AN ABSTRACT OF THE THESIS OF

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Title: Effect of several Apple Rootstocks on Growth, Yield Components and Leaf Area Estimates on 'Starkspur Supreme Delicious' Trees.

Abstract approved: ______________________
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Growth, yield components and leaf area were evaluated on 'Starkspur Supreme Delicious' apple on nine rootstocks: MAC 24, EMLA 7, EMLA 26, OAR 1, MAC 9, 0.3, EMLA 9, M 9, and EMLA 27. Estimates of planting density based on growth, estimates of leaf area based on four independent variables and the relationships among yield components, fruit quality, growth and leaf area were investigated during 1985.

Tree height, tree spread and trunk cross sectional area were highest for trees on MAC 24 followed for EMLA 7 while trees on EMLA 26, OAR 1, MAC 9, 0.3, EMLA 9 and M 9 were less in these values in descending order, with the most dwarfing on EMLA 27. Estimates of planting densities indicated higher densities with tree canopy spread than TCSA based on standard trees of the age except on EMLA 27.

The densities for trees on MAC 24 and EMLA 7 were estimated 426 and 496 trees/ha. respectively, while for the rootstocks with intermediate size ranged from 700 to 1000 trees/ha. The highest density was for EMLA 27 with 1824 trees/ha.

Flower cluster, fruit number, yield and leaf area were highest in the least size controlling rootstocks MAC 24 and EMLA 7, and in general these were a function of tree size. MAC 9 had the highest flowering density, crop density and yield efficiency followed by 0.3, EMLA 26 and EMLA 9. Potential yields based on the estimated planting density were also highest for MAC 9.

Fruit on OAR 1 had greatest soluble solids, firmest at harvest, but were the smallest. Fruit on EMLA 7 which had the lowest soluble solids were largest. A negative correlation between flowering density and fruit set among the rootstocks was found. Crop density influenced fruit size and weight. Fruit on EMLA 7, MAC 24 and EMLA 9 were the largest but these trees had the lowest crop density. There was a high correlation of fruit number with yield indicating this was the main component of yield. The leaf-fruit ratio was negatively correlated with flowering density, crop density and yield efficiency and the ratio was lowest on the more efficient rootstocks MAC 9, 0.3 and M 9 while those of MAC 24 and EMLA 7 were highest.

No differences were seen among the regression lines of leaf area and 4 independent variables obtained from trees on various rootstocks and within rootstock. Fresh weight was the best estimate of leaf area but because of greater speed and simplicity, branch cross sectional area was chosen to predict leaf area. Total leaf area per tree decreased from the least size controlling rootstocks to the most dwarfing rootstocks. Tree leaf area index ranged from 1.69 in MAC 24 to 0.87 in 0.3, but it did not always increase proportionately to tree size. Orchard leaf area index from estimated planting densities showed low values in all rootstocks but a slight increase with the tree size. This indicated that trees at the estimated densities are not intercepting the maximum quantity of light.

EFFECT OF SEVERAL APPLE ROOTSTOCKS ON GROWTH, YIELD COMPONENTS AND LEAF AREA ESTIMATES ON ‘STARKSPUR SUPREME DELICIOUS’ TREES.

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PREFACE

This study consists of three topics, presented here as three separate papers. The first, which will be submitted to the Fruit Varieties Journal covers the work related to the effect of rootstock on growth. This study was designated to fill some of the gaps in our knowledge of the new rootstocks as they relate to tree size and potential spacing. This would provide a means of determining, in part, the planting density for the new combinations under the conditions of soil,site and training system used.

The second and third papers will be submitted to the Journal of the American Society for Horticultural Science. The second paper deals with the yield components and fruit quality as influenced by apple rootstocks, and the relationships of these components with leaf area and growth. The results should indicate the best combinations.

The third paper estimates the leaf area of a tree from the ratio leaf area to girth, to cross sectional area of the branch or to the fresh or dry weight of the leaves. Calculations of leaf area index and leaf-fruit ratio were evaluated. This would provide a fast non-destructive method to assess tree leaf area and bearing surface.

All of these papers are interrelated. The major theme concerns tree size and yield components on the apple rootstocks, partly because of my interest on the subject, and also because of the need to emphasize the importance of proper spacing, maximum surface bearing and the development of potential yields of new scion/rootstock combinations.

EFFECT OF SEVERAL APPLE ROOTSTOCK ON GROWTH, YIELD COMPONENTS AND LEAF AREA ESTIMATES ON 'STARKSPUR SUPREME DELICIOUS' TREES

LITERATURE REVIEW

Introduction

World apple production increased from 28.3 (1969 to 1971) to 36.2 and 35.6 of metric tonnes (MT) in 1979 and 1980 respectively. Apples are the second most widely produced deciduous fruit in the world. The major producers of apples during 1980 were the U.S., France, Italy, China, U.S.S.R., Germany (FR), Japan, Argentina, India and Brasil. (FAO, 1981).

On a tonnage basis, apples are the second leading deciduous fruit grown in U.S. For 1985 apple production represented 29 % of the non-citrus fruit crop and was second only to grapes. U.S. commercial apple production totaled 3.90 million MT 1985, 6 % below the previous year's crop, and 7 % more than the 1983 crop. Washington the leading state produced 1.05 million MT, 29 % less than the previous year. Michigan ranked second with 550,000 MT produced, up 43 % from the last year. Production in New York, the third ranking state, totaled 530,000 million MT, up 4 % from 1984 (USDA, 1985). The State of Oregon ranks ninth in 1982 with 1.9 % of the total U.S. apple production (USDA, 1982). The principal cultivars growing in these states are 'Delicious', 'Golden Delicious', 'McIntosh', 'Rome Beauty', 'Jonathan' and 'York'. These six cultivars account for 80 % of the U.S. crop (Childers, 1983).

Importance of Rootstocks

Only in recent years has there been world wide interest in planting of dwarf and semi-dwarf tree fruits. Dwarfing stocks have been used for over 50 years in Europe where they originated but other countries, particularly the United States and Canada, have turned to them because of the many advantages over the large trees such as (a) reduction in labor and production costs per bushel, (b) higher production per unit area, (c) early bearing and (d) improvement in color and marketability of the fruit, plus several lesser advantages (Tukey, 1964; Heinicke, 1975).

Dwarfing and semi-dwarfing rootstocks are presently used sparingly in the United States, but many problems have occurred including poor root anchorage, susceptibility to soil born diseases, and lack of hardiness (Cummins and Aldwinckle, 1974; Doll, 1975; Ferree, 1978; Tyler, 1981; Wyatt, 1981).

Because of the rather limited experience with new stock/scion combinations of compact trees under a broad set of conditions, suggestions on their use should be accepted with reservation. Growers can convert from standard to compact trees gradually when practice continues to look good.

Coordinated efforts are being made to evaluate newly-introduced rootstock systems upon apple tree growth and fruting. In 1980 the North Central Project ‘ NC - 140 ’, in cooperation with the International Dwarf Tree Association, Oregon Rootstocks, Inc., Hilltop Orchards and Stark Brothers Nursery have initiated plantings in 27 states and 3 Canadian provinces. Plantings will continue as new become available.

The NC - 140 committee consists of researchers from accross the United States interested in testing new rootstocks. In recent years, researchers from provinces of Canada and Mexico have joined NC - 140 as cooperators so that most of the apple production areas of North America are active in the group. The goals of this group are to quickly expose new rootstocks to widely varying soil and climatic conditions to shorten the time necessary for evaluating these rootstocks. The best way to achieve this goal is through cooperative plantings that are handled under uniform cultural practices of : spacing, training, fertilization and data collection. The data are sent to a central location, analized and made available to all cooperators. This group of researchers also shares information on stress tolerance of rootstocks and their performance in various management systems (Ferree, 1982,1983).

Although cooperative rootstock testing requires each researcher to follow guidelines established by the NC - 140 committee and may limit the utilization of local cultural practices not used in other areas, the advantages of these trials for the whole industry are great. Past experiences indicate that it takes 20 - 30 years to gain needed experience on a diversity of soil types and climatic conditions with new rootstocks. These uniform trials should easily cut that time in half.

Results from these plantings will provide growers, extension agents and researchers an opportunity to comparision their results with those from other locations and facilitate an understanding for the type of recomendation needed in each area.

Ten replications of one of these uniform trials already planted in Corvallis, Oregon with the next rootstocks are : EMLA 9, EM 9, EMLA 27, MAC 9, OTTAWA 3, OAR 1, EMLA 7, EMLA 26 and MAC 24. This report is a compilation of data concerning their performance to date. The cultivar chosen for this study, as outlined by the NC - 140 research committee, was StarkSpur Supreme Red Delicious (Paganelli cv. virus-free) on nine different rootstocks.

Characteristics of the Rootstocks

The rootstocks will be described in order of vigor, starting with the most vigorous rootstock and ending with the least vigorous clones in this trial.

MAC 24. This rootstock is a selection in the Michigan Apple Clone series (female parent was Robusta 5). Trees on this rootstock are vigorous in the MM 111 or standard size class. It has a shallow spreading root system and is well anchored. Root suckering is experienced, which indicates that this could be a cultural problem for the future (Simons, 1983; Carlson, 1978, 1982; Dennis,1979).

EMLA 7. This rootstock is from East Malling, released in 1974-75 and is considered completely virus-free. It is considered to have the same horticultural characteristics as M.7a, but exibits greater vigor.(Perry and Carlson,1983). EMLA 7 produces trees twice the size of those of M.9, or 55% the size of trees on seedling rootstock. It is less precocious and has lower cropping efficiency than EMLA 9 or EMLA 26. EMLA 7 is moderately resistant to collar rot and fire blight and has less suckering than M.7 and M.7a (Oregon Rootstock, Inc., 1985).

EMLA 26. A virus-indexed EMLA 26 clone was introduced by East Malling in 1969/70. This rootstock is very similar to M.26 except that it is virus-free and should be considered to give slightly more vigor to scion varieties. This clone, as M.26, should still be considered highly susceptible to poorly drained and droughtly soils, crown rot and fire blight. Also this stock develops large burrknots. EMLA 26 is intermediate in vigor between EMLA 9 and EMLA 106, being smaller than EMLA 7 and producing a tree 40% the size of that on seedling rootstock. (Oregon Rootstock, Inc.,1985).

OAR 1. In Oregon, plantings of Gravenstein on domestic seedling stocks were made in 1943 and 1948. Many of these trees were blown down by high winds in 1962. Among the survivors was a conspicuously dwarfed tree which was very productive. Suckers from the stock of this tree were propagated by Dr Melvin Westwood of Oregon State Universityand called OAR 1 (Oregon Apple Rootstock No.1). At Geneva, OAR 1 has been susceptible to Wooly Apple Aphid and moderately susceptible to fire blight. The OAR 1 rootstock has been as precocious as M.9 (Cummins and Aldwinckle,1982).

0.3. This stock was introduced by Agricultural Canada as part of the Ottawa series. It is the most dwarfing stock of this series and was selected from Robin X M.9 progeny. Compared to M.9, it appears to be slightly less dwarfing, better anchored and not nearly as brittle, as resistant to crown rot, and similarly susceptible to fire blight and to Wooly Apple Aphid, and more difficult to propagate. Suckering is rare. This stock is sensitive to apple stem grooving virus. This clonal stock could be a replacement for M.26. The major value of 0.3 though, may be as an interstem (Cummins and Aldwinckle, 1982; Cummins, 1984; Spangelo et al 1974).

MAC 9. This rootstock is another selection of the Michigan Apple Clones selected in 1959 from a group of seedlings obtained from open pollinated trees of M.1 through 16, Robusta 5 and Alnarp 2. The flower parent was M.9. (Carlson and Perry,1986). MAC-9 is capable of producing a free standing tree, whoses stature is similar to that on M.26 or about 50% compared to seedling rootstock (Carlson, 1978,1980). At Geneva, its susceptible to fire blight and WAA is similar. It is very precocious and fruitful and has not suckered (Cummins and Aldwinckle,1982; Cummins,1984).

EMLA 9. This clone was selected in East Malling and is a newly released, virus-free clone of M.9. This clone, as M.9, requires deep, rich soil, and produces a tree six to eight feet in height, depending on the system of training. EMLA 9 should be expected to produce a slightly more vigorous tree and be a slightly less precocious than M.9 (Perry and Carlson,1983). Although the efficiency of cropping is similar on virus-free clones of both M.9 EMLA and M.9a, the latter is much less productive on the stoolbed (Parry,1980; Webster,1983).

M 9. This stock was selected at East Malling from a number of stocks of Juane de Metz, a rootstock with a very long history. M 9 produces trees 20-35% the size of standard trees, is very precocious and fruitful, poorly anchored with a tendency to sucker. Trees on M 9 typically develop small root system with relatively brittle roots and invariably need expensive stakes for efficient support (Webster,1984). The stock has a long history in both the US and Europe and is used as the standard in this trial.

EMLA 27. This is a super-dwarfing clone, released as virus-free from East Malling. This stock was bred from a cross made in 1929, using M.13 as a seed parent and EMLA 9 as the pollen parent. It is less winter hardy than M.9 and produces trees than ten to twenty percent smaller than M 9. EMLA 27 can be considered moderately tolerant to crown rot but susceptible to WAA and fire blight. Suckers are rare. Scions on EMLA 27 are extremely precocious and efficient producers, particularly suited for home gardens and patio plantings (Perry and Carlson;1983).

Rootstock effect on Growth.-

Size control, and sometimes an accompanying change in tree shape, is one of the most significant rootstocks effect. This seem to be largely because the rootstock causes the vigor of a given scion cultivar to be altered. Predictions of rootstock effect cannot be made certainty without considering the entire system in which it is used, including the particular cultivar used as the scion top, which can modify the rootstock influence.

Several workers have reported differences in tree size on the same rootstock when they used 'Delicious' strains with different growth habit. They concluded that using a spur growth habit strain reduced vegetative growth and the trees were characterized by short internodes, enhanced precocity and in some cases greater fruit setting ability (Westwood and Zielinski, 1966; Westwood et al, 1967;

Lord et al, 1980; Ferree et al, 1982).

Symptomless viruses can occur in plants which, may exert a dwarfing influence. Campbell (1976, 1980) working with EMLA clones free of all known viruses and compared with the same clones with latent virus infections showed that the later reduced the growth and yield of the trees.

The dwarfing effect of certain rootstocks is attributable, in large part, to the induction of early bearing and subsequental decreased vegetative vigor (Roberts and Blaney, 1967). The reduction in vegetative growth resulting from cropping has been noted many times. Maggs (1963) found that cropping trees had 50 % more leaf area proportionate to total vegetative increment, and 50 % less root than deblossomed trees, and this diversion of metabolites to the crop changed the pattern of growth in the rest of the tree.

The total length of shoots growing in the year following a heavy crop is reduced to about the same extent as is shoot growth in the cropping year. The cummulative effects of cropping lead to great differences in size between trees deblossomed from planting and those allowed to crop normally (Jackson, 1984).

Studies in England (Mckenzie, 1961) indicate that apple rootstocks known to produce dwarf trees have a high proportion of bark to wood in the lateral roots, whereas vigorous stocks have a lower proportion of bark to wood. Also, much of the functional wood tissue of roots of dwarfing apple stocks is composed of living cells, whereas the wood of vigorous stocks consisted of relative large amounts of lignified tissue without living cells contents.

In spite of much research, the effect of rootstocks and interstocks of apple have never been adequately explained. Recent attempts at explanation have emphasised transport in the phloem and xylem as the basis of the effects. Lockard and Schneider (1981) postulated a dwarfing mechanism in which the auxin produced by the shoot tip is translocated down the phloem and the amount arriving at the root influences root metabolism and affects the amount and kind of cytokinins synthesized and translocated to the shoot through the xylem. The auxin in the phloem is oxidized or otherwise degraded by compounds in the bark and the amount of active auxin reaching the roots will vary in different cultivars. Phenols may be important growth controlling compounds in apple bark as they interact with auxins in many different ways, i.e., promote oxidation, act synergistically, and influence synthesis and possibly translocation.

Jones (1986) in a more recent study of the endogenous growth regulators and rootstocks/scion interactions reported that with apple, studies with isolated shoots suggest that the cytokinins which are transported from rootstock to scion in the xylem sap have a major control in shoot growth and any effect of rootstock or interstock on these growth regulators is likely to be of greater significance than effects on the phloridzin, gibberellins or ABA of the sap. The graft union of dwarfing rootstocks or interstocks with the scion appear to deplete the solute of the xylem sap including the cytokinins.

Often, tree size is measured as tree height, tree spread and cross sectional area of the trunk. Since tree height and spread are directly modified by pruning, the later can be used as a good indicator of the mass of the above ground portion of the tree to make comparisions of tree size (Westwood and Roberts, 1970).

Several workers have compared the growth of dwarfing clones with that of seedling rootstock and showed that the later was largest.(Crabtree and Westwood 1976; Schneider et al, 1978; Seeley et al, 1979; Larsen and Fritts, 1982). In a comparision of 3 dwarfing rootstocks Denby (1982) and Crassweller and Ferree (1982) reported trees on M 9 were the smallest in height, within row spread and trunk circumference.

In the same NC-140 trials in Illinois, Ontario, California, Oregon and Michigan, the results indicated that tree size was affected by rootstock. MAC 24 were largest and EMLA 27 were smallest (Simons, 1983; Elfving, 1984; Micke, 1984; Lombard et al, 1985; Perry and Carlson, 1986).

Rootstock effect on Planting Density.-

As new rootstock are developed, all scion/rootstock combinations must be tested and compared to standard trees to determine the final tree size and the planting density.

Optimal use of rootstock must consider yield potential together with the proper spacing for the desired scion/rootstock combination. A highly efficient combination spaced too far apart will never achieve maximum potential yield per acre, and planted too close would result in excess shading, low fruit set, and poor quality (Westwood et al, 1986).

Planting density depends principally on the genetic combination of the variety scion and rootstock, as well as enviromental, edafic and cultural aspects and the training system used. Since tree size is related to trunk cross sectional area, this measurement can be used to compare the tree size of the new scion/rootstock combination to the standard sized tree. The relative size, expressed in percent of standard size, can be used to establish planting densities (Lombard et al, 1985).

Jackson (1970,1978b) and Verheij et al (1973) have defined various parameters to evaluate optimum planting densities, among which are the ratio between tree height and width of the alley and Leaf Area Index (LAI). Tree height should not be more than 1.5 to 2 times that of the clear alley and a LAI not more than 0.50 to 1.00 over the cropping zone of the tree and not more than 2.50 to 3.00 in total in order to permit the tree to intercept the maximum quantity of light.

Seeley et al (1979) stated that the major factor in determining the tree spacing required for a free-standing planting system is tree spread, and this was influenced by both rootstock and scion. These values should be of use in determining tree spacing for free-standing trees under conditions leading to moderately vigorous growth.

Orchard density, is not a linear function of the number of trees per acre, nor can it be measured at any particular moment (Cain, 1970). Tree spacing must be in reasonable agreement with natural tree growth. Ferree et al (1982) reported that the spur habit Delicious strains have a greater yield efficiency than standard strains and their compact growth habit and earlier fruting permits more intensive planting which improves orchard efficiency.

Mullins and Dayton (1982) showed that yield of Red Delicious and Golden Delicious trees on either MM-106 or MM-111 rootstock were almost doubled when tree density increased from 109 to 208 trees per acre. However, heavy pruning was required to maintain trees on the alloted space, especially at the higher densities. The effort seemed justified in terms of productivity early in the life of the orchard.

In an evaluation of various orchard design alternatives for greatest efficiency, Cain (1972) suggested that maximum efficiency in a hedgerow orchard would be achieved by trees with a spread of 10 feet and a maximum height of 12 feet.

Proctor et al (1974) used tree spread to suggest possible planting distances for 7 cultivars on M-26 rootstock. They assumed a suitable between-tree spacing based in tree spread and allowed 2 mt. (6 ft) for tractor access and calculated the planting distances.

Parry (1977) mentioned that measurements of the area occupied by the crown are of practical value for the purpose of estimating an appropiate tree density on which rough predictions of yield per ha. can be based. From regressions of crown area with stem cross sectional area, conversion tables were derived for each rootstock to suggest the spacing appropiate for all combinations and sites.

Lombard (1985) used trunk cross sectional area for estimates of planting densities and mentioned that planting densities are based on filling the bearing surface to a maximum within 5-10 years with a clear alley way of 1.5 m for orchard traffic. To figure spacing of the planting, one must consider the training system used (ie: fruiting wall system, open centred tree). Lombard showed calculations that can be used for estimating approximate spacing which can be adjusted to other considerations such as soil, moisture, etc.

Westwood and Roberts (1970) reported that to obtain the maximum number of trees per acre, tree spread was measured and two feet were added to the spread and spacing figured as a rectangule : Spacing = spread X (spread + 2'). Using the average of cross sectional area of the trunk and the number of trees per acre Westwood and Roberts (1970) and Chaplin et al (1979) obtained a table that show the Bearing Potential or density of the orchard. Dwarf Plantings should develop maximum bearing potential in 8 to 10 years, while standard trees at the proper filling space should attain 3/4 bearing potential in 10 years.

Rootstock effect on Flowering.-

Dwarfing rootstocks usually cause the trees to bear much younger. In apples flower initials usually form during the summer of the year preceding blossoming in bud terminals on the short shoots known as spur. In certain circumstances, however they can form in axillary buds carried on the current year's extension growth. In tip-bearing cultivars, they regularly develop in the terminal bud of the long shoot (Luckwill, 1970).

There are two major requirements for the initation of flower primordia in buds of the current season shoot's. The first is the cessation of the 'anti-flowering' gibberellins stimulus from the apical growing region, and the second is the presence in the xylem sap of a concentration of cytokinins sufficient to partially relieve the dormancy of the lateral buds. As with long shoots, endogenous gibberellins seem to be implicated as a major ‘flower inhibiting’ factor in flower initiation in spurs (Luckwill, 1970).

Time to first flowering can be dramatically modified by selection of rootstock on which a given cultivar is budded. In general, rootstock which impart size control tend to induce early flowering. In contrast rootstocks resulting in vigorous tree growth (ie., seedling, MM-111, MM-106, M-2) are associated with delayed flowering. Semi-dwarf rootstock like M-26 and M-7 are intermediate (Buckovac, 1984).

Ferree (1976) confirmed the increased precocity induced by dwarfing rootstocks and showed that trees on M-9 and M-26 developed significantly more flower clusters than on the semi-standard MM-106 and MM-111. Webster (1984) showed that the rootstock had influence on number of flower clusters per tree, and during the first year the most dwarfing stocks were more precoces, but later his data indicated that the number of flower cluster per tree decreased as the vigor of the rootstock decreased.

Bloom density, (number of flower cluster/cm^2 of trunk cross sectional area) is important because it indicates the number of flower present relative to tree size and could be used as a measure of precocity in the early years (Ferree, 1976).

Crabtree et al (1976) concluded that for each rootstock tested, that bloom density was inversely related to tree vigor. Trees on seedling rootstock had the lowest values and trees on M-7 rootstock the highest values.

Carlson and Perry (1986) reported that in the NC-140 trial in

East Lansing, Michigan, bloom density in the fifth leaf has been superior for MAC-9, followed by EMLA-9, EMLA-27, Ottawa-3, M-9 and EMLA-26. However the differences were not statistically significant. The most vigorous rootstock EMLA-7, MAC-24 and OAR-1 showed the lowest values in bloom density. Other NC-140 trials in several states and Canada have shown similar trends in blossom and fruit production. (Elfving, 1984).

In order for a tree to be fruitful it must not only produce flowers, but these flowers must set and develop into fruits. The ability of flowers to develop into fruits is expressed as percent fruit set, and is the number of fruits developing per 100 clusters (Lombard and Dennis, 1985)

Blasco et al (1982) found significant differences between rootstocks on Initial and Final Fruit Set. The poorest fruit set was on M-7 rootstock and the highest on M-26 and M-9. They concluded, that it may have been because trees on M-9 have less vigorous shoot growth and an earlier termination of this growth within the season than did trees on the other rootstock in this experiment. It is known that fruit-shoot competition can result in fruit shed (Quinlan and Preston, 1971).

Evaluations of yield components on "Red Prince Delicious" trees budded on 8 Michigan Apple Clones (Carlson, 1978) revealed considerable influence of stock on fruit set (Dennis, 1978,1981). For example, in 1978 and 1980 set was 27 and 14 fruit/100 flower clusters respectively, on MAC-9 (dwarfing) vs 8 and 3 fruits on MAC-11, a more vigorous clone, even though flower density was significantly less on

MAC-11 in 1980.

Dennis (1981) reported that strains of "Delicious" and rootstock can have marked influence on fruit set. In some cases this results from differences in flower density, but in others they are independent of them. Flowering Density and Fruit Set have been reported to be negatively correlated (Roberts, 1947; Dennis, 1981; Tami, 1984).

Costante et al (1982) working with interstem apple trees on four different cultivars showed that fruit set and yield were higher for trees on M-9/MM-106 than on M-9/MM-111, with the exception of Oregon Spur Red Delicious.

Effect of Crop Load in Fruit Size

Under optimum conditions most tree fruits will set more fruit than needed for a full crop. Fruit thinning is done to reduce limb breakage, to increase fruit size, to improve color and quality, and to stimulate floral initation for next's year crop. (Westwood,1978; Childers, 1983).

Increasing the leaf/fruit ratio by removing some of the fruits causes the remaining fruit to be larger, but not in direct proportion to the increase in the number of leaves per fruit. Experimental evidence has shown that in standard sized trees good size and quality can be obtained when fruits of most varieties are spaced to allow about 30 to 40 average size leaves in the vicinity of each fruit. If 50 or more leaves are left per fruit, there appears to be little additional increase in size and quality of the fruit. (Magness and Overley, 1929).

The optimum number of leaves is somewhat lower, however for compact mutuants and dwarf trees, whose leaves are more efficient than those on the standard trees, because they are exposed to direct sunlight for more hours of the day (Westwood, 1978). According to English researchers as cited by Childers (1983) with fully dwarfed trees about 10 leaves per fruit are adequate because more of the photosynthate apparently go into fruting.

Brown (1976) showed the effect of spacing on size, grade and cash returns 'Winesap' by spacing individual fruit from 3-4 inches, 6-7 inches and 9-10 inches apart on 12 year trees in Oregon. Exact spacing, however is not necessary since some cross-transfer of food within the leaves allows bunched fruits to size well (Hansen, 1969). Under the conditions in this experiment, peak returns were obtained by thinning the fruit to a distance of 6-7 inches on the branches. Thinning to a distance of 9-10 inches was not better than 6-7 inches.

Rootstock effect on Fruiting

Fruiting involves fruit number, crop density, yield per tree and yield efficiency and can be influnced by rootstock, variety, density and training system.

Crasweller and Ferree (1983) working with 2 cultivars, 3 rootstocks and 2 training systems showed differences in fruit number per tree. The cultivar Early Red One produced more fruit number per tree than Oregon spur, and among the rootstocks M 26 had a greater average number of fruit per tree than M 7 or M 9 when trained to a a trellis system instead of staked.

Fruit number per tree was also reported by Blasco (1976) to be significantly different among the rootstocks studied. The most vigorous rootstock MM-106 had the highest and the most dwarfing rootstock M-9 obtained the lowest values. Westwood et al (1986) working with various cultivars with size controlling rootstocks from 3 test plots four years old, reported that larger size trees usually produced more fruit per tree than small ones, except seedling.

Forshey and Elfving (1977) reported a positive relationship of fruit number with yield in different orchards.

Crop Density indicates the yield per plant or unit thereof and thus reflects both flower density and fruit set. A heavy set following a light bloom can result in the same crop density as a light set following a heavy bloom. (Lombard and Dennis, 1985).

Strang (1979) has used crop density to evaluate the effect of frost, while other have used it to adjust crop load for proper fruit size. (Cook and Dennis, 1984).

Dennis (1979, 1981) reported significant differences in crop density among 8 Michigan Apple Clones with Red Prince Delicious studied. The results showed that MAC-9 had the greatest values and MAC-11 the lowest. Tami (1984) working with 4 different rootstocks during 2 years, reported that rootstocks affected crop density in 1982 but not in 1983. In 1982, trees on OAR-1 had the lowest crop density . M 7 and MM 106 were intermediate and M 26 the highest.

The influence of rootstocks on yield per tree is well documented. Schneider et al (1978) obtained higher yields with Gold spur and Red spur on MM 106 than on seedling rootstock. Fallahi (1983) obtained the highest yield with trees of Starkspur Golden

Delicious on MM 106 compared to those on seedling, M 1, M7, OAR 1 and M 26.

Reports published elsewhere showed that cummulative yields per tree is generally greater on the more vigorous rootstocks except on seedling (Ferree, 1978; Czynczyk, 1979; Denby, 1982; Ferree, 1982).

Yield depends also on the type of cultivar used. Hence, in a high density orchard, Westwood et al (1976) obtained higher yields with Golden Delicious than with Starking Delicious on M 9 rootstock. Seeley et al (1979) reported that spur type Delicious strain such as Miller spur apple produced more on several rootstocks than the regular type strain Red Prince.

Campbell and Sparks (1976) and Campbell (1980) have shown that trees on EMLA 9 and EMLA 7 rootstocks considered completely virus free cropping significantly more compared with the same clones with latent virus infections in the cultivar Cox Orange Pippin.

Yield efficiency integrates bloom, fruit set and fruit size based on the bearing surface occupied by the tree. Because the bearing surface of individual trees increases linearly with trunk-cross sectional area, the latter is simple to use (Westwood, 1978). Yield Efficiency is particularly useful in evaluating/comparing cropping systems such as trellising, training, and rootstocks. (Lombard et al, 1983; Sansavini et al, 1980; Ferree and Hall, 1980).

Cook and Dennis (1984) in 8 commercial orchards, showed the general relationship between yield efficiency as a measure of crop load and fruit size. As yield efficiency increases, fruit size declines.

Most results have shown that yield efficiency is usually lowest for seedling rootstock. (Forshey and Mckee, 1970; Crabtree and Westwood, 1976; Larsen and Fritts, 1982; Ferree et al, 1982; Westwood et al, 1986 ;). Other research has shown differences among clonal rootstocks, in which the ratio of crop to tree size usually decreases with increasing vigor, though the relationship is not linear (Parry, 1977; Czynczyk, 1979; Denby, 1982; Crasweller and Ferree, 1982).

Campbell (1980) working with 4 healthy and infected rootstocks on Worcester reported that when the crop weight to trunk area ratio was compared, the data showed that the differences between treatments was minimal. The smaller virus infected trees cropped as well as the healthy ones, in proportion to their size.

Spangelo et al (1974) reported that Ottawa-3 was the most efficient rootstock on two cultivars compared with M-26 or other Ottawa clones. Dennis (1981) presented data on 3 years performance of Michigan Apple Clones on Red Prince Delicious and showed that MAC-9 was the highest in yield efficiency and the rootstocks MAC-11 and MAC-24 were the lowest.

Other reports from the same national trial in Ontario, Canada, and Michigan indicated that the best combination in yield efficiency was with MAC 9 rootstock (Elfving, 1984; Perry and Carlson, 1986).

Rootstock effect on Fruit Quality

Westwood et al (1967) found that apple fruits from light cropping trees were larger due to an increased number of cells and in some cases larger cells than from heavy cropping trees.

Westwood and Blaney (1963) found that trees of Red Delicious apple produced more elongated fruit on vigorous rootstocks (seedling, M 1, M 16, M 2). They noted that relative fruit lenght varied with rootstock in the same way as shoot growth, suggesting that the rootstocks somehow affect the hormonal balance (GA's and cytokinins which affect fruit development in particular planes.

Fallahi et al (1985) reported differences in fruit quality on 6 rootstocks with Starkspur Supreme Golden Delicious. Fruit on OAR 1 had greater soluble solids, more yellow color and were relatively firmer at harvest, but were smaller. They added that fruit of M 7 had lower soluble solids than most of the other rootstocks tested.

Forshey and Elfving reported a positive relationship between fruit number and yield but a negative relationship between fruit size and yield. Fallahi et al (1985) showed a negative correlation of soluble solids and firmness with yield.

Campbell (1980) after grading the fruit showed that apples from virus free rootstocks were much larger than those on trees on infected ones, with Cox on EMLA 9, 69 % of the Class 1 fruit was over 60 mm whereas on the 2 infected clones of M 9 only 53 % were over 60 mm.

Leaf Area

The dry matter and economic yield (fruit) of apple orchards appears to be directly proportional to their interception of radiant energy. This is especially true when comparing young orchards of the same rootstock/scion combination managed in a consistent way but growing under a range of densities (Jackson, 1978).

Orchards crops, tend to attain their maximum leaf area by mid-summer but usually intercept no more than 65 to 70 % of available light at full canopy and may take many years to attain this level (Jackson, 1980).

Leaf area measurements are often needed in studies of fruit growth and development (Haller and Magness, 1925; Hansen, 1977), calculations of net assimilation rates (Barden, 1971; Avery, 1977), evaluation of trellis training system (Ferree and Hall, 1980; Sanavini et al, 1980), and other physiological processes in apple. Also, leaf area measurements have been used to calculate leaf area index and leaf area mass (Barlow, 1980; Hughes and Proctor, 1981).

Marshall (1968) reviewed the methods for leaf area measurements requiring destructive and non destructive sampling in considerable detail. Even for non destructive methods, a representative sample of leaves needs to be collected (Ackley et al, 1958). Freeman and Bolas (1956) developed a very rapid technique involving a transparent grid which is calibrated so as to read leaf area directly from observation of the maximum leaf width and the distance from the leaf base at which this is found.

Extension shoot leaves are usually appreciably larger than short-shoot (i.e.,spurs) leaves (Barlow, 1969; Jackson, 1970), so sampling methods must ensure that both populations are properly presented.

Leaf area per plant is an inappropiate measurement of the leafiness of a whole crop since it does not take into account the spacing of the plants, a factor which must clearly be involved in any estimate of ‘crop leafiness’(Hunt, 1982). To overcome this difficulty Watson (1947) introduced the most crop-oriented concept of leafiness in relation to land area. This he named leaf area index, LAI, and defined it as a leaf area per unit area of land.

To obtain good estimates of Orchard LAI the relationship between leaf area and the girth of the branch or trunk bearing the leaves can be used to supplement the detailed measurements. Holland (1968) showed that the total leaf area on a branch of Cox’s Orange Pippin was related to its girth. He suggested that the leaf area per tree could be estimated from trunk girth provided that the K value was first established from a sample of 15 to 20 branch girths and leaf areas (not necessarily from the same tree).

A similar approach has been used by Idenko and Rasulov (1976) who devised a system based on the relationship between the cross sectional area of the first four primary branches and the total leaf surface of these branches. Barlow (1969) also studied leaf area-branch diameter relationships for Cox trees on M 9 and M 16 which had been pruned either very lightly or heavily for 14 years and either deblossomed or allowed to crop and obtained values for the standard error of the coefficient of regression similar to Holland’s.

Comprenshive data on the buildup of LAI over the years have yet to be published, but it is clear that the process is generally slow and is greatly dependent on tree vigor, spacing and management (Jackson, 1980). Consequently, it is reasonable to suppose that if apple trees were planted at a spacing appropiate to their potential size, the orchard would not attain its ceiling LAI very soon.

Little comprehensive data have been published, Jackson (1975b) found at 9 years old trees on cox on an orchard basis values of 1.49 on MM 104 and 1.36 on M 26. Verheij and Verwer (1973) studied a mature orchard of Golden Delicious on M 9 and M 2 and found the LAIs for typical, well grown hedgerows to be 2.15 and 2.45 respectively. Based on the effects on fruit yield and quality they concluded that the latter was too dense.

Heinicke (1964) studied mature trees pruned to either open center shapes, if they were very large ‘standard’ trees, or as a modified center-leader trees if they were smaller (semi-standard, semi-dwarf and dwarf) and found LAIs ranging from 3.1 to 4.6. In a more typical orchards with alleways for tractor access, Jackson (1970) reported the highest LAI recorded in a cropping orchard at East Malling Research Station to be 2.6.

I. TREE GROWTH AND ESTIMATES OF PLANTING DENSITIES FOR STARKSPUR SUPREME DELICIOUS APPLE ON SEVERAL ROOTSTOCKS

ABSTRACT

The tree growth and estimates of planting densities of ‘Starkspur Supreme Delicious’ apple on several rootstocks of the series Michigan Apple Clones (MAC), East Malling Long Ashton (EMLA), East Malling (M), Ottawa (O.) and Oregon Apple Rootstock (OAR) were evaluated during the 6th year in 1985. The 9 rootstocks were: MAC 24, MAC 9, EMLA 7, EMLA 26, EMLA 9, EMLA 27, M 9, O.3, and OAR 1. Tree height, tree spread and trunk cross sectional area (TCSA) was greatest for trees on MAC 24 followed by EMLA 7 while trees on EMLA 26, OAR 1, MAC 9, O.3, EMLA 9, and M 9 were smaller in size, in descending order, and intermediate in growth. Trees on EMLA 9 were significantly different only in tree spread from trees on M 9. The most dwarfing rootstock was EMLA 27. Estimates of planting densities indicated higher densities with tree canopy spread than TCSA based on standard trees of the age except for EMLA 27. The densities for trees on MAC 24 and EMLA 7 were estimated 424 and 496 trees/ha. respectively, while the densities for the rootstocks with intermediate size ranged from 700 to 1000 trees/ha. The highest density for the more dwarfing stock EMLA 27 was estimated at 1824 and 2747 trees/ha using canopy and TCSA respectively.

INTRODUCTION

As new rootstocks are developed, all new scion/rootstock combinations must be tested and compared to standard trees to determine the final tree size and the planting density. Tree spacing must be in reasonable agreement with natural tree growth.

Growth and performance of apple trees on dwarfing rootstocks have been reported recently (Crabtree and Westwood, 1976; Scneider et al, 1978; Seeley et al, 1979; Denby, 1982; Larsen and Frits, 1982). While tree size on a given rootstock varied with age and location, size relative to trees on seedling or a standard stock was quite consistent. Also, tree size by rootstock from national trials in several States and Canada have been reported (Simmons, 1983; Elfving, 1984; Lombard et al, 1985; Perry and Carlson, 1986).

Planting densities depend principally on the final phenotipic expression of the scion and rootstock, and also on the site/soil characteristics, cultural aspects and the training system used (Lombard et al, 1985). A highly efficient combination spaced too widely will never achive maximum potential yield per acre, and planted too closely would result in excess shading, low fruit set, and poor quality (Westwood et al, 1986).

Various parameters to evaluate planting densities have been defined, such as the ratio between tree height and width of the alley and the leaf area index (Jackson, 1970, 1978b; Verheij and Verwer, 1973). Several methods have been used to estimate planting densities: the tree canopy spread (Proctor et al, 1974; Seeley et al, 1979) ; the area occupied by the crown (Parry, 1977); and the trunk cross sectional area (TCSA) (Lombard, 1985; Lombard et al, 1985; Westwood et al, 1986).

The present paper reports growth studies of ‘Starkspur Supreme Delicious’ apple on nine different rootstocks and estimates of planting densities based on tree spread and cross sectional area of the trunk.

MATERIALS AND METHODS

The trial was located near Corvallis, Oregon, on Oregon State University's Lewis Brown farm. The plot, which is a part of a national trial was planted in 1980, and the studies were conducted during 1985.

The plot of 45 trees was replicated in 5 blocks of 9 rootstocks, spaced 3.5 x 5.5 m. The cultivar grafted was Starkspur Supreme Delicious (Paganelli cv. virus-free). Pollenizer rows every third row consisted of 'Macspur' and 'Starkspur Golden Delicious' trees on M 26 rootstocks. The nine rootstocks evaluated were : EMLA 7, EMLA 26, EMLA 9, EMLA 27, M 9, MAC 9, MAC 24, 0.3, and OAR 1.

The soil is an uniform silty clay loam. 'Creeping Red' fescue was planted in the rows of a 2 m. width plus a weed free strip of 1.5 m. down the tree row with a use of herbicides. Irrigation is by low head sprinklers, and trees were irrigated every 3 weeks at 50 mm of precipitation.

Measurements of the following parameters were taken after the harvest, prior to pruning:

1) tree height was measured at the highest point using a pole scale at the tree center; 2) tree width was measured in two directions; the width in the east - west direction (between trees), and the north - south orientation (between rows); 3) trunk diameter was measured at 30 cm above the soil and transformed to cross-sectional area of the trunk ; additionally, TCSA of 'Cascade spur Delicious' on seedling rootstock at 1.75 x 5.5 m were taken.

Two methods for estimating planting densities were considered :

In the first method, the density was based on tree canopy spread plus 1 m between trees and plus 2 m between rows for orchard traffic. Estimates of planting densities were then calculated from expanded tree canopy.

TCSA has been used to relate tree size (Westwood and Roberts, 1970), and also to determine the percent of standard size against known combinations (Lombard et al, 1985; Westwood et al, 1986). TCSA of 51.53 cm^2 for "Cascade spur Delicious" on seedling rootstock was used as a known combination, at the same age, and in the same site and growth habit. This combination was determined to be 79 % of a standard tree (Westwood et al, 1986). Using the TCSA of a standard tree size of 65.22 cm^2 (100 %) comparisions were made to determine the percent tree size of each rootstock. The appropriate planting density was calculated by dividing the percent of standard tree into the density of the standard combination of 247 trees/ha.

The experiment was laid out in a randomized block design with rows as a blocking factor. Data obtained for each parameter of growth were analyzed separately. Statistical analyses were made on tree height, average tree width and TCSA. Means were statistically analized using ANOVA at the 5 % level. When comparing more than two means, Waller-Duncan-Bayes procedure (BLSD) test at k=100 ratio was used for mean separation (Steel and Torrie, 1980). A substitute value for a missing observation was computed and one degree of freedom from the total and the error was lost. (Snedecor and Crochan, 1980).

RESULTS AND DISCUSSION

Relative tree size by canopy dimension.

Tree height was affected by rootstocks (Table 1). There was a significant break in height differences among 5 groups of rootstocks. The groups were from highest to lowest heights : 1) MAC 24; 2) EMLA 7; 3) EMLA 26, OAR 1; 4) MAC 9, 0.3, EMLA 9, M 9; 5) EMLA 27. Simons (1983) found the same relative order in tree height before fruiting occurred, but he reported trees on O 3 were the highest, which could be due to the lack of fruiting.

Tree canopy width was affected by rootstocks (Table 1). Similiarly, there were 5 tree size groups among the 9 rootstocks : 1) MAC 24; 2) EMLA 7; 3) EMLA 26, OAR 1, MAC 9, 0.3, EMLA 9; 4) M 9; 5) EMLA 27. But some of the width groups contained a different rootstock makeup with significant differences occurring between trees on EMLA 9 and M 9. Simons (1983) reported a similiar grouping of the rootstocks by canopy width. However, he reported a greater width for M 9 as compared with EMLA 9, perhaps because his data were taken on trees in the pre-fruiting stage of development.

Relative tree size by TCSA.

Tree size by TCSA was influenced by rootstocks (Table 1), which has been an indicator of the above-ground portion of the tree mass (Westwood and Roberts, 1970). Again, 5 groups were found, similiar to tree height. The groups were in descending order : 1) MAC 24; 2) EMLA 7; 3) EMLA 26, OAR 1; 4) MAC 9, 0.3, EMLA 9, M 9; 5) EMLA 27.

Others have shown similar rootstock trends in TCSA reported in the same national trials (Simons, 1983; Micke, 1985; Lombard et al, 1985; Carlson and Perry, 1986; Perry and Carlson, 1986).

Studies by Dennis (1979, 1981) involving Michigan Apple Clones (MAC) indicated that MAC 24 and MAC 11 were the largest trees and MAC 9 the smallest by TCSA. However, Gilbert (1982) reported trees on MAC 9 and MAC 24 were similar in tree size after 8 years in the orchard due to shallow soil.

Few workers (Campbell, 1980; Elfving, 1984; Westwood et al, in press); have shown statistical differences in tree size between EMLA 9 and M 9 rootstocks suggesting that the site conditions can influence tree size .

Tree characteristics related to rootstocks.

Subjective ratings of horticultural characteristics made on the rootstocks (Table 4) showed that trees on MAC 24 and O 3 had crown root suckers, while trees on M 9, EMLA 9, EMLA 7 and 0.3 had root suckers. Trees on EMLA 26 and M 9 had more burrknots than the 7 other rootstocks. Trees on EMLA 27, M 9 and EMLA 9 had the most wobble in planting hole, and the highest degree of top of tree leaning on trees of M 9, EMLA 27 and 0.3 indicating that these rootstocks need support system to crop. Also, trunk leaning from the ground occurred on trees of M 9, 0.3, EMLA 9, EMLA 27 and EMLA 26 suggesting that trees on these rootstocks probably need a support during the early years.

The best spacing for Starkspur Supreme Delicious on any rootstocks will depend on soil type and growing conditions. In this trial, where the in row spacing was 3.5 m , there was some canopy overlap with MAC 24 rootstock by the 6th year. However no problems have been encountred with between row spacing.

Planting densities based on canopy width.

Canopy width data suggest possible planting distances. Estimated planting densities are presented in Table 2 based on the canopy width plus 1 m between tree spacing and allowing 2 m between rows for tractor access. Trees on M 9 were estimated to have a spacing of 2.78 x 3.56 m and a density of 1010 trees/ha. This density was 19 and 15 % higher than trees on EMLA 9 and MAC 9 respectively.

Planting densities based on TCSA.

The use of TCSA of young trees relative to known and standard combinations at the same age and site can indicate relative tree size for planting densities of new scion/rootstocks combinations (Lombard, 1985). Therefore, we calculated the relative tree sizes based on the TCSA of 65.22 cm^2 for a standard size tree (100 %) at the same age and site and then estimated possible planting densities for several new rootstocks allowing 1.5 m for alley clearance.

Tree size of MAC 24 and EMLA 7 were greater than a standard size tree while those on EMLA 26 and OAR 1 were 44 and 43 % (Table 3). Estimated planting densities using TCSA were lower as compared with those of tree canopy width except on EMLA 27. This could be explained by a relatively small trunk diameter compared to the tree spread.

These results agree with those reported by Lombard et al (1985) who used TCSA for estimating planting density from the same plot one year earlier. However, they found lower densities for all the combinations. The higher densities were attributed to smaller tree size because of closer spacing used in this study increasing competition between trees or because of the spur growth habit of the scion used.

CONCLUSION

1. Two methods of estimating planting density are in pretty good agreement except, when extremes in tree size are involved.

2. Rootstock M 9 decreased tree size compared to EMLA 9 but was not significant. However, planting density increase in 19 % for M 9.

3. Trees on rootstocks EMLA 27, M 9, EMLA 9, and 0.3 need a support system to crop because of wobble in the planting hole, trunk leaning from the ground and top of tree leaning.

Table 1. Tree Height, Tree Canopy Width and Trunk cross sectional area (TCSA) of ‘Starkspur Supreme Delicious’ on 9 apple rootstocks of 6 years old trees spaced 3.5 x 5.5 m

Rootstock	Tree Height (cms)	Tree Spread (cms)	Trunk cross sec. area (TCSA) (cm^2)
MAC 24	355.2	337.2	79.47
EMLA 7	318.0	301.4	55.37
EMLA 26	237.6	228.8	28.59
OAR 1	258.6	216.8	28.26
MAC 9	212.4	195.2	20.71
0.3	212.4	222.4	20.02
EMLA 9	215.4	203.6	19.14
M 9	187.6	167.0	16.28
EMLA 27	121.8	90.6	5.98
BLSD(k=100)	31.7	35.3	8.12

Table 2. Tree Canopy Spread and possible Planting Densities of 'Starkspur Supreme Delicious' on 9 apple rootstocks based on Canopy Width of 6 years old trees spaced at 3.3 X 5.5 m

Rootstock	Tree Canopy Width Plus 1 m for in Row Spacing (m)	Tree Canopy Width Plus 2 m for between Rows Spacing (m)	Estimated Planting Density (trees/ha)
MAC 24	4.49	5.25	424
EMLA 7	4.07	4.95	496
EMLA 26	3.26	4.32	710
OAR 1	3.19	4.14	757
MAC 9	3.02	3.88	853
0.3	3.24	4.20	735
EMLA 9	2.99	4.08	820
M 9	2.78	3.56	1010
EMLA 27	1.85	2.96	1826

Table 3. Trunk cross sectional area (TCSA), Relative Tree Size and estimated Planting Densities of ‘Starkspur Supreme Delicious’ on 9 apple rootstocks of 6 years old spaced at 3.5 X 5.5 m

Rootstock	Trunk cross sec. area (cm^2)	Relative Tree Size To Standard (%)	Estimated Planting Density (trees/ha)
MAC 24	79.4	122	203
EMLA 7	55.3	85	291
EMLA 26	28.5	44	562
OAR 1	28.2	43	575
MAC 9	20.7	32	773
0.3	20.2	31	798
EMLA 9	19.1	29	853
M 9	16.2	25	989
EMLA 27	5.9	9	2747
SEEDLING *	51.5	79	313

* Cascade spur on seedling rootstock.

Table 4. Subjective Rating of Horticultural Characteristics of 'Starkspur Supreme Delicious' on 9 apple rootstocks.*

Characteristic	Rootstocks								
	O 3	EMLA 7	EMLA 9	EMLA 26	EMLA 27	M 9	MAC 9	MAC 24	OAR 1
Trunk leaning from soil	2	5	2	3	3	2	5	5	5
Top of tree leaning	2	5	3	3	2	2	4	5	5
Suckers from root crown	2	5	4	5	5	4	4	1	5
Suckers away from trunk	3	3	3	4	5	3	5	5	5
Burrknots	5	4	3	1	5	2	3	5	5
Wobble in planting hole	3	4	2	4	1	2	4	5	5

* A rating of 1 was given when the expression of the characteristic was very undesirable, and a rating of 5 indicated the expression of that characteristic is very desirable from a horticultural viewpoint.

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II. YIELD COMPONENTS, FRUIT QUALITY AND THE RELATIONSHIP WITH GROWTH AND LEAF AREA OF 'STARKSPUR SUPREME DELICIOUS' APPLE ON SEVERAL ROOTSTOCKS

ABSTRACT

Yield components and fruit quality of 'Starkspur Supreme Delicious' apple on nine rootstocks [Michigan Apple Clones (MAC 24 and MAC 9), East Malling Long Ashton (EMLA 7, EMLA 26, EMLA 9 and EMLA 27), Ottawa (0.3), Malling (M 9), and Oregon Apple Rootstock (OAR 1)] were evaluated on 6 year trees in 1985. Flower cluster, fruit number, yield and leaf area per tree were found to be a function of trunk cross sectional area (TCSA). When the data were standarized by dividing by TCSA, MAC 9 rootstock had the highest flowering density, crop density and yield efficiency, followed by 0.3, EMLA 26 and EMLA 9. Potential yields based in the estimated planting density were also highest for MAC 9. Fruit on OAR 1 rootstock had greatest soluble solids and were firmest at harvest, but were smallest. Fruit on EMLA 7 had lowest soluble solids and were largest. There was a negative correlation between percentage of fruit set and flowering density among the rootstocks. Crop density influenced fruit size and weight. Fruit on EMLA 7, MAC 24 and EMLA 9 was larger with lower crop density. The high correlation of fruit number with yield indicated that it was the chief component of yield. The leaf to fruit ratio had a high negative correlation with flowering density, crop density and yield efficiency and the ratio was lowest on more efficient rootstocks MAC 9, 0.3 and EMLA 9.

INTRODUCTION

High tree density is important in obtaining maximum fruit yields (Westwood et al, 1976). This has stimulated interest in size controlling clonal rootstocks, which are attractive for a number of reasons. Small trees simplify most hand operations such as picking, pruning, training and thinning resulting in easier, safer and more efficient operation (Heinicke, 1975). Yield per unit of tree size can be greater with size controlling rootstocks (Forshey and Wayne, 1970; Westwood et al, 1976; Denby, 1982; Larsen and Fritts, 1982; Westwood et al, 1986), which can also developed earlier flowering and fruiting (Visser, 1973; Crabtree and Westwood, 1976; Dennis, 1981).

Small trees allow close spacing and better light interception within the canopy for fruit development and growth (Heinicke, 1964; Verheij and Verwer, 1973; Palmer and Jackson, 1977; Jackson, 1980). Also small trees are easier to maintain in a medium or high density planting.

Comparative tree yields on various apple rootstocks have been based on cumulative yields for several years (Crabtree and Westwood, 1976; Denby, 1982; Ferree, 1980; Ferree et al, 1982; Lord et al, 1980), but the components of yield are seldom presented. Funt et al (1981) have shown that planting densities with an earlier yield return are more desirable than those with lighter densities which yield equal or greater cropping levels at a later years.

Two goals of crop research are to measure the contribution of various yield components and to assess the treatment effect on those contributions (Fraser and Eaton, 1983; Eaton et al, 1986).

The present paper reports studies of the main effects and interactions of yield components, fruit quality, growth and leaf area of Starkspur Supreme Delicious apple on some well known and less known size-controlling rootstocks.

MATERIALS AND METHODS

The studies were conducted in Corvallis, Oregon during 1985, utilizing the Oregon State University Lewis Brown research farm. The plot of 6 year old trees is part of a national trial. The soil is an uniform silty clay loam. 'Creeping Red' fescue sod is planted in the row of a 2 mt. width plus a weed free strip of 1.5 m down the tree row with the use of herbicides. Irrigation is by low head sprinklers, applying 50 mm of moisture every three weeks during the summer.

The experiment consists of 45 trees in five replicated blocks of nine different rootstocks, spaced 3.5 X 5.5 m in row and between row, respectively. The cultivar used was 'Starkspur Supreme Delicious'. Two tree rows interplanted in the main plot were used as pollinizer trees of 'Macspur' and 'Starkspur Golden Delicious' on M 26 rootstock. The 9 rootstocks evaluated were : 0.3, EMLA 7, EMLA 9, EMLA 26, EMLA 27, M 9, MAC 9, MAC 24 and OAR 1.

The Yield components studied were divided in three parts : 1) flowering, 2) fruiting and 3) fruit quality. Each of these areas will be discussed separately.

1. Flowering

Whole tree counts of clusters were made on each rootstock in five replications to determine the rootstock's influence on flower cluster numbers, and flowering density .

The number of all flower clusters during the first pink stage in the spring were counted and recorded, at the same time measurements of the trunk diameter were taken and converted to the trunk cross-sectional area (TCSA). Flowering density was obtained by dividing the number of clusters by the TCSA, for units of flower clusters/cm^2.

2. Fruiting

For the fruiting component, the whole tree of each rootstock was chosen to determine the rootstock effect on fruit set, crop density, and yield efficiency for the 1985 year, and the cumulative yield and yield efficiency for the period of 1982-1985.

Fruit set was based on number of flower clusters per tree and after June drop the number of fruits removed by thinning and the number of retained fruits at harvest were counted. The total fruit number (thinned and harvested) was converted to fruit set. Fruit set at harvest was based on fruit retained. The units for this parameter was fruit number/100 clusters.

The percent of thinned fruit after June drop was based on the total number of fruits before thinning. To calculate the crop density, fruit number before hand thinning, was divided by TCSA (fruit number/cm^2). Fruit number at harvest was used for final crop density. Yield efficiency based on weight of harvested fruit per TCSA was obtained for each tree, by measuring trunk diameter after harvest and converted to TCSA. Yield efficiency units are Kgs/cm^2.

Cumulative yield efficiency was calculated on the total yield through 4 years divided by TCSA reached after the 1985 season. Potential yields per surface area for each scion-rootstock combination was calculated from the tree and planting density based on tree size previously estimated (Table 3). The unit for potential yield were ton/ha.

III. Fruit Quality

To evaluate the effect of the rootstocks on fruit quality, 5 fruit were taken randomly from each tree, at harvest time, and kept in the cold storage until November 10 when quality observations were conducted. Fruit diameter and length were taken and averaged per replication. The fruit length/diameter ratio (L/D) was also obtained. Fruit weight in g. per fruit was obtained at harvest from the yield in kgs divided by the number of fruits. Fruit firmness was based on pressure testing of two pared sides of each of the 5 fruits per tree. Magness Taylor Pressure Tester equipped with an 11 mm plunger in units of lbs/in^2 and later converted to newtons was used. The 5 fruit were juiced and soluble solids were taken with a refractometer.

Statistical Analysis.

The experiment was laid out in a randomized block design with rows as the blocking factor. Data obtained in each parameter were analyzed separately. Statistical analysis were made for the effect of rootstocks on all data obtained in 1985, and cummulative yield and cummulative yield efficiency during 1982-85. Linear correlations were calculated for all possible interactions among the yield components, fruit quality, TCSA and leaf area parameters.

Means were statistically analyzed using ANOVA at the 5 % level. When comparing more than two means, Waller-Duncan-Bayes procedure (BLSD) test at k=100 ratio was used for mean separation. (Steel and Torrie, 1980). Where one experimental unit was lost, we computed a substitute value for the missing observation, and lost one degree of freedom from the total and from the error. (Snedecor and Crochan, 1980).

RESULTS AND DISCUSSION

Flowering

Flower clusters number was significantly affected by rootstocks (Table 5). Trees on MAC 24 and MAC 9 had the highest values and twice the value of M 9. But flower number on MAC 24 and MAC 9 were not significantly different from trees on EMLA 7, EMLA 26, OAR 1 and 0.3. With the exception of MAC 9, larger trees produced more flower clusters per tree than small ones (Webster, 1984; Dennis, 1981). However, Ferree (1976) found dwarfing rootstocks produced more flower cluster per tree, and the precocity occurred in early years after planting. But the rootstock effect on precocity could be not detected in this study because of the advanced age of these trees by the 6th leaf.

When we related the number of flower clusters by tree size based on TCSA, we observed significant differences among several rootstocks (Table 5). In contrast with the results obtained on number of flower clusters per tree, flowering density increased as rootstock vigor decreased with some exceptions. Trees on rootstock MAC 9 had considerably higher flowering density than on other rootstocks, about 50 % greater than either M 9 or 0.3, although it was not significantly different. Although the later rootstocks produced well exposed canopies because of growth control, they still had much less flower initation. Therefore the rootstock MAC 9 may initiate more flowers because of increase as cytokinin or less gibberellin from the roots (Luckwill, 1970). The most vigorous rootstock in this trial MAC 24 and EMLA 7 produced trees with the lowest values in flowering density, and half as much as the trees on M 9. These results and those reported by Dennis (1979,1981) and by Crabtree and Westwood, (1976) noted that flowering density was inversely related to tree size. Generally, the more dwarfing stocks produced the highest percentage of flowering buds, because of less dense growth which allowed greater light penetration of trees on vigorous rootstocks (Heinicke, 1964; Verheij and Verwer, 1973).

Carlson and Perry (1986) reported also that MAC 9 has been superior in blossom efficiency as compared to 8 other rootstocks, while the most vigorous rootstocks in their study had the lowest values. However, they found that EMLA 9 and EMLA 27 produced more flowering per cm^2 than the virus infected rootstock M 9, in contrast with our data suggesting that soil or site conditions may affect the rootstock because of the differences in TCSA between the two locations. TCSA values for a comparable rootstocks were greater in the Michigan site.

Fruiting

As reported in Table 6, the percentage of fruit removed was consistent among rootstocks, indicating that proportional thinning occurred in relation to the total fruit number in each tree. Lack of significance in fruit removal is due in part, because the decision to leave one fruit per cluster at thinning. This will be reflected in fruit size and yield which will be discussed in fruit quality and in the correlations with leaf area.

Rootstock affected only fruit set prior to thinning (Table 5).

Trees on rootstock EMLA 7 had the highest fruit set, which was statistically different only from trees on EMLA 27, MAC 9 and OAR 1. The most dwarfing rootstock EMLA 27 had the lowest fruit set, and was significantly different from EMLA 7 and EMLA 26.

Heavy flowering is often associated with low percentage of fruit set in apple because of competition between flowers and young fruits (Dennis, 1979). Our results indicate that EMLA 7 and MAC 24 rootstocks with light flowering density had high fruit set, contrasting with MAC 9 which had heavy flowering but a low fruit set. Roberts (1947), Dennis (1981) and Tami (1984), reported a negative correlation between percent of flowering and fruit set. However, Dennis (1979,1981) found trees on MAC 9 flowered heaviest and set the largest number of fruits per clusters among 8 Michigan Apple Clones. Other workers have shown limited data that rootstocks influenced fruit set (Blasco, 1982; Constante, 1982; Webster,1984). Problem of uniform thinning appears that EMLA 7 set more clusters from which removing all but one fruit per cluster favored a higher set at harvest.

The fruit number per tree at harvest was generally related to tree size as affected by rootstock (Table 6). The highest values were obtained on trees of the least dwarfing rootstocks, MAC 24 and EMLA 7 and they produced twice as much as those on M 9. However only those on MAC 24 was statistically different from the 8 other rootstocks. Trees on EMLA 7 were nearly the same as EMLA 26 and MAC 9 producing 55 to 60 % more fruit than M 9. The fruit number differences between the virus free EMLA 9 and the infected M 9 was minimal and not significant. The most dwarfing stock EMLA 27 had the least number of fruit,72 % less than M 9. With the exception of OAR 1, fruit number per tree declined as tree size decreased, because the least controlling stock develop a greater structure to support more fruits. Similar results were reported by Blasco (1976), Crasweller and Ferree (1983), and Blasco et al (1982) who found that the most vigorous rootstocks produced more fruits per tree.

Crop density, the fruit number by tree size based on TCSA, was affected significantly by rootstocks (Table 6). The trees on MAC 9 had the highest crop density, and no significant difference in crop density from trees on M 9, 0.3 and EMLA 26. M 9 produced 21 % greater crop density than EMLA 9 , but the difference was not significant. The most vigorous rootstocks MAC 24 and EMLA 7 had the lowest crop density but this was within the significant range of the crop densities on rootstock EMLA 27 and OAR 1. Crop density of trees on EMLA 27 was 35 % less than on M 9. However, even the lowest values are within the optimum range for crop density 3 to 6 fruits/cm^2 (Lombard and Dennis, 1985).

Crop density is a function of flowering density and fruit set (Lombard and Dennis, 1985; Tami, 1984). Trees on MAC 9 which had a heavier bloom and a lighter set resulted in the same relative crop density as trees on M 9 which had a lighter bloom and heavier set. Also, Dennis (1979, 1981) when comparing crop densities of trees on a series of Michigan Apple Clonal rootstocks showed trees on MAC 9 with the highest values and MAC 11 and MAC 24 with the lowest. Tami (1984) reported that OAR 1 had the lowest crop density among 4 rootstock tested while those on M 26 had the highest. The large difference in crop density between EMLA 9 and M 9 occurred because the latter is more dwarfing (Campbell, 1980;).

Those rootstocks with the least growth control had the lowest crop density but not much less than the most dwarfing rootstock. These small differences indicate that the effect of the rootstock on tree size was not the main factor that affected crop density, but perhaps the less dense canopy and/or increase the production of growth substances in the roots such a cytokinins (Jones, 1986).

There was a significant effect on yield by rootstocks (Table 6). The least dwarfing rootstocks MAC 24 and EMLA 7 rootstocks produced the greater yield almost 3 times greater than trees on M 9. The lowest yield was obtained on the most dwarfing stock EMLA 27, only 1/4th of tree yield on M 9 and the yield on EMLA 27 was significantly different from the other 8 rootstocks. Yield on trees with OAR 1 rootstock was the second lowest . Yield per tree was related to tree size, except on OAR 1. This relationship was similarity reported by Parry (1977), Blasco (1982), Micka (1984), Webster (1984) and Elfving (1984); but Dennis (1979, 1981) found a disimilar relationship.

The small yield differences between EMLA 9 and M 9, were reported by Campbell (1976) with 'Worcester Permain' and 'Egremont Russet', however comparision of the two on 'Cox's Orange Pippin' showed a statistical differences in yield.

Expressing the yield in Kgs per cm^2 of TCSA as yield efficiency allowed the comparision of tree productivity based on tree size, demonstrating some significant differences among the rootstocks

(Table 6). The most productive trees were on MAC 9 rootstock but which was not significantly greater than trees on 0.3, EMLA 26, EMLA 9 and M 9. The rootstocks OAR 1 and MAC 24 had the least yield efficiency, but they were not significantly different from trees on EMLA 7 and EMLA 27.

Rootstocks with intermediate tree size (MAC 9, 0.3, EMLA 26, EMLA 9) were the most efficient because most of the photosynthates are directed toward the fruit production rather than wood production (Spangelo et al, 1974; Dennis, 1981; Elfving, 1984; Perry and Carlson, 1986). Some have mentioned that the ratio of yield to tree size usually decreased with increasing tree size, though the relationship was not linear. (Parry, 1977; Czynczyk, 1979; Denby, 1982; Crasweller and Ferree, 1983).

The smaller trees on virus infected M 9 cropped as well as the virus cleaned on EMLA 9 in proportion to their size, as Campbell (1980), and Westwood et al (1986) found on spur cultivars.

The cumulative yield from 1982 to 1985, and the cumulative yield efficiency for the 9 rootstocks tested is presented in Table 7. In the the third year, trees on EMLA 9 had the highest yield but there was no significant difference with trees on EMLA 26, MAC 9 and M 9 suggesting that these rootstocks are very precocious.

Ferree (1976) reported that the dwarfing rootstocks M 9 and M 26 were more precocious than the semidwarf MM 106 and MM 111. This may indicate that some rootstocks crop early because of the early export of growth substances such as cytokinins or the lack of gibberellins from the root to increase an early flower initation (Luckwill, 1970).

Trees on MAC 24 had the highest yield from the fourth to the sixth year, followed very closely by EMLA 7 while EMLA 27 was the lowest. The highest tree yields were possible on the least growth controlling stocks MAC 24 and EMLA 7 because of better supporting structure or greater fruit bearing surface developed in the early years. These high sustained yields did not reduce tree size to those rootstocks with greater growth control. This suggest that from the fourth year and on the yield was associated with tree size, since the larger trees produced proportionately more (Micka, 1984; Webster, 1984). However trees on OAR 1 were the exception since they were slow to crop relative to its size.(Tami, 1984; Elfving, 1984).

Through the 4 years EMLA 9 has been superior in yield compared with M 9 because of greater tree size, because of the lack of known viruses. However, the yield difference through the 4 years was not significant which Campbell (1976) also found with "Worcester Permain" and "Egremont Russet" in England. Cummulative yield from 1982 to 1985 paralleled the annual yields in which rootstocks with larger trees produced greater yield.

To determinate the tree productivity related to tree size from the rootstock used, cummulative yield efficiency was taken from 1982 to 1985. Data in Table 7 indicates that ‘Starkspur Supreme Delicious’ trees on MAC 9 were significantly more productive than 8 all rootstocks, except EMLA 9. The least efficient rootstocks were MAC 24 and OAR 1 (Dennis, 1981; Elfving, 1984; Perry and Carlson, 1986). When cummulative yield efficiency was compared between EMLA 9 and M 9, the difference was minimal. The smaller trees from the virus infected M 9 cropped in proportion to tree size, as did EMLA 9.

The rootstocks effect on potential yield based on 1985 yield and tree size and the cummulative potential yield for 1982-85 and tree size are presented in Table 9. Using tree spread as estimator of planting density (Table 2) gave the highest potential yields, except on EMLA 27 compared to those of TCSA (Table 3) based on 'Cascade Spur Delicious'/seedling rootstock.

Potential yields based on density estimated from tree spread and the 1985 data were highest for trees on EMLA 26, followed closely for MAC 9, EMLA 7 and MAC 24. It indicates that trees on EMLA 26 and MAC 9, although producing less tree yield can produce greater yield per surface area when planted to the appropiate planting density (Lombard et al, 1985). Yield potential of EMLA 9 was greater than M 9, even though M 9 could be planted in a greater density. The lowest potential yields are for trees on EMLA 27 and OAR 1 because of their low yield efficiency. Potential cummulative yields from 1982 to 1985 followed the same trend found for 1985 yields for the 8 rootstocks, except for MAC 9 which had higher cummulative yields because of higher yield efficiency and better precocity.

Using TCSA of the seedling rootstock for estimation of planting density (Table 3) gave lower potential yields as compared with tree spread to estimate planting density, except for EMLA 27. Trees on EMLA 27 had greater potential yield because they have a relatively small trunk diameter compared to tree spread. The more vigorous rootstocks MAC 24, EMLA 7 and OAR 1 have the lowest potential yields because of relatively larger trunk diameter compared to tree spread.

These results agree with those reported by Lombard et al (1985) who used TCSA for estimating planting density and the potential yields in the same plot one year earlier. However, they found that trees on EMLA 27 were least efficient in cummulative yield while we noted that MAC 24, EMLA 7 and OAR 1 where less efficient than trees on EMLA 27. These differences are due to the difference in seedling rootstock and the scion used which produced less growth because of closer planting at 1.75 m X 5.5 m which increased competition between trees.

III.Fruit Quality

The fruit quality parameters are presented in Table 8 and there were statistical differences among the rootstocks. Most of the apples from trees on all rootstocks averaged in the 7.20 to 8.12 cm size range and between 169 to 258 grams weight, which is considered fruit of good quality. The rootstocks EMLA 7, EMLA 9 and MAC 24 had the largest and heaviest fruit, which could be from the lower crop density obtained permitting better fruit growth.

The fruit on MAC 9 rootstock was small which was related to high crop density level (Table 6). However, fruit on OAR 1 were the smallest, although the tree had comparable crop density as trees on MAC 24 and EMLA 7 which had the largest fruit. Size and weight of apples from the virus free trees on EMLA 9 were much larger and significantly different from trees on the virus infected M 9. Similiar results were presented by Campbell (1980). But the difference could be related to a crop density in this study.

The soluble solids in the fruit was statistically different among the rootstocks (Table 8). Fruit on OAR 1 rootstock had the highest soluble solids (significant at 5 %) compared to fruit on the other eight rootstocks. Fruit on EMLA 7 had the lowest soluble solids. Also, Fallahi (1983) and Fallahi et al (1985) obtained high soluble solids from fruit on OAR 1. Therefore, OAR 1 rootstock may have a direct effect on soluble solids besides on crop load. However, Tami (1984) reported that the higher soluble solids of OAR 1 could be due to smaller fruit because of high crop load. Fruits on the other rootstocks have intermediate levels of soluble solids and was not dramatically affected by crop load. However, the high soluble solids of fruit on MAC 24, may have been due to the higher fruit/leaf ratio (Table 22).

The effect of the rootstocks on the firmness of the fruit was significantly affected (Table 8). Fruits on OAR 1 were firmer than the other rootstocks, although differences were not significant from MAC 24 and M 9. Rootstocks MAC 9 and EMLA 9 produced relatively softer fruit. This differences were perhaps, because the relative sizes of fruit, small fruit on OAR 1 and large fruit on EMLA 9. Although the results of MAC 24 and MAC 9 complicate the issue, these results are within general agreement with those of Fallahi (1983), Tami (1984) and Fallahi et al (1985). They found that fruit on OAR 1 were firmer than those on M 26.

Correlations among Yield Components, Fruit Quality Factors, Leaf Area/tree, Leaf Area/fruit and Trunk cross-sectional Area.

Correlations between Yield components and Fruit Quality.

Flower Cluster

Flowering density, fruit set, fruit number and yield was correlated significantly with number of flower cluster/tree at 1 % level (Table 10). The correlation was positive with flowering density (r = 0.38), fruit number (r=0.80), and yield (r=0.69), but negative with fruit set (r=-0.62). There was a strong correlation with fruit number indicating that 65% of the variation on fruit number was explained by the variation on number of flower cluster. There was a weak correlation with flowering density indicating that only 15% of the variation on flowering density was accounted by the variation on number of flower cluster/tree, which suggest that other factors such as tree size play a role in the variation of flowering density.

Flower Density

Fruit set, crop density, yield efficiency, fruit weight and fruit diameter was correlated with flowering density (Table 11). The correlation was positive and significant at 1 % level with crop density (r=0.79), and yield efficiency (r=0.63) but negative with fruit set (r=-0.63), fruit weight (r=-0.55) and at 5% level with fruit diameter (r=-0.38). A negative correlation of flowering density with fruit set has been reported by Roberts (1947), Dennis (1981) and Tami (1984).

Fruit Set

Crop density at 1 % level, fruit weight and fruit diameter at 5 % level were significantly correlated with fruit set (Table 12). The correlation was positive with fruit weight (r=0.55) and with fruit diameter (r=0.44) but negative with crop density (r=-0.36). Dennis (1981) reported a negative correlation between fruit size and fruit set. The low correlation of fruit set with crop density indicates that the later is more dependent of another factor such as flowering density. However, Dennis (1981) found yield efficiency correlated with fruit set.

Crop Density

Yield efficiency, fruit weight, fruit diameter (at 1 % level), and soluble solids (at 5 % level) were significantly correlated with crop density (Table 13). There was a positive correlation with yield efficiency (r=0.89), but negative with fruit weight (r=-0.59), fruit diameter (r=-0.45) and soluble solids (r=-0.38). Forshey and Elfving, (1977) reported a significant correlation of crop density with fruit weight. There was a weak correlation of crop density with soluble solids suggesting that other factors such as leaf-fruit ratio, fruit number, yield per tree and yield efficiency also influenced the content of soluble solids in the fruit.

Fruit Number

Yield/tree (at 1 % level) and soluble solids (at 5 % level) was significantly correlated with fruit number/tree (Table 14). The correlation of fruit number was positive with yield/tree (r=0.95), but negative with soluble solids (r=-0.38). A strong correlation of fruit number with yield/tree was also reported by Forshey and Elfving (1977, 1979). They reported fruit number as the main factor affecting yield.

Yield

Fruit weight and fruit diameter (1 % level), and soluble solids (5 % level) was significantly correlated with yield (Table 15). The correlation was positive with fruit weight (r=0.50) and fruit diameter (r=0.48) but negative with soluble solids (r=-0.37). The strong correlation was with fruit weight indicating that 25% of the variation on fruit weight is explained by the variation on yield, which indicates that fruit weight is also dependent of other factors such as crop density and fruit number.

Yield Efficiency

Soluble solids (r=-0.50) and firmness (r=-0.35) were significantly correlated with yield efficiency at 1 % and 5 % level respectively (Table 16). Both correlations were negative and indicated that as yield efficiency was increased soluble solids and firmness were decreased. These low correlations suggest that other factors such as fruit size and leaf area were also involved on the variation of this fruit quality factors. But fruit quality based on soluble solids and firmness are reduced with high yield efficiency.

Fruit Weight

Fruit diameter (r=0.85) was significant and positively correlated with fruit weight (Table 17).

Correlations between Leaf Area/tree, Leaf Area/fruit, yield components and fruit quality factors.

Leaf Area per tree

Those significant yield components and fruit quality factors correlated with leaf area per tree are presented in Table 18. The correlations were positive with number of flower cluster (r=0.44), fruit number (r=0.72), yield (r=0.83), fruit weight (r=0.53), fruit diameter (r=0.43), firmness (r=0.33) and leaf area/fruit (r=0.77). But there was a negative correlation with flowering density (r=-0.51), crop density (r=-0.57) and yield efficiency (r=-0.47). All the correlations were highly significant (1 % level) except firmness (5 % level).

Leaf Area per fruit

Those factors of yield and fruit quality correlated significantly with leaf area per fruit are presented in Table 19. The correlations were positive with fruit set (r=0.36), yield (r=0.41), fruit weight (r=0.67), fruit diameter (r=0.50) and firmness (r=0.30) but a negative correlation was found with flowering density (r=-0.74), crop density (r=-0.84) and yield efficiency (r=-0.72). These correlations were highly significant (1 % level) for all the factors except fruit set and firmness (5 % level). Correlations of leaf-fruit ratio with fruit size, fruit quality and flower bud formation have been reported elsewhere (Haller and Magness, 1925; Haller and Magness, 1933; Magness, 1928; Magness and Overly, 1929).

Correlations of TCSA as index of growth with yield components, fruit quality factors and leaf area.

The significant correlations of yield components, fruit quality and leaf area with trunk cross sectional area as index of growth are presented in Table 20). The correlations were positive with number of flower cluster (r=0.50), fruit number (r=0.76), yield (0.86), fruit weight (r=0.53), fruit diameter (r=0.46), firmness (r=0.31), leaf area/tree (r=0.96) and leaf area/fruit (r=0.73) but negative with flowering density (r=-0.49), crop density (r=-0.61) and yield efficiency (r=-0.51). The negative correlations are expected because TCSA is a denominator in those parameters. However, these correlations indicates that TCSA is a good measure of leaf area and yield as confirmed by the highest r values.

CONCLUSION

1. The rootstock MAC 9 has been superior in blossom and fruit production efficiency.

2. 0.3 and the virus free rootstocks EMLA 9, EMLA 26 and EMLA 7 performed well along with the virus infected M 9. The rootstock M 9 might be prefered to EMLA 9 for conditions and cultivars that have excessive growth since tree size appears to be the major difference between M 9 and EMLA 9.

3. Future analysis by multiple linear regression would be more helpful to determine the contributions of the various parameters.

Table 5. Effect of rootstocks on flower cluster number, flowering density and fruit set of 'Starkspur Supreme Delicious' apple. 1985

Rootstock	Flower Cluster 1	Flowering Density 2	Fruit Set Before Thinning 3	Fruit Set At Harvest 4
MAC 24	332.8	5.88	183.10	84.14
EMLA 7	250.2	5.84	253.60	108.74
EMLA 26	235.0	10.82	213.55	81.53
OAR 1	213.4	9.47	147.10	70.84
MAC 9	306.8	17.40	146.06	65.06
0.3	210.4	12.77	198.67	84.73
EMLA 9	194.6	10.80	184.88	76.12
M 9	149.4	11.80	189.10	81.54
EMLA 27	55.4	10.79	124.60	57.06
BLSD(k=100)	122.9	5.96	87.41	N.S.

1) Number of flower cluster per tree.
2) Number of flower cluster/sq.cm of TCSA.
3) Number of fruit/100 cluster.
4) Number of fruit/100 cluster.

Table 6. Effect of rootstocks on fruit number, crop density, percent of fruit removed, yield and yield efficiency on 'Starkspur Supreme Delicious' apple. 1985

Rootstock	Fruit Number 1	Percent of Fruit Removed 2	Crop Density 3	Yield 4	Yield Efficiency 5
MAC 24	261.8	53.40	3.36	64.08	0.814
EMLA 7	226.4	54.62	4.03	58.26	1.038
EMLA 26	194.6	60.55	7.11	43.06	1.552
OAR 1	134.0	50.83	4.76	22.32	0.782
MAC 9	186.6	54.28	8.99	33.90	1.644
0.3	155.0	56.43	7.82	32.60	1.636
EMLA 9	127.4	57.79	6.47	29.52	1.510
M 9	121.2	48.75	8.13	23.24	1.486
EMLA 27	32.6	54.08	5.29	5.94	0.930
BLSD(k=100)	61.07	N.S.	2.25	12.0	0.368

1) Number of fruits per tree.
2) Number of total fruit/Number of thinned fruit X 100.
3) Number of fruits/sq.cm of TCSA.
4) Kilograms per tree.
5) Kilograms/sq.cm of TCSA.

Table 7. Effect of rootstocks on yield, cummulative yield, and cummulative yield efficiency of ‘Starkspur Supreme Delicious’ apple. 1982-1985

Rootstock	Yield[1]					Cummulative Yield Efficiency[2] 82-85
	82	83	84	85	82-85	
MAC 24	0.94	18.00	55.80	64.08	138.82	1.75
EMLA 7	1.28	15.80	44.92	58.26	120.26	2.17
EMLA 26	2.16	12.80	24.60	43.06	82.62	2.84
OAR 1	0.12	10.40	21.26	22.32	54.10	1.91
MAC 9	1.96	13.00	26.40	33.90	75.26	3.68
0.3	0.42	5.00	18.80	32.60	56.82	2.82
EMLA 9	2.92	10.60	20.20	29.52	63.24	3.22
M 9	1.62	7.20	13.68	23.24	45.74	2.85
EMLA 27	0.50	2.00	4.80	5.94	13.24	2.07
BLSD(k=100)	1.92	7.64	11.53	12.00	28.42	0.89

1) Kilograms per tree.
2) Kilograms/sq.cm of TCSA.

Table 8. Effect of rootstocks on fruit diameter, fruit weight, soluble solids and firmness of ‘Starkspur Supreme Delicious’ apple. 1985

Rootstock	Fruit Diameter 1	Fruit Weight 2	Fruit Firmness 3	Soluble Solids 4
MAC 24	7.96	245	77.66	13.80
EMLA 7	8.12	258	73.39	12.88
EMLA 26	7.88	219	72.76	13.08
OAR 1	7.24	169	78.28	15.08
MAC 9	7.40	186	70.45	13.04
0.3	7.74	212	72.05	13.28
EMLA 9	8.04	243	71.07	13.08
M 9	7.56	187	74.21	13.28
EMLA 27	7.38	202	71.70	13.52
BLSD(k=100)	0.36	33	1.11	0.49

1) Diameter in cm/fruit.
2) Weight in grams/fruit.
3) Pressure in Newtons.
4) Percent of soluble solids.

Table 9. Effect of rootstocks on potential yield, and cummulative potential yield based on 2 methods for estimates of planting density of 'Starkspur Supreme Delicious' apple. 1982-1985.

Rootstock	Density	Using tree Spread[1]		Density	Using TCSA[2]	
	Trees/ha.	85	82-85	Trees/ha.	85	82-85
		(ton/ha)			(ton/ha)	
MAC 24	424	27.1	58.8	160	10.2	22.2
EMLA 7	496	28.8	59.6	230	13.4	27.6
EMLA 26	710	30.5	58.6	445	19.1	36.7
OAR 1	757	16.8	40.9	450	10.0	24.3
MAC 9	853	28.9	64.1	614	20.8	46.2
0.3	735	23.9	41.7	630	20.4	35.5
EMLA 9	820	24.2	51.8	665	19.6	42.0
M 9	1010	23.4	46.1	782	18.1	35.7
EMLA 27	1826	10.8	24.1	2129	12.6	28.1

1) Spacing =tree spread within row + 1m X tree spread between row + 2m

2) Spacing based on trunk cross-sectional area of 'Cascade spur Delicious' on seedling rootstock.

Table 10. Significant linear correlations of yield components and fruit quality associated with flower cluster number of ‘Starkspur Supreme Delicious’ apple on several rootstocks.

Correlated Factors[y]	R Value
Flowering Density (cluster/sq.cm)	0.38 *
Fruit Set (No. fruit/100 cluster)	- 0.42 **
Fruit Number (fruit No./tree)	0.80 **
Yield (Kgs/tree)	0.69 **

* Significant at 0.05 level.
** Significant at 0.01 level.
y n = 43

TABLE 11. Significant linear correlations of yield components and fruit quality associated with Flowering Density (cluster/ sq.cm) of 'Starkspur Supreme Delicious' apple on several rootstocks.

Correlated Factors[y]	R Value
Fruit Set (No.fruit/100 cluster)	- 0.63 **
Crop Density (No. fruit/sq.cm)	0.79 **
Yield Efficiency (Kgs/sq.cm)	0.67 **
Fruit Weight (grams/fruit)	- 0.55 **
Fruit Diameter (cms/fruit)	- 0.38 *

* Significant at 0.05 level.
** Significant at 0.01 level.
y n = 43

Table 12. Significant linear correlations of yield components and fruit quality associated with fruit set (No. fruit/100 cluster) of ‘Starkspur Supreme Delicious’ apple on several rootstocks.

Correlated Factors[y]	R Value
Crop Density (No. fruit/sq.cm)	- 0.36 *
Fruit Weight (grams/fruit)	0.53 **
Fruit Diameter (cms/fruit)	0.44 **

* Significant at 0.05 level.
** Significant at 0.01 level.
y n = 43

Table 13. Significant linear correlations of yield components and fruit quality associated with crop density (No.fruit/sq.cm) of 'Starkspur Supreme Delicious' apple on several rootstocks.

Correlated Factors[y]	R Value
Yield Efficiency (No. fruit/sq.cm)	0.89 **
Fruit Weight (grams/fruit)	- 0.59 **
Fruit Diameter (cms/fruit)	- 0.45 **
Soluble Solids (%)	- 0.38 **

* Significant at 0.05 level.
** Significant at 0.01 level.
y n = 43

Table 14. Significant linear correlations of yield components and fruit quality associated with fruit number per tree of ‘Starkspur Supreme Delicious’ apple on several rootstocks

Correlated Factors[y]	R Value
Yield (Kgs./tree)	0.95 **
Soluble Solids (%)	0.37 *

* Significant at 0.05 level.
** Significant at 0.01 level.
y n = 43

Table 15. Significant linear correlations of yield components and fruit quality associated with yield (Kgs./tree) of 'Stark spur Supreme Delicious' apple on several rootstocks.

Correlated Factors[y]	R Value
Fruit Weight (grams/fruit)	0.50 **
Fruit diameter (cms/fruit)	0.48 **
Soluble Solids (%)	- 0.37 *

* Significant at 0.05 level.
** Significant at 0.01 level.
y n = 43

Table 16. Significant linear correlations of yield components and fruit quality associated with yield efficiency (Kgs./sq.cm) of 'Starkspur Supreme Delicious' apple on several rootstocks.

Correlated Factors[y]	R Value
Soluble Solids (%)	- 0.50 **
Firmness (Newtons)	- 0.35 *

* Significant at 0.05 level.
** Significant at 0.01 level.
y n = 43

Table 17. Significant linear correlations of yield components and fruit quality associated with fruit weight (grams/fruit) of 'Starkspur Supreme Delicious' apple on several rootstocks.

Correlated Factors[y]	R Value
Fruit Diameter (cms/fruit)	0.85 **

* Significant at 0.01 level.
y n = 43

Table 18. Significant linear correlations of yield components and fruit quality associated with leaf area per tree (sq.cm) of 'Starkspur Supreme Delicious' apple on several rootstocks.

Correlated Factors[y]	R Value
Flower Cluster (No. cluster/tree)	0.44 **
Flowering Density (No. cluster/sq.cm)	- 0.51 **
Crop Density (No. fruit/sq.cm)	- 0.57 **
Fruit number (No. fruit/tree)	0.72 **
Yield (Kgs/tree)	0.83 **
Yield Efficiency (Kgs/sq.cm)	- 0.47 **
Fruit Weight (grams/fruit)	0.53 **
Fruit Diameter (cms/fruit)	0.43 **
Firmness (Newtons)	0.33 *
Leaf Area/Fruit (sq.cm/fruit)	0.77 **

* Significant at 0.05 level.
** Significant at 0.01 level.
[y] n = 43

Table 19. Significant linear correlations of yield components and fruit quality associated with leaf area per fruit (sq.cm/fruit) of ‘Starkspur Supreme Delicious’ apple on several rootstocks.

Correlated Factors[y]	R Value
Flowering Density (No. cluster/sq.cm)	- 0.74 **
Crop Density (No. fruit/sq.cm)	- 0.84 **
Fruit Set (No. fruit/100 cluster)	0.36 *
Yield (Kgs/tree)	0.41 **
Yield Efficiency (Kgs/sq.cm)	- 0.72 **
Fruit Weight (grams/fruit)	0.67 **
Fruit Diameter (cms/fruit)	0.50 **
Firmness (Newtons)	0.30 *

* Significant at 0.05 level.

** Significant at 0.01 level.

y n = 43

Table 20. Significant linear correlations of yield components, fruit quality and leaf area associated with trunk cross sectional area (sq.cm) of 'Starkspur Supreme Delicious' apple on several rootstocks.

Correlated Factors^y	R Value
Flower cluster (No. cluster/tree)	0.50 **
Flowering Density (No.cluster/sq.cm)	- 0.49 **
Crop Density (No. fruit/sq.cm)	- 0.61 **
Fruit Number (No fruit/tree)	0.76 **
Yield (Kgs/tree)	0.86 **
Yield Efficiency (Kgs/sq.cm)	- 0.51 **
Fruit Weight (grams/fruit)	0.53 **
Fruit Diameter (cms/fruit)	0.46 **
Firmness (Newtons)	0.31 *
Leaf Area/Tree (sq.cm/tree)	0.96 **
Leaf Area/Fruit (sq.cm/fruit)	0.73 **

* Significant at 0.05 level.
** Significant at 0.01 level.
y n = 43

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III. ESTIMATES OF LEAF AREA, LEAF AREA INDEX AND LEAF-FRUIT RATIO OF ‘STARKSPUR SUPREME DELICIOUS’ APPLE ON SEVERAL ROOTSTOCKS.

ABSTRACT

Relationships between branch circumference (BC), branch cross sectional area (BCSA), fresh weight (FW) and dry weight (DW) with the measured leaf area (MLA) between as well as within rootstocks were evaluated on ‘Starkspur Supreme Delicious’. Rootstocks of the series Michigan Apple Clones (MAC), East Malling Long Ashton (EMLA), East Malling (M), Ottawa (O.) and Oregon Apple Rootstock (OAR) were used during the 6th year in 1985. The 9 rootstocks included were: MAC 24, MAC 9, EMLA 7, EMLA 26, EMLA 9, EMLA 27, M 9, O.3 and OAR 1. There was no difference among the regression lines obtained from various rootstocks and within rootstock for the 4 independent variables. FW was the best estimate of leaf area, but because of greater speed and simplicity, BCSA was chosen to predict total leaf area/tree using a equation with the combined data, LA = Ln 6.623 + 1.142 Ln BCSA. Total leaf area by rootstock decreased from the largest (MAC 24) to the most dwarfing rootstock (EMLA 27). Tree leaf area index did not increase proportionately to tree size, but did range from 1.69 for MAC 24 to 0.87 for O.3. Orchard leaf area index showed low values in all rootstocks and a slight increase with tree size, indicating that trees at the estimated densities are not intercepting the maximum quantity of light. Trees of the rootstocks MAC 9, O.3 and M 9, had the lowest leaf-fruit ratio while MAC 24 and EMLA 7 were the highest.

INTRODUCTION

The leaf area of a given crop-canopy provides a fair estimate of its photosynthetic capacity. In crop-growth analysis, leaf area often represents a key index and bears a close relation to dry-matter accumulation, crop yield and quality.

Leaf area measurements are often needed in studies of fruit growth and development (Haller and Magness, 1925; Hansen, 1977), calculations of net assimilation rates (Barden, 1971; Avery, 1977; Ferree and Palmer, 1982), evaluation of trellis training systems (Maggs and Alexander, 1973; Ferree and Hall, 1980; Sansavini et al, 1980), and other physiological processes in apple. Also, leaf measurements have been used to calculate leaf area index and leaf mass (Barlow, 1980; Hughes and Proctor, 1981).

Marshall (1968) reviewed the methods for leaf area measurements requiring destructive and non-destructive sampling in considerable detail. Even for the non destructive method, a representative sample of leaves or branches need to be collected (Ackley et al, 1958; Holland, 1968), measurements determined and leaf area obtained with an area integrating meter or a planimeter (Marshall, 1968).

Those techniques that involve simple measurements such as length, width, the product length-width and branch diameter are usually time-saving and non-destructive. Thus successive measurements may be made in the field on the same leaf or branch without adversely affecting its normal physiological functions.

Similar investigations have shown that relationships between branch girth or branch cross sectional area and leaf area differ between sampling dates, but those relationship are uniform among branches within as well as between trees and are seldom affected by the presence or absence of crop or the degree of pruning (Holland, 1968; Barlow, 1969). To determine if a significant difference existed among several prediction models from rootstock and crop, comparisions were made between branches of the same tree and branches of trees on different rootstocks.

The main objective of this study was to establish regression models which correlated the leaf area of 'Starkspur Supreme Delicious' apple to simple measurements and to determine the effect of rootstock using several models. A second objective was to compare the estimated total leaf area , the leaf area index and the leaf-fruit ratio among rootstocks.

MATERIALS AND METHODS

The study was conducted at the Lewis Brown Farm of the Oregon State University, Corvallis during 1985, on 45 trees 6 year old, spaced 3.5 x 5.5 m in five replicated blocks on nine different rootstocks. The cultivar used was ‘Starkspur Supreme Delicious’, and the pollinizer trees in every third row consisted of ‘Macspur’ and ‘Starkspur Golden Delicious’ on M 26.

The nine rootstocks were : EMLA 7, EMLA 26, EMLA 9, EMLA 27, M 9, MAC 24, MAC 9, 0.3 and OAR 1. The soil is an uniform silty clay loam. ‘Creeping Red’ fescue was planted in the rows of a 2 m width plus a herbicide strip of 1.5 m. Irrigation is by low head sprinklers, and they were irrigated every 3 weeks at 50 mm.

The trees were trained to a central leader with successive light pruning and allowed to crop after the third leaf. Five trees on different rootstocks were selected at random from the block and used to develop the models to estimate leaf area. After harvest, in late September, five branches on each tree of four rootstocks (EMLA 7, EMLA 26, EMLA 9 and MAC 9) were selected from the middle third of the tree (Holland, 1968), while 15 branches was selected from a tree on EMLA 7 and equally divided from the lower, middle and upper third of the tree. The basal branch circumference was recorded and transformed to cross sectional area. The total leaf area on each sample branch was determined in the laboratory, after leaf removal of the tree using an area meter (model Li-3100, Li-Cor Inc., Lincon NE) fitted with a transparent belt accessory and calibrated to 0.01 cm. In addition the fresh and dry weight of the leaves on each sampled branches was determined to the nearest milligrams.

Linear reggression equations using the least squares method was examined by fitting the linear regression Ln Y= Ln k + b Ln X corresponding to the relationship $A = k X^b$, where A = leaf area, X = independient variable, and k and b are constants for a given set of data (Neter et al, 1983).

The regression was fitted both for the leaf area of branches sampled in one tree and the leaf area of branches sampled in several trees. Individual leaf area determined with the area meter was the dependent variable while the branch circumference (BC), branch cross sectional area (BCSA), fresh weight (FW) and dry weight (DW) were used independent variables. The regression equation was also fitted both before and after eliminating tree-to-tree variation. Comparisions among the regression lines in each model were tested using a F test (Neter et al, 1983).

The regression with BCSA was fitted after eliminating tree-to-tree variation and used for calculate total leaf area on each tree. For this calculation, the main branches i.e., those arising from the central trunk, were numbered successively from the base upwards, the last numbered branch being the central trunk and all that remained above the branch.

The method of estimating total leaf area for each rootstock in the five replications was by summation of the leaf area on each branch of a given tree estimated from its BCSA as based on a leaf area/BCSA regression.

The leaf/fruit ratio on each tree was obtained by dividing the total leaf area of the tree by fruit number. Leaf area index for each tree was calculated by using the ratio of leaf area to ground area covered by the tree as well as total ground area between trees as suggested by Barlow (1970).

Statistical analysis using a randomized block design with rows as a blocking factor was made on total leaf area per tree, leaf/fruit ratio and leaf area index based on ground area covered by the tree. Means were statistically analysed using ANOVA at the 5 % level. Where comparing more than two means Waller-Duncan Bayesian k-ratio t Test procedure (BLSD) was used for mean separation (Steel and Torrie, 1980). Where one experimental unit was lost, we computed a substitute value for the missing observation and lost one degree of freedom from the total and from error (Snedecor and Crochan, 1980).

RESULTS AND DISCUSSION

Correlation coefficients (r) were calculated for the independent variables: branch circumference (BC), branch cross sectional area (BCSA), fresh weight (FW) and dry weight (DW) against the dependent variable the measured leaf area (MLA).

All r values were highly significant at $P < 0.001$ (Table 21). When plotted against MLA, the highest r values was with FW and then followed by DW. There was considerable difference in r values of sampling sites where there was an increase of r value when samples were between trees for BC and BCSA but a decrease r value for FW and DW.

The best fit for our data was using the power curve $Y = aX^b$, transformed or linearized equation $\mathrm{Ln}\ Y = \mathrm{Ln}\ a + b(\mathrm{Ln}\ X)$, and values were calculated where Ln Y equals MLA and X represents BC, BCSA, FW or DW; a = intercept coefficient and b = slope or regression coefficient. The results are presented in Table 22. In all cases the highest coefficients of determination (R^2) and smallest standard error for the regression coefficient were obtained when FW was used as the independent variable.

To determine if there were differences between site of the branches sampled (within trees or between trees), the equations within each parameter were compared using an F test. No significant differences ($P > 0.01$) between slope or intercept coefficients of the two sampling sites on each parameter were found.

Hence, new equations were calculated using the combined between and within branch sample data for BC, BCSA, FW, and DW as the independent variables. Four new equations of the combined data had intermediate values for coefficient of determination (R^2) while the standard errors were acceptable for estimate leaf area (Holland, 1968; Barlow,1969).

FW can be considered as an adequate estimator of leaf area if site conditions, leaf age, nutritional status of the plant and other enviromental factors are taken into consideration when establishing the equation to estimate leaf area. However, using fresh weight involve a destructive model when total leaf area of the plant is required. With this in mind, FW can be used to establishing a calculated leaf area (CLA) when area integrating equipment is not available. There was a high correlation of CLA with MLA in grapevines (Sepulveda and Kliewer, 1983; Smith and Kliewer, 1984).

There was good correlation and predictive ability (R^2) with DW as an estimator of leaf area, but DW would be complicated because leaf drop occurs over a long period.

On the basis speed and simplicity, the following equations were used to predict the leaf area (PLA) for the trees on different rootstocks : PLA = Ln 3.763 + 2.269 Ln BC (Figure 1), and PLA = Ln 6.6234 + 1.142 Ln BCSA (Figure 2). The values for b and the standard error of the regression coefficient, when using BC as the independent variable agrees closely with those reported by Holland (1968), although his intercept coefficients were slightly higher. When BCSA was used as the independent variable, the intercept coefficient found in this study were larger than those obtained by Barlow (1969), but the slope was above the same.

However, some accuracy for the estimation was sacrificed because of leaf size differences. If greater accuracy is desired, a separate equation including small leaves could be established. Barlow (1969) and Jackson (1970) reported that extension shoot leaves are usually appreciably larger than leaves from short shoots (i.e.,spurs), so sampling methods must ensure that both populations are properly represented.

Total leaf area on the tree was obtained by summation of individual branches using BCSA as independent variable of the regression equation. There was significant differences in total leaf area between 5 groups of rootstocks (Table 23). The groups were: MAC 24 > EMLA 7 > EMLA 26, OAR 1, EMLA 9 and 0.3 > MAC 9 and M 9 > EMLA 27.

Total leaf area by rootstock agreed with that reported by Heinicke (1964) who reported that total leaf area decreased on trees from seedling to dwarfing rootstock. But, his values were higher on the same rootstock, because of increased growth habit of the standard cultivar that he used and the age of the trees.

A high correlation ($r = 0.96$) of total leaf area with tree size was reported (Table 18) among the 9 rootstocks used.

Leaf area index on tree basis was calculated by dividing the total leaf area by the ground area covered for the tree, and the values ranged from 1.69 for MAC 24 to 0.87 for 0.3 (Table 23) The difference was significant between two groups of rootstocks: 1) MAC 24, EMLA 7, and EMLA 27; 2) OAR 1, EMLA 26, EMLA 9, M 9, MAC 9 and 0.3.

Although there is a great difference in total leaf area among the rootstocks, the difference in tree leaf area index is not great. Tree leaf area index did not increase proportionately to tree size, although the largest tree did have the highest leaf area index.

The leaf area index of trees in the plot under study was less than that reported previously, in which trees on M 9 rootstock had leaf area index of 2.94 (Heinicke, 1964). These differences could be explained because the ground area covered by the tree and tree height in our study was less. However, when considering the leaf area index and the size of the trees, Heinicke (1964) found the foliage in the smaller trees was more closely spaced. But he found the more dense foliage of the dwarf and semidwarf trees was exposed to more light than the less because there was a greater surface area per volume in the small trees compared with the largest trees.

Leaf area index on orchard basis was obtained from multiplying the planting density (Table 2) times the total leaf area and divided by one hectare. The values ranged from 0.81 on MAC 24 to 0.204 on EMLA 27 (Table 23). Orchard leaf area index increased proportionately with tree size, largest trees have the highest and smallest trees have the lowest. But the values are lower than those values reported elsewhere (Heinicke, 1964., Jackson, 1970., Jackson, 1975b, Verheij and Verwer, 1973., Palmer and Jackson, 1977., Ferree and Hall, 1980). However, they reported an increase in orchard leaf area index as tree size decreased.

Lower values of orchard leaf area index reflects that the trees are not intercepting the maximum quantity of light (Jackson, 1970, 1978b, Verheij and Verwer, 1973), which suggest that planting densities must be increased for the rootstocks to attain the maximum leaf area index.

Leaf area per fruit was calculated from estimated tree leaf area and fruit number at harvest. Leaf-fruit ratio showed a significant differences among rootstocks (Table 23). The values ranged from 733 cm^2 on MAC 24 to 227 cm^2 on MAC 9. Although the more vigorous rootstocks did have the higher leaf-fruit ratio it was not proportionately to tree size as based on 3 rootstock groups: MAC 24, EMLA 7 > OAR 1, EMLA 9 > EMLA 26, EMLA 27, M 9, 0.3 and MAC 9. The leaf-fruit ratios were correlated to flowering density (r=-0.84), crop density (r=-0.74) and yield efficiency (r=-0.72) which indicated that the more efficient rootstocks did have the lowest leaf-fruit ratio (Table 19).

Leaf-fruit ratio are often related with fruit size, flower bud formation and fruit quality (Haller and Magness, 1925., Haller and Magness, 1933., Magness, 1928., Magness and Overly, 1929). Correlating leaf-fruit ratios with fruit size and fruit quality (Table 19) were variable by rootstock perhaps due to the genetics of the rootstocks such as with OAR 1 which had an intermediate ratio value of 429 cm^2 but had the lowest fruit size and highest fruit firmness and soluble solids.

Table 21. Correlation coefficients (r) for MLA (measured leaf area) on BC (branch circumference), BCSA (branch cross- sectional area), FW (fresh weight), and DW (dry weight) of 'Starkspur Supreme Delicious' apples under two different sampling sites and their combined data.

Dependent variable	sampling sites	Correlation coefficients[1] Independent variables			
		BC	BCSA	FW	DW
MLA	within a tree*	0.80	0.79	0.99	0.97
MLA	between trees**	0.94	0.94	0.97	0.95
MLA	combined ***	0.94	0.94	0.98	0.97

* n = 15

** n = 20

*** n =35

1) All r values were significant at the 0.1 % level

Table 22. Relationship between branch circumference (BC), branch cross sectional area (BCSA), fresh weight (FW), and dry weight (DW) on measured leaf area (MLA) of Starkspur Supreme Delicious apple.

Treatments	Regression equation	R^2 *	Std. error of estimate
Combined data[1]	Ln MLA = Ln 3.763 + 2.269 LnBC	.88	0.253
	Ln MLA = Ln 6.623 + 1.142 LnBCSA	.88	0.251
	Ln MLA = Ln 3.273 + 1.006 LnFW	.97	0.111
	Ln MLA = Ln 4.746 + 0.903 LnDW	.95	0.151
Within trees[2]	Ln MLA = Ln 4.765 + 1.619 LnBC	.64	0.243
	Ln MLA = Ln 6.878 + 0.762 LnBCSA	.62	0.250
	Ln MLA = Ln 3.577 + 0.927 LnFW	.98	0.054
	Ln MLA = Ln 4.811 + 0.885 LnDW	.95	0.084
Between trees[3]	Ln MLA = Ln 2.576 + 2.852 LnBC	.89	0.216
	Ln MLA = Ln 6.176 + 1.430 LnBCSA	.89	0.216
	Ln MLA = Ln 3.231 + 1.015 LnFW	.95	0.138
	Ln MLA = Ln 4.538 + 0.950 LnDW	.92	0.186

* Significant at 0.01 % level
1) n = 35
2) n = 15
3) n = 20

Table 23. Total leaf area/tree, leaf-fruit ratio, tree leaf area index, and orchard leaf area index of ‘Starkspur Supreme Delicious’ apple on 9 rootstocks of 6 year old trees spaced at 3.5 X 5.5 m.

Rootstock	Total LA (sq.cm)	Tree LAI	Orchard LAI	Leaf/fruit (sq.cm/fr)
MAC 24	191,395.1	1.694	0.811	732.9
EMLA 7	128,491.2	1.451	0.637	594.2
EMLA 26	59,401.0	1.092	0.421	320.6
OAR 1	53,148.6	1.158	0.402	429.3
MAC 9	39,651.8	1.043	0.338	227.0
0.3	40,557.4	0.877	0.298	265.5
EMLA 9	44,310.0	1.119	0.363	409.0
M 9	32,981.0	1.029	0.246	271.6
EMLA 27	11,173.2	1.499	0.204	294.8
BLSD (k=100)	19,706.9	0.473		142.2

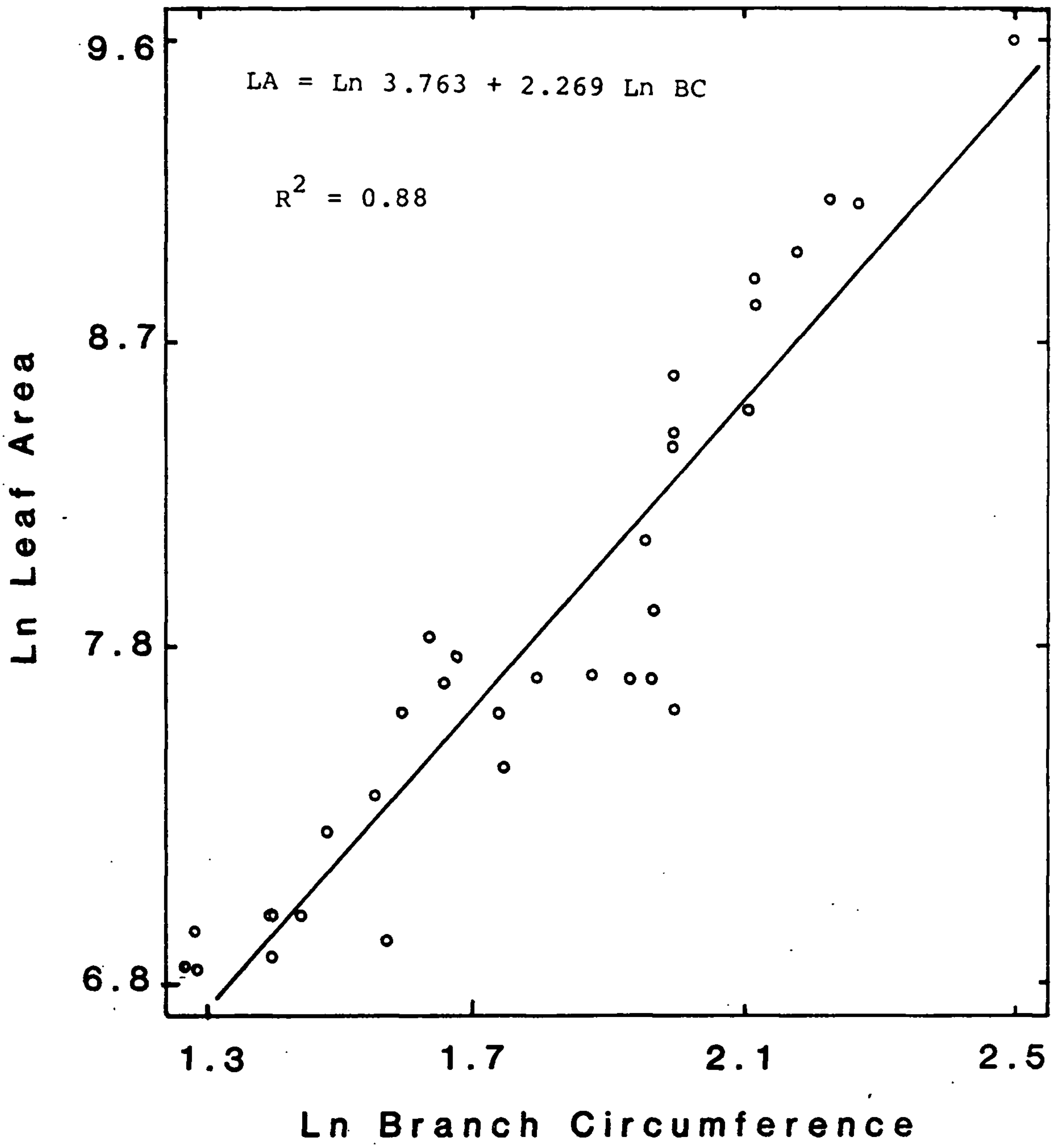

Figure 1. Linear equation, using Ln of Branch Circumference of different rootstocks as independent variable, to predict leaf area of 'Starkspur Supreme Delicious' apple.

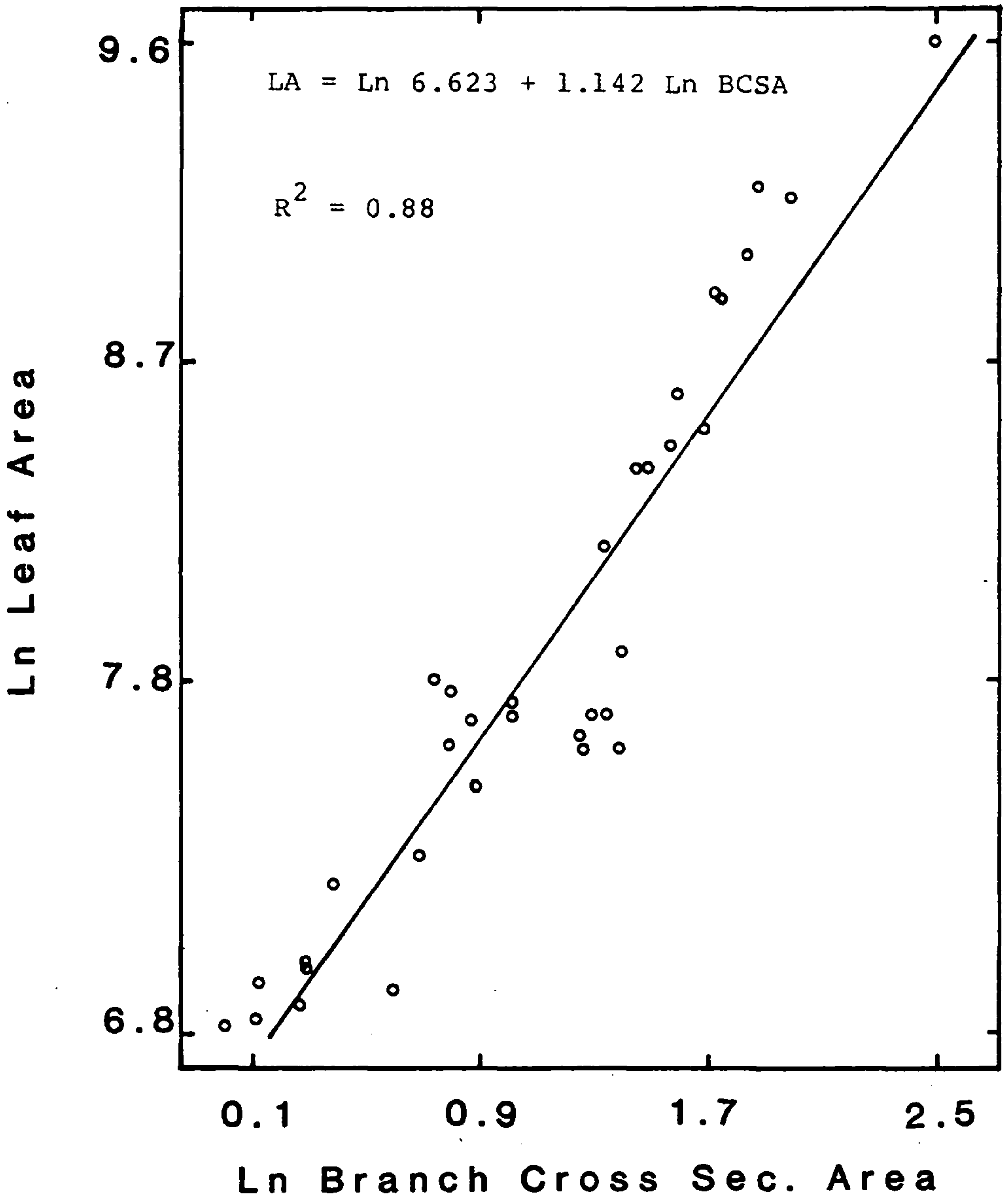

Figure 2. Linear equation, using Ln of Branch Cross Sectional Area of different rootstocks as independent variable, to predict leaf area of ‘Starkspur Supreme Delicious’ apple.

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