scab-resistant cultivars was no longer urgent. The most notable development in apple cultivar improvement, the discovery of spur-type compact-size trees, came from the industry. Apple breeders ignored this development. Although this character can be relatively easily incorporated into breeding lines, none of the recently introduced new cultivars are spur-type.

At present, breeders want to develop early ripening, late keeping, red or yellow cultivars that are resistant to diseases and insects. Special consideration is given to developing late blooming cultivars for the hills of Virginia and Georgia and early ripening cultivars for the Southeast. The apple scab program still continues and mildew is the other most important disease for which resistance is sought. Three projects have been started to develop collar-rot-resistant rootstocks for apples. There are numerous projects for testing existing cultivars for local adaptation (Table 1). Because of cost and lack of past success in apple breeding, two of the seven major breeding projects have been discontinued recently and an additional one has been seriously curtailed. Despite all the difficulties, any further decrease in breeding efforts would be a grave mistake. We expect that the time will come when trees will be smaller and orchards be replanted more often. At that time introduction of new cultivars will be easier. Breeders, however, must develop cultivars suitable for such plantings. They also must decrease the time required for developing cultivars by using new techniques developed for shortening juvenile period of trees. Inheritance patterns of desirable characters also should be evaluated and data should be stored in computers that could be consulted to aid in selecting parents to rapidly develop new cultivars when specific needs arise.

Culture and physiology of the tree

Dewey and Schuneman (2) recently identified 5 important defects that may develop during the growing season or result from harvesting operations that are responsible for a large part of the offgrade fruit. These defects are: small fruit (less than 2-1/4 inch), lack of red color, limb rub, russeting, and bruising during harvest. With the exception of russeting, the defects arise from the fact that the fresh-fruit apple industry is based on standard trees. Much of the small and green fruit is produced in the inside of the canopy of these trees. Limb rub and bruising during harvest also occur much more frequently on fruit from these large trees.

Considerable work has been done to replace the large trees on standard rootstocks either with trees on dwarfing

Table 1. Projects concerning breeding and genetics of apples reported in CRIS in 1971.

Type	No. of projects
Major breeding projects	7
Breeding for rootstocks	3
Development of new cultivars by irradiation	3
Use of chemical mutagens	1
Cultivar testing in apple producing areas	7
Cultivar testing in nonapple producing areas	11

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rootstock or with spur-type trees. Projects are in progress on tree spacing, pruning, rootstock testing, enhancing flower formation of trees in high density orchards, and fruit thinning of spur-type trees (Table 2). With the introduction of smaller trees, tree density has increased. Heinicke (4) modified the small bush tree and adapted it to maximum light utilization by developing the central-leader tree for high-density orchards. This type tree eliminates most of the disadvantages of the standard tree. High-density orchards with central-leader trees fit well into present orchard operation. Growers can use large equipment in plantings of 300 trees/acre, yet take care of residual standard trees in their orchard. The central-leader tree, however, is still too large to provide comfortable working surface for pruning and harvest and has a limited potential per acre. Even this advanced tree and planting plan can be considered only as an intermediate step toward the ultra-high-density orchards of the future. Our research must prepare for dwarf trees in ultra-high-density orchards which are the only units with sufficient potential to provide a profitable yield of high-quality fruit.

The cultural requirements of ultra-high-density orchards are completely unknown. These orchards will allow us to put many new cultural changes into practice; and because they will be "short-range orchards" being replanted more often than standard or high-density orchards, cultural practices can be more easily updated.

In our climate the existing dwarfing rootstocks are not suitable for ultra-high-density orchards. Rootstock M 27, the possible replacement for M 9, is untried outside the United Kingdom. If it can withstand our high soil temperatures, it may be the rootstock of the future; if not, we must breed rootstocks suitable for our conditions. Own-rooted, spur-type trees may provide an answer. If we wish to use ungrafted trees, a meristem tissue culture method of propagation could decrease the high initial cost of trees. Scattered efforts to develop such propagation methods with apples have been unsuccessful, but there is no reason to believe that this cannot be done if enough effort is exerted.

To produce higher yields, we have succeeded in unbalancing tree growth and nutrition. This has increased the occurrence and number of metabolic disorders so that they have become major causes of decreasing fruit quality. Projects are underway to discover the nutritional requirements necessary to avoid the physiological disorders, cork spot, bitter pit, and internal breakdown; to elucidate the role of zinc in apple nutrition; to investigate interactions between nutrition and other cultural factors, especially growth regulators; and to learn more about foliar feeding. Projects are listed in Table 2. The criteria used to measure effective nutrition have changed. Yield is no longer the only consideration. Tree growth, fruit quality, set, and storage life are used in evaluating the effectiveness of nutritional treatments.

Table 2. Projects concerning culture and physiology of apples reported in CRIS in 1971.

Type	No. of projects
High density plantings	3
Stock scion relationship (including interstem)	4
Rootstock trials	10
Anatomy of graft union	2
General culture studies	2
Fruit thinning	4
Fruit thinning, mode of action	3
Effect of growth regulators on flowering	7
Juvenility studies	2
Natural hormone content of trees	3
Low temperature injury, protection	6
Effect of SADH on trees and fruit	3
Effect of growth regulators on fruit shape	3
Fruit growth studies	2
Effect of growth regulators on plant metabolism	1
Photosynthetic studies	3
Nitrogen metabolism of growth regulator treated apples	1
Nutrition, sand-waterculture	2
Nutrition, field study	9
Nutrition cultural factors combined	2
Nutrition, leaf feeding	2
Internal bark necrosis	4
Study of physiological disorders of fruit	4
Water relations, irrigation	4
Mechanical pruning	2

Drastic changes in tree types and planting density make a re-evaluation of nutrition necessary. In high- or ultra-high-density orchards, tree size must be carefully controlled. The tree cannot outgrow its allotted space, and at the same time it should produce large quantities of fruit. We do not know the unique nutritional requirement of such a tree. Experience with standard trees cannot be simply transferred to the changed conditions.

Nitrogen nutrition must be reviewed. The source of N, whether nitrate or ammonia, may make a difference in growth, hardiness, flowering, and fruit quality. Nitrogen nutrition, regardless of source, is generally too high. In some orchards, growth is not satisfactory unless the leaf-N levels are very high. The fruit from these orchards is, of course, of poor quality. For such high N levels to be required for growth, other nutrients must be out of balance with nitrogen or with one another. This brings up the question of how best to express the nutritional status of the tree—as the absolute level of elements, or as proportions of the elements to each other. We not only do not know the answer to the above question; we do not know what plant parts or what fraction of the tissue extract best express the nutritional status of the tree with respect to the adequacy of nutrition for optimum growth, yield, and fruit quality.

The calcium status of orchards has been generally ignored. Adequate Ca in the fruit unquestionably increases fruit quality; but in order to put more Ca into the fruit, we must consider the entire physiology of the tree. It is not enough merely to supply Ca to the soil because the tree may not be able to take it up. We must consider the distribution of this element throughout the tree, its movement into the fruit, and its subsequent dilution by growth. The complexity of nutrition research and the interaction of nutrition with the rest of the physiology of the tree are illustrated best by the uptake of this element. Pruning, thinning, N, and perhaps several other nutrient elements must be adjusted before adequate Ca will reach the fruit.

The use of growth regulators on apples is receiving much attention (Table 2). Existing projects include fruit thinning, enhancement of flowering, effect of succinic acid,2-2-dimethylhydrazide (SADH) and (2-chloroethyl)phosphonic acid (ethephon) on trees and fruit and the effect of growth regulators on bud-break, on fruit color, and on enhancing the senescence of leaves after harvest. With all the efforts exerted so far, fruit production is still not regular enough. There is a small but important yearly crop fluctuation that makes efficient marketing difficult. Crop fluctuation can be eliminated only by better thinning and/or by enhancing flower initiation. Even after 30 years of work, thinning is not satisfactory in several areas or on several cultivars. Little is known about flower initiation. We do not have good compounds to enhance red color. The combination of SADH and ethephon is the best now available, but it is usable only on fruit that is to be marketed soon after harvest. Therefore, it can be used on early cultivars only. A color-enhancing compound that will increase red color without advancing maturity is needed.

Winter hardiness is an increasing concern. Leaves of vigorous trees stay green too long after fruit harvest, and these leaves are killed by frost without translocating their sugar and mineral-nutrient content into the woody part of the tree. Conceivably, if we succeed in promoting slow senescence of the leaves after harvest, thus forcing them to translocate their content, the hardiness of the woody part of the tree will increase. This is presently not possible. All the presently known senescence-inducing compounds are defoliants, and after treatment leaves fall without translocating their content.

We know little about the natural hormonal makeup of the tree and the fruit. Fruit ripens faster off the tree than on the tree; leaves yellow faster after apples are harvested than when fruit is left on the tree; trees on dwarfing rootstocks become dwarf only after initiation of flowering and fruiting; nutrient content of leaves from trees bearing heavy crops is usually higher than that of leaves from trees producing few apples; and hormones translocated from the seeds of fruit supposedly prevent flower-bud initiation. Scientists working with hormones need to study the hormone content of the tree at various phases of differentiation. Because interactions of hormones are important, determining the levels of a given hormone without knowing the levels of others is not enough. If we know the hormone levels of the tree at critical times, we may be able to influence the desired hormonal balance by the external application of growth regulators.

The use of growth regulators merely to change the shape of fruit is of little importance. If growth regulators could be found, however, that would alter the shape of the fruit by increasing the cell number in the fruit so that the fruit would have many small cells instead of fewer large cells, the changing of shape might have wide application. Small-celled fruit is known to be firm and to store well, whereas large-celled fruit is subject to breakdown.

Only one study is underway on the effects of altering the environment with cooling sprinkling. Another study is using trickle irrigation that, besides supplying water, may also supply nutrients constantly and uniformly. Which of these systems will prove to be effective in a given environment is not known at present. However, when such new orchard-management systems, which would involve considerable investment for the growers, are being tried, all should be compared under similar conditions.

Postharvest handling

Quality and grade standards are outdated. They are based solely on appearance, and the consumers have no way to judge the quality of the beautiful, red, polished apples they see in the market. Experience has taught them that these good-looking apples may be soft, overripe, and not fit to eat. Present grades for apples express only the appearance and not the quality of fruit. Growers may have to ship apples at a given pressure in order to provide "crisp" fruit for the consumers. It is unfair to put all the burden on the growers, however. Apples are often mishandled during shipment and in the market. Improper handling makes them soft and mealy. Therefore, a firmness requirement under which apples cannot be sold would also be desirable. This would necessitate a double requirement for firmness, one minimum for shipping and one for selling in the market. Currently, several projects for developing measurements for maturity and texture of apples are underway, but none of them are designed to collect data necessary to establish the above requirement.

Prediction of harvest time has always been important. Our best methods need to be refined. Very soon, however, we must be able to predict not only the expected quantity of apples and the time of harvest but also the quality of the harvested fruit. Knowing the quality in advance of harvest would aid growers in deciding how best to dispose of the crop. We have indications that this can be done. We may have to use entirely different measures, such as relating the quality of the fruit to its Ca content in midseason. Similarly, we can determine the incidence of disorders that develop early in the season (cork spot, russet) and predict the quality of apples at harvest. We may even be able to correlate the amount of extra-fancy apples with air temperature during a given time period prior to harvest.

Softening of apples after harvest is undesirable. With all the work on texture of fruit, including its relation to pectins, cellulose, pectic enzymes, etc., we are still trying to influence the firmness of apples by regulating the rate of ripening only. For example, the major difference between 'York Imperial', which stays firm almost indefinitely, and other cultivars is the high hemicellulose content of its cell walls rather than its degree of ripeness (8). We should try to influence firmness of the fruit by promoting the development of hemicelluloses in the fruit.

Ripening of apples is a series of concomitant processes (6). Recent work with the use of SADH and gibberellins indicates that these processes can be separated, and one can be enhanced or delayed independently of others. This is important because we have no good way to preserve the quality of slightly overmature fruit. Work with reduced-pressure storage of such fruit could be very significant in the future.

Problems of mechanical harvesting are numerous. Several projects have been initiated to develop machinery for harvesting both standard and dwarf trees (Table 3). Efforts are presently aimed at harvesting culinary fruit but only exploratory work is being done on harvesting fruit for the fresh market. The basic machines, the first step in mechanization, are already developed. We have to develop methods to handle the fruit after harvest. Time between harvest and processing may be several months. Fruit harvested by machine may have to be sorted quickly and treated with fungicides to preserve it in good quality for processing. Abscission-promoting chemicals are needed on some cultivars to facilitate easier fruit removal. These chemicals also enhance ripening of the fruit. How much of the ripening effect the processing industry can tolerate remains to be determined.

There are several projects (Table 3) designed to find methods of producing a good-quality product from apples not quite suitable for conventional processing. They include work on processing of cultivars grown primarily for fresh fruit market; blending soft and firm apples for sauce; retaining firmness of canned apple slices; and the effect of fruit maturity on product quality. There are several projects concerning dehydrated apples including some designed to prevent, during the dehydration process, the loss of volatiles responsible for flavor of the fruit. With the advent of mechanical harvesting and the use of fresh market or double utilization cultivars for processing, the quality of fruit suitable for processing can be more variable than it has been in the past. Research, therefore, will have to find methods to produce a uniform finished product from variable raw material.

Protection of trees and fruit

There are 79 projects involving protection of apples (Table 4). The apple industry is using more protective chemicals per acre than are used for any other crop. There are good reasons for this; apples have more pests than most other crops and the tree as well as the fruit must be protected. In humid regions this necessitates numerous sprays. We have to find ways to reduce the actual amount of chemicals used per acre. This is desirable both to decrease cost and to preserve our environment. Low- or ultra-low-volume sprays may allow us to reduce the amount of pesticides. However, we do not know the limit of the reduction that will still provide us good protection.

Some cultural practices may provide a certain degree of resistance to the trees. For example, certain rootstocks and/or high K fertilization may make the trees more resistant to fire blight. Neither method is good enough to protect the trees completely, but they may enable us to reduce the number of

Table 3. Projects concerning postharvest handling of apples reported in CRIS in 1971.

Type	No. of projects
Determining maturity	15
Mechanical harvesting	16
Processing	19
Natural constituents of fruit	7
Packaging	2
Processing waste disposal	2
Control of post-harvest diseases	7
Storage of fruit	5
Handling after harvest	9
Texture of fruit	4

sprays needed. We must continue to seek other aspects of cultural practices that can be altered to decrease the number of sprays needed. Unfortunately, we go in a completely opposite direction by recommending M 26 rootstock, which sensitizes cultivars to fire blight, thus necessitating more sprays.

In cases where integrated control is in use, such as with mite control, we have to consider its further integration with cultural practices. Carbaryl, for example, though a good thinning agent is also a miticide. Because it interferes with the integrated mite control, it should be replaced with another equally effective thinning compound. In the future, we must look more at the "protection system" rather than the protection methods.

Whether apple trees should be free of latent viruses is open to question. Some think this is absolutely essential (5); others feel that we gain very little by propagating everything on virus-free stock and by using only virus-free scions. We do not know how long virus-free trees stay virus free. Furthermore, we do not know the effect of infecting a virus-free tree with one of the latent viruses. More work is needed in this field before new lines of thinking can be developed.

Economics of production

Present projects in economic research are designed to establish a better competitive position of apples in various regions, to analyze market structures, and to determine cost of various operations (Table 5). In the changing apple industry, the present research in economics does not reflect the immediate and future needs of the industry. The research appears to be confined to limited areas and to concentrate on less important questions.

Because of social and economic changes, the future apple industry cannot depend on seasonal labor during the harvest peaks. Economists must examine alternatives. How can we provide year-around employment for the majority of workers in the apple orchard? This is a complicated question.

Before we attempt to outline the problem, a few other considerations must be introduced. The use of apple juice appears to have increased in the last few years. Is the apple industry beginning to undergo changes, perhaps on a lesser scale, that the orange industry has undergone in the past? If so, we need to know what the future demands for apple juice will be. Juice apples probably will be grown on standard trees, harvested by simple machines designed for a shake-and-pick-up operation, and juiced immediately. This is a very different type of operation than we outlined earlier in this paper for growing fresh market apples.

Table 4. Projects concerning protection of apple tree and fruit reported in CRIS in 1971.

Type	No. of projects
Bacteria	8
Nematodes	3
Viruses	10
Fungus diseases	7
Specific insects	15
Mites	17
Spray schedule development	13
Residue research	2
Mouse control	3
Bird control	1

Economists must also examine the changes growers face within the sphere of apple production. Labor requirements in the dwarf orchards during the growing season probably will increase and harvest labor decrease. This is the type of change we desire. However, if we want to promote such a change in the orchards, we have to know how every new operation will affect the labor picture.

The number of apple cultivars is constantly decreasing. Either extreme of too many or too few cultivars is costly. The proper mix of cultivars has to be examined from the points of view of the market, labor, and storage. Growers must be advised, on the basis of research, of the best cultivars to plant for each situation.

Growers sometimes introduce a new operation without proper testing and evaluation. A notable example is the introduction of mechanical citrus pruner to apples. This costly machine not only "saves" labor at the time when labor saving is not needed but decreases both the quantity and quality of the fruit produced and makes the harvest operations more difficult. A new operation should be evaluated before introduction, and growers warned against possible economic loss.

Therefore, future economic research in apple production will have to be operations research, taking all phases of apple production, marketing, and social systems into account. Every change in the operation will have to be considered in its relation to the entire scope of the apple business.

Conclusions

There are many unanswered small problems that researchers need to solve. There is no need to list them. Individual researchers know them and they will be solved in due course. The emphasis in the future, however, will have to be placed on the complex problems that require multidisciplinary approaches. Presently, agricultural and horticultural researchers very rarely work in teams. The analysis of the present problems reveals that many stem from isolated research. Individual researchers have done a good job in solving certain problems. The industry has introduced these results and the end result has been an unbalancing of the entire production process. The remedy is to organize research, form teams, and look at the important problems and how they interrelate with one another in such a way that the work would be replicated rather than duplicated. Unfortunately, at present there is no organization that could attempt to coordinate such work. Apples are grown in all four regions of the Cooperative State Research Service; therefore, regional projects are not wide enough to cover the entire apple-production area. The Agricultural Research Service is involved in only a small part of apple research with a limited number of scientists; hence, it cannot do the coordinating. Individual States, of course, represent only their own segment of apple research. The International Apple Institute does not have a research committee that could bring pressing production problems to the attention of research administrators. Perhaps the best solution would be to get scientists, or at least leaders of various groups, together to discuss the possibilities of coordination. We realize that this approach to research is controversial, but to us it seems necessary.

Table 5. Projects concerning economics of apple production reported in CRIS in 1971.

Type	No. of projects
Competitive position of apples in various regions	12
Market structure, demand supply analysis	3
Use of computer aiding managers of apple orchards	2

Rather than ordered cooperation, we would like to see cooperative order in apple research.

Literature Cited

1. Dayton, D. F., J. B. Mowry, L. F. Hough, Catherine H. Bailey, E. B. Williams, Jules Janick, and F. H. Emerson. 1970. Prima - an early fall red apple with resistance to apple scab. *Fruit Var. & Hort. Dig.* 24:20-22.
2. Dewey, D. H., and T. J. Schuneman. 1972. Quality and packout of storage apples. *Mich. Agr. Expt. Sta. Res. Rpt.* 147:1-6.
3. Harris, C. I., and D. R. Walker. 1969. An analysis of the inputs for horticultural research in 1967. *HortScience* 4:285-287.
4. Heinicke, Don R. 1968. High density plantings and the central leader tree. *Goodfruit Grower* 1968 December.
5. Hudson, J. P. 1971. Fruit growing in the future. *Scientific Hort.* 23:92-99.
6. Hulmc, A. C. 1970. Biochemistry of fruits and their products. Vol. 1. Academic Press. 620 p.
7. Magness, J. R. 1937. Progress in apple improvement. *U. S. Dept. Agr. Yearbook* 1937:575-614.
8. Tavakoli, M., and R. C. Wiley. 1968. Relation of trimethylsilyl derivatives of fruit tissue polysaccharides to apple texture. *Proc. Amer. Soc. Hort. Sci.* 92:780-787.
9. Wadleigh, C. H., and R. S. Dyal. 1972. The best kept secret. *HortScience* 7:369-372.
10. Way, Roger D. 1971. Apple cultivars. *Search-Agriculture* 1:1-84.