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CONTENTS

There are numerous direct and indirect ways to regulate the vegetative and productive activity of fruit trees. Pruning is among the techniques that most markedly influence the vigour and production of a plant. In the past, this practice was almost exclusively limited to operations carried out during the period of vegetative rest, while today there is a tendency also for “green” interventions or interventions during the summer when the plant is fully active. New acquisitions in the field of plant physiology, in particular relative to the interception of light by the crown and the translocation of photosynthates in terms of the complex relationship which exists between source and sink, have given greater importance to green pruning and recognized its significant role.

This special issue has, thanks to the collaboration of internationally recognized scholars, brought together a series of articles dedicated to green pruning. After an initial introductive article, the topic is discussed in light of the most modern approaches with regard to the principal fruit species, giving attention to the most important techniques and problems present for each.

Enrico Rinaldelli

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Basic considerations about pruning deciduous fruit trees

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Key words: architecture, correlate function, fruit trees, growth, pruning.

Abstract: Crop yield and fruit quality performance determine the economic value of the orchard system. Once the basic traits of the orchard design are defined, pruning may represent a powerful tool to modulate the vegetative and productive behaviour of the trees. The various pruning manipulations involve variations in growth, size and geometry of the plant and their effects are explained in terms of correlate functions among the tree organs. In spite of its potential, pruning can not overcome the effects of some basic mistakes made in design and management of the orchard. Basic concepts about pruning developed in the past are reassessed in light of recent knowledge on architecture and growth of the tree.

1. Introduction

Yield and quality performance of fruit crops results from the co-ordinated and integrated functioning of several components which constitute the "orchard system". This system must be carefully assembled in all its components in order to respond to the diverse environmental, social and economic constraints.

Designing the system means to define the physical arrangement of the trees, their shape and all the agronomic practices to apply during the entire life span of the orchards. All the system components must be implemented at the time of the orchard design determining its basic traits such as planting density, training system, and scion and rootstock combination. In addition to these physical traits it is necessary to define the proper pruning strategy to be adjusted year by year to the chosen training system taking into account also the agronomic operations direct to the management of the soil root relationship.

Pruning is the basic tool to manipulate fruit tree architecture and behaviour in order to achieve economically sound crop yield and fruit quality. "Pruning" includes a very large and diversified number of operations involving the aerial organs and the root system, performed both during rest and vegetative season (for a glossary of pruning terms see: Baldini and Scaramuzzi, 1962; Liebster and Pesserl, 1982; Ingels *et al*., 2002). Once the major traits of the orchard have been defined, the pruning strategy may then enter into discussion. The main objective in training fruit trees is the modulation of competition among the vegetative and reproductive parts of the tree, which essentially means the manipulation of the source-and-sink relationships occurring in the plant taking into account other basic objectives such as light interception and distribution in the canopy, and biomass partition properly directed toward the fruits.

The relationships between pruning and processes of growth, fruit bearing and senescence assume a strategic relevance as almost every pruning operation affects the growth of a tree or its organs on either a short- or long-term scale. Pruning is a very powerful tool but it cannot overcome the effects of basic mistakes in design and management of the orchard. The significance of the architecture and growth traits of trees and their relationships with reproductive activities are essential to understanding how pruning may affect the functioning of the orchard system.

In this paper the principal aspects of plant architecture and growth relevant to pruning are examined; since "pruning" includes many diverse operations, a large range of combinations of winter and summer pruning manipulations is possible and therefore their potential effects on tree behaviour are considered and explained in terms of the source-and-sink relationship and competition among sinks.

A number of the references cited in this paper may seem dated, but it must be said that studies and experiments on pruning have recently become rare whereas during the 1980s and '90s scientists, researchers and field experts paid great attention to this inalienable orchard management practice. Italian contributions to the knowledge of the physiological and practical basis of pruning have been particularly important, as shown by fundamental papers and reference books on this topic (Dotti, 1949; Morettini, 1963; Bargioni, 1992; Sansavini and Errani, 1998; Branzanti and Ricci, 2001). It seems, however, useful to reas-

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sess these contributions in light of recent knowledge on the architecture and growth of trees.

2. Tree architecture

The identification of tree architecture traits is relevant to the pruning strategy. According to Costes *et al.* (2006) plant architecture includes two independent notions: branching and connection between plant units (topology), and the spatial location, orientation, size and shape of the vegetation elements (geometry). Tree architecture includes physical structures and physiological functions of fruit trees, and is therefore related to space and time aspects. The multilevel approach of the tree (whole tree, branch, leaf and fruit) should be stated and tree architecture should be described by canopy height, width and shape, by fruiting and vegetative shoot types and their relative proportions, spatial distribution, branching, and growth dynamics. Canopy porosity or density should also be considered as light interception and distribution, and pest occurrence are concerned (Simon *et al.*, 2007).

The orchard structure, function and production may be understood if, in addition to tree architecture, phenotypic plasticity and phenology are considered. Trees are modular organisms which develop by reiteration of elementary botanical elements whose anatomical, morphological, dimensional and functional traits change during ontogeny and accordingly to various life stages (Bathélémy and Caraglio, 2007). During ontogeny plant appearance varies with form and/or structure and with temporal and/or topological changes and, therefore, it is of high practical relevance to orchard design and management (Fig. 1).

Tree architecture depends on the nature and relative arrangement of each of the tree's parts. At any given time, the architecture is a result of equilibrium between internal growth events and external environmental constraints. Pruning must take into account this natural fact and hence it must follow the natural behaviour of the fruit tree and direct it toward the desired economic goals.

The main morphological traits used in describing tree architecture are the growth processes, branching modalities, morphological differentiation of axes and location of the reproductive structures (Barthélémy and Caraglio, 2007).

Growth processes. Organogenesis and extension are two distinct but co-ordinated morphogenetic events that result in the primary growth of a plant. These events basically determine the stem of a plant, which can be considered a succession of internodes and nodes, on which a leaf (or leaves) and axillary bud (or buds) are located; the node and the subtending internode represent the basic structural unit of the plant body (metamer or phytomer).

A tree, whatever its final size, is initially formed by the activity of at least two primary meristems, one to develop the aerial part and one the root system, but the subsequent increment in diameter of woody axes (aerial and subterranean) is determined by the activity of secondary meristems.

In many species, the apex of the aerial axes may abscise or abort after a time of functioning or it may shift into reproductive structure or other organs: this behaviour is defined as determinate growth. On the other hand, when the apical meristem of the axes maintains indefinitely its growth potential, an indeterminate growth (or extension of the axis) occurs.

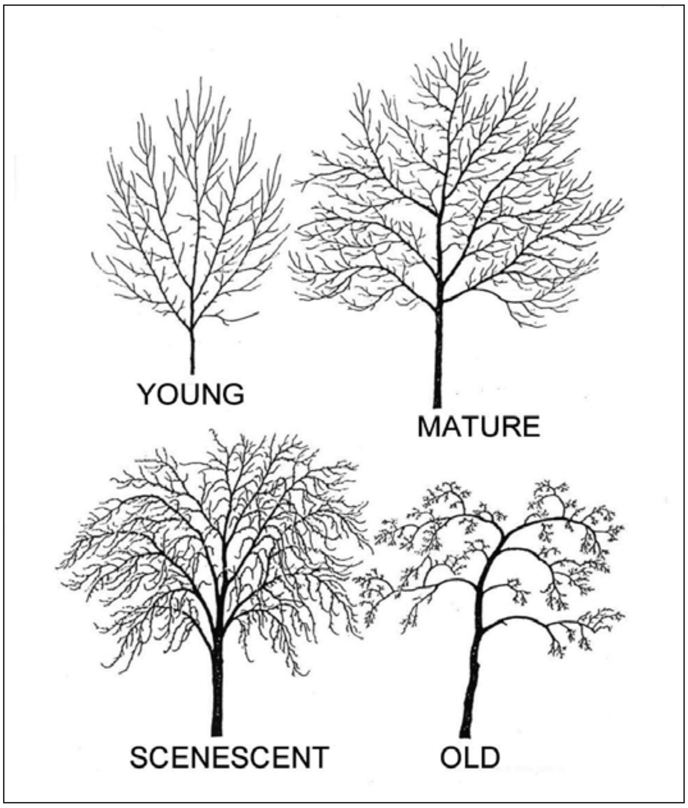

Fig. 1 - Evolution of the tree crown during plant life (from Hilkenbäumer, 1953).

Continuous growth occurs when a shoot does not show a marked endogenous cessation of extension, a case usually occurring in uniform equatorial climates or environments. When a shoot shows marked endogenous extension periodicity and cessation, rhythmic growth occurs. Rhythmic extension of leafy shoots is the typical pattern of deciduous fruit trees in which meristem activity shows an alternation of periods of rest and of active extension. The rest period marks on an axis portion a zone of short internodes and/or cataphylls corresponding to the protective organs of the bud from which the axis derives. Rhythmic growth of the stem may combined with continuous or more frequently with a rhythmic organogenesis pattern.

Preformation and neoformation. When metamers and organs of a shoot are already present in the bud before the elongation of the axis deriving from it, the shoot is called preformed. In other cases, more metamers and organs than those included in the bud appear on the shoot and are neoformed by the apical meristem. Fruit trees show a strong polymorphism in axis development (Costes *et al.*, 2006) (Fig. 2). Preformed shoots are usually short axes (brachyblast) which after bud burst elongate slightly due to the extension of the preformed metamers. In horticulture short shoots are referred to different names according to the species and to their reproductive or vegetative structures. In stone fruit species, they are called ‘leaf rosettes’ or ‘clusters’ if they bear, respectively, only leaves or an apical vegetative bud and a variable number of lateral flower buds. In pome fruit species, the short preformed shoots are called ‘dards’ when they are vegetative or ‘spurs’ when they bear also flowers (Fig. 2). In many fruit species (cherry, apple and pear trees in particular) the spurs can be one-year-old brachyblasts or consist of a perennial set of branched shoots, which have all remained brachyblasts. Longer shoots may be also preformed (mesoblasts) and in this case their limited length derives only from the elongation of internodes; mesoblasts can carry only vegetative buds or carry some lateral flower buds (stone fruits) or an apical fruit bud (pome fruits) and, in any case, are called ‘brindles’(Fig. 2). Preformation and neoformation can also be combined to produce much longer shoots (auxiblasts) in fruit trees; they are usually vegetative axes in pome fruits (Fig. 2), whereas in stone fruits they can bear numerous lateral flower buds as in peach tree.

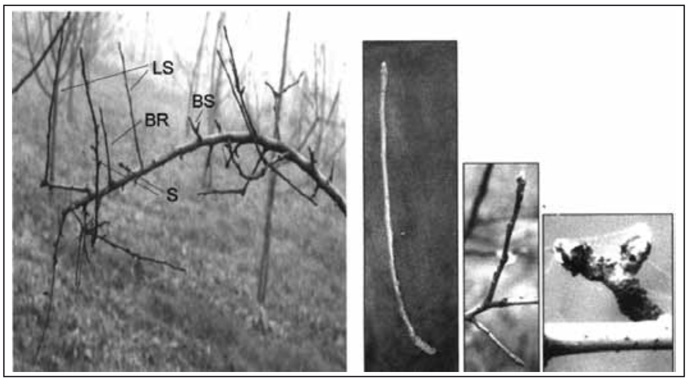

Fig. 2 - Polymorphism of the axes on an apple branch. *Left*: S (brachyblast) and BS (brachyblast on a bourse) and BR (mesoblast) are preformed shoots, LS (auxiblast) are preformed and neoformed shoots. *Right*: Long shoot, brindles and spurs on a bourse.

Branching process. The complex architecture of a tree consists of several axes, one derived from another by repetitive processes (Fig. 3). The branching process is based on axillary meristems located just beside the initiated leaf at a node. More than one axillary bud may be found at the axil of a leaf as in the case of mixed shoots of peach trees or other stone fruit species.

The branching pattern of an axis can be monopodial or sympodial according to its indeterminate or determinate growth pattern, respectively. In the case of a sympodial pattern, one, two or more branches may develop after the death, abscission or transformation of the apex. In fruit trees one or two branches arise more commonly. Rectilinear stems may be composed of a succession of metamers or growth units or annual shoots, all produced by a single meristem or by a linear succession of sympodial modules (Barthélémy and Caraglio, 2007).

Continuous branching occurs when all the axillary meristems of a stem develop into lateral shoots; rhythmic branching occurs when lateral axes are grouped as distinct tiers with an obvious regular alternation of unbranched and branched nodes on the parent stem. Branching may be diffuse if only some nodes of the parent axis bear a lateral axis or if a regular distribution of branches in tiers is no evident.

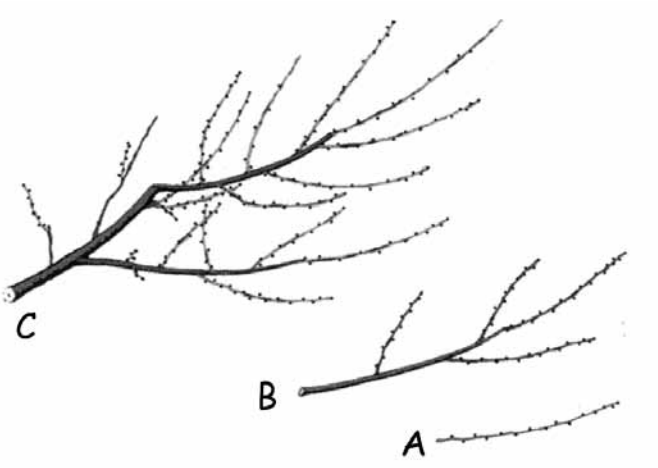

Fig. 3 - Evolution of a one-year axis (A) into two-year (B) and three-year (C) branches.

Acrotony, basitony and mesotomy. The positional preferential development of lateral branches on a vertical parent axis may be classified into three categories. Acrotony is the prevalent development of lateral axes in the distal part of the parent axis or shoot, whereas basitony consists in the prevalent development of branches on the proximal part; mesotony is used to denote a privileged development of branches in the middle part of the axis. The topological arrangement of lateral branches along a parent axis is often associated with an increasing or decreasing gradient in length and/or vigour of the branches. In fruit trees, all three categories of lateral axis development are present with some variations even in the same species. The topological arrangement of branches in the tree crown can be strongly modified by pruning.

Hypotomy, epitomy and amphitomy. Considering that an axis may diverge from the vertical, the privileged arrangement of lateral axes on a parental axis is very different if this is horizontal, curved or slanted. The privileged zone may be the upper, lateral or basal position of the parent axis and the terms are respectively epitony, amphitony and hypotomy (Fig. 4). In many fruit trees epitony is

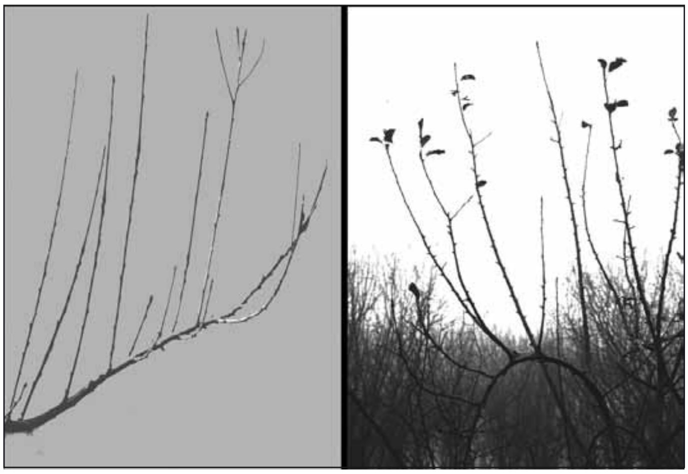

Fig. 4 - Development of lateral axes on an axis. Slanted parent axis of peach tree (left) and curved parent axis of apple tree (right).

a very common feature (Costes *et al*., 2006), it is often associated with the survival of old branches in old trees (Fig. 5). Hypotomy is characterized by a privileged development of lateral axes in the curvature zone of a branch. Amphitony occurs frequently on rectilinear horizontal or slightly slanted branches. The latter two features may be combined in slanted and curved branches and their incidence in the expansion of lateral branch complexes is of the outmost importance in the aerial architecture of many woody plants. Amphitony is a frequent behaviour in rectilinear branches while epitony and hypotony are characterized by the predominant development of lateral axes on the convex side of the curved, downwardly- or upwardly-oriented branches. As they are highly influenced by axis orientation, these branching features are frequently combined with topological arrangement along axes (acrotony, basitony, mesotony) and these combinations can strongly influence the bud fate according to their topological position and space orientation within the tree canopy.

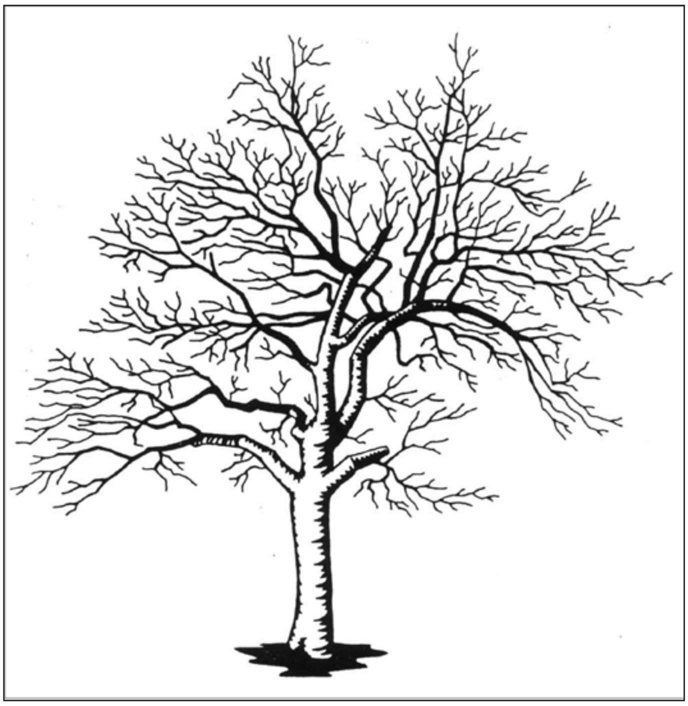

Fig. 5 - Evident epitomic behaviour in an old apple tree (from Liebster and Pesserl, 1982).

Polymorphism of axes. The orientation of an axis and the spatial disposition of its leaves are of major importance in the growth strategy of a tree. Within a single tree, some of these axes are essential in plant skeleton edification; some are involved in space exploration whereas others are more directed toward reproductive function or light interception and photosynthesis. The differentiation of axes and bud fate may be highly specialized and very different structures (i.e. flowers, inflorescences, spine, shoot, etc.) may be found in a single leaf axil and in a precise position, but the differentiation of an axis may not be an irreversible process. Depending on modifications of internal or external conditions or after architectural traumatism or manipulation (pruning), reversion of axis differentiation may frequently occur, indicating that shoot differentiation and bud fate are controlled by a whole plant network of correlated and environmental conditions. The polymorphism of axes is common in fruit trees and represents a morphological differentiation determined by meristem expression and activity. It is common that several types of axis coexist on the same individual tree. However axis specialization is very significant when a tree is trained and pruned for fruit production since in this tree a balanced distribution among skeleton axes, reproductive axes and vegetative axes used for renewal fruiting shoots (Fig. 6) must be found.

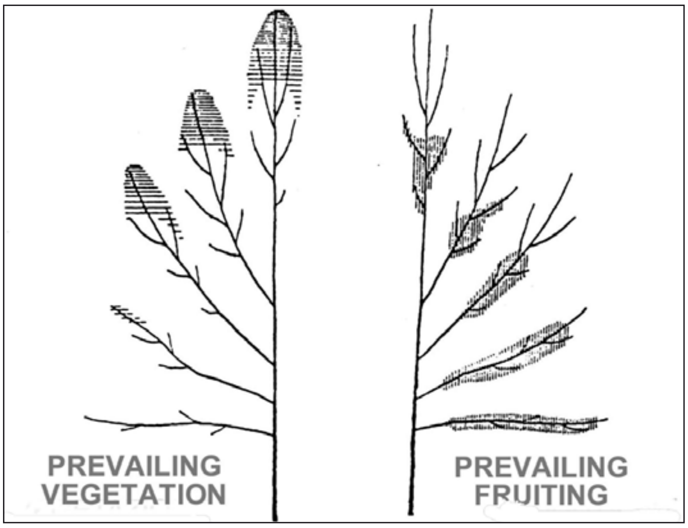

Fig. 6 - In the tree canopy the polymorphims of axes is differently located. In some parts vegetative structures prevail and in others reproductive structures are predominant (redrawn from Hilkenbäumer, 1953).

Orthotropy, plagiotropy, and mixed axes. Orthotropic axes are generally erect to vertical with a radial symmetry, bear leaves in spiral, opposite or verticillate disposition, and lateral axes in all spatial directions; orthotropy is generally associated with plant skeleton edification and the colonization or exploration of vertical space. By contrast, horizontal to slanted oriented axes (plagiotropy) show a bilateral symmetry with distichous phyllotaxis and lateral axes arranged in one plane; plagiotropy is generally concerned with exploration and exploitation of the horizontal space and reproductive functions.

In many trees an axis may present an orthotropic proximal portion and a plagiotropic distal end or vice versa. The superimposition of such “mixed axes” is a distinctive feature of trunk edification in trees, but it can be strongly manipulated by pruning (Fig. 7).

The position of sexuality and reproductive organs can be terminal or lateral and the onset of these organs involves dramatic changes in the architecture of the trees because its impact on plant growth and branching. The lateral or terminal position of reproductive organs is of great relevance for the orientation of the axis that supports the organs (Fig. 8).

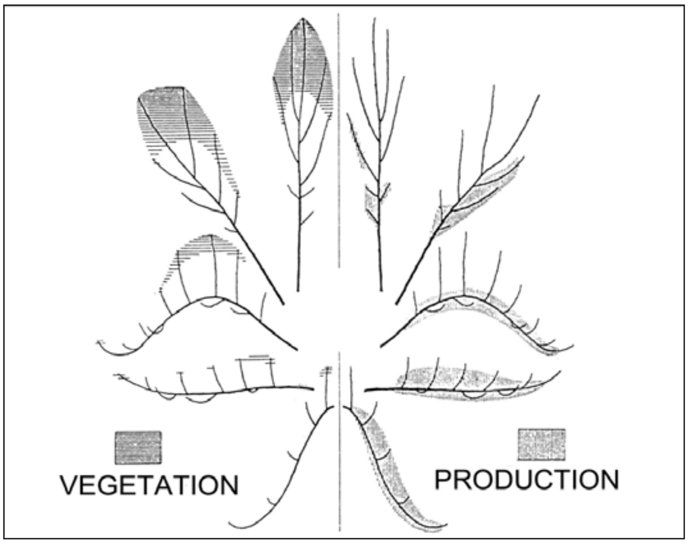

Fig. 7 - The relative location of vegetative and reproductive activities may be changed by variations of growth direction of axes imposed by pruning.

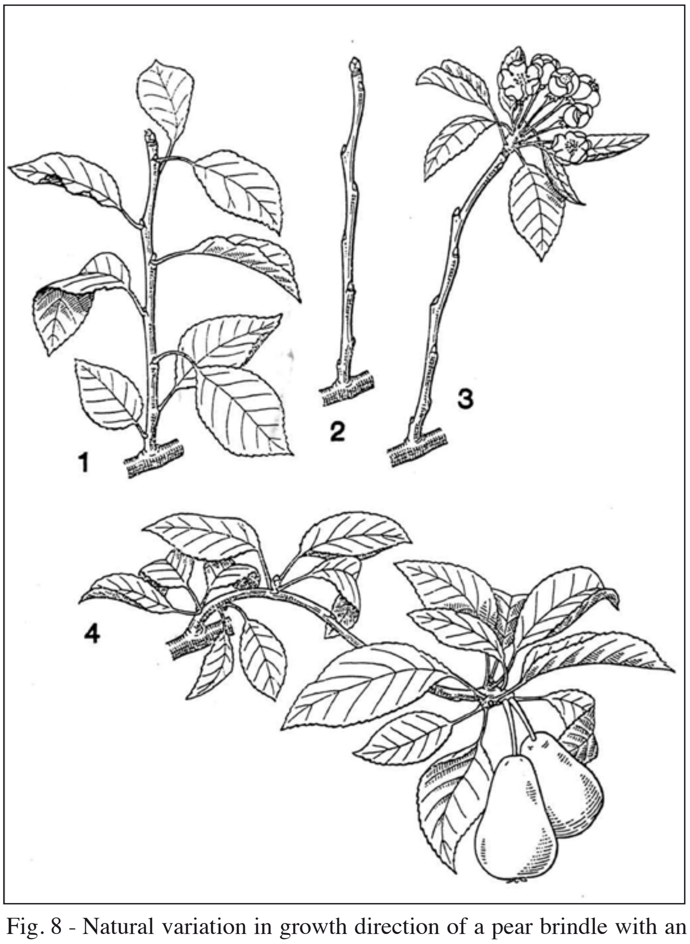

Fig. 8 - Natural variation in growth direction of a pear brindle with an apical fruit bud (from Grisvard, 1957).

Architectural model. The growth pattern of a fruit tree species which determines the successive architectural phases must be taken into account if a proper and specific training and pruning is to apply to the trees. The architectural model derives from an inherent strategy that defines both the manner, in which the plant elaborates its form, and the resulting structure. The model results from the nature and the sequence of activity of endogenous morphogenetic processes as determined by the basic growth program on which the entire architecture is established and realized under the environmental and cultivation constraints.

A particular combination of simple morphological features may identify typical architectural models: a) the growth pattern (determinate vs. indeterminate growth; rhythmic vs. continuous growth); b) the branching pattern (terminal vs. lateral branching vs. no branching; monopodial vs. sympodial branching; rhythmic vs. continuous vs. diffuse branching; immediate vs. delayed branching; c) the morphological differentiation of axes (orthotropic vs. plagiotropic vs. axes with orthotropic and plagiotropic portions); d) the position of reproductive structures (lateral vs. terminal fruiting) (Barthélémy and Caraglio, 2007).

The tree architecture can be considered a hierarchical branched system in which the axes are grouped into categories according to their morphological, anatomical or distinctive functional features. This branch system, even if very complex, is composed of a simple sequence of axes characterizing its basic architecture. The simple architectural unit lasts during the whole life span of some tree species while in most trees it is possible to recognize repeated architectural units during their development, late in ontogeny, or under particular conditions. This process is called "reiteration"; more precisely it is a morphogenetic process through which the tree duplicates its own elementary architecture. This process may be demonstrated in several structures such as water shoots, root suckers, etc. These reiterated structures may derive from dormant meristems and in this case are called proleptic or delayed. In other cases, reiteration may be a consequence of a shift in the functioning of the apical meristem of a growing shoot that will finally produce a less differentiated structure; in this case, the reiteration is described as sylleptic or better immediate.

The trees develop by the repetition of elementary construction units conforming to their model and a differentiation sequence in the activity of their whole set of meristems. The specific and exact structure of a particular organ in a given location within the architecture of the tree may be considered as the result of a complex of several ontogenetic and morphogenetic factors that influences all plant organization levels, at each stage of plant development and during its whole life span. Although environmental factors may modulate these sequences of differentiation, they almost never modify the inherent morphogenetic and ontogenetic constructional project of the plant organization. This is also true for horticultural manipulations such as training and pruning, confirming that it is advisable to follow the fruit tree's development without radically changing its vegetative and reproductive behaviour. In other words, the branching order of an axis must be respected since the higher the order, the higher its degree of differentiation. When the architecture of a branched tree must be manipulated, the modification must be carefully considered according to the specific branching pattern, gradients (acrotony, basitony, mesotony) and the axis spatial orientation and/or geometry (hypotony, epitony, amphitony). In a given plant species, or even in a single tree, very different situations may be observed: at a given stage of development, homologous botanical structures with different features coexist on the same individual (e.g. short vs. long shoots or reproductive vs. vegetative shoots) whereas, by contrast, similar elementary structures with the same morphological features (short shoots with vegetative or reproductive features) may be observed in very different plant ages or stages of development.

This may be defined as the physiological age of the meristem, which may generally be characterized by a particular combination of several morphological, anatomical and/or functional attributes of a given plant structure derived from this meristem. The physiological age of the meristem depends on its location in the plant architecture and on the stage of development of the plant; its expression may be modulated by environmental factors and obviously by cultural practices, particularly by pruning (Fig. 9). The physiological age of a meristem relates to the degree of differentiation of the structure it produces. Typical features of the physiologically aged structures are, for example, the short axes of many trees: growth units are short, bear flowers and may have a short lifetime. These highly differentiated axes may be considered physiologically old whatever their moment of appearance. By contrast, main axes consisting of vigorous growth units and/or annual shoots may be considered physiologically young products and generally appear only in young trees or in strongly pruned fruit trees. Identification of meristem age of is very important in order to understand the comprehensive architecture of a plant or even its plasticity, i.e. the effects of the environment and/or of cultivation practices on its development and structure (phenotypic plasticity).

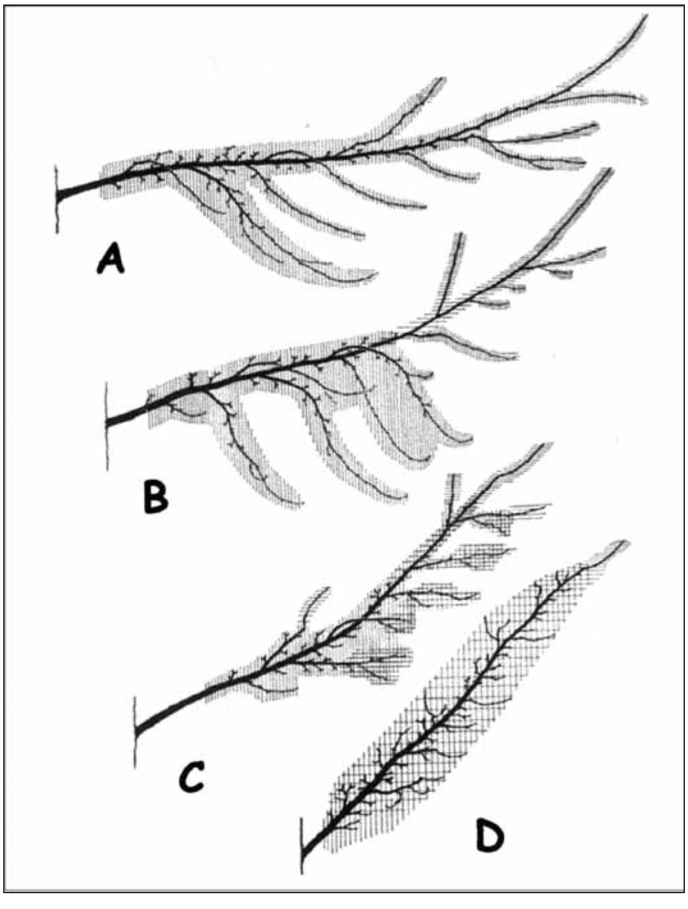

Fig. 9 - Formation of lateral axes of different types and ages on an apple tree branch pruned according to the various pruning criteria used in four training systems, which diverge from the natural behaviour very little (A) to very much (D) (redrawn from Hilkenbäumer, 1953).

3. Tree growth

The growth of a living being means the irreversible increase of dry matter, and more currently the term is used for any positive variation in shape, size or fresh weight of an individual or a part of it. Trees are characterized by secondary growth processes and by a continuous formation of woody tissue, part of which is non-living biomass. The woody part has the essential functions of tree support, sap transport, and storage of water, nutrients and carbohydrates. From the stand point of modern horticulture, trees of large size are not desirable because they invest a large part of energy and resources in building up and maintain their woody frame. The growth rate of the whole tree is of great economic meaning since it determines, in addition to dry matter accumulation, other important events such as the overcoming of juvenility (if the tree develops from a seed), the duration of the initial low productivity stage, and the acquisition of high fruiting and competing capability. Practically speaking, in a grafted fruit tree a fast initial growth rate is an economic advantage for rapidly attaining its definitive size, which in modern fruit trees should be as small as possible in order to realize a high ratio between fruit load and woody frame (Bargioni, 1988).

Tree growth (i.e. permanent increase of dry matter) is balanced between the development of new leaves and new roots. The new leaves exert a positive feedback on the assimilate production and similarly the new roots a positive feedback on absorption of more water and nutrients.

At the beginning of a tree's life, the major part of assimilates produced by the leaves is invested in the construction of the root system. As long as the root system does not achieve an adequate size to supply a sufficient amount of water and nutrients, the reproductive potential of the tree remains zero or extremely low. During maturity the canopy-root ratio is relatively stable and fruiting is kept more or less constant. When the tree attains a given size, the costs of maintaining the structure become very high and fewer and fewer resources are available to sustain root system growth, since its competition potential is weak in relation to other plant organs, particularly fruits. Less water and nutrients are then available to the crown, reducing net photosynthesis and assimilate potential and, as a consequence, senescence of the tree is triggered. The net investment of the various resources which enter in and exit out of the tree and partition of the biosynthesis products are two important determinants of the balanced growth of a tree. Water, nutrients, carbohydrates, organic acids, lipids, proteins, hormones etc. may be utilized in different ways and times in relation to the physiological balance of the tree. The amount and partition of photosyntates gives a good indication of the growth potential of the tree or of its organs because they are the source of energy which can be used at the time or stored. Source-sink interactions, that is the transitory destination of assimilates and their final partition, determine the rate and expression of the relative growth of the plant organs and therefore the architecture and size of the tree.

The aim of tree and orchard management is to channel the major part of assimilates toward the reproductive structures, limiting that directed toward other plant organs without affecting the functioning of the whole system.

Individual tree architecture can vary greatly based on the growth strategy of the plant but can be modified by the environment and cultivation conditions (phenotypic plasticity). An example related to orchard design is the competitive stress induced by planting density (Fig. 10). In comparison to a widely spaced population, closely spaced tree populations have a more limited volume of soil available for the individual root systems and thus fewer resources are supplied to the tree canopy. With close spacing, individual trees are smaller and less branched, but the ratio between fruits and woody structure (or volume of the crown) is higher than in individuals in a widely spaced population. Not all plant characters are affected equally by the competitive stress, and some effects tend to be species- and environment-specific (Cannel, 1983). Light interception and distribution in the canopy may play a concomitant role in plant growth; in the tree canopy the behaviour at high incident irradiance depends on the degree of light saturation of the leaves, which in turns depends on their geometrical arrangement and the geometry of the tree, which determine the ratio between direct and diffuse radiation (Connor, 1983). From outside to inside the canopy the quantity of light decreases sharply, as does the light quality (Proctor, 1978). Taking into account the variation of light quality inside the canopy (visible light, red/far red, UV), plant form and reproductive performance may be different in dense or open canopies because of the photomorphogenic and photoperiodic effects (Connor, 1983). In stands composed of genetically identical trees, like orchards, the effects of competitive stress can be even more emphasized if appropriate pruning and management practices are not applied. The contribution of pruning to the shape, growth and functioning of the tree can be relevant but it does not introduce dramatic variations in the natural vegetative growth habit of the fruit tree.

4. Correlative functions

The correlative functions within an individual tree (i.e. competition and cooperation among the plant organs) deserve particular attention because they offer some basic concepts for pruning, which L.H. Bailey illustrated very well a long time ago in "The Pruning Manual" published as first edition in 1898. It is worthwhile to report exactly what he wrote.

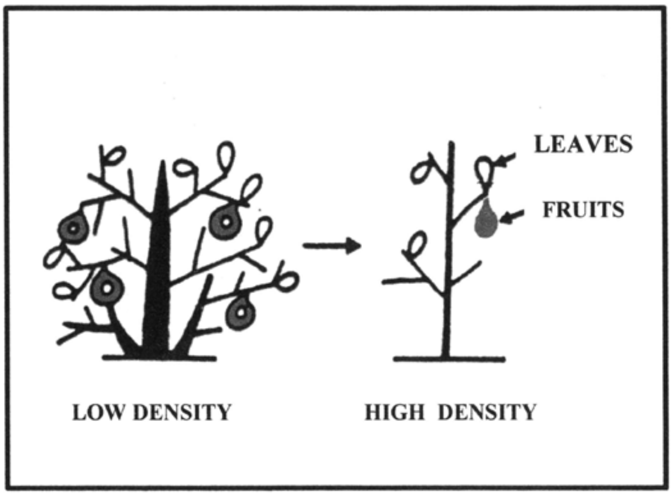

Fig. 10 - Effect of planting density on tree structure. Closely planted trees bear more fruits per unit canopy volume than widely spaced trees because of phenotypic plasticity (Cannel, 1983).

"A tree is essentially a collection or a colony of individual parts. Every branch, even every joint of the branches, may do what another branch does - it may bear leaves, flowers and seed. Every branch competes with other branches; and there are more germs of branches - that is, more buds - than there can be branches on any tree, or in any other plant that by its nature produces many branches. No two branches of a tree are exactly alike, but are what their position or condition or heredity makes them to be. Some are strong and some are weak. That is, there is no definite or proper size or shape for any branch, as there is for different members of an animal or of a flower. The limbs and organs of an animal are not competitors but co-partners, each performing some functions or office, that another does not, and they all attain a definite maturity of size and shape. But a branch in a tree-top never attains its full size until it ceases to grow and thereby begins to die. Branches are not so much organs as competing individuals. If all these statements are true, then three conclusions follow: there is a contest among the branches of a plant, and some of the contestants perish; the destruction of these branches may conduce to the betterment of those remaining; all the branches of a tree are not necessary to it, but some of them may be superfluous or detrimental to it. In other words, pruning may follow as natural course."

In this context the manipulation of trees by pruning is amply justified in an orchard. Citing again Bailey, "Of course there is a kind of partnership between the branches of a tree, for we assume that each strong branch makes a contribution to the development of the root-system and trunk-system, and there is not the same separateness as between wholly different plants; yet the contest between these branches is apparent, and it has special significance to the present discussion."

Of course these considerations may be extended to the other organs of the tree: buds, twigs, shoots, flowers, fruits and roots.

Taking into account the functional equilibrium between the size and activity of the shoots (carbon fixation) and size and activity of the fine roots (absorption of water and nutrients), that in a constant environment, favouring continuous growth, tends to maintain a constant ratio of root/shoot relative growth rates (Cannel, 1985), it is evident that removing a part of a tree by pruning represents a loss of a given amount of tissue and in replacing the lost part the tree expends a certain amount of assimilates. This may seem nonsense, but it is necessary to keep in mind the goals of the orchard, which are the economics and adjustment of tree-environment interactions. Tree vitality is not impaired by removing a part of it unless the removal is so great that it interferes with nutrition (growth) of the remaining parts, for example a great removal of photosynthetic leaf surface or of adsorbing roots.

Taking into account plant homeostasis, it is obvious that if part of the shoots or branches are removed, assimilates are devoted to rebuilding the lost part and fewer are directed toward the root system, and vice versa. If part of the roots are suppressed, the shoots resume their growth only when the pruned part of the root system is rebuilt and the root/shoot equilibrium is re-established, other aspects remaining constant (Richards and Rowe, 1971). Therefore, shoot pruning temporarily checks root growth, while root pruning temporarily checks shoot growth: the more pruned off, the greater the check in growth, and the longer it takes for the plant to recover the root/shoot relationship that existed before pruning. Thus, shoot pruning is a means of promoting new shoot growth, and root pruning is a means of promoting new root growth (Cannel, 1985). Therefore when part of the treetop is cut away, if not too severely, the tree resources are directed toward the remaining growing points and the tree develops, for example, more vigorous shoots. The consequence is that a correctly pruned tree appears more vigorous and also, as reported by Dotti (1949), more productive and long-living than an unpruned tree.

For the purpose of this paper, the genetic and metabolic processes causing and governing these correlative functions will not be considered but instead some of the most relevant organ and function competitions for the tree resources are addressed from a phenotypic point of view. Hierarchic but not univocal relationships are often established among tree organs and they contribute to the correlative functions that may involve organs of the same or different type.

5. Correlative relationships between organs of the same type

In this section relationships between meristems, buds, shoots, branches, flowers and fruits are considered. The most important correlative functions are those among the meristems present on a shoot since they originate all the organ typologies. The role of apical dominance, that varies amply according to genotype, development stage and environmental conditions, is known. Apical dominance also affects the functional relationships of the buds, determining different vegetative gradients along the shoot. These phenomena offer an important basis for pruning practices.

In peach the number of sylleptic shoots appeared to be related to the growth rate displayed by the parent shoot during the early part of the growing season (four to five weeks after bud break). Parent shoots with high growth rate formed sylleptic shoots in a greater number than the pinched back ones in which apical dominance was completely abolished. Therefore growth rate in the early growing season may play a stronger role than pinching in feather formation. Apex removal by pinching (summer pinching) changes the physiological status of a growing shoot, whereas bending affects only the shoot growth rate, thus its feathering (Giulivo and Ramina, 1974).

An interesting case, reported by Hilkenbäumer (1953), regards the number and distribution of buds on a tree. Three cases are considered and are shown in figure 11: a) when a tree carries a very high number of buds, on each axis a large number of weak shoots are produced and a part of buds remain silent; b) if all the axes are heavily and evenly pruned back, the number of buds is reduced and fewer but vigorous shoots originate in the same manner on each branch; c) if one axis is heavily pruned back and the other two lightly, weak shoots are produced by the former and strong shoots by the latter axes in contrast with case b. Cases a and b may be explained by the assimilate partition among many or few buds (Hilkenbäumer, 1953). For case c, which is more difficult to explain, it is suggested that the less pruned axes dominate the heavy pruned axis because they bear more buds and sprout earlier, becoming thus stronger sinks. This may be considered an example of the independence-competition among axes of a tree.

The fewer the shoots are allowed to grow with a severe pruning, the longer they are (Fig. 12). When only very few shoots are present on the tree, not only are they thicker with larger leaves and have longer internodes, but some of the lateral buds grow out to form short shoots or feathers (Abbot, 1984). The leading shoot (dominant position) is however always longer than those below it (Fig. 13). Whichever parent axis is manipulated (Fig. 14), there is

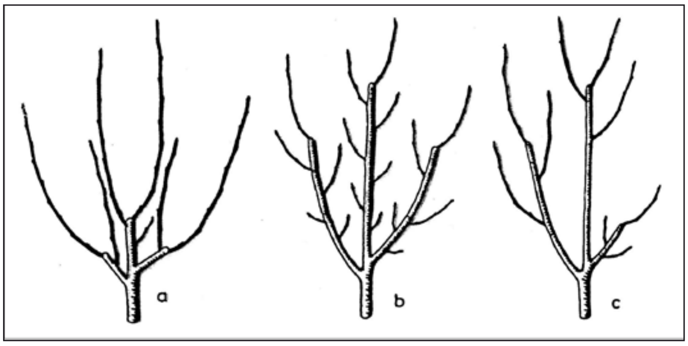

Fig. 11 - Vegetative responses of branches headed back with different intensities (A and B) or uneven intensity (C) (redrawn from Hilkenbäumer, 1953).

always one lateral axis that assumes dominance over the other axes. These factors clearly indicate the competition between homologous vegetative organs.

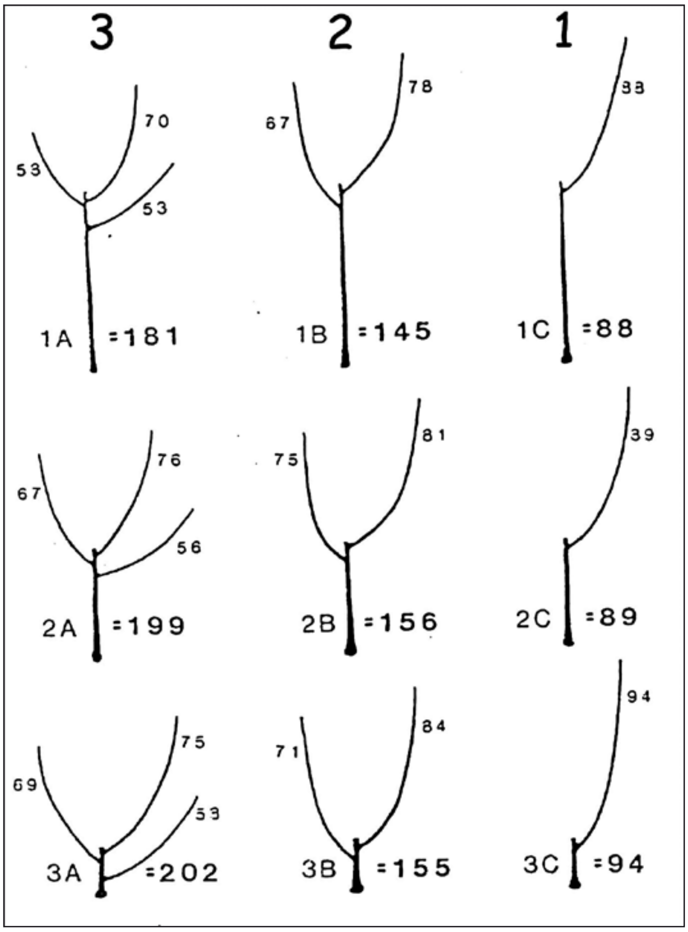

Fig. 12 - Effects of light, medium and severe pruning (one, two, three shoots on a headed-back one-year-old apple tree) (Abbott, 1984).

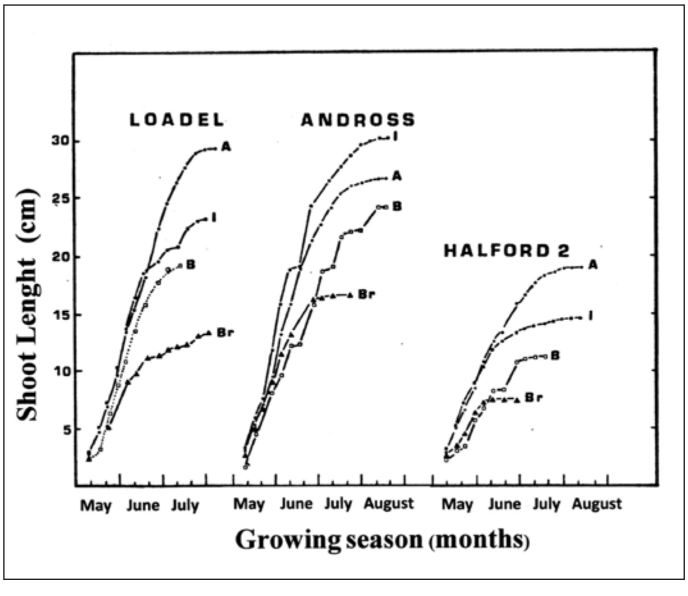

Fig. 13 - Elongation in apical (A), sub-apical (B, I) long shoots and in brindle (Br) shoots of three cultivars of peach tree with different ripening time (Giulivo *et al*., 1981 a).

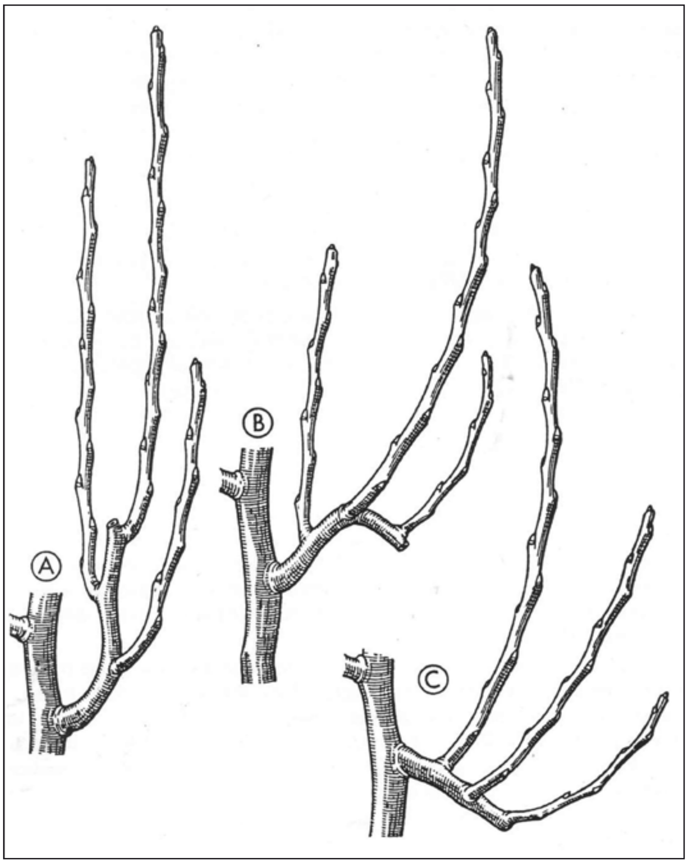

Fig. 14 - Position of the dominant shoot in headed-back vertical (A), curved (B) and slanted (C) parent axes (da Grisward, 1953).

A typical case of competition among homologous organs is the high abscission potential or reduced development and growth of fruits that are located, respectively, below or above the fruit that sets first in the corymbs of apple and pear trees (Fig. 15). The effect of fruit set priority on competition was also reported in peach tree where the fruitlets which set first and start to grow rapidly have the lowest probability of abscission (Ramina 1981; Giulivo *et al*., 1981 b).

6. Correlative relationships between organs of different types

The strength of relationships among organs are dynamic and change over the growing season and year. Usually the organs that have the larger mass (size) and grow more actively dominate the other organs of the plant. The relationship between vegetative and reproductive structures is a typical case. When shoot growth is very intense, fruit growth is limited and vice versa (Fig. 16) (Giulivo *et al*., 1981 b; Pitacco and Giulivo, 1992).

In an unpruned tree parts of canopy exist where vegetation dominates and parts where fruiting is prevalent. The position of a vegetative axis in space determines the vegetative-reproductive relationship (Fig. 6); in a vertical axis the vegetative activity is strongly favoured and fruiting is repressed. If an axis occupies a lower position in

Fig. 15 - Competition of the first setting fruitlet over the other fruitlets of the same corymb of pear (left) and apple tree (right).

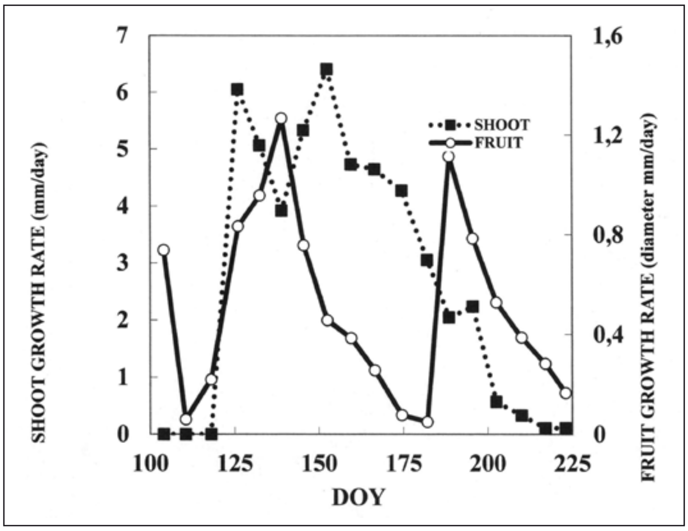

Fig. 16 - Seasonal growth rate of shoots and fruit of peach tree, cv. Andross. When the former is high, the latter is low, and *vice versa* (Pitacco and Giulivo, 1992).

the crown and tends toward a plagiotropic position, the relationship is reverted. This phenomenon obviously offers a great opportunity to manipulate a tree with winter and summer pruning. It can be assumed that every manipulation limiting growth can increase the reproductive activity, i.e. fruit bud differentiation and fruit development and growth. Two typical cases may be reported: a) by bending, the elongation rate of a growing shoot is decreased but bud differentiation is favoured; b) with limited nitrogen availability the vigour of the tree is depressed but the fruiting capability is increased (Hilkenbäumer, 1953).

The relationship between fruitlets and shoot carried by a bourse of apple tree can be an interesting case of transient competition between a leafy shoot and a reproductive organ carried by the same plant structure (brachyblast). Usually the fruitlets carried by the bourse corymb present a steady abscission for some weeks after full bloom but, if the shoot of the bourse is removed early, fruitlet abscission is delayed and reduced; the fruits on bourse deprived of the shoot growth less and at their final size results much smaller than that of fruits on a normal bourse carrying a shoot (Abbot, 1984). This is a consequence of fruit abscission in the corymb, but it may also be an effect of the transport of assimilates to the fruit which takes place when the leaves of the bourse shoot become active exporting organs.

As the season progresses, the developing fruits have an increasing demand for assimilates: after some weeks from fruit set they are diverted from shoot and root growth, bud differentiation and later from reserve storage. Increasing the fruit load has a dramatic effect: fruit bud differentiation is progressively reduced to a certain threshold, beyond which it is completely abolished (Fig. 17).

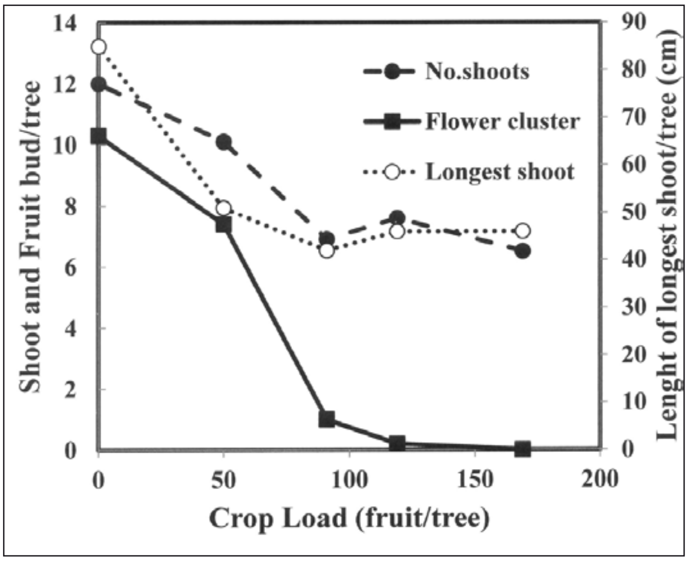

Fig. 17 - Effects of increasing fruit load of apple tree on shoot and fruit bud formation and on elongation of the longest shoot. (Abbott, 1984)

The presence of fruits on the tree slows down the formation of fruit buds as long as the fruits remain on the tree (Fig. 18); the later the harvest, the stronger the effect (Giulivo *et al.*, 1981 a).

A heavy crop load, induced by a very low fruit load during the previous year, strongly reduces shoot growth, flower differentiation for the next year and storage of reserve

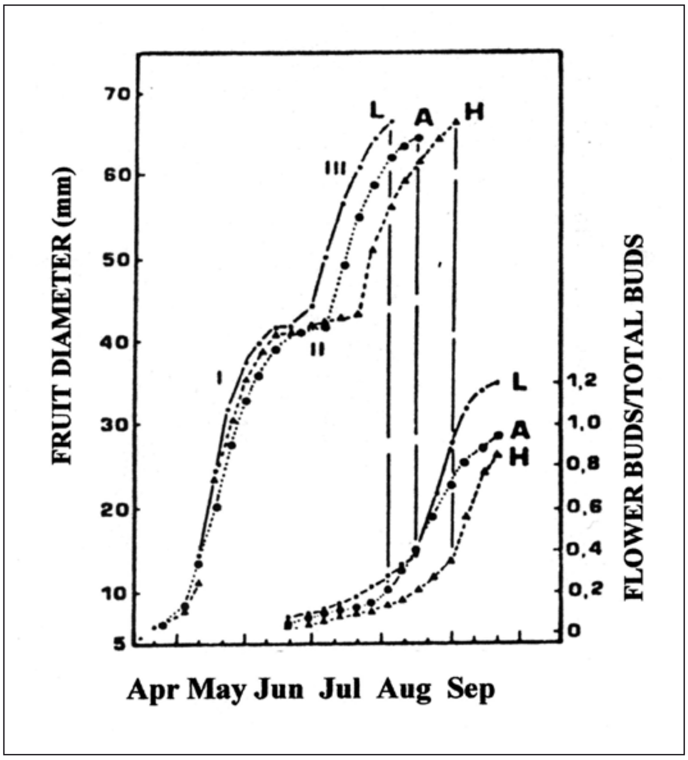

Fig. 18 - Fruit growth and percent of fruit bud formed on shoots of three cultivars of peach tree with different ripening times (Giulivo *et al.*, 1981 a).

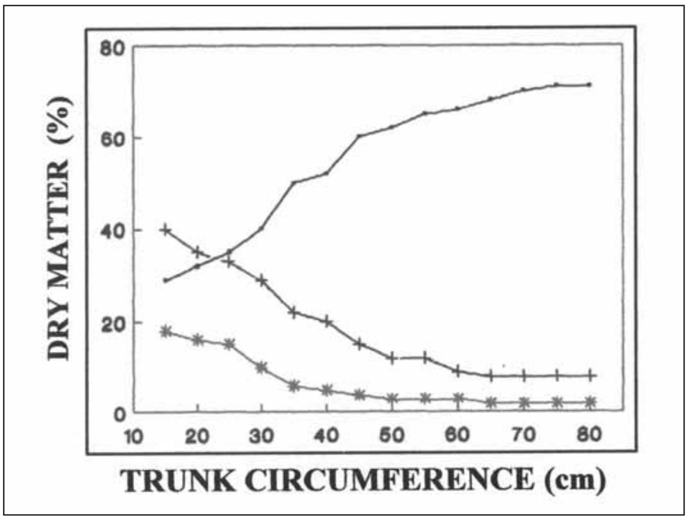

Fig. 19 - Dry matter partition among fruits (points), tree crown (crosses) and root system (asterisks). At increasing tree age represented by the trunk circumference less and less dry matter is allocated in the permanent structure of the tree (redrawn from Chalmers and Van den Ende, 1975).

materials (Giulivo, 1990). This can explain the succession of on- and off-years. A large number of developing fruits requires a great amount of assimilates which are diverted from vegetative growth and bud differentiation and this is a clear example of competition between different plant organs or functions. Flower or fruit thinning in the on-year is a powerful tool for modulation of the competition exerted by the fruits (Ramina, 1981; Abbot, 1984). Over-cropping and under- cropping, subsequent to off- and on-years, can be to some extent overcome by winter pruning, decreasing or increasing the number of fruiting structures of the tree.

The onset of fruiting is a dramatic event in the behaviour of a tree and the relative growth of plant parts is radically changed (Chalmers and Van den Ende, 1975): as the crop potential of the tree increases with time (Fig. 19), fewer and fewer resources are allocated in the permanent structures of the tree (trunk, branches and root system). This means that cropping of the tree is over time an aging factor and its regulation is a way to delay senescence of the plant. The regulation of cropping by summer and/or winter pruning represents a powerful tool for the maintenance of long-lasting economic performance of fruit trees.

During the growing season a heavy fruit load reduces root growth; very strong vegetation acts in a similar way, limiting fine root formation (Willianson and Coston, 1989). The partitioning of assimilates between shoots and roots is strongly affected by the water status of the tree (Schultze, 1982).

In many cases and in some stages of development the competition between tree organs is often connected with cooperation. The dynamic relationship between shoots and fruit within the whole tree, and also within a single leafy shoot, is particularly relevant. In fact, in an early stage of fruit growth (Fig. 20) the relationship shoot/fruit depends on the number of sinks and their relative position along the mixed shoot, as shown by an experiment on one-year-old peach shoots (Giulivo and Ramina, 1975).

Complex relationships among sinks occur, even within a single node of a shoot as observed in peach tree. It is

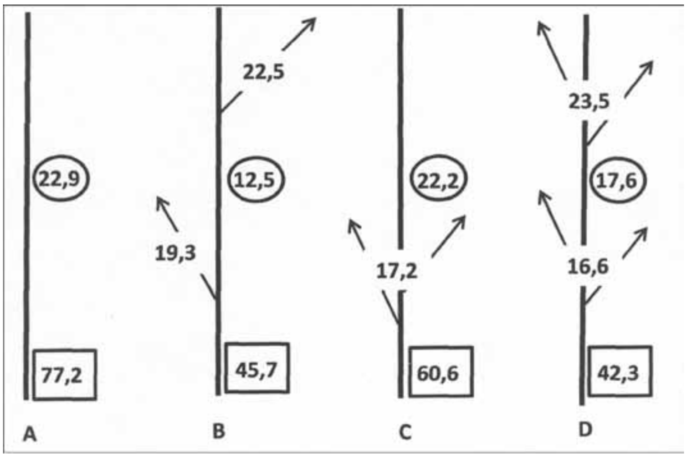

Fig. 20 - Fruit- shoot correlative relationships on peach one-year-old mixed shoots 0.2 m long. (Circles = fruit; arrows = shoots; square = basal leaf of mixed shoot treated with 14C, all other organs were removed). The organ (or organs) at the higher position was always the strongest sink. The fruit was a very strong sink (situation A); when the fruit was in between two shoots its strength was strongly reduced (situation B); when the fruit was above two shoots it was dominant (situation C) and therefore the relative organ position changed the sink relationship; the number of shoots above and below the fruit change the relationship between the organs (situations B and D). (Giulivo and Ramina, 1975).

known that different combinations of vegetative and flower buds occur at the nodes of peach mixed shoots; if a single fruit originates at a node initially it grows faster than the one or two fruits which are associated with a node with a growing shoot, but after some time, when the shoot rate decreases, these fruits attain a larger size (Casella, 1949; Giulivo, data not published). This may be explained by the contribution of the shoot leaves to the assimilate requirement by the fruits, in agreement with the results reported by Abbot (1984) on the shoot/fruit relationship carried by an apple bourse.

It would be possible to mention many other correlative functions, but the cases mentioned here should be adequate to stress the significance of these relationships in pruning management.

7. Conclusions

The efficiency of the orchard system is a primary requirement for economic success in fruit growing and therefore the architecture of the stand, with an appropriated use of the space available, can permit an efficient use of light, water and nutrients to sustain the basic physical and physiological processes involved in the functioning of the system. Sometimes space utilization (planting density) is too low or too high; in the former case light interception by the canopies becomes too scarce and soil evaporation too high; in the later, reciprocal shading of the trees assumes considerable weight. Sometimes the structure of the canopy is not optimal, as it may be too dense or too sparse and consequently the conditions inside the canopy are such that leaf and fruit functioning may be modified, pest proliferation may be promoted or light interception may be too scarce to maintain the various functions and processes of the canopy. In designing tree architecture, three basic indexes must be considered: the ratio between the tree parts above and below the ground, the ratio between leaf area surface and canopy volume, and the leaf area surface per unit of fruit weight. These indexes are satisfied differently in the various orchard models in relation to the applied training system and pruning criteria. Different training systems with a similar pruning criterion tend to have more or less the same production behaviour while different pruning criteria applied to the same training system tend to induce different crop performance (Sansavini and Musacchi, 1994). Pruning practices are thus a powerful means to modify tree functioning: pruning generally reduces the primary production of the orchard but may induce a great improvement of the performance of the system. The details of pruning for maximum fruit bud production and adequate fruit size and ripening differ for different species but it is possible to identify some general principles.

The various pruning techniques have very different effects on the growth and fruiting of a tree; heading-back or removal of organs, variations of spatial position and/or orientation of vegetative axes and transient modification of sap transport induce very different reactions. Interventions directed to shortening or removing an axis generally involve vegetative responses which are more or less strong in relation to location, intensity and when they are performed. Particular attention is required because strong negative or positive effects on the vegetative and reproductive equilibrium of the tree may arise. The negative effects regard mainly an excessive vegetative reaction but, if the pruning is carefully performed, the tree develops a species-specific fruiting structure more adequate to the economic goal of the orchard.

The detachment of fruits (thinning) performs a particular role in realizing a correct fruit-to-leaf ratio in the tree where the crop load is too heavy in relation to the leaves of the canopy.

Changing the position or the growth direction of the axes in the space (rectilinear, slanted, curved) generally decreases the growth rate and vigour of shoots and branches, improving the formation of reproductive structures. Therefore this type of manipulation assume a great importance in training the fruit trees.

Some pruning techniques, which tend to modify sap transport (incision above or below a bud, bark ringing, strangulation or girdling, shoot twisting and crashing, etc.), influence the relationships among sinks and the source-sink and thus they may stimulate or limit the development of an organ.

Whatever the manipulations of the above-ground part of the tree, root functioning is modified, but taking into account tree homeostasis, any modification to the root system affects the performance of the canopy. Therefore root pruning may be very useful for controlling tree vigour or improving root growth in adult trees.

All pruning manipulations mentioned involve variations in plant growth, size and geometry, thus modifying the architecture and functioning of the tree and affecting its productive life.

The timing of pruning manipulations is of great importance since the effects on the tree may be very different. In recent years summer pruning tends to prevail over winter pruning in most fruit tree species (Bargioni, 1988; Sansavini and Corelli, 1990; Costa, 1997; Sansavini *et al.*, 1999; Neri and Sansavini, 2004). This tendency is mainly based on two reasons: to form small-sized trees and to follow the natural species-specific behaviour of the tree. Under the same cultivation conditions winter pruning tends to stimulate the vegetative reaction, whereas summer pruning generally has positive effects on reproductive activity. This may be due to the more powerful action of summer manipulations on source-sink relationships, and among sinks. Summer pruning, however, may reduce leaf area surface or the ratio between young, mature and old leaves and this may have some consequence on the photosynthetic performance of the canopy, which can be of some importance when light availability is limited. The timing of summer manipulation of the canopy is critical: if performed when vegetation is growing very fast. In this case the responses of tree may be too strong and consequently a consistent amount of resources are invested in the edification of new vegetative structures or the density of the canopy may be increased. The timing of root pruning is as important as the time of canopy pruning since it has positive effects in the spring when it controls tree vigour, whereas it acts negatively if performed in late summer when storage of reserve materials is needed for the next year.

In the last few decades summer pruning (mainly pinching) has been extended to nurseries to train trees of some fruit species (apple, peach, etc.) carrying some feathers which speed up the construction of the tree crown in the orchard. In this way is possible the shortening of the unproductive period or to have young trees more suited for high density orchards or some particular training system (Sansavini and Corelli, 1990; Vigl, 1999; Neri and Sansavini, 2004).

In the 1990s some attempts were made to reduce production costs by omitting pruning during the training of trees and thereafter applying very simplified and superficial pruning, relying on thinning to equilibrate fruit load and leaf area surface. The performance of this technique, called 'no-pruning', was quite disappointing because of the serious drawbacks on fruit quality, such as variability in size and ripening of the fruits. Even in high density planting, without an appropriate adaptation of the training system, pruning was not able to overcome the excessive tree competition that determines premature aging of the fruiting structures, excessive shading, crop alternation and poor fruit quality (Sansavini, 1999). Therefore it may be concluded that pruning will always be an unavoidable operation, taking into account the economical goal of the orchards.

In conclusion, the best pruning derives from a clear production target and from precise planning while considering tree general physiology, the peculiar characteristics of the fruit species, cultivars, clones, scion-rootstock combinations, and the local environmental and cultivation conditions. Finally, it is important to remember that pruning represents only one of the many manipulations which can be performed in the orchard yet it cannot overcome basic mistakes made in designing the system.

References

ABBOT D.L., 1984 - *The apple tree - Physiology and Management*. - Grower Books, London, UK, pp. 90.

BAILEY L.H., 1916 - *The Pruning Manual. Being the eighteenth edition, revised and reset, of The pruning-book, which was first published in 1898* - Macmillian Company, New York, USA, pp. 407.

BALDINI E., SCARAMUZZI F., 1962 - *Glossario dei termini usati nella potatura degli alberi da frutto a foglia caduca*. - Tipocolor, Firenze, Italy, pp. 24.

BARGIONI G., 1988 - *Forme di allevamento e tecniche di potatura: come cambieranno?* - Frutticoltura, L(1-2): 97-103.

BARGIONI G., 1992 - *Potatura degli alberi da frutto*, pp. 393-494. - In: BALDONI L., G. BARGIONI, M. DEVREUX, O. FAILLA, C. FIDEGHELLI, G. FONTANZZA, F. GORINI, R. JONA, F. LALATTA, G. MARACCHI, R. PAGLIETTA, G. RAPPARINI, C. XILOYANNIS, and A. ZOCCA. *Frutticoltura generale*. REDA, Roma, Italy, pp. 644.

BARTHÉLÉMY D., CARAGLIO Y., 2007 - *Plant architecture: a dynamic, multilevel and comprehensive approach to plant form, structure and ontogeny*. - Ann. Bot., 99: 375-407.

BRANZANTI C.E., RICCI A., 2001 - *Manuale di Frutticoltura*. - Edagricole, Bologna, pp. 103-141.

CANNEL M.G.R., 1983 - *Plant management in agroforestry: manipulation of tree, population densities and mixture of trees and herbaceous crops,* pp. 455. - In: HUXLEY P.A. (ed.) *Plant Research and Agroforestry*. International Council for Research in Agroforestry, Nairobi, Kenya, pp. 617.

CANNEL M.G.R., 1985 - *Dry matter partitioning in tree crops*, pp. 160. - In: CANNEL M.G.R., and J.E. JACKSON (eds.) *Attributes of trees as crop plants*. Institute of Terrestrial Ecology Publisher, pp. 592.

CASELLA D., 1949 - *Mezzi per attenuare la cascola delle gemme, dei fiori e dei frutticini nelle specie legnose fruttifere*. - Atti III Conv. Naz. di Frutticoltura, Ferrara, Italy, pp. 200-212.

CHALMERS D.J., VAN DEN ENDE B., 1975 - *Productivity of peach trees: Factors affecting dry-weight distribution during tree growth*. - Ann. Bot., 39: 423-432.

CONNOR D.J., 1983 - *Plant stress factors and their influence on production of agroforestry plant associations*, pp. 401. - In: HUXLEY P.A. (ed.) *Plant Research and Agroforestry*. International Council for Research in Agroforestry, Nairobi, Kenya, pp. 617.

COSTA G., 1997 - *Potatura di produzione e diradamento dei frutti negli impianti di pianura*. - Proceeding Symposium Melicoltura di Pianura: quale futuro, Verona, Italy, 12 April.

COSTES E., LAURI P.E., REGNARD J.L., 2006 - *Analyzing fruit tree architecture: implications for tree management and fruit production*. - Horticultural Reviews, 32: 1-61.

DOTTI F., 1949 - *Recenti vedute sulla potatura dei fruttiferi*. - Atti III Conv. Naz. di Frutticoltura, Ferrara, pp. 213-230.

GIULIVO C., 1990, - *Basi fisiologiche della potatura degli alberi da frutto*. - Proceedings "La Potatura degli Alberi da Frutto negli Anni 90", Verona, Italy, 27 April.

GIULIVO C., RAMINA A., 1974 - *Osservazioni sulla formazione dei germogli anticipati nel pesco. II contributo*. - Riv. Ortoflorofrutt. It., 3: 170-176.

GIULIVO C., RAMINA A., 1975 - *Competizione tra germogli e giovani frutti di pesco*. - Riv. Ortoflorofrutt. It., 4: 273-280.

GIULIVO C., RAMINA A., COSTA G., 1981 b - *Il contributo del sottoprogetto 5 alle conoscenze dei processi di abscissione e maturazione dei frutti* - Proceedings I Fitoregolatori nel Controllo Chimico della Produzione degli Alberi da Frutto, Ferrara, Italy, 26-27 March.

GIULIVO C., RAMINA A., SCRITTORE G., 1981 a - *Accrescimento e sviluppo riproduttivo in cultivar di pesco con diversa epoca di maturazione dei frutti*. - Proceedings I Fitoregolatori nel Controllo Chimico della Produzione degli Alberi da Frutto, Ferrara, Italy, 26-27 March.

GRISVARD P., 1957 - *La taille des arbres fruitiers*. - La Maison Rustique, Paris, Frances, pp. 160.

HILKENBÄUMER F., 1953 - *Obstbau*. - Paul Parey, Berlin und Hamburg.

INGLES C., GEISEL P.M., UNRUH C.L., 2002 - *Fruit trees: training and pruning deciduous trees*. - ANR, Publication 8057, UCD, Davis, CA, USA, pp. 7.

LIEBSTER G., PESSERL G., 1982 - *Fachausdrücke des Obstbaumschnittes - Lexikon in deutscher, Wörterbuch in englischer, französicher, italienischer und niederländischer Sprache*. - Mitteilungen Klosterneuburg, 32: 50-100.

MORETTINI A., 1963 - *Frutticoltura Generale e Speciale*. - REDA, Roma, Italy, pp. 612.

NERI D., SANSAVINI S., 2004 - *Attualità della potatura nella frutticoltura intensiva*. - Frutticoltura, LXVI(1): 14-23.

PITACCO A., GIULIVO C., 1992 - *Dinamica della crescita dei germogli e dei frutti in cultivar di pesco a diversa epoca di maturazione*. - Giornate scientifiche S.O.I., Ravello, Italy, 8-10 April.

PROCTOR J.T.A., 1978 - *Apple photosynthesis: microclimate of the tree and orchard*. - Hort. Sci., 6: 641-643.

RAMINA A., 1981 - *La dinamica della cascola ed alcuni aspetti fisiologici dell'abscissione nel diradamento chimico dei frutti di pesco (*Prunus persica*, L. Batsch)*. - Conv. I Fitoregolatori nel Controllo Chimico della Produzione degli Alberi da Frutto, Ferrara, 26-27 March.

RICHARDS D., ROWE R.N., 1971 - *Effects of root restriction, root pruning and 6-benzilaminopurine on the growth of peach seedlings*. - Ann. Bot., 41: 729-740.

SANSAVINI S., 1999 - *Potatura in libertà*. - Frutticoltura, LXI(3). 5-6.

SANSAVINI S., CORELLI GRAPPADELLI L., COSTA G., LUGLI S., MARANGONI B., TAGLIAVINI M., VENTURA M., 1999 - *Ricostituzione degli impianti e revisione degli indirizzi produttivi della peschicoltura romagnola*. - Frutticoltura, LXI(3): 8-20.

SANSAVINI S., CORELLI L., 1990 - *La potatura e le forme di allevamento del melo*. - Proceedings La Potatura degli Alberi da Frutto negli Anni '90. Verona, Italy, 27 April, pp. 65-99.

SANSAVINI S., ERRANI A., 1998 - *Frutticoltura ad Alta Densità, Impianti, Forme di Allevamento e Tecniche di Potatura*. - Edagricole, Bologna, Italy, pp. 593.

SANSAVINI S., MUSACCHI S., 1992 - *Modelli di impianto, architettura e potatura nei moderni pereti*. - Frutticoltura, LVI(2): 7-18.

SCHULTZE E.D., 1982 - *Plant life forms and their carbon, water and nutrient relations*, pp. 615-676. - In: LANGE O.L., P.S. NOBEL, C.B. OSMOND, and H. ZIEGLER (eds.) *Physiological Plant Ecology, II. Encyclopedia of plant physiology*. Springer Verlag, Berlin, Germany.

SIMON S., SAUPHANOR B., LAURI P.E., 2007 - *Control of fruit tree pests through manipulation of tree architecture*. - Pest Technology, 1(1): 33-37.

VIGL J., 1999 - *L'allevamento del melo a "spindle"*. - Frutticoltura, LXI(3): 29-32.

WILLIAMSON J.G., COSTON D.C., 1989 - *The relationship among root growth, shoot growth, and fruit growth of peach*. - J. Amer. Soc. Hort. Sci., 2: 180-183.

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Summer pruning in table grape

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Abstract: This paper reviews cultural practices to improve fruit quality in table grape during vegetative and reproductive seasons. Summer pruning in table grape (*Vitis vinifera* L.) has more effects than winter pruning, above all with regard to plant productivity and final number of bunches for harvesting. Thinning is one of the most cultural technique and it consists in the elimination of vegetative or reproductive organs in excess. Other summer canopy management techniques include leaf removal, fruit shoots positioning, shoot trimming and girdling.

1. Introduction

Summer pruning is a cultural techniques which drives vine vigour to ensure fruit quality and plant vegetative balance. While summer pruning is the most expensive cultural operation - 44.2% of total management costs (Crescimanno *et al*., 2011) - it helps to improve the microclimate in the canopy, promotes good ripening of the grapes and creates less suitable conditions for the development of pathogens. Good results depend on the vegetative-productive behaviour of the vineyard, intensity and age of cultural operation (Crescimanno *et al*., 1986). Summer pruning defines the final productivity of plants by modifying the number of shoots per plant with shoot thinning, the number of clusters per shoot with cluster thinning, and the number of berries per bunch with berry thinning. Other summer operations include leaf removal, shoot trimming and girdling *(*Di Lorenzo, 2003*)*. General indications about summer pruning techniques to enhance quality of production are very difficult to formulate because cultivar behaviour, vigour of the vineyard and environmental conditions must all be considered.

2. Leaf removal

Leaf removal causes a reduction of vine leaf area. If it occurs at or before bloom, it may cause berry drop, a reduction in fruit set or a reduction in bud fertility in the following season (Candolfi-Vasconceloset and Koblet, 1990). The intensity of leaf removal should be based on canopy density and light penetration into the fruit zone. The removal of basal leaves around the clusters is widely adopted to improve grape quality and to reduce the incidence of fungal infection (Gubler and Marois*,* 1987; Caspari *et al*., 1998).

Leaf removal should be performed near berry set or after fruit softening (Dokoozlian *et al*., 2000 a). The leaves immediately above the cluster are the main source for photosynthates translocated to the cluster, particularly during the early stages of its development (Hunter and Visser, 1988). Also at pea-size stage the loss of basal leaves increases fruit abscission, reduces berry size and decreases bud fertility; it has no effect when applied at veraison (Caspari *et al*., 1998). After berry setting, usually all primary leaves and lateral shoots beginning from the base of the shoot to the node opposite the top cluster on each shoot are removed. Elimination of apparently superfluous sinks, such as lateral shoots, reduces canopy density and °Brix, but it has minor impact on TA and pH (Reynolds and Wardle, 1989; Barbagallo *et al*., 2007 a). The leaves left on the vines after defoliation increase photosynthetic activity to recover the reduction on total leaf area activity and to supply the photoassimilates demand of sinks (Poni *et al*., 2006; Scafidi *et al*., 2010). On the other hand, Candolfi-Vasconcelos and co-workers (1994) found that defoliated plants had similar or even slightly lower photosynthetic rates compared to control plants, not only during the stress period but also in the following season. A photosynthesis response to leaf removal may be apparent only if the source-sink ratio is sufficiently limited. Under conditions of source deficiency due to leaf removal in the fruit zone, plants promote the activity of apical meristems to replace the missing leaf area (Barbagallo *et al*., 2007 b). Basal leaves should not be removed before veraison, especially in varieties susceptible to heat damage or sunburn like 'Red Globe', 'Thompson Seedless'.

During fruit ripening leaves opposite the clusters have limited importance compared to the younger leaves at the top of the canopy (Candolfi-Vasconcelos *et al*., 1994; Hunter *et al*., 1995). Younger leaves show a higher transpi-

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ration rate, but also higher water use efficiency than those opposite the clusters (Candolfi-Vasconcelos *et al*., 1994).

Some weeks before harvest random defoliation is usually undertaken to fully develop the colour of white, red and some black grape varieties.

3. Thinning

Thinning consists in the elimination of vegetative or reproductive organs in excess. It is very rarely performed before bloom since negative climatic events can lead to the loss of many shoots or irregular fruit set; in some areas and for some cultivars thinning performed before bloom can lead to excessive fruit set and tight bunches.

Shoot thinning

Shoot thinning is the elimination of double, weaker and sterile shoots and it is very important to aerate the canopy, improve the growth of remaining shoots and adjust cluster numbers. There may be an advantage with shoot thinning in vigorous vines to reduce shoot crowding and thus increase light exposure of the remaining shoots. Shoot thinning should be performed when shoot length reaches 25-30 cm. (Dokoozlian *et al*., 2000 b) when it is possible to define which shoots have bunches in good position and which are well located as pruning material for the next year. On spur-pruned vines two shoots per spur are retained and latent shoots are removed from older wood, arms and cordons, while cane-pruned vines are sometimes shoot thinned, especially when several canes are wrapped together on a single wire.

Cluster thinning

Cluster thinning is usually performed after fruit set in order to adjust the crop load, distribute clusters evenly on the vine and canes, select the best clusters (shape, size and position) and eliminate those that are misshaped and weak (Figs. 1 and 2). Generally the aim is to have an equal number of cluster and shoots on the plant, leaving two clusters on the distal shoots. The number of flowers per inflorescence, berry per cluster and cluster weight (Table 1) is positively affected by the node position long the cane (Sottile *et al*., 1996). A cluster/shoot ratio of less than 0.8 usually determines a reduction in terms of yield (Tables 2 and 3) without any significant improvement in terms of quality (Di Lorenzo, 2003). Several studies demonstrated that crop removal significantly increases soluble solids (Fig. 3) and berry colour (Dokoozlian *et al*., 1995). In a trial conducted on 'Flame Seedless' in Fresno California, berry weight, size and fruit composition varied little among vines thinned one week prior to bloom and those thinned four weeks following fruit set (Dokoozlian *et al*., 1995).

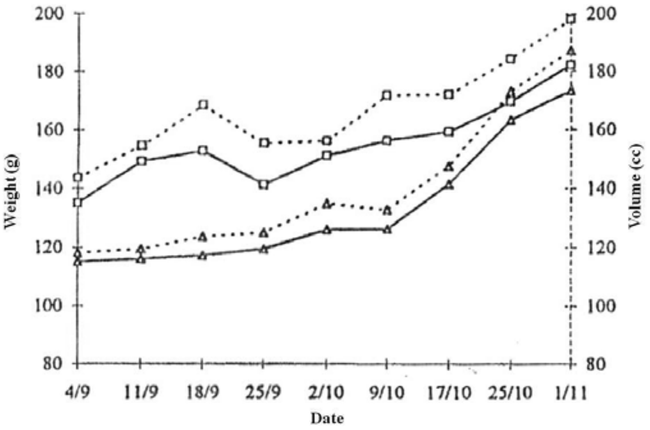

Fig. 1 - Effect of cluster thinning on evolution of berry weight (dotted line) and volume (continuous line) in treated (square) and control (triangle) plants.

Fig. 2 - Cluster thinning.

Table 1 - Influence of node position on number of flowers per inflorescence, number of berries per cluster, and berry and cluster weight (Sottile *et al*., 1996)

Node position	Flower (No.)	Berry (No.)	Berry weight (g)	Cluster weight (g)
1-4	258	101	7.0	779
5-9	517	128	7.3	1015
10-12	744	148	6.9	1090

Berry thinning

Berry thinning is a widely performed technique and involves the removal of a few berries from the cluster (Di Lorenzo, 2003). This operation is necessary to decrease the compactness of bunches and to give them a more attractive shape with large, uniform-size berries (Fig. 4 - Table 4). Berry thinning is performed when berries are at pea-size in order to give more uniform clusters in terms of weight and shape, satisfying packaging and marketing needs. In some cases for some cultivars, the partial removal of inflorescence or flowers with small scissors or small combs is performed in order to avoid an excessive clusters weight and/or closeness (Di Lorenzo, 2003). How the berries are removed depends on the cultivar. The best results are ob-

Table 2 - Influence of cluster:bud ratio on production of grape cv. Italia. Score of grapes from different vineyards and different thesis (Crescimanno *et al*., 1986)

Vineyards	Different time					
	I		II		III	
	0.6	0.8	0.6	0.8	0.6	0.8
1	627.45	509.15	592.20	565.40	581.17	499.62
2	680.17 ab	539.25 b	724.47 a	708.97 a	731.80 a	704.95 a
3	336.27 ABab	305.20 ABcd	355.67 Aab	230.77 Bc	393.22 Aa	303.65 ABbc
4	948.55	816.72	960.07	842.97	846.05	860.92
2A	919.72	890.85	945.70	845.75	851.62	894.35
3A	821.75 ab	871.47 ab	698.35 b	782.85 ab	946.00 a	787.62 ab
4A	832.05 a	633.78 b	714.30 ab	756.52 ab	818.62 ab	774.40 ab

Values sharing the same letter are not significantly different from each other by Duncan's multiple range test at P≤ 0.01 and P≤ 0.05.

Table 3 - Influence of cluster:bud ratio on production of grape cv. Italia. Score of grapes from different vineyards and different thesis (Crescimanno *et al*., 1986)

	Different time					
	I		II		III	
Vineyards	0.6	0.8	0.6	0.8	0.6	0.8
1	-	-	-	-	-	-
2	9	8	9	8	8	8
3	-	-	-	-	-	-
4	9	8	8	8	7	8
2A	10	9	8	8	9	8
3A	10	9	9	9	9	8
4A	10	7	10	10	8	8
Thesis average	9.6	8.4	8.8	8.6	8.2	8
Time average	9		8.7		8.1	

- = Poor quality of the product (not packable).

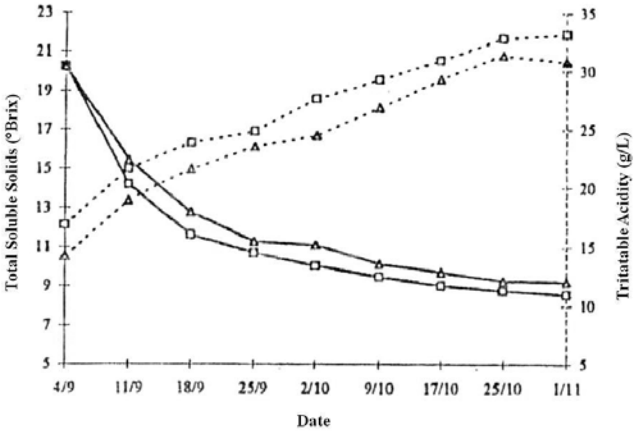

Fig. 3 - Effect of cluster thinning on evolution of °Brix content (dotted line) and total acidity (continuous line) in berries of treated (square) and control (triangle) plants.

tained with the "helicoidal" method, which consists of eliminating shoulders arranged in a spiral around the axis of the rachis. Another method is the "fish spine" system where two parallel cuts are made on each side of the axis of the rachis, but without injuring it. The resulting bunch is very flat, but when the berries grow, the respective ramification occupies the space around the rachis. In 'Thompson Seedless' the most common method is to clip the cluster leaving only the upper four to six shoulders (Dookolzian *et al*., 1995); in 'Red Globe' and 'Flame Seedless' usually the upper six to eight shoulders are kept (Dookolzian and Hirschfelt, 1995); in Superior Seedless® one-third of the bottom part of the cluster is removed. In cultivars such as 'Italia', instead, berry thinning requires plucking small seedless or irregularly developed berries by hand, a very expensive operation which may take up to 50-80 labour days/hectare.

In seedless varieties the use of giberelic acid (GA_3) is widespread; dose and time of application is highly dependent on the variety. The success of treatment is extremely variable, and is greatly influenced by climate during flow-

Fig. 4 - Berry thinning.

Table 4 - Effect of two different thinnings on qualitative traits (Di Lorenzo, 2003)

Thinnings	Cluster weight (g)	Berry weight (g)	Berry weight variation coefficient (%)	Closeness index
Thinning intensity more than 40% of traditional	626	10.6	23.1	2.59
“Traditional” berry thinning	934	8.9	28.1	3.39

ering (especially air temperature). One of the goals of breeding programs is to obtain varieties that do not require berry thinning.

4. Girdling and cane-scoring

Girdling is the removal of a ring of bark (only phloem) around the trunk or bases of the individual canes, while scoring is a simple knife-cut encircling the branch (Fig. 5 a and b). The phenological stage at which girdling is carried out is the greatest factor determining the nature and magnitude of the obtained effects (Di Lorenzo, 2003). Both operations stop movement through the phloem, modifying the hormonal balance of the vine after girdling (Kriedemann and Lenz, 1972) and consequently producing an increase of carbohydrates above the girdle (Weaver and McCune, 1959); carbon exchange between the shoot and the rest of the vine is thus eliminated.

Girdling reduces net CO_2 assimilation rate and stomatal conductance of leaves until the girdle heals (Kriedemann and Lenz, 1972; Williams and Ayars, 2005). Water use efficiency decreases following girdling without an application of GA_3 at berry set. Once the girdle heals, vine water use increases up to harvest (Bucks *et al*., 1985; Williams and Ayars, 2005). The reduction in stomatal conductance, and concomitant reduction in vine water use in response to girdling is probably due to an accumulation of abscisic acid (ABA) in the leaves (Loveys and Kriedemann, 1974; During, 1978; Williams *et al*., 2000; Williams and Ayars, 2005).

Girdling has negative effects on some berry characteristics, such as a decrease of malic acid concentration in the must (Orth *et al*., 1994).

The effect of girdling is reduced by leaf removal and declines while the number of leaves decreases (Caspari *et al*., 1998). Cane girdling at 12°Brix sugar content on cv. Vittoria determines a qualitative improvement of grapes (Tables 5 and 6): particularly, single girdling increases ratio sugar: acidity, double girdling (first time performed at pea-size stage, second time at veraison) increases the berry weight (Fig. 6) (Di Lorenzo and Gambino, 2010). Cane-scoring increases the average berry size of ‘Emperatriz’ seedless grape and bunch weight compared to unscored vines, but has no effect in ‘Aledo’ seeded grape (Casanova *et al*., 2009). The author supposes that in seeded fruits the availability of carbohydrates is guaranteed by the seed’s ability to synthesize plant growth hormones leading to powerful sink capacity, while seedless fruit has an insufficient sink capacity to grow.

Trunk girdling is a more rapid technique than cane girdling and all clusters are subjected to treatment. With cane girdling or scoring there may be a few clusters, located below the cut, that remain unaffected. The bark ring removed has to be complete; incomplete cuts result ineffective (Jensen *et al*., 1979).

Usually the girdle cut heals in approximately four weeks through callus formation that recovers the vascular connections (Williams *et al*., 2000).

Girdling and cane scoring are carried out seven to 10 days before flowering to improve berry-set, at berry set to increase berry size, and at veraison to advance sugar and colour development in red varieties.

Fig. 5 - Cane girdling and trunk girdling.

Table 5 - Effect of early girdling (1), girdling at 12°Brix sugar content (2), and double girdling (3) on parameters of berries at ripening on cv. Vittoria (Di Lorenzo *et al.*, 2010)

	Average berry weight ±SE (g)	Weight range			Average P.D. ±SE (mm)	Average E.D ±SE (mm)	Average berry form (DP/DE)
		<6	6-8	> 8			
1	8.3 c ±0.20	15	42	43	27.3 bc ±0.39	21.1 b ±0.30	1.30 ±0.02
2	7.4 b ±0.16	21	44	35	26.8 b ±0.23	19.7 a ±0.20	1.47 ±0.01
3	8.7 c ±0.19	10	35	55	27.8 c ±0.33	21.0 b ±0.17	1.32 ±0.01
Control	6.8 a ±0.10	38	43	19	25.0 a ±0.21	21.1 b ±0.14	1.18 ±0.01

In a trial of trunk girdles applied at fruit set on ‘Crimson Seedless’, vines girdled at fruit set produced larger berries compared to vines girdled at berry softening and ungirdled vines. Trunk girdles applied at fruit set increased berry weight 38%, berry length 12% and berry diameter 10% compared to the fruit of ungirdled vines. The berry weight and diameter of vines girdled at veraison were significantly lower than those of ungirdled vines, while the berry length of these treatments was similar. In addition, berry firmness of vines girdled at fruit set was significantly greater compared to vines girdled at berry softening and ungirdled vines. Due primarily to their larger berry size, the total yield of vines girdled at fruit set was approximately 45% greater than vines girdled at berry softening and ungirdled vines. A fruit quality defect among the girdling treatments was poor colour, and so only a portion of this increase in total yield was packable fruit (Dokoozlian *et al.*, 1995; Dokoozlian *et al.*, 2000 a). In contrast, in the same variety, Brar and coworkers (2008) indicated that girdling at berry set was an effective practice to stimulate berry colour development. In ‘Autumn Royal’ berry weight can be increased 10 to 15% by girdling at berry set, but also in this variety girdling delays colour development and harvest (Dokoozlian *et al.*, 2000 a).

Table 6 - Effect of early girdling (1), girdling at 12°Brix sugar content (2), and double girdling (3) on harvest parameters (cv. Vittoria) (Di Lorenzo *et al.*, 2010)

	Soluble solids °Brix		Total acidity (g/l)	
	05-07	15-07	05-07	15-07
1	13.2 b	13.3 a	5.8 a	5.5 a
2	12.0 a	14.2 b	6.2 b	5.8 b
3	13.2 b	13.5 a	5.8 a	5.9 b
control	12.0 a	13.5 a	6.2 b	5.8 b

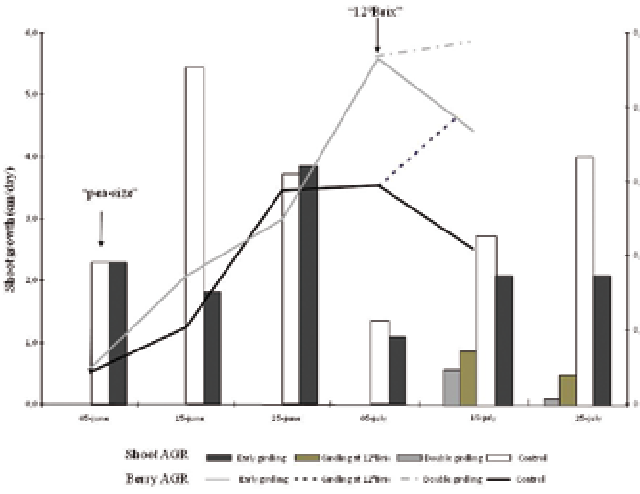

Fig. 6 - Effect of early girdling (1), girdling at 12°Brix sugar content (2), and double girdling (3) on growth rate of the shoot and berry (Di Lorenzo and Gambino, 2010).

Trunk girdling at berry set and bunch thinning, in an early-season black seedless table grape variety (Sugrathirteen® or Midnight Beauty®) improved berry size, sugar content and berry firmness (Gentilesco *et al.*, 2011).

Girdling increases the risk of skin burn, and should never be done on the same vine more than once a year. Repeated girdling over a number of years may reduce bunch size and the life expectancy of the plant.

5. Shoot trimming

Intensive growth of vines in warm climates requires measures to control vigour in order to ensure fruit quality and vegetative balance of the plants. The main control measure, besides the careful use of water and fertilizers, is shoot trimming which is usually performed after flowering; the exact moment depends on the cultivar and the objective of the culture (Camargo, 2005). Shoot trimming carried out just before bloom may improve fruit set: in fact in this stage it stops trophic competition of top shoot. In “T”, “Y” or open gable trellis, shoot trimming or hedging can be performed to improve cluster exposure to sunlight and to reduce humidity within the fruit zone. Early hedging may stimulate lateral shoot growth. Hedging should be performed after berry softening to avoid potential problems with fruit sunburn. Both sides of the canopy should be trimmed to allow the uniform penetration of sunlight into the canopy interior. Care must be taken not to remove too much foliage when hedging as excessive foliage removal may slow fruit maturation and significantly retard fruit colour development (Dokoozlian *et al.*, 2000 a).

6. Plant growth regulators

Plant growth regulators play a notable role in current worldwide table grape cultivation. Some of these can be included among summer management techniques, in order to reduce berry set, increase berry size and accelerate or improve fruit ripening. Before discussing their effects and possible uses, it must be pointed out that in each country there are different rules and regulations for their use (e.g. forchlorfenuron and ethephon are forbidden in many countries).

Gibberellic acid (GA$_3$)

Gibberellic acid (GA$_3$) is commonly used to reduce fruit set and increase berry size of seedless table grape cultivars. GA$_3$ rates and timing applications are quite specific and depend on the cultivar, region, and desired effects on berry growth and fruit quality (Dokoozlian *et al.*, 1995).

GA$_3$ sprays are generally carried out:

- *Several weeks before bloom* to elongate the cluster rachis.

  While many studies have reported that pre-bloom GA$_3$ application has no effect on cluster length or compactness at harvest (Dokoozlian, 2000), commercially it is still used (about 10 ppm rate). It could have a negative influence on bud fruitfulness in the following year.

- *Between 30 and 100% bloom* to improve berry thinning.

  The mechanism by which gibberelic acid works as fruit thinner is still not understood. An initial hypothesis was that GA$_3$ acts as a pollenicide, interfering with pollen germination, however many studies have shown that the GA$_3$ concentration normally applied for thinning does not reduce pollen germination. Some authors suggest, instead, that GA$_3$ applied at bloom alters the endogenous hormone balance causing flower or fruit abscission. The most reliable hypothesis is that GA$_3$ induces nutrient competition between flowers and shoots, and among flowers/small fruits within the cluster. In the latter case GA$_3$ stimulates nutrient competition among berries, and so physiologically advanced berries become strong sinks, while weaker berries are unable to compete for nutrients and drop (Dokoozlian, 2000).

  The GA$_3$ rate is closely related to variety and climate conditions, and it can vary from 1 to 20 ppm. A higher rate of GA$_3$ applied at bloom generally does not improve thinning, but can significantly increase the number of shot berries per cluster. Single or multiple applications usually result in similar levels of fruit thinning, however it seems that multiple applications produce larger berries at harvest compared to single applications (Dokoozlian, 2000). GA$_3$ spray at bloom often produces inadequate levels of berry thinning, which results in a need for manual berry thinning.

- *After fruit set* to increase berry size.

  Gibberellic acid applied to growing berries increases cell division and elongation.

  Also in this case the rate depends on the cultivar and prefixed quality target. The timing of application has a big influence on the efficacy of treatment; usually berry size should be in the range 4-6 mm, to a maximum of 10 mm. GA$_3$ treatments can increase berry size at harvest 50% or more, but they delay fruit maturity and reduce berry colour in red varieties (Dokoozlian, 2000). Also in this stage, high rates might cause a decrease in bud fruitfulness in the following year.

  GA$_3$ molecules enter in plant tissues better if applied in low pH solution (pH ≈ 4) since at low pH GA$_3$ molecules are neutral and are able to move easily through plant tissues.

Forchlorfenuron (CPPU)

Forchlorfenuron (CPPU) is a synthetic cytokinin that increases cell division and elongation.

Usually, CPPU can be sprayed on grape:

- *Immediately before bloom* to increase fruit set (≈ 10 - 20 g/ha) (Dokoozlian, 2000);
- *After fruit set* to increase berry size (≈ 5 - 40 g/ha).

  In different varieties ('Thompson Seedless', 'Ruby Seedless', 'Redglobe' and 'Melissa') CPPU applied at fruit set increased berry weight, diameter and length, while CPPU applied at fruit softening had no significant effect on berry growth. A two-week delay in harvest of most cultivars was obtained when 9-12 mg/l CPPU was applied at berry set, while pigment accumulation was either delayed or significantly reduced (Dokoolzian, 2001).

  CPPU does not reduce the fruitfulness of either seedless or seeded table grape cultivars, while it increases the rachis size and the force required to remove berry from the capstem (Dokoolzian *et al.*, 1995).

Ethephon

Ethephon (trade name Ethrel®) is commonly applied to red-pigmented table grape cultivars at the beginning of fruit ripening to enhance berry colour. The active ingredient in ethephon, [(2-chloroethyl) phosphonic acid], produces ethylene upon its degradation. Ethylene is an endogenous plant hormone that accelerates the ripening of many fruits, including grapes.

Ethephon, applied on 'Crimson Seedless' when approximately 5 to 10% of the berries were showing red colour, had no effect on fruit soluble solids content, however vines treated with ethephon had lower titratable acidity compared to untreated vines (Dokoozlian *et al.*, 1995).

Ethephon had no significant effect on berry weight, length or diameter, while it significantly improved fruit colour, increasing packable yield (+38%), but significantly reduced berry firmness compared to untreated vines (Dokoozlian *et al.*, 1995).

Abscisic acid (ABA)

The plant hormone abscisic acid (ABA) appears to be one of the factors for anthocyanin accumulation. Exogenous applications of ABA increased the anthocyanin content of grape skins (Peppi *et al.*, 2006; Peppi *et al.*, 2007).

Application of abscisic acid (ABA) may improve colour more effectively than ethephon, but it may potentially influence postharvest quality, though in a trial carried out on 'Crimson Seedless' the ABA and ethephon treatments did not affect berry firmness or predispose the fruit to postharvest shatter (Cantína *et al*., 2007). In that trial grapes treated with 300 μl l^{-1} ABA coloured quickly and thus were harvestable about 30 days earlier than untreated grapes, and 10 days earlier than grapes treated with ethephon. On average, grapes treated with 150 μl l^{-1} ABA were harvestable at about the same time as grapes treated with 300 μl l^{-1} ABA or ethephon, and grapes treated with either 150 μl l^{-1} ABA or ethephon were harvestable about 15 day before non-treated grapes. However, TSS, TA, and the ratio of TSS to TA differed among treatments. Grapes treated with 300 μl l^{-1} ABA were harvested at the lowest TSS, followed by grapes treated with 150 μl l^{-1} ABA, and grapes treated with ethephon or not treated. Grapes treated with 300 μl l^{-1} ABA or ethephon had the highest acidity (≈ 5.0 g l^{-1}) and the lowest TSS:TA ratio (Cantína *et al*., 2007).

In 'Flame Seedless' 300 ml l^{-1} ABA applied at veraison was superior to the other ABA concentrations and to ethephon applied at any of the tested times. Moreover, any concentration of ABA between 75 and 300 mg l^{-1} applied after veraison improved colour better than ethephon applied at the same time (Peppi *et al*., 2006), although the same rate in 'Red Globe' increased pigmentation and improved colour, it also caused fruit softening (Peppi *et al*., 2007).

References

BARBAGALLO M.G., GRIPPI F., SCAFIDI P., LINO T., 2007 a - *Effetti delle modificazioni artificiali del microclima sulla qualità dell'uva della cv 'Pinot nero'*. - Quad. Vitic. Enol. Univ. Torino, 29: 125-139.

BARBAGALLO M.G., VESCO G., PISCIOTTA A., CROSTA L., DI LORENZO R., 2007 b - *Effetti del regime colturale e della sfogliatura sull'attività vegetativa e produttiva della cultivar Nero D'Avola*. - Quad. Vitic. Enol. Univ. Torino, 29: 141-154.

BRAR H.S., SINGH Z., SWINNY E., CAMERON I., 2008 - *Girdling and grapevine leafroll associated viruses affect berry weight, colour development and accumulation of anthocyanins in 'Crimson Seedless' grapes during maturation and ripening* - Plant Science, 175: 885-897.

BUCKS D.A., FRENCH O.F., NAKAYAMA F.S., FANGMEIER D.D., 1985 - *Trickle irrigation management for grape production*. - Proceedings of the Third International Drip/Trickle Irrigation Congress, Fresno, CA, ASAE Publication No. 10-85, vol. I, ASAE, St. Joseph, MI, USA, pp. 204-211.

CAMARGO U.A., 2005 - *Grape management techniques in tropical climates*. - XIV International Gesco Viticulture Congress, pp. 251-256.

CANDOLFI-VASCONCELOS M.C., KOBLET W., 1990 - *Yield, fruit quality, bud fertility and starch reserves of the wood as a fuction of leaf removal in* Vitis vinifera *L. evidence of compensation of stress recovering*. - Vitis, 29: 199-221.

CANDOLFI-VASCONCELOS M.C., KOBLET W., HOWELL G.S., ZWEIFEL W., 1994 - *Influence of defoliation, rootstock, training system, and leaf position on gas exchange of Pinot noir grapevines*. - Am. J. of Enol. Vitic., 45(2): 173-180.

CANTÍNA C.M., FIDELIBUSB M.W., CRISOSTO C.H., 2007 - *Application of abscisic acid (ABA) at veraison advanced red color development and maintained postharvest quality of 'Crimson Seedless' grapes*. - Postharvest Biology and Technology, 46(3): 237-241.

CASANOVA L., ROSSIA D.G., CASANOVA R., AGUSTI M., 2009 - *Scoring increases carbohydrate availability and berry size in seedless grape 'Emperatriz'*. - Scientia Horticulturae, 122: 62-68.

CASPARI H.W., LANG A., ALSPACH P., 1998 - *Effects of girdling and leaf removal on fruit set and vegetative growth in grape*. - Am. J. Enol. Vitic., 49(4): 359-366.

CRESCIMANNO F.G., DI LORENZO R., OCCORSO G., SOTTILE I., BARBAGALLO M.G., RAIMONDI S., 1986 - *Influenza del rapporto grappoli su gemme sulla produzione dell'uva Italia coltivata in diversi tipi di terreno nel canicattinese*. - Convegno nazionale sulle uve da tavola e uve apirene, Canicattì (AG), 13-14 november, pp. 123-149.

CRESCIMANNO M., CUPANI D., GALATI A., 2011 - *Uva da tavola, strategie per margini più alti*. - L'Informatore Agrario, 10: 53-55.

DI LORENZO R., 2003 - *The world table grape production*. - Atti del GiESCO, Uruguay, pp. 219-228.

DI LORENZO R., GAMBINO C., 2010 - *Effetti dell'incisione anulare sul comportamento vegeto-produttivo della cultivar di uva da tavola Vittoria*. - Rivista di Frutticoltura e di Ortofloricoltura, 1-2: 20-24.

DOKOOZLIAN N., 2000 - Plant *growth regulator use for table grape production in California*. - Proc. 4th Int. Symp. Table Grape, 2000.

DOKOOZLIAN N., 2001 - *Influence of Forchlorfenuron (CPPU) on the growth and composition of table grapes*. - ASEV 52nd Annual Meeting, San Diego, California, USA.

DOKOOZLIAN N., HIRSCHFELT D.J., 1995 - *The influence of cluster thinning at various stages of fruit development on flame seedless table grapes*. - Am. J. Enol. Vitic., 46(4): 429-436.

DOKOOZLIAN N., LUVISI D., MORIYAMA M., SCHRADER P., 1995 - *Cultural practices improve color, size of 'Crimson Seedless'*. - Cal. Agric., 49(2): 36-40.

DOKOOZLIAN N., PEACOCK B., LUVISI D., VASQUEZ S., 2000 a - *Cultural practices for Crimson seedless table grapes*. - Pub. TB 16-00, University of California, USA.

DOKOOZLIAN N., PEACOCK B., LUVISI D., VASQUEZ S., 2000 b - *Cultural practices for Autumn royal table grapes* - Pub. TB 17-00, University of California, USA.

DURING H., 1978. - *Studies on the environmentally controlled stomatal transpiration in grape vines. II. Effects of girdling and temperature*. - Vitis, 17: 1-9.

GENTILESCO G., AMENDOLAGINE A.M., GIANNANDREA M.A., NOTARANGELO L., ROCCOTELLI S., SURIANO S., SAVINO M., ROMANAZZI V., TARRICONE L., 2011 - *Effects of crop load and time of girdling on Sugrathirteen® table grape: first results*. - Proceedings of GiESCO XVII international Symposium, Asti-Alba, Italy, pp. 419-422.

GUBLER W.D., MAROIS J.J., - 1987 - *Control of Botrytis bunch rot of grape with canopy management*. - Plant Dis., 71: 599-601.

HUNTER J.J., RUFFNER H.P., VOLSCHENK C.G., LE ROUX D.J., 1995 - *Partial defoliation of* Vitis vinifera *L. cv. Cabernet Sauvignon/99 Richter: Effect on root growth, canopy efficiency, grape composition, and wine quality*. - Am. J. Enol. Vitic., 46: 306-314.

HUNTER J.J., VISSER J.H., 1988 - *Distribution of 14-C photosynthate in the shoot of* Vitis vinifera *L. cv Cabernet Sauvignon. The effect of leaf position and developmental stage of the vine*. - S. Afr. J. Enol. Vitic., 9(1): 3-9.

JENSEN F., LUVISI D., SWANSON F., LEAVITT G., MITCHELL G., MAYER G., 1979 - *Effects of complete and incomplete girdles on Thompson Seedless and Ribier table grapes*. - Am. J. Enol. Viticult., 27: 65-67.

KRIEDEMANN P.E., LENZ F., 1972 - *The response of vine leaf photosynthesisto shoot tip excision and stem cincturing*. - *Vitis*, 11: 193-197.

LOVEYS B.R., KRIEDEMANN P.E., 1974. - *Internal control of stomatal physiology and photosynthesis I. Stomatal regulation and associated changes in endogenous levels of abscisic and phaseic acids*. - Austral. J. Plant Physiol., 1: 407-415.

ORTH C.H.F., STEVENS S., VAN DIK B.W., 1994 - *Palatability of Dauphine table grape - Is it affected by different viticoltural practices?*. - Proc. International Symposium on table grape Production, Anaheim, California, USA, 28-29 June, pp. 223-226.

PEPPI M.C., FIDELIBUS M.W., DOKOOZLIAN N., 2006 - *Abscisic acid application timing and concentration affect firmness, pigmentation, and color of 'Flame Seedless' grapes*. - Hortic. Sci., 41: 1440-1445.

PEPPI M.C., FIDELIBUS M.W., DOKOOZLIAN N., 2007 - *Application timing and concentration of abscisic acid affect the quality of 'Redglobe' grapes*. - J. Hortic. Sci. Biotechnol., 82: 304-310.

PONI S., BERNIZZONI F., CANALINI L., CIVARDI S., INTRIERI C., 2006 - *Effects of early leaf removal on shoot photosynthesis, yield components, and grape quality*. - Am. J. Enol. Vitic., 57: 397-407.

REYNOLDS A.G., WARDLE D.A., 1989 - *Impact of various canopy manipulation techniques on growth, yield, fruit composition, and wine quality of Gewürztraminer*. - Am. J. Enol. Vitic., 40: 121-129.

SCAFIDI P., PISCIOTTA A., SQUADRITO M., DI LORENZO R., BARBAGALLO M.G., 2010 - *Effetto dell'epoca di sfogliatura sul comportamento vegeto-produttivo della cv Cabernet Sauvignon in Sicilia*. - Italus Hortus, 17: 33-41.

SOTTILE I., DI LORENZO R., BARBAGALLO M.G., GIUFFRIDA S., 1996 - *Characteristics of inflorescence and cluster of tablegrape "Italia" cultivar as influenced by position on fruit cane and shoot*. - GESCO 9th Groupe Europèen d'Etudes des Systèmes de Conduite de la Vigne, Budapest. Hungary, pp. 137-142.

WEAVER R.J., MCCUNE S.B., 1959 - *Girdling: its relation to carbohydrate nutrition and development of Thompson Seedless, Red Malaga and Ribier grapes*. - Hilgardia, 28: 421-456.

WILLIAMS L.E., AYARS J.E., 2005 -*Water use of Thompson Seedless grapevines as affected by the application of gibberellic acid* (*GA_3*) *and trunk girdling practices to increase berry size*. - Agricultural and Forest Meteorology, 129: 85-94.

WILLIAMS L.E., RETZLAFF W.A., YANG W., BISCAY P.J., EBISUDA N., 2000 - *Effect of girdling on leaf gas exchange, water status, and non-structural carbohydrates of field-grown* Vitis vinifera *L. (cv. Flame Seedless)*. - Am. J. Enol. Vitic., 51: 49-54.

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Traditional and innovative summer pruning techniques for vineyard management

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Key words: cluster thinning, grape composition, leaf removal, shoot hedging, shoot thinning, vegetative growth.

Abstract: This review paper highlights physiological and vine performance effects of widely adopted summer pruning operations such as leaf removal, shoot trimming and positioning and cluster thinning. Leaf removal is addressed either under its traditional configuration, i.e. removing in dense canopies some or all leaves around clusters usually pre-veraison to improve fruit microclimate and facilitate spraying and early (pre-flowering) defoliation primarily aimed at inducing looser clusters via a concurrent reduction of fruit-set and berry size. Time consuming and still non mechanisable cluster thinning is evaluated primarily in terms of response variability *vs.* season and intensity with emphasis on lack of significant reduction of final yield per vine in thinned treatments when large crop compensation occurs. Variability of expected final grape composition improvements in thinned vines is also discussed based on the actual vine balance when the operation is performed. Although fully mechanisable, shoot trimming is still a debated choice in terms of timing and severity. While severe (i.e. fewer than six or seven main leaves retained) and late (i.e. several weeks after bloom) cuts should possibly be avoided, the effects of shoot trimming on final grape composition is discussed as a function of seasonal changes in leaf area development, demography, fraction of lateral leaves from the total and leaf to fruit ratio. It is indicated that, for vertically shoot-positioned trellises, if the support trellising is correctly designed and vine vigour is balanced, timing and severity of trimming are dictated by the vine "itself" rather than by grower choices. Overall, this review underscores the importance of leading the vineyard to a "natural" control of vegetative growth, which would minimise the need for an extensive use of summer pruning. In other words, such vineyard operations should be viewed not just as something the growers "have to do", instead as specific tools used to achieve targeted final grape composition.

1. Introduction

Summer pruning is a fairly broad term comprising a set of practices performed on the canopy during the growing season with an array of aims, including regulation of size, vigour and crop and reduction of the susceptibility to biotic and abiotic stress. If it is considered that at least two such operations, e.g. selective shoot and cluster thinning, still require manual execution, the total amount of necessary seasonal labour, calculated as man × hr/ha, readily exceeds the demand for winter pruning and becomes a primary determinant of vineyard economics (Intrieri and Poni, 1995). While it is commonly heard that the 'perfect' vineyard needs no summer pruning, perfect in reality has proved to be a very rare occurrence. Yet, we should certainly like to see vineyards of the future moving towards a more focused application of summer pruning operations. The major change is that a given summer cut is not solely or exclusively seen as something the grower "has to do", say, to accommodate adjustments for excessive shoot growth or canopy density. Rather it should also be viewed as something that the grower may 'use' to head vine and cluster growth towards better grape composition or to specific features consonant with adjustments needed because of climate change.

Along with traditional summer pruning operations, which define the grapevine canopy management strategy and include cluster and shoot thinning, shoot positioning and hedging, elimination of lateral shoots and late season basal leaf removal, over the last few years innovative summer techniques such as pre-flowering leaf removal (Poni *et al.,* 2006; Intrieri *et al.,* 2008; Poni *et al.,* 2008; Diago *et al.,* 2010 a; Palliotti *et al.,* 2011 b) or early and late season anti-transpirant sprays (Palliotti *et al.,* 2010 and 2011 a) have been introduced. These latter management practices are useful in any situation where the main aims are to reduce the vine yield and improve both technological and phenolic maturation. Moreover, global warming is leading to a progressive shift toward sub-tropicalization of several viticulture areas, shorter time intervals between phenological stages (Schultz, 2000; Jones *et al.,* 2005) as well as increased probability for berry sunburn (Spayd *et al.,*

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2002; Tarara and Spayd, 2005; Greer *et al.,* 2006). Finally, clear evidence does exist for faster ripening leading to significant increases in grape sugar concentration at harvest (Dokoozlian, 2009).

2. Leaf removal

This operation has been historically defined as "the removal of some leaves from the fruiting area between fruit set and veraison" (Smart, 1973) with the prevailing aim to ameliorate bunch microclimate and reduce rot incidence in canopies that are too dense (Gubler *et al.,* 1991). Ongoing research has provided knowledge to distinguish two types of leaf removal aimed at quite distinct goals.

Traditional leaf removal

Although this practice may have different purposes, it is usually employed from fruit set to veraison on high-density canopies to improve light exposure and air circulation around the clusters, with substantial benefits in terms of pigmentation and tolerance to rot (Smart, 1985; Bledsoe *et al.,* 1988; Gubler *et al.,* 1991; Percival *et al.,* 1994; Reynolds *et al.,* 1996). This operation can be done manually, requiring up to about 60 hr/ha, although increasing labour costs nowadays strongly advise a mechanical approach which can be easily performed in less than 2 hr/ha. The best timing for machine use is about one to two weeks prior to veraison when berries are still hard while specific bunch weight is already much higher than that of leaves.

Yield may not change (Bledsoe *et al*., 1988; Smith *et al.,* 1988; Hunter *et al.,* 1995) or might even occasionally increase as compared with non-defoliated vines (Zoecklein *et al.,* 1992). The variability of the impact that leaf removal has on yield and their components is likely dependent upon the negative effects on fruit set and berry growth in the current year and positive effects on bud induction and differentiation for the next year's crop via an improvement in canopy microclimate. Although this type of leaf removal usually leads to undeniable improvements in fruit composition, which more frequently are a slight increase in sugars and ripe fruit characters and a decreased malic acid content and attenuated herbaceous and grassy wine characters (Smart, 1985; Reynolds *et al.,* 1996; Zoechlein *et al.,* 1992; Scheiner *et al.,* 2010), its popularity has probably decreased over the last two decades due to either advancement in leaf and whole-canopy physiology and new pressure from global warming.

A study from Petrie *et al*. (2003) found that leaf removal from the lower quarter of the canopy during the lag phase of berry growth caused a significant decrease of whole-vine photosynthesis, even on a per-unit leaf area basis, thus suggesting that the lower portion of the canopy contributed more than the upper portion to the whole-vine carbon budget. A possible explanation of this finding is that although basal, and hence older leaves are removed by defoliation, they are also the largest leaves along the shoot and their size can offset lower photosynthetic rates (Poni *et al.,* 1994). Therefore, lowering shoot photosynthesis might not be negligible especially for leaf removals performed after fruit set.

Removal of all the leaves from the fruiting area, which thereby exposes the clusters to full sun, might lead in warm climates to compromised fruit composition because of excessive berry temperatures, which can hinder colour formation and cause a sharp drop in malic acid concentrations (Spayd *et al.,* 2002; Tarara *et al.,* 2008). For such reasons and in association with increasing concern for berry sunburn, criteria for applying leaf removal have become more restrictive and more often conceive retaining some leaf cover around the fruiting area. Differentiation in the actual need and/or severity of leaf removal also depends upon specific planting choices. For instance, no or very light defoliation is usually applied on the south facing side of an east-west oriented row, whereas more severe leaf stripping might be required on the north facing row side; basically the same applies for west- and east facing sides of north-south oriented rows, respectively.

More physiological insights have also been provided about "why" a traditional leaf removal might become mandatory. Backward to the still shareable rule indicated from Dr. Shaulis in that "no leaf removal is needed if while standing in front of a canopy at veraison about 50-60% of the clusters are visible", other more recent findings have shown that in a significant number of cases, excessive canopy crowding in the bunch zone leading, in turn, to the need of stripping leaves, is caused by other wrong or rushed vineyard management choices (Fig. 1). One example is worthwhile above all: spur pruned vertically shoot positioned (VSP) cordon-trained canopies are usually prone to leaf removal due to too high shoot density per meter of canopy length. Yet, this often happens as vines burst many either secondary or base bud originated shoots casting additional shade in the bunch area. More equilibrated vines would better comply with the shared requirement that, on average, one shoot is expected from each single retained node and, if so, the subsequent leaf removal would become quite likely unnecessary.

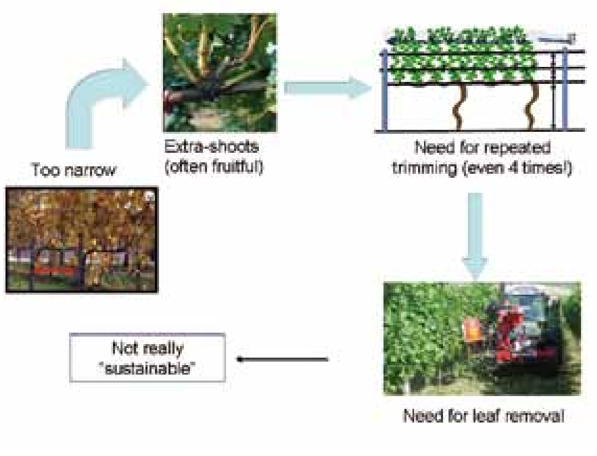

Fig. 1 - Interrelationships of excessive shoot vigour stimulated by a too narrow within-row vine spacing and related consequences on summer pruning needs (drawn by Authors).

Early leaf removal

This practice has mainly been inspired from long-standing knowledge according to which carbohydrate supply at flowering is a primary determinant of fruit set (Coombe, 1959; May *et al.,* 1969). The temporary source limitation induced by removing an average of six main basal leaves before flowering has led, under a broad array of genotypes and growing conditions, to a significant decrease in fruit-set, which in turn increases cluster looseness and tolerance to rot (Gubler *et al.,* 1991; Poni *et al.,* 2006; Intrieri *et al.,* 2008; Poni *et al.,* 2008; Diago *et al.,* 2010 a). Yet, the most important outcome is that, irrespective of genotype, this early leaf removal markedly improves grape composition and wine sensory properties as compared to non-defoliated shoots (Poni *et al.,* 2006; Diago *et al.,* 2010 a; Palliotti *et al.,* 2011 b).

There are multiple mechanisms involved in such a positive response. Defoliated shoots generally have a higher final leaf-to-fruit ratio than control, thus implying that the yield reduction induced by defoliation was more than proportional to the leaf removal constraint due to a fruit-set and berry-size effect (Poni *et. al.,* 2006). Furthermore, it is known that a precocious source limitation carried out in the form of defoliation or darkening the basal shoot zone hastens translocation of assimilates towards the cluster (Quinlan and Weaver, 1970). Improved grape composition in the defoliated shoots also relates to the 'quality' of the source. For example, it is indeed true that removing the main six basal leaves at pre-bloom causes an abrupt and severe decrease in vine photosynthesis [75% less than with not-defoliated (ND) according to Poni *et al.,* 2008]. However, removing source leaves around bloom also triggers a series of dynamic changes in canopy growth, age and photosynthesis. Defoliated vines have a 'younger' canopy at veraison since median and apical shoot leaves at this time are now mature and more lateral leaves may be present as a compensating reaction to early main leaf removal, while some, albeit temporary, photosynthetic compensation usually occurs in both main and lateral leaves of defoliated plants. Poni *et al.* (2008) have recently shown that whole canopy net CO_2 exchange rates (NCER) monitored uninterruptedly for three months in defoliated (D) vs. non-defoliated Sangiovese vines indicated no differences in data expressed on a per-vine basis. Yet when the same data were given on a per-unit leaf area basis, defoliated vines showed higher rates than ND vines (4.75 μmol $m^{-2} s^{-1}$ *vs.* 4.16 μmol $m^{-2} s^{-1}$) and, most importantly, NCER/yield increased by 38% in D vines, thus resulting in enhanced carbohydrate supply for ripening (Table 1).

However, the most intriguing outcome from these early-season defoliation tests is that a significant increase in relative skin mass has consistently been found in separate field studies conducted on a three-year basis in cv. Barbera (Poni and Bernizzoni, 2010), regardless of absolute berry mass (Fig. 2). It is reasonable to think that such an early

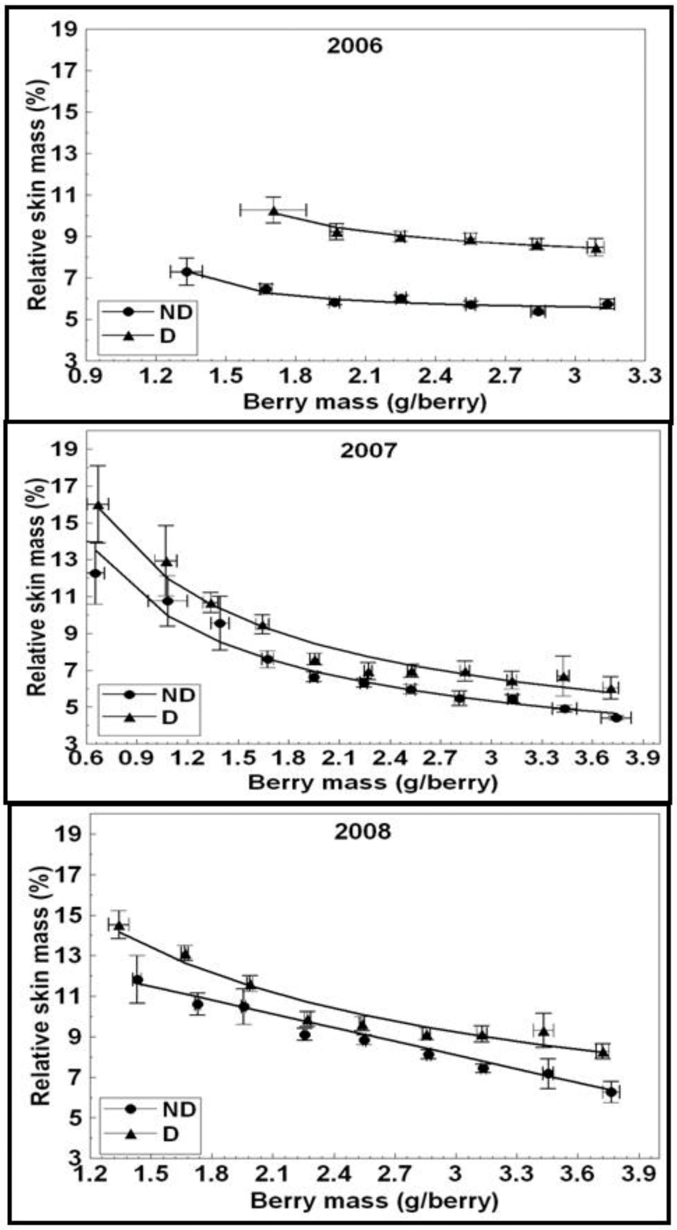

Fig. 2 - Correlation between relative skin and berry mass in 2006, 2007 and 2008 for non defoliated and defoliated Barbera grapevines (from Poni and Bernizzoni, 2010).

Table 1 - Effects of early defoliation on yield components and whole shoot net CO_2 exchange rate (NCER)/fresh fruit mass

Treatment	Flowers/cluster (no.)	Fruit set (%)	Total berries/ cluster (no.)	Cluster weight (g)	Berry weight (g)	NCER shoot/yield (nmol/s x g)	Cluster compactness (rating)
Control	435	38.8	169	334	1.98	2.43	6.60
Defoliated	487	21.0	103	207	2.01	3.31	4.25
Significance	NS	**	**	**	NS	**	**

**, NS= significant at P ≤ 0.05 or not significant, respectively.

basal leaf removal, besides favouring berry hardening in the long run, would also impose more favourable microclimate conditions for cell division and berry skin deposition, which typically takes place within four to five weeks after flowering. Mescalchin *et al*. (2008) have shown in Pinot Gris that the earlier the defoliation, the lesser the incidence of skin burning on VSP and pergola-trained varieties due to both more time allowed for cluster cover after treatment and adaptation towards the formation of a thicker skin.

Mechanization is feasible by preferably using at pre-flowering (i.e. closed-flower stage) an air pressure blowing machine which can run two passages per row in about 5-7 hr/ha (Intrieri *et al.,* 2008). Best performance is obtained on canopies characterized by vertical and well positioned shoots and on cultivars having mostly erect inflorescences.

It has to be kept in mind that early leaf removal is specifically recommended in highly productive vineyards which often present heavy, thick bunches very susceptible to rot. Based on the constancy of the results obtained under the above circumstances, this practice is nowadays an interesting alternative to traditional methods of crop control such as bunch thinning. Advantages are feasibility of mechanization, hence cost saving, and different mechanisms by which the crop level on the vine is adjusted. If early leaf removal is chosen, the primary regulation for crop restriction is via a decrease in fruit set with or without a significant reduction in berry size. Therefore, cluster number is unchanged, yet each bunch is smaller and looser. Conversely, hand bunch-thinning, besides being time consuming, drastically lowers bunch number per vine and favours undesirable yield compensation mechanisms such as larger berries and heavier clusters (Ough and Nagaoka, 1984; Keller *et al.,* 2005).

Anti-transpirant applications

A very recent development of the above work investigated whether the precocious, albeit temporary, source limitation sought with early leaf removal can be induced through the non-invasive and easy-to-do application of anti-transpirants (Palliotti *et al.,* 2010). Their use could sort out the inherent limitations of high labour demand for manual work while eliminating the risks of direct damage to the inflorescences linked to the use of a leaf plucker. Results reported for cvs. Sangiovese and Ciliegiolo subjected to pre-bloom treatment of anti-transpirant Vapor Gard® (a.i. di-1-*p*-menthene at 3% concentration, Intrachem Bio Italia, Grassobbio, BG, Italy) show similar reductions of net photosynthesis (from 30% to 70%) over several weeks after spraying as compared to control vines (Fig. 3). The treated Sangiovese vines showed reduced yield, berry weight, cluster compactness and, on a two-year basis, lower vigour and unchanged vine capacity per year. At harvest, the treated vines showed higher °Brix in all seasons and higher anthocyanin concentration two years out of three. Overall, early-season applications of a film-forming anti-transpirant caused a leaf function limitation strong enough to reduce yield and cluster compactness through smaller final berry size.

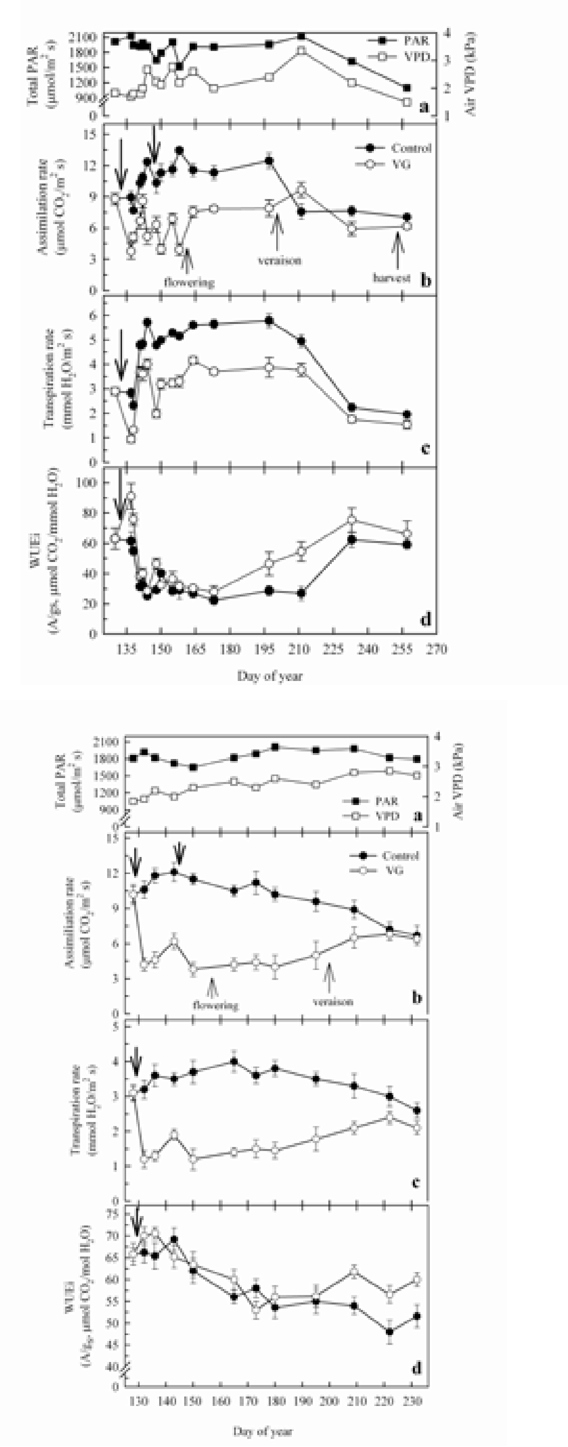

Fig. 3 - Seasonal trends of air vapour pressure deficit (VPD) and total photosynthetic active radiation (PAR) (a), assimilation rate (b), transpiration rate (c) and intrinsic water use efficiency (d) recorded on fully expanded, median Sangiovese (top image) and Ciliegiolo (bottom image) leaves sprayed twice with anti-transpirant Vapor Gard® at 3% (T) or left unsprayed (C). Bold arrows indicate the time of application. Data are means ± SE (from Palliotti *et al.,* 2010).

Over the last decade, climate change along with improvements in vineyard management and clonal selection have exerted a strong impact on vine yield and grape and wine composition. Among the most important effects, the increase in grape sugar concentration at harvest, is to be considered, which resulted in wines with high alcohol content (Vierra, 2004; Duchêne and Schneider, 2005; Godden and Gishen, 2005). There is a surge of interest from the wine industry in tools suitable to lower wine alcohol content such as the de-alcoholisation process which also agrees with the EU legislative measure No 606/2009. Conversely, it would thus be helpful to find strategies able to reduce grape sugar concentration in the vineyard, thus limiting the need to operate in the winery without detrimental effects on wine characteristics. In association with traditional management practices which can be used to slow down the accumulation of sugars in the grape berry, interest is growing in late season applications of anti-transpirants. In a recent contribution by Palliotti *et al.* (2011 a), the anti-transpirant Vapor Gard® sprayed about one month before harvest significantly delayed sugar accumulation in Sangiovese, Tocai rosso and Trebbiano Toscano berries which, at harvest, had -1.2 to -2.7 less °Brix than the un-sprayed control according to genotype and crop load. The temporary reduction of photosynthesis, due to the film formed by the anti-transpirant, limited the amount of assimilates translocated into the ripening berry, thus lowering must sugar concentration with a potential effect on wine alcohol content.

3. Cluster thinning

The achievement of an adequate balance between growth and fruiting can be obtained by the regulation of crop level through cluster thinning treatments. Despite additional labour costs, cluster thinning might play an important role in all cases where over cropping occurs (e.g. excess of vigour due to cultivar and rootstock, high soil fertility, low planting density, use of drip fertigation, etc.) and in cases where winter pruning severity has not overcome cropping due to high bud fertility. The negative effects of over cropping include delay in grape maturation, worsening of overall grape quality, increased susceptibility to biotic disease and poor wood maturity (Winkler *et al.,* 1974). Furthermore, different environmental parameters, particularly air temperature, light intensity, photoperiod and soil water content, together with phyto-hormones and the availability of mineral ions are known to influence bud fertility and fruit-set (Srinivasan and Mullins, 1981). Therefore, it is not always possible to regulate the yield level by solely adjusting bud load, especially in vineyards with low planting density and in years and areas characterized by unfavourable environmental conditions.

However, the results regarding the effects of high yield levels on fruit composition (sugar, acidity, colour, etc.) and wine quality (taste, flavours, colour and potential for aging) are quite contradictory. For example, some authors found an increase in anthocyanin concentration upon cluster thinning (Bravdo *et al*., 1984 a, Reynolds, 1989; Guidoni *et al.,* 2002), whereas no improvement in anthocyanin content or wine colour in cluster-thinned vines were found by Bravdo *et al. (*1984 b) and Ough and Nagaoka (1984). Location, application time and intensity of cluster thinning treatment significantly affected the results and can therefore justify, at least in part, the discrepancy of the experimental results in literature.

The results of a three-year trial on the effects of three levels of cropping (0%, 20% and 40% cluster thinning treatments) applied just before veraison in Sangiovese, Merlot and Cabernet Sauvignon showed that this management practice caused a significant reduction of yield only at the 40% severity and in two out of the three seasons studied (Table 2) (Palliotti and Cartechini, 1988). In each cultivar, in 1995 and 1996, yield was linearly correlated with cluster thinning intensity. Cluster thinning treatment at the 40% level caused a reduction of vine yield that ranged from 22% to 47%. The reduction of yield observed was, in general, not proportional to the cluster thinning intensity due to a significant increase of berry and clus-

Table 2 - Effects of cluster thinning on yield and cluster characteristics in Sangiovese, Merlot and Cabernet Sauvignon grapevine cultivars

Cultivar	Thinning	Yield (kg/vine)			Cluster/vine (n°)			Cluster weight (g)			Berry weight (g)		
		1995	1996	1997	1995	1996	1997	1995	1996	1997	1995	1996	1997
Sangiovese	0%	12.4	11.3	10.1	40.6	46.4	39.9	306	245	251	2.30	2.36	2.33
	20%	11.8	9.5	10.0	35.1	34.3	32.9	340	271	300	2.47	2.60	2.68
	40%	9.5	6.9	9.5	25.2	22.6	24.3	381	308	387	2.70	2.82	3.38
Significance		**	***	NS	**	***	**	***	***	***	***	***	***
r^2		0.76	0.92	---	0.76	0.94	0.75	0.90	0.89	0.92	0.87	0.94	0.96
Merlot	0%	8.1	8.7	8.7	57.8	64.1	60.5	147	137	149	1.70	1.82	2.03
	20%	7.7	8.0	8.2	49.5	52.1	50.5	159	154	160	1.76	1.83	2.12
	40%	6.1	6.6	7.9	35.4	38.8	37.5	172	170	212	1.92	1.94	2.53
Significance		*	***	NS	***	***	***	***	***	***	***	*	**
r^2		0.47	0.87	---	0.84	0.91	0.83	0.89	0.91	0.84	0.85	0.46	0.73
Cabernet S.	0%	7.2	7.9	6.2	56.1	58.9	51.6	131	135	123	1.35	1.94	1.39
	20%	7.4	7.0	6.1	44.2	47.6	42.2	167	146	146	1.60	2.02	1.57
	40%	5.6	4.2	6.0	32.2	27.9	30.5	176	154	198	1.70	2.06	1.89
Significance		*	***	NS	***	***	***	***	***	***	**	**	***
r^2		0.42	0.84	---	0.90	0.93	0.92	0.85	0.87	0.84	0.72	0.70	0.84

*,**,***, NS= linear component significant at $P \le 0.05, 0.01, 0.001$, or not significant, respectively.

ter weight. At the 20% intensity of cluster thinning, vine self-regulation warranted full yield compensation through significantly increased berry size and cluster weight. In 1997, due to quite favourable environmental conditions for ripening, +156 and +143 degree-days, base 10°C, as compared to 1995 and 1996, respectively, and lower rainfall during the two months prior to harvest, the impact of the 40% cluster thinning on vine yield was negligible.

Total soluble solids, anthocyanins and phenolics increased linearly with thinning severity in two out of the three seasons (Tables 3 and 4). Juice pH and titratable acidity (TA) were rather variable, although cluster thinning tended to reduce TA and increase pH (Table 3). In 1995 and 1996, improvements in soluble solids content in cluster-thinned vines were consistent with lower yield levels (Table 3) whereas the reduction of titratable acidity and the slight increase of juice pH were probably attributable to an earlier ripening. Similar results have also been reported by Looney (1981), Bravdo *et al.* (1984 a) and Reynolds (1989).

Table 3 - Effects of cluster thinning on soluble solids, titratable acidity and pH at harvest in Sangiovese, Merlot and Cabernet Sauvignon grapevine cultivars

Cultivar	Thinning	Soluble solids (°Brix)			Titratable acidity (g/l)			Juice pH		
		1995	1996	1997	1995	1996	1997	1995	1996	1997
Sangiovese	0%	17.3	17.1	21.4	8.5	8.2	6.3	3.01	3.08	3.26
	20%	18.0	18.9	21.8	8.8	7.5	6.1	3.04	3.11	3.22
	40%	18.4	21.1	22.0	8.0	7.2	5.9	3.04	3.12	3.21
Significance		*	***	NS	NS	**	NS	NS	NS	NS
r^2		0.54	0.94	---	---	0.71	---	---	---	---
Merlot	0%	20.6	21.0	21.4	9.7	6.8	6.5	3.13	3.29	3.32
	20%	21.4	21.2	22.8	9.5	6.7	6.3	3.15	3.27	3.28
	40%	22.6	22.8	22.6	8.8	6.5	6.4	3.18	3.44	3.36
Significance		**	**	NS	**	NS	NS	***	NS	NS
r^2		0.79	0.67	---	0.64	---	---	0.85	---	---
Cabernet S.	0%	20.2	21.0	21.6	9.7	8.0	7.6	3.05	3.21	3.22
	20%	20.0	21.4	22.2	9.5	7.9	7.1	3.09	3.19	3.23
	40%	22.0	23.2	22.0	8.8	7.5	7.2	3.13	3.25	3.27
Significance		*	**	NS	*	NS	NS	*	NS	NS
r^2		0.55	0.74	---	0.55	---	---	0.46	---	---

*,**,***, NS= linear component significant at $P \leq 0.05, 0.01, 0.001$, or not significant, respectively.

Table 4 - Effects of cluster thinning on anthocyanins, polyphenols and total nitrogen content at harvest in Sangiovese, Merlot and Cabernet S. grapevine cultivars

Cultivar	Thinning	Anthocyanins (mg/cm^2 berry skin)			Polyphenols (mg/cm^2 berry skin)			Total nitrogen (% s.s.)	
		1995	1996	1997	1995	1996	1997	1996	1997
Sangiovese	0%	0.412	0.453	0.602	1.42	1.95	1.34	0.35	0.56
	20%	0.580	0.596	0.652	1.89	2.37	1.84	0.56	0.56
	40%	0.610	0.692	0.639	1.94	2.42	1.87	0.49	0.70
Significance		***	***	NS	**	*	NS	NS	**
r^2		0.83	0.96	---	0.80	0.57	---	---	0.65
Merlot	0%	0.491	0.487	0.576	1.51	1.63	1.24	0.42	0.49
	20%	0.571	0.554	0.641	1.73	2.00	1.46	0.63	0.49
	40%	0.824	0.742	0.653	2.10	2.37	1.56	0.49	0.53
Significance		***	***	*	**	**	NS	NS	NS
r^2		0.90	0.91	0.49	0.68	0.77	---	---	---
Cabernet S.	0%	0.652	0.786	0.691	1.80	1.91	2.08	0.38	0.29
	20%	0.670	0.772	1.021	2.10	2.60	2.52	0.70	0.42
	40%	1.024	0.942	1.073	2.70	2.84	2.55	0.56	0.56
Significance		**	*	***	***	**	NS	NS	***
r^2		0.78	0.62	0.83	0.81	0.79	---	---	0.95

*,**,***, NS= linear component significant at $P \leq 0.05, 0.01, 0.001$, or not significant, respectively.

Data pooled from cultivars and years resulted in negative correlations between total soluble solids and yield level, while positive linear relationships were found between anthocyanins in berry skin and soluble solids in berry juice (Fig. 4). Overall, regulation of yield through cluster thinning is strictly dependent on year; the grape composition is generally improved and this assumes particular importance in seasons marked by unfavourable environmental conditions or in very productive vineyards due to either high fertility cultivars (i.e. Sangiovese) or soils. The increase of polyphenols and anthocyanin content recorded in both 20% and 40% cluster-thinned vines is of great significance for the production of high quality red wine, especially when targeted to aging. Since manual cluster thinning is a very expensive operation due to large labour requirements, its mechanization is a very needed, yet largely unresolved issue. In Grenache and Tempranillo grapevines trained to vertical, shoot-positioned mechanical berry thinning performed with a grape harvester was effective to reduce yield while achieving more ripened grapes and wines with higher alcohol and pH values, more intense colour and increased phenolic compounds (Diago *et al.,* 2010 b).

4. Shoot hedging

Practices aimed at manipulating vegetative growth during late-spring and summer, particularly in vigorous vineyards, can substantially influence yield and grape composition (Intrieri *et al*., 1983; Kliewer and Bledsoe, 1987; Reynolds and Wardle, 1989). Hedging is a common management practice used to maintain canopy shape, reduce vine vigour, improve the microclimate in the fruiting zone, increase the efficiency of disease treatments and facilitate harvest and access of machines to the vineyard rows. Compared with other summer management practices used for similar purposes, such as leaf removal and pulling of lateral shoots, hedging is commonly used because it can

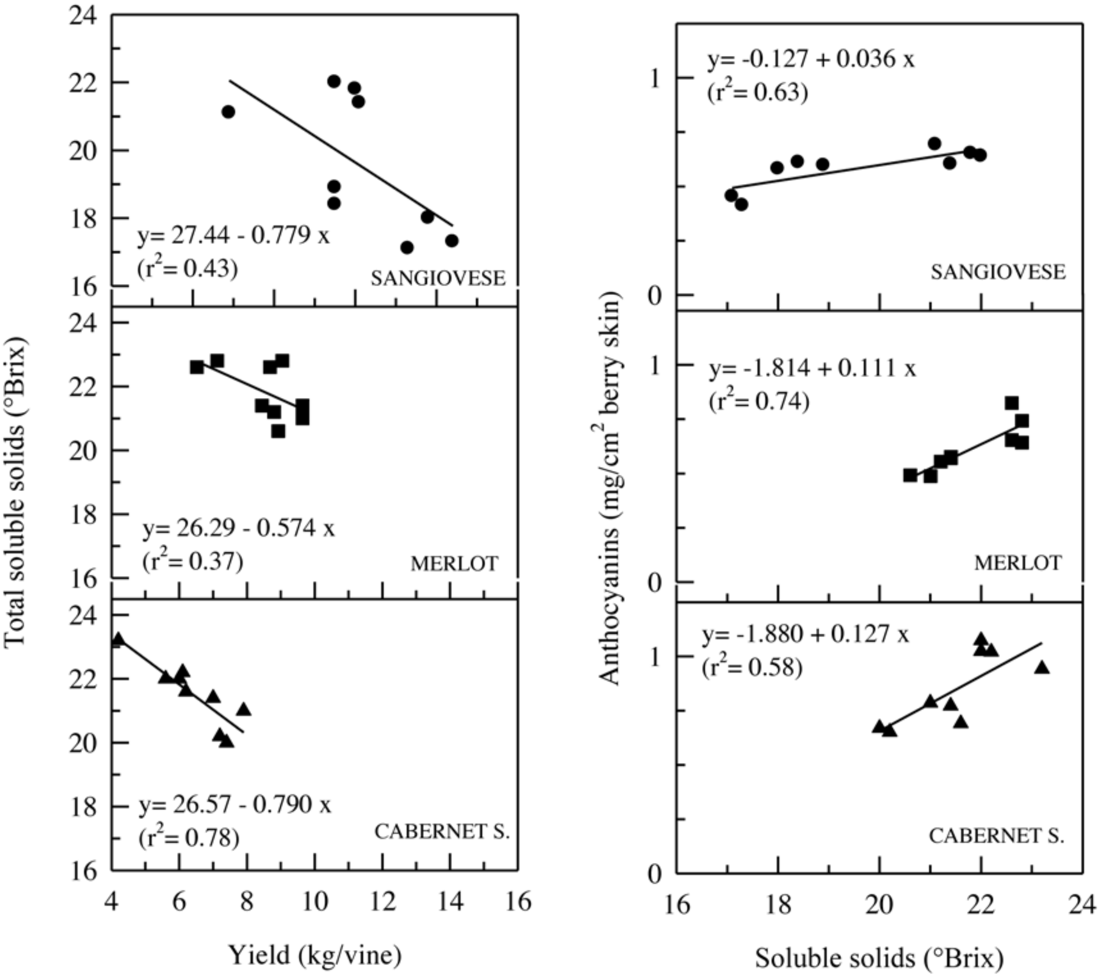

Fig. 4 - Relationship between yield per vine and total soluble solids (left) and total soluble solids and anthocyanins content in the berry skin at harvest (right).

be done completely mechanically and therefore is easy, fast and cheap. The effects of hedging on yield and fruit quality, considering the variables of timing and severity of application, are strictly associated to the ability of the cultivar to develop lateral shoots and their photosynthetic capacity from veraison to harvest (Cartechini *et al.,* 1998).

The impact of hedging severity on vine performance is well known; severe hedging, i.e. less than six main leaves retained per shoot, generally reduces grape quality (Kliewer and Bledsoe, 1987; Reynolds and Wardle, 1989; Palliotti, 1992), whereas the time of application is rather controversial because other factors may also influence these effects such as bud load, shoot orientation, training system, environmental conditions, soil characteristics, water availability, and so on (Intrieri *et al*., 1983; Reynolds and Wardle, 1989).

Vertical shoot positioned (VSP) training systems are normally trimmed when their shoots exceed the wires placed at the top of the canopy. Therefore, the timing is poorly dependent on grower's decisions and it is instead a function of intrinsic shoot vigour and vine balance. A balanced vineyard would reach the height suitable for trimming around fruit set, whereas an excessively vigorous one would get to the same growth stage much earlier, therefore making shoot trimming more likely to be repeated again later in the season. Timing of trimming follows different rules when performed on sprawl canopies (i.e. a single high wire trellis) where an early (pre-flowering) shoot trimming might be made necessary by the need to induce mostly upright shoot growth habits.

A two-year trial, aimed at assessing the effect of timing of hedging (one and five weeks after full bloom, AFB) on yield and grape composition in different red and white grapevine cultivars grown on fertile clay soil and trained to a single high wire trellis, showed that hedging at the 9-10th node on primary shoots, carried out one week AFB, markedly changed canopy characteristics, yield and grape composition (Fig. 5 and Tables 5, 6, 7 and 8) (Cartechini *et al.,* 1998). In untrimmed Sangiovese, Cabernet Sauvignon and Verdello vines, leaf area build up progressed rapidly from about 30 to 120 days after bud burst (Fig. 5). The development of laterals and relative leaf area occurred from 60 to 110 days after bud burst in Sangiovese and from 60 to 140 days after bud burst in Cabernet Sauvignon and Verdello.

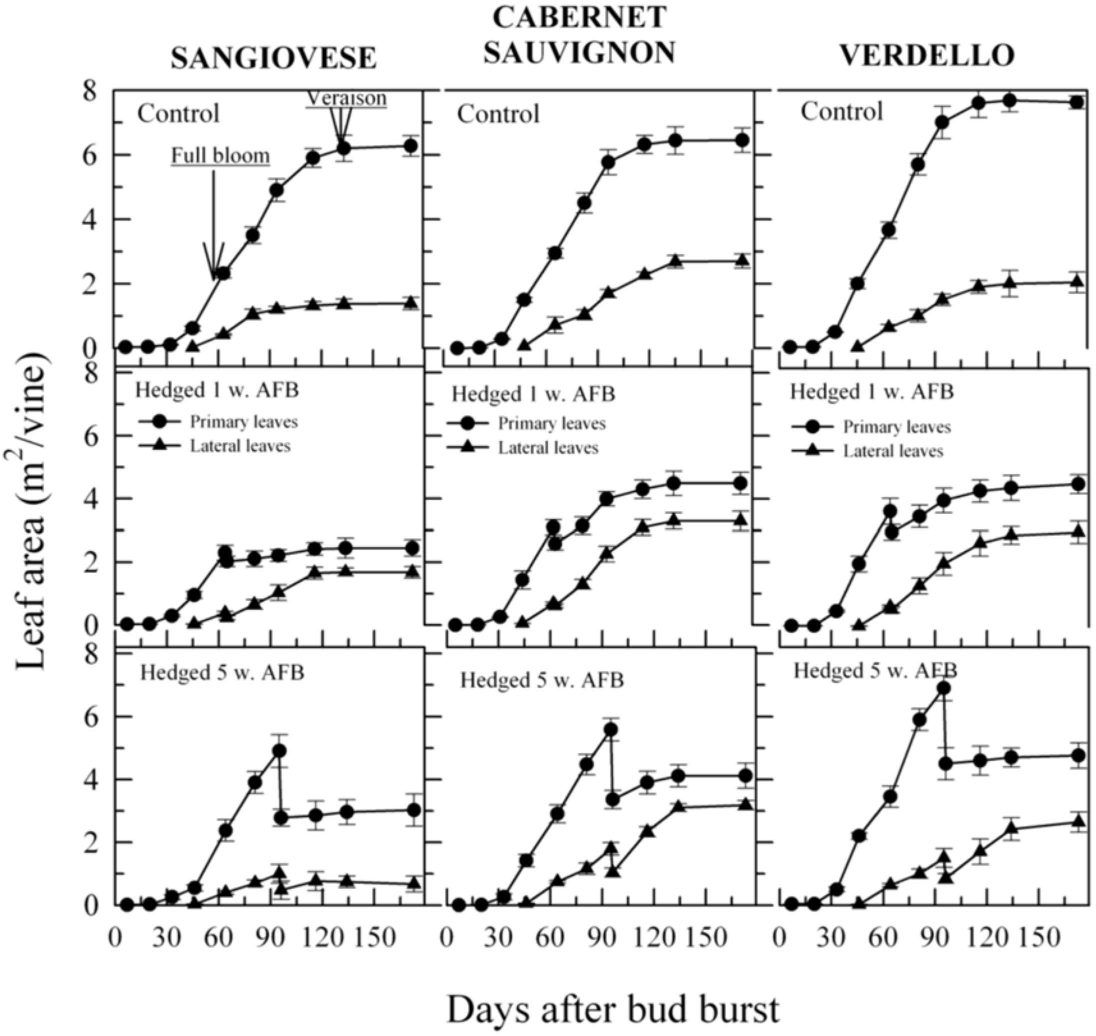

Fig. 5 - Development of primary and lateral leaves in Sangiovese, Cabernet Sauvignon and Verdello grapevine cultivars hedged one and five weeks after full bloom (AFB) as compared to the untrimmed control (n = 3 ± SE).

In all the cultivars, from flowering to veraison, the total leaf area increased more than three-fold. At the end of canopy growth, the Sangiovese had less total leaf area than Cabernet Sauvignon and Verdello (-1.5 and -2.0 m^2/vine, respectively) and the laterals represented 18, 32 and 22% of the total leaf area in Sangiovese, Cabernet Sauvignon and Verdello, respectively. Up to the end of canopy growth, Sangiovese, Cabernet Sauvignon and Verdello hedging one and five weeks AFB produced about 1.1, 3.9 and 3.5 and 0.9, 3.4 and 3.1 m^2 of new leaves per vine, respectively, derived mainly from lateral development.

In all cultivars, early-hedging, one week AFB, generally increased the contents of soluble solids, total nitrogen and total polyphenols (Tables 6, 7 and 8) as well as anthocyanins content in the red cultivars (Table 8). Early-hedging significantly reduced the titratable acidity and juice pH in all the cultivars (Table 6 and 7). Late-hedging, five weeks AFB, instead significantly reduced yield in Sangiovese and, except for Sauvignon blanc, the soluble solid content was significantly reduced as well as anthocyanins content in both red cultivars.

The positive outcomes of the early-hedging were likely dependent upon a cultivar's ability to develop lateral shoots after trimming (Fig. 5). All the cultivars with a good capacity to produce laterals, such as Cabernet Sauvignon, Verdello, Drupeggio and Sauvignon blanc, responded better to early summer pruning as shown by the increased cluster weight and yield and improved contents of soluble solids, total polyphenols and nitrogen content. Trimming vines increased lateral growth and

Table 5 - Yield and average cluster weight at harvest in vines of different grapevine cultivars hedged one and five weeks after full bloom (AFB) and control (n= 60)

Cultivar	Yield (kg/vine)			Cluster weight (g)		
	Control	Hedged 1 week AFB	Hedged 5 weeks AFB	Control	Hedged 1 week AFB	Hedged 5 weeks AFB
Sangiovese	7.4 b	7.3 b	6.0 a	279.8 b	292.4 b	253.5 a
Cabernet S.	6.0 a	7.8 b	5.5 a	122.9 a	143.7 b	110.5 a
Verdello	7.0 a	8.2 b	6.9 a	215.6 a	276.6 b	218.7 a
Drupeggio	7.4 a	9.1 b	7.2 a	238.7 a	275.7 b	235.4 a
Sauvignon b.	4.0 a	5.2 b	3.9 a	106.5 a	129.3 b	103.8 a

For each grapevine cultivar, the means followed by different letters are significantly different at $P \leq 0.05$.

Table 6 - Soluble solids content and titratable acidity at harvest in different grapevine cultivars hedged one and five weeks after full bloom (AFB) and control

Cultivar	Soluble solids (°Brix)			Titratable acidity (g/l)		
	Control	Hedged 1 week AFB	Hedged 5 weeks AFB	Control	Hedged 1 week AFB	Hedged 5 weeks AFB
Sangiovese	23.2 b	23.9 b	21.8 a	6.6 b	6.1 a	6.8 b
Cabernet S.	23.4 b	23.7 b	22.9 a	7.1 b	6.6 a	7.3 b
Verdello	19.4 b	21.0 c	17.8 a	8.5 b	8.0 a	8.6 b
Drupeggio	20.3 b	21.9 c	18.1 a	8.4 b	7.8 a	8.3 b
Sauvignon b.	20.5 a	23.1 b	20.4 a	8.8 b	8.2 a	9.0 b

For each grapevine cultivar, the means followed by different letters are significantly different at $P \leq 0.05$.

Table 7 - Juice pH and berry nitrogen content at harvest in vines of different grapevine cultivars hedged one and five weeks after full bloom (AFB) and control

Cultivar	Juice pH			Total nitrogen (% d.w.)		
	Control	Hedged 1 week AFB	Hedged 5 weeks AFB	Control	Hedged 1 week AFB	Hedged 5 weeks AFB
Sangiovese	3.42 b	3.35 a	3.36 a	0.48 a	0.63 b	0.45 a
Cabernet S.	3.40 b	3.22 a	3.29 a	0.63 a	0.98 b	0.55 a
Verdello	3.06 b	3.00 a	2.99 a	0.42 a	0.59 b	0.41 a
Drupeggio	3.08 b	3.03 a	3.04 a	0.44 a	0.68 b	0.38 a
Sauvignon b.	3.07 b	3.01 a	3.02 a	0.51 a	0.66 b	0.45 a

For each grapevine cultivar, the means followed by different letters are significantly different at $P \leq 0.05$.

Table 8 - Anthocyanins and total polyphenol content at harvest in the berry skin of different grapevine cultivars hedged one and five weeks after full bloom (AFB) and control

Cultivar	Anthocyanins (mg/cm^2 berry skin)			Polyphenols (mg/cm^2 berry skin)		
	Control	Hedged 1 week AFB	Hedged 5 weeks AFB	Control	Hedged 1 week AFB	Hedged 5 weeks AFB
Sangiovese	0.754 b	0.958 c	0.412 a	1.65 b	2.24 c	1.09 a
Cabernet S.	1.095 b	0.998 b	0.773 a	2.07 a	2.96 b	1.90 a
Verdello	---	---	---	0.88 a	1.25 b	0.80 a
Drupeggio	---	---	---	0.91 a	1.19 b	0.81 a
Sauvignon b.	---	---	---	0.82 a	1.12 b	0.75 a

For each grapevine cultivar, the means followed by different letters are significantly different at $P \leq 0.05$.

the total final leaf area was always less than that recorded in control vines (from 15 to 49% less). At harvest, in all the grapevines tested, early-hedging reduced the leaf/fruit ratio from 33 to 45% in comparison to the control vines and improved the soluble solids content (from 0.3 to 1.6°Brix), whereas late-hedging caused a reduction of both leaf/fruit ratio and soluble solid accumulation in the berries (Fig. 6). The rejuvenation of leaf area in the canopy following early-hedging and their high photosynthetic efficiency from veraison to harvest of the newly formed lateral leaves (Fig. 7) likely reduced the leaf area per gram of fruit required to achieve adequate ripeness. These laterals also translocate assimilates to the subtending clusters very efficiently (Candolfi-Vasconcelos and Koblet, 1990). Negative results found on late-hedged vines, also reported by other authors (Intrieri *et al.*, 1983; Palliotti, 1992), are probably linked to the fact that lateral shoots compete with the developing grapes for carbohydrates, causing delayed berry growth and sugar accumulation.

Early-trimming reduced titratable acidity as compared to control vines due to greater cluster exposure to sunlight

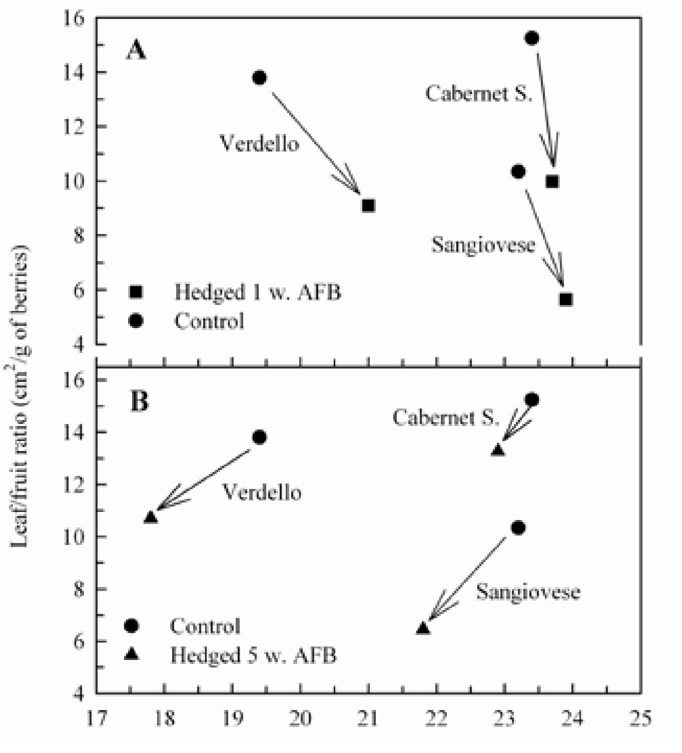

Fig. 6 - Relationship between must total soluble solids and leaf/fruit ratio at harvest in vines of Sangiovese, Cabernet Sauvignon and Verdello either untrimmed or trimmed one (A) and five (B) weeks after full bloom (AFB).

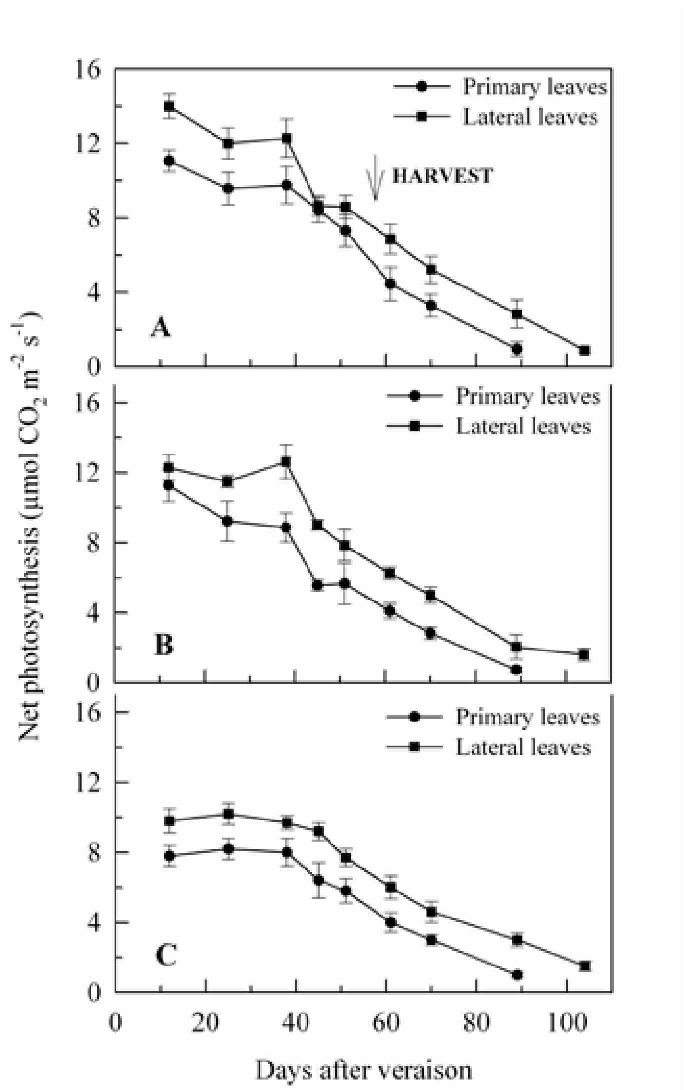

Fig. 7 - Evolution of net photosynthesis of primary and lateral leaves from veraison to leaf fall in Sangiovese, Cabernet Sauvignon and Verdello grapevine cultivars (n = 8 ±SE).

and a consequent decrease of malic acid content due to respiration activity. In addition, the reduced must pH with early-hedging is probably linked to the reduction of both the malic acid and potassium contents in the must in association with lower total leaf area. Bledsoe *et al.* (1988) found a significant positive correlation between these two parameters and juice pH.

In all the grapevine cultivars that develop many laterals after hedging, the greater transpiration rate (from +15 to 35%, data not shown) assessed in these leaves, compared with primary ones, particularly in August and September, may aggravate susceptibility to vine water stress especially in hot environments and in particularly dry years. During the first two weeks of November, the laterals on the vines had net photosynthesis values that ranged from 0.7 to 1.6 μmol CO_2 m^{-2} s^{-1} (Fig. 6), in a period when all the carbohydrates fixed are very useful for the reserve accumulation, and therefore for increased cold hardiness (Wample and Bary, 1992) and even for budbreak and initial shoot growth the following season. Thus, at the end of the season care must be taken to maintain the integrity of these leaves until total abscission occurs. Early winter pruning, practiced in some viticulture areas, should be avoided.

5. Shoot positioning

In VSP canopy trellis systems, shoot positioning is performed to maintain canopy form and shoot separation, to create a uniform distribution of leaves that minimizes cluster shading as well as to optimize canopy light interception and allowing the transit of mechanical equipment between rows. Shoot positioning also exerts a positive effect on disease incidence and severity; usually disease pressure is lessened due to increased air flow and sunlight penetration inside the vine canopy. Another important effect of this canopy management technique is that it has a positive impact on the development of fruitful buds and therefore for the vine yield in the following year.

The way shoot positioning is performed depends mainly on the training systems. In a VSP system the process consists of directing the shoots growing up between a set of catch wires as they develop. The vertically positioning of shoots can be done manually or using movable wires and done several times during the growing season. Mechanical shoot positioning on VSP trellis systems with specialized equipment has undergone a notable increase in recent years.

On Geneva Double Curtain (GDC) training system the shoots are positioned downward and separated out from the permanent cordon in order to reduce the vigour of shoots and attain optimal canopy density. In the GDC trellis, shoot positioning is performed on the interior part of the canopy to maintain two distinct canopies avoiding excessive shading in the central part of the canopy. Usually, in most training systems, shoot positioning is performed one or two weeks after bloom, before tendrils have become firmly attached. For best results, however, two or three shoot positioning runs during the season are needed.

6. Conclusions

Vineyard management should aim to achieve and maintain high efficiency over time, which is closely dependent on the ability to control the competition both between-and intra-vine. This approach would warrant a fair and fruitful balance between vegetative and productive activity of the vines and the best expression of grape quality (Smart and Robinson, 1991) without costly additional inputs. Since the "perfect" vineyard able to reach and maintain this equilibrium in a natural way during the season is generally utopia, summer pruning often plays a crucial role.

In light of the climate change in progress, an important challenge for old and new vineyards will be the matching of tradition and innovation. This raises the question of new techniques of canopy management, availability of rootstocks of low-to-moderate vigour, new cultivars better adapted to higher temperatures and water shortage and more intense mechanization. The latter assumes particular importance especially when the wines produced must be sold in un-bottled form or within large organized distribution (LOD) chains, like supermarkets, hypermarkets and discount markets. Currently, at least in Italy, LOD commercialize about 70% of the entire Italian wine production (which corresponds to about 48-50 million hl per year) (ISMEA, 2007), where the binomial "adequate quality"-"moderate selling price" is still dominant.

Global warming requires rapid adaptation and poses the crucial question of ripening modulation. In white grape varieties, the major challenge is the preservation of organic acids and primary grape flavours; whereas in black-berried cultivars the priority is producing wines with moderate alcohol content without modifying colour intensity and wine sensory. Some traditional and innovative canopy management practices can help to achieve these results, such as light pruning (Petrie *et al.,* 2003), early leaf removal (Poni *et al.,* 2006; Palliotti *et al.,* 2011 b), late defoliation and severe summer pruning (Stoll *et al.,* 2010), use of anti-transpirants (Palliotti *et al.,* 2010, 2011 a), canopy treatment of exogenous auxins (Böttcher *et al.,* 2010) and brassinosteroid and brassinazole steroidal hormones (Symons *et al.,* 2006). However, such lines of research will require more data inputs to better clarify the causes responsible for variability in vine yield, grape composition and wine quality according to seasons and grapevine varieties and to develop the best operative strategy for crop regulation.

References

BLEDSOE A.M., KLIEWER W.M., MAROIS J.J., 1988 - *Effects of timing and severity of leaf removal on yield and fruit composition of Sauvignon blanc grapevines*. - Am. J. Enol. Vitic., 39: 49-54.

BÖTTCHER C., HARVEY K., FORDE C.G., BOSS P.K., DAVIES C., 2010 - *Auxin treatment of pre-veraison grape (*Vitis vinifera *L.) berries both delays ripening and increase the synchronicity of sugar accumulation*. - Aust. J. Grape Wine Res., 17: 1-8.

BRAVDO B., HEPNER Y., LOINGER C., COHEN S., TABACMAN H., 1984 a - *Effect of crop level on growth, yield and wine quality of a high yielding Carignane vineyard*. - Am. J. Enol. Vitic., 35: 247-252.

BRAVDO B., HEPNER Y., LOINGER C., COHEN S., TABACMAN H., 1984 b - *Effect of crop level and crop load on growth, yield, must and wine composition, and quality of Cabernet Sauvignon*. - Am. J. Enol. Vitic., 36: 125-131.

CANDOLFI-VASCONCELOS M.C., KOBLET W., 1990 - *Yield, fruit quality, bud fertility and starch reserves of the wood as a function of leaf removal in* Vitis vinifera. *Evidence of compensation and stress recovering*. - Vitis, 29: 199-221.

CARTECHINI A., PALLIOTTI A., LUNGAROTTI C., 1998 - *Influence of timing of summer hedging on yield and grape quality in some red and white grapevine cultivars*. - Acta Horticulturae, 512: 101-110.

COOMBE B.G., 1959 - *Fruit-set development in seeded grape varieties as affected by defoliation, topping, girdling, and other treatments*. - Am. J. Enol. Vitic., 10: 85-100.

DIAGO M.P., VILANOVA M., BLANCO J.A., TARDAGUILA J., 2010 b - *Effects of mechanical thinning on fruit and wine composition and sensory attributes of Grenache and Tempranillo varieties (*Vitis vinifera *L.)*. - Austr. J. Grape Wine Res., 16: 314-326.

DIAGO M.P., VILANOVA M., TARDAGUILA J., 2010 a - *Effects of timing of early defoliation (manual and mechanical) on the aroma attributes of Tempranillo (*Vitis vinifera *L.) wines*. - Am. J. Enol. Vitic., 61: 382-391.

DOKOOZLIAN N., 2009 - *Integrated canopy management: a twenty year evolution in California*. - Proceedings Recent Advances in Grapevine Canopy Management, July 16, Davis, California, USA, pp. 43-52.

DUCHÊNE E., SCHNEIDER C., 2005 - *Grapevine and climatic changes: a glance at the situation in Alsace*. - Agron. Sustain. Dev., 25(1): 93-99.

GODDEN P., GISHEN M., 2005 - *Trends in the composition of Australian wine*. - The Australian and New Zealand Wine Industry Journal, 20(5): 21-46.

GREER D.H., ROGIERS S.Y., STEEL C.C., 2006 - *Susceptibility of Chardonnay grapes to sunburn*. - Vitis, 45: 147-148.

GUBLER W.D., BETTIGA L.J., HEIL D., 1991 - *Comparisons of hand and machine leaf removal for the control of Botrytis bunch rot*. - Am. J. Enol. Vitic., 42: 233-236.

GUIDONI S., ALLARA P., SCHUBERT A., 2002 - *Effect of bunch thinning on berry skin antocyanin composition of* Vitis vinifera *cv. Nebbiolo*. - Am. J. Enol. Vitic., 53: 224-226.

HUNTER J.J., RUFFNER H.P., VOLSCHENK C.G., LE ROUX D.J., 1995 - *Partial defoliation* of Vitis vinifera *L. cv. Cabernet Sauvignon/99 Richter (1995). Effect on root growth, canopy efficiency, grape composition, and wine quality*. - Am. J. Enol. Vitic., 46: 306-314.

INTRIERI C., FILIPPETTI I., ALLEGRO G., CENTINARI M., PONI S., 2008 - *Early defoliation (hand versus mechanical) for improved crop control and grape composition in Sangiovese (*Vitis vinifera *L.)*. - Austr. J. Grape and Wine Res., 14: 25-32.

INTRIERI C., MAGNANINI E., SILVESTRONI O., 1983 - *Effetti della potatura verde sul comportamento vegetativo e produttivo di Albana e Sangiovese*. - Vignevini, 5: 57-62.

INTRIERI C., PONI S., 1995 - *Integrated evolution of trellis training systems and machines to improve grape quality and vintage quality of mechanized Italian vineyards*. - Am. J. Enol. Vitic., 46: 116-127.

JONES G.V., WHITE M.A., COOPER O.R., STORCHMANN K., 2005 - *Climate change and global wine quality*. - Climatic Change, 73: 319-343.

KELLER M., MILLS L.J., WAMPLE R.L., SPAYD S.E., 2005 - *Cluster thinning effects on three deficit-irrigated* Vitis vinifera *cultivars*. - Am. J. Enol. Vitic., 56: 91-103.

KLIEWER W.M., 1970 - *Effect of time and severity of defoliation on growth and composition of 'Thompson Seedless' grapes*. - Am. J. Enol. Vitic., 21: 37-47.

KLIEWER W.M., BLEDSOE A., 1987 - *Influence of hedging and leaf removal on canopy miroclimate, grape composition, and wine quality under California conditions*. - Acta Horticulturae, 206: 157-168.

LOONEY N.E., 1981 - *Some growth regulator and cluster thinning effects on berry set and size, berry quality, and productivity of De Chaunac grapes*. - Vitis, 20: 22-35.

MAY P., SHAULIS N.J., ANTCLIFF A.J., 1969 - *The effect of controlled defoliation in the Sultana vines*. - Am. J. Enol. Vitic., 20: 237-250.

MESCALCHIN E., BOTTURA M., CAINELLI R., FELLIN F., GOBBER M., LUCIN R., MARGONI M., MATTEDI F., MICHELOTTI F., PATTON A., PENNER F., RIBOLLI F., 2008 - *Sfogliare precocemente la vite per evitare scottature e Botrite*. - L'Informatore Agrario, 17: 39-45.

OUGH C.S., NAGAOKA R., 1984 - *Effect of cluster thinning and vineyard yields on grape and wine composition and wine quality of Cabernet Sauvignon*. - Am. J. Enol. Vitic., 35: 30-34.

PALLIOTTI A., 1992 - *Energia radiante, produttività delle foglie e fotosintesi in* Vitis vinifera *L*. - Doctoral Thesis, Istituto di Coltivazioni Arboree, University of Perugia, Italy.

PALLIOTTI A., CARTECHINI A., 1998 - *Cluster thinning effects on yield and grape composition in different grapevine cultivars*. - Acta Horticulturae, 512: 111-119.

PALLIOTTI A., GATTI M., PONI S., 2011 b - *Early leaf removal to improve vineyard efficiency: Gas exchange, source-to-sink balance, and reserve storage responses*. - Am. J. Enol. Vitic., 62: 219-228.

PALLIOTTI A., PONI S., BERRIOS J.G., BERNIZZONI F., 2010 - *Vine performance and grape composition as affected by early-source limitation induced with anti-transpirants in two red* Vitis vinifera *L. cultivars*. - Aust. J. Grape Wine Res., 16: 426-433.

PALLIOTTI A., SILVESTRONI O., PONI S., 2011 a - *Controllo degli zuccheri nell'uva con il pinolene*. - L'Informatore Agrario, Suppl. n. 13, pp. 29-32.

PERCIVAL D.C., FISHER K.H., SULLIVAN J.A., 1994 - *Use of fruit zone leaf removal with* Vitis vinifera *L. cv. Riesling grapevines. I. Effects on canopy structure, microclimate, bud survival, shoot density, and vine vigor*. - Am. J. Enol. Vitic., 45: 123-132.

PETRIE P.R., TROUGHT M.C.T., HOWELL G.S., BUCHAN G.D., 2003 - *The effect of leaf removal and canopy height on whole-vine gas exchange and fruit development of* Vitis vinifera *L. Sauvignon blanc*. - Func. Plant Biol., 30: 711-717.

PONI S., BERNIZZONI F., 2010 - *A three-year survey on the impact of pre-flowering leaf removal on berry growth components and grape composition in cv. Barbera vines*. - J. Intern. Sci. Vigne et du Vin, 44: 21-30.

PONI S., BERNIZZONI F., CIVARDI S., 2008 - *The effect of early leaf removal on whole-canopy gas exchange and vine performance of* Vitis vinifera *L. cv. Sangiovese*. - Vitis, 47: 1-6.

PONI S., CASALINI L., BERNIZZONI F., CIVARDI S., INTRIERI C., 2006 - *Effects of early defoliation on shoot photosynthesis, yield components, and grape quality*. - Am. J. Enol. Vitic., 57: 397-407.

PONI S., INTRIERI C., SILVESTRONI O., 1994 - *Interactions of leaf age, fruiting and exogenous cytokinins in Sangiovese grapevines under non-irrigated conditions. I. Gas exchange*. - Am. J. Enol. Vitic., 45: 71-78.

QUINLAN J.D., WEAVER J.R., 1970 - *Modification of pattern of the photosynthate movement within and between shoots of* Vitis vinifera *L*. - Plant Physiol., 46: 527-530.

REYNOLDS A.G., 1989 - *Impact of pruning strategy, cluster thinning, and shoot removal on growth, yield, and fruit composition of low-vigor De Chaunac vines*. - Can. J. Plant Sci., 69: 269-275.

REYNOLDS A.G., WARDLE D.A., 1989 - *Effects of timing and severity of summer hedging on growth, yield, fruit composition, and canopy characteristics of de Chaunac. II. Yield and fruit composition*. - Am. J. Enol. Vitic., 40: 299-308.

REYNOLDS A.G., WARDLE D.A., NAYLOR A.P., 1996 - *Impact of training system, vine spacing, and basal leaf removal on Riesling. Vine performance, berry composition, canopy microclimate, and vineyard labor requirements*. - Am. J. Enol. Vitic., 47: 63-76.

SCHEINER J.J., SACKS G.L., PAN B., ENNAHLI S., TARLTON L., WISE A., LERCH S.D.,VAN DEN HEUVEL J.E., 2010 - *Impact of severity and timing of basal leaf removal on 3-isobutyl-2-methoxypyrazine concentrations in red winegrapes*. - Am. J. Enol. Vitic., 61: 358-364.

SCHULTZ H.R., 2000 - *Climate changes in viticulture: a European perspective on climatology, carbon dioxide and UV effects*. - Austr. J. Grape Wine Res., 6: 2-12.

SMART R.E., 1973 - *Sunlight interception by vineyards*. - Am. J. Vitic. Enol., 24: 141-147.

SMART R.E., 1985 - *Principles of grapevine canopy microclimate manipulation with implications for yield and quality. A review*. - Am. J. Enol. Vitic., 36: 230-239.

SMART R.E., ROBINSON M., 1991 - *Sunlight into Wine. A handbook for wine Grape Canopy Management*. - Wine Canopies & their Importance: 1-2; Quality Assurance in Vineyards. Winetitles, Adelaide, Australia, pp. 88.

SMITH S.I., CODRINGTON C., ROBERTSON M., SMART R.E., 1988 - *Viticultural and oenological implications of leaf removal for New Zealand vineyards*, pp. 127-133. - In: SMART R.E., R.J. THORNTON, S.B. RODRIGUEZ., and J.E. YOUNG (eds.) *Proceedings of the second international symposium for cool climate viticulture and oenology*. New Zealand Soc. for Viticulture and Oenology, Auckland, New Zealand, pp. 365.

SPAYD S.E., TARARA J.M., MEE D.L., FERGUSON J.C., 2002 - *Separation of sunlight and temperature effects on the composition of* Vitis vinifera *cv. Merlot berries*. - Am. J. Enol. Vitic., 53: 171-182.

SRINIVASAN C., MULLINS M.G., 1981 - *Physiology of flowering in the grapevine - A review*. - Am. J. Enol. Vitic., 32: 47:63.

STOLL M., LAFONTAINE M., SCHULTZ H.R., 2010 - *Possibilities of reduce the velocity of berry maturation through various leaf area to fruit ratio modifications in* Vitis Vinifera *L. Riesling*. - Le Progrès Agricole et Viticole, 127: 68-71.

SYMONS G.M., DAVIES C., SHAVRUKOV Y., DRY I.B., REID J.B., THOMAS M.R., 2006 - *Grapes on steroids, Brassinosteroids are involved in grape berry ripening*. - Plant Physiol., 140: 150-158.

TARARA J.M., JUNGMIN L., SPAYD S.E., SCAGEL C.F., 2008 - *Berry temperature and solar radiation alter acylation, proportion, and concentration of anthocyanin in Merlot grapes*. - Am. J. Enol. Vitic., 59: 235-247.

TARARA J.M., SPAYD S.D., 2005 - *Tackling sunburn in red wine grapes through temperature and sunlight exposure*. - The Good Fruit Grower, 56: 40-41.

VIERRA G., 2004 - *Pretenders at the Table - Are table wines no longer food friendly?* - Wine Business Monthly, 11(7).

WAMPLE R.L., BARY A., 1992 - *Harvest date as a factor in carbohydrate storage and cold hardiness of Cabernet Sauvignon grapevines*. - J. Amer. Soc. Hort. Sci., 117: 32-36.

WINKLER A.J., COOK J.A., KLIEWER W.M., LIDER L.A., 1974 - *General Viticulture*. - Univ. Calif. Press. Berkeley, USA.

ZOECKLEIN P.W., WOLF T.K., DUNCAN N.W., JUDGE J.M., COOKE M.K., 1992 - *Effects of fruit zone leaf removal on yield, fruit composition and fruit rot incidence of Chardonnay and White Riesling (*Vitis vinifera *L.) grapes*. - Am. J. Enol. Vitic., 43: 139-148.

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Summer pruning effect on tree growth and fruit production of persimmon

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Key words: pinching, secondary shoot, topping, tree vigor, water sprout.

Abstract: This paper reviews the effect of summer pruning in persimmon (*Diospyros kaki* Thunb.) with regard to its positive and negative aspects on tree growth and fruit production. In order for this practice to be of a significant value, a clear understanding is needed to appreciate the fact that so many variables are involved and much remains to be substantiated. Major reasons for summer pruning of persimmon are to improve fruit quality by enhancing light penetration into the tree canopy and to restrict vegetative shoot growth. Summer pruning generally suppresses tree growth even though it elevates leaf activity. Positive effects of summer pruning on skin color, soluble solids, and appearance of fruits are observed mainly in those orchards where the trees are heavily dormant-pruned to lower tree height and to secure space in high density plantings. Secondary shoot pruning and topping could also improve fruit quality, increasing flower bud formation of remaining shoots. Summer-pruning effects are highly dependent on its severity and timing to affect tree growth, shoot regrowth, reserve accumulation, and fruit quality.

1. Introduction

Persimmon trees, having no dwarf rootstocks of commercial value, tend to grow high. Lowering tree height by heavy dormant pruning has been a routine practice for efficient management of many persimmon orchards. In densely planted orchards, heavy pruning is an inevitable practice to restrict tree size. This practice, in turn, causes vigorous shoot growth resulting in an excessive crowding of the canopy. Poor fruit set and excessive supply of nitrogen also stimulate the occurrence of vigorous shoots. Tree crowding not only hinders orchard operations, but deteriorates fruit quality as the tree interior becomes heavily shaded. Shoots of vigorous and succulent growth make the tree susceptible to anthracnose (*Colletorichum gloeosporioides*) when humidity within the canopy is high.

Summer pruning is one of many options to alleviate the problems of crowding, ensuring adequate light penetration into the canopy and controlling excessive shoot growth. However, removal of shoots during growing season involves the loss of functional leaf surface, which may lead to reduced tree development and fruit growth. Loss of leaf area may also reduce reserve accumulation for early growth the next season. The effect of summer pruning on physiological process and tree growth seems well documented in other deciduous fruit crops, but limited studies have been conducted in persimmon. In this paper we evaluate the effects of summer pruning on tree growth, fruit quality, and nutrient composition of perennial organs in persimmon.

2. Tree response to summer pruning

Vegetative growth

Since removal of active leaf area reduces the production of dry matter during the growing season, summer pruning suppresses vegetative growth in other fruit crops, the effect of which is closely related to pruning severity, timing and cultivars (Taylor and Ferree, 1984; Rom and Ferree, 1985; Marini and Barden, 1987; Mediene *et al*., 2002; Zamani *et al*., 2006). In young 'Fuyu' and 'Nishimurawase' persimmons, thinning 26% of total shoot length in late July reduced dry weight of dormant one-year-old twigs, but it did not significantly affect total dry weights of aerial wood and the root (Choi *et al*., 2003 a). The result might be related in part to a high photosynthetic activity of remaining leaves until later in the season as shown in leaf chlorophyll concentrations (Fig. 1). Although not significant, negative relationships were observed between the increment of trunk cross-sectional area and pruning severity in the same experiment (Choi *et al*., 2003 a) and summer heading-back (Song *et al*., 2001).

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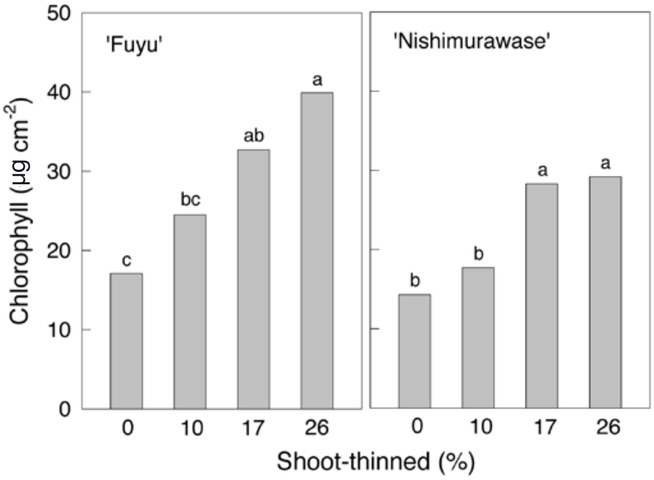

Fig. 1 - Effect of different severities of shoot thinning on 22 July on leaf chlorophyll of five-year-old 'Fuyu' and 'Nishimurawase' persimmon on 3 November. Chlorophyll content includes chlorophylls a and b. Values sharing the same letter are not significantly different from each other by Duncan's multiple range test at $p \leq 0.05$ (Choi *et al*., 2003 a).

Leaf activity

Summer pruning is known to increase photosynthesis, dark respiration, and transpiration of shoot leaves in other fruit crops (Taylor and Ferree, 1981; Marini and Barden, 1982; Myers and Ferree, 1983). As shoot thinning severity in late July increased in 'Nishimurawase' persimmon, specific leaf weight tended to become higher (Table 1). Chlorophyll content per unit area increased by 1.9-fold and 2.3-fold in 'Fuyu' and about 2-fold in 'Nishimurawase' trees that had been thinned 17% and 26% of their shoots, respectively (Fig. 1). Results indicated that photosynthesis can hardly compensate for the leaf area that has been removed, and there would be a sizable reduction in the production of photosynthates depending on pruning time

Regrowth

It is possible that shoot regrowth following summer pruning can have serious negative effects on the supply of photosynthates to fruit and shoot and resistance to diseases and pests (Forshey *et al.*, 1992; Choi *et al.*, 2003 b). In addition, excessive regrowth may reduce flower bud formation by gibberellins produced during shoot regrowth (Forshey *et al.*, 1992). The extent of regrowth following summer pruning was influenced by the time and severity (Miller, 1982; Ferree *et al.*, 1984). When 'Fuyu' persimmon was summer-pruned on 20 June or 4 July, the earlier pruning produced more secondary growth more than the later one (Fujimura, 1932). Summer pruning after late July, when buds enter physiological rest, did not result in a great problem of regrowth in persimmon trees, but heavy summer pruning may stimulate some buds to break into growth (Table 1). Heading-back cuts in vigorous shoots would easily induce regrowth more than thinning cuts. Late July through early August is the appropriate time for thinning out vigorous shoots to avoid regrowth in South Korea.

Reserve accumulation

Early loss of foliage from pruning may result in reduced carbohydrate levels of the tree, and that could adversely affect cold hardiness (Marini and Barden, 1987). When the current shoots were thinned up to 26% of their total length in late July in young 'Fuyu' and 'Nishimurawase' persimmon, the differences in non-structural carbohydrates and inorganic nutrients in four- to five-year-old wood of above-ground parts and the large root, measured on 2 April the following year, were not consistent with the pruning severity the previous summer (Choi *et al*., 2003 a). This result might be due to the increased activity of the leaves as presented in chlorophyll concentration in figure 1. However, thinning 50% of total shoots decreased carbohydrate concentration in one-year-old shoots of field-grown 'Nishimurawase' (Table 2) but not in those of 'Fuyu' (Choi *et al*., 2003 b). In the same experiment, the severe summer pruning also reduced flower buds in both cultivars the following year, since low carbohydrates in the shoots (Choi *et al*., 2011) and excessive regrowth (Forshey *et al*., 1992) were negatively related to flower bud formation.

3. Fruit quality affected by summer pruning

Summer pruning has been recommended to improve

Table 1 - Effect of summer pruning severity on 29 July on light penetration and tree growth of 'Nishimurawase' persimmon (Choi *et al*., 2003 b)

Shoot-thinned (%)	Light penetration (%)	TCSA increment (%)	Regrowth (cm/tree)	SLW ($mg \cdot cm^{-2}$)	Leaf SPAD reading
0	11.3 b	6.8 a	0 a	10.14 b	51.6 a
25	24.7 a	7.8 a	63 a	10.92 ab	52.8 a
33	27.9 a	7.4 a	163 a	10.93 ab	51.8 a
50	30.9 a	6.1 a	215 a	11.18 a	54.8 a

After summer pruning of seven-year-old trees, the leaf-fruit ratio was changed from 20 of 0% thinning to 10 of 50% thinning in an orchard planted at 3.5 x 2 m.
TCSA= trunk cross-sectional area.
SLW= specific leaf weight.
Mean values in each column with the same letter are not significantly different by Duncan's multiple range test at $p \leq 0.05$.

Table 2 - Effect of summer pruning severity on 29 July on concentrations of carbohydrates and inorganic elements in dormant shoots of 'Nishimurawase' persimmon on 17 February (Choi *et al*., 2003 b)

Shoot-thinned (%)	Carbohydrates (% DW)		Inorganic elements (% DW)				
	Soluble sugars	Starch	N	P	K	Ca	Mg
0	12.2 a	5.4 a	0.60 a	0.21 b	0.60 a	0.36 b	0.17 a
25	12.0 a	4.4 ab	0.62 a	0.24 ab	0.73 a	0.39 ab	0.17 a
33	10.3 a	3.5 ab	0.60 a	0.24 ab	0.74 a	0.43 a	0.17 a
50	9.7 a	3.2 b	0.62 a	0.28 a	0.75 a	0.44 a	0.18 a

After summer pruning of seven-year-old trees, the leaf-fruit ratio was changed from 20 of 0% thinning to 10 of 50% thinning in an orchard planted at 3.5 x 2 m.
Mean values in each column with the same letter are not significantly different by Duncan's multiple range test at p≤ 0.05.

fruit quality in vigorous persimmon by increasing light interception (Mowat, 1987; Ullio, 2003; George *et al*., 2005; Yamada, 2008). However, there was no consistent effect of the pruning on fruit characteristics in many studies. Table 3 shows that thinning out some water sprouts in late July increased skin color with no reduction in fruit size. This kind of positive result might be possible in vigorous 'Fuyu' trees in densely-planted orchards, and the leaf-fruit ratio after the pruning was sufficiently high. Kim (2010) also found larger size and higher coloration of fruits in vigorous 'Fuyu' trees after thinning out some water sprouts in late July. Lower water consumption and thus improved water status during the growing season after summer pruning could benefit fruit growth and relieve the potential detriment due to carbohydrate shortage in apple (Li *et al*., 2003) and peach (Lopez et *al*., 2006). Fruit firmness was not significantly changed by the differences in pruning severity (Tables 4 and 5).

Table 3 - Effect of removing water sprouts on 28 July on light penetration and fruit characteristics in vigorous 'Fuyu' persimmon orchard (Choi *et al*., 2005)

Treatment	Light penetration (%)	Fruits		
		Average weight (g)	Skin color (Hunter a)	Soluble solids (°Brix)
Non-pruning	15	243	27.9	15.0
Summer pruning	33	257	29.8	15.2
Significance	**	NS	*	NS

By summer pruning of 1-year-old trees, water sprouts were removed to maintain leaf-fruit ratio 20 in an orchard planted at 6 x 3 m.
NS= not significant; * = significant at P≤ 0.05; ** = significant at P≤0.01.

Size, soluble solids, and skin color of persimmon fruits decreased when the leaf-fruit ratio was low (Choi *et al*., 2010). The appropriate leaf-fruit ratio for quality 'Fuyu' fruits has been set at about 20 in Korea (Choi *et al*., 2010) and Japan (Kishimoto, 1975; Yamamura *et al*., 1989). Loss of leaf area by summer pruning results in poor fruit quality

Table 4 - Effect of summer pruning severity on 28 July on fruit characteristics of 'Fuyu' persimmon harvested on 31 October (Choi *et al*., 2003 b)

Shoot-thinned (%)	Average weight (g)	Skin color (Hunter a)	Fruit firmness (N)	Soluble solids (°Brix)	Skin damage (%)
0	234 a	27.6 a	20.7 a	15.2 a	13.2 a
10	244 a	28.4 a	21.9 a	15.7 a	9.3 cb
20	249 a	28.3 a	20.1 a	15.1 a	7.8 c
30	233 a	29.5 a	20.3 a	15.3 a	9.8 b

After summer pruning of seven-year-old trees, the leaf-fruit ratio was changed from 39 of 0% thinning to 28 of 30% thinning in an orchard planted at 6 x 3 m.
Skin damage: blemish or stains on fruit skin.
Mean values in each column with the same letter are not significantly different by Duncan's multiple range test at P≤0.05.

Table 5 - Effect of summer pruning severity on 29 July on fruit characteristics of 'Nishimurawase' persimmon harvested on 26 September (Choi *et al*., 2003 b)

Shoot-thinned (%)	Average weight (g)	Skin color (Hunter a)	Fruit firmness (N)	Soluble solids (°Brix)	Skin damage (%)
0	144 a	32.2 a	34.3 a	14.5 a	8.8 a
25	139 a	32.2 a	33.4 a	14.0 ab	3.7 ab
33	137 a	31.2 ab	32.5 a	13.6 ab	4.6 ab
50	141 a	27.7 a	31.9 a	13.0 b	1.6 b

After summer pruning of seven-year-old trees on 29 July, the leaf-fruit ratio was changed from 20 of 0% thinning to 10 of 50% thinning in an orchard planted at 3.5 x 2 m.
Skin damage: blemish or stains on fruit skin.
Mean values in each column with the same letter are not significantly different by Duncan's multiple range test at p≤0.05.

if the pruning significantly reduces the ratio. When leaf-fruit ratio decreased to less than 13 with severe removal of the shoots, fruit size, skin color or soluble solids were significantly reduced (Table 5) (Choi *et al*., 2003 a). On the other hand, strong winds result in blemish of fruit skin due to rubbing of shoots and leaves against fruits (George *et al*., 1997 a). Skin staining of persimmon fruits is often caused by humid conditions in autumn (George *et al*., 1997 a), which become aggravated by the shoots growing vigorously. Thinning out some of the shoots in summer reduces these damages by improving the micro-environment within the tree canopy (Tables 4 and 5). Therefore, summer pruning has been recommended as a means to reduce the occurrence of skin staining (George *et al*., 1997 a, 2005), especially in newly-released Japanese cultivars like a crack-susceptible 'Taishu' (Yakushiji and Nakatsuka, 2007). The influence of summer pruning on fruit quality varies by the degree of canopy crowding and the timing and its severity, as has been documented in other fruit crops (Marini and Barden, 1987; Forshey *et al*., 1992; Zamani *et al*., 2006).

4. Water sprout management

Removing all water sprouts of vigorous trees too early in the season may induce severe regrowth (Fujimura, 1932), which disturbs light penetration and reserve accumulation in perennial organs (Kappel *et al*., 1983). Therefore, instead of removing all water sprouts, thinning some of them combined with bending or twisting the remaining ones down to horizontal in June may be recommended (Park and Choi, 2000; Huh *et al*., 2003; George *et al*., 2005). Securing leaf area even in water sprouts helps prevent the regrowth that may be related to the action of hormones produced in old leaves (Forshey *et al*., 1992). Some of the water sprouts may have some value as mother branches the next season. Water sprouts of 'Fuyu' could form flower buds as long as their terminal buds are set by early August in South Korea (Choi *et al*., 2011): they could serve as fruiting branches for the following year. In vigorous trees with poor fruiting, using the sprouts as mother branches to set fruits the next season is extremely important to make up for the yield reduction as well as to control tree vigor. When the sprouts were twisted and bent down under horizontal in mid- to late June after thinning out some, flower buds were formed in 84 to 97% of them the following year (Park and Choi, 2000). Changes in endogenous hormones might be closely involved in this treatment, particularly low gibberellin and high cytokinin, which play a role in flower bud formation (Banno *et al*., 1985). Heading-back pruning to four buds is also practiced in New Zealand to ensure future fruiting site from water sprouts (Mowat, 1987).

5. Secondary-shoot pruning, pinching and topping

Secondary growth from shoot terminal occurs from mid-June in vigorous persimmon trees (Nii, 1980; Park *et al*., 2003). Secondary growth often induced fruit drop (George *et al*., 1997 b). Park *et al*. (2003) studied the heading-back effect of secondary shoots leaving two to three basal leaves of the secondary growth on 'Fuyu' persimmon. When the heading-back was done on fruiting shoot, they found that the shoots had a lower dry weight which was accompanied by an increase in fruit weight. The result indicated the necessity of such cuts for fruit growth. Compared with the heading-backs before 10 July or after 10 August, those on 25 July produced the largest fruits in-season and exhibited the highest percentage of shoots that bore flowers and fruits the following year, indicating that pruning the secondary shoots on 25 July helps to direct the assimilates to fruit growth and flower bud development, not to vegetative growth.

'Nishimurawase' persimmons tend to bear staminate, not pistillate, flowers when the trees are old and not vigorous enough. Chijiwa and Hayashi (2007) reported a way to use water shoots to serve as fruiting mother branches for the next season by pinching at 15 cm from the base between May and June. Shoots left after the pinching or summer shoots regrown from the cut bore more pistillate and fewer staminate flowers the following year than the un-treated water shoots. Takano (1994) also reported a better mother branch formation by pinching adventitious buds of persimmon. The size of trees and yield efficiency are among the most important considerations in high density orchards. When the vigorous shoots of young 'Uenishiwase' persimmon were topped to a 30-cm length in early June, followed by the removal of the regrowth, trunk growth decreased and fruit set increased the following year (Song *et al*., 2001). The occurrence of secondary growth after heading was dependent on the treatment date. Topping the shoots at the fourth bud from the terminal on 20 May promoted secondary growth of 'Hiratanenashi' persimmon, but the same treatment after 22 June did not (Hasegawa and Nakajima, 1984). The summer topping of long shoots in summer was effective in forming fruiting shoots the following year in their lower parts. Pinching and topping the shoot would promote flower bud formation of that shoot if regrowth is not severe.

6. Conclusions

Severe summer pruning could suppress vegetative and fruit growth due to the lowered photosynthetic capacity, reducing the carbohydrate reserves in persimmon tree. However, summer pruning which is appropriate to tree vigor and environmental conditions would increase production of quality fruits by improving light distribution in the tree canopy or restricting vegetative growth. Since tree vigor is a result of the complex interactive effects with cultural practices, the pruning alone should not be used as a tool for controlling vegetative growth. It is necessary to incorporate the pruning into a comprehensive program such as tree training, fruiting, irrigation, and fertilization to reduce vigorous growth. Growers should employ summer pruning methods while carefully monitoring for potentially negative effects on tree growth and fruit quality.

References

BANNO K., HAYASHI S., TANABE K., 1985 - *Effects of SADH and shoot-bending on flower bud formation, nutrient components and endogenous growth regulators in Japanese pear* (Pyrus serotina *Rehd*.). - J. Japan. Soc. Hort. Sci., 53: 365-376.

CHIJIWA H., HAYASHI K., 2007 - *The formation of fruiting mother shoot from water shoot by pinching in Japanese persimmon*. - Hort. Res., 6: 265-270.

CHOI S.T., KANG S.M., PARK D.S., SONG W.D., AHN G.H., 2003 a - *Effect of different severities of summer pruning on fruit characteristics and tree growth in young 'Fuyu' and 'Nishimurawase' persimmon*. - J. Korean Soc. Hort. Sci., 44: 569-574.

CHOI S.T., PARK D.S., AHN G.H., 2003 b - *Studies on efficient production and quality improvement of sweet persimmon - Effect of summer pruning on fruit qualities of sweet persimmon*. - Rural Development Administration Report. Suwon, Korea, pp. 5-34. (in Korean with English summary).

CHOI S.T., PARK D.S., KANG S.M., 2011 - *Nutrient accumulation and flower bud formation affected by the time of terminal bud set on water sprouts of persimmon*. - HortScience, 46: 523-526.

CHOI S.T., PARK D.S., KANG S.M., CHO Y.C., 2010 - *Effect of fruit-load on the growth, absorption, and partitioning of inorganic nutrients in young 'Fuyu' persimmon trees*. - Sci. Hort., 126: 408-412.

CHOI S.T., PARK D.S., KIM S.C., 2005 - *Summer pruning and management for vigorous persimmon trees*. - 2005 Farming technology. Rural Development Administration. Suwon, Korea. (in Korean)

FERREE D.C., MYERS S.C., ROM C.R., TAYLOR B.H., 1984 - *Physiological aspects of summer pruning*. - Acta Horticulturae, 146: 243-252.

FORSHEY C.G., ELFVING D.C., STEBBINS R.S., 1992 - *Training and pruning apple and pear trees*. - Amer. Soc. Hort. Sci., pp. 60-63.

FUJIMURA J., 1932 - *Effects of summer pruning on the secondary growth of one-year-old persimmon and Japanese pear trees*. - J. Japan. Soc. Hort. Sci., 3: 9-20.

GEORGE A.P., MOWAT A.D., COLLINS R.J., 1997 a - *Factors affecting blemishing of persimmon in New Zealand and Australia*. - Acta Horticulturae, 436: 171-178.

GEORGE A.P., MOWAT A.D., COLLINS R.J., MORLEY-BUNKER M., 1997 b - *The pattern and control of reproductive development in non-astringent persimmon (*Diospyros kaki *L.): a review*. - Sci. Hort., 70: 93-122.

GEORGE A.P., NISSEN B., BROADLEY R., COLLINS R.J., RIGDEN P., JEFFERS S., ISAACSON B., LEDGER S., 2005 - *Sweet persimmons grower's handbook*. - Department of Primary Industries and Fisheries, Brisbane, Queensland, Australia.

HASEGAWA K., NAKAJIMA Y., 1984 - *Effects of topping on the growth and fruit quality of the Japanese persimmon*. - Res. Rpt. Kochi Univ. (Agr.), 33: 43-53.

HUH M.S., SONG I.K., CHO D.H., JEONG Y.S., 2003 - *Bending effect of vigorous shoot on persimmon tree*. - 2003 Annual Research Report. Gyeongsangbuk-do Agr. Res. Ext. Serv. Daegu, Korea. (in Korean)

KAPPEL F., FLORE J.A., LAYNE R.E.C., 1983 - *Characterization of the light microclimate in four peach hedgerow canopies*. - J. Amer. Soc. Hort. Sci., 108: 102-105.

KIM B.S., 2010 - *Development of cultivation techniques for the stable production of high quality sweet persimmon fruits to export - A study on quality enhancement of sweet persimmon for export by stable tree vigor*. - Rural Development Administration, Suwon, Korea. (in Korean).

KISHIMOTO O., 1975 - *Estimations of optimum range of degree of fruit thinning and desirable fruit weight in Japanese pears and persimmon tree*. - J. Japan. Soc. Hort. Sci., 43: 368-376.

LI K., LAKSO A.N., PICCIONI R., ROBINSON T., 2003 - *Summer pruning reduces whole-canopy carbon fixation and transpiration in apple trees*. - J. Hort. Sci. Biotechol., 78: 749-754.

LOPEZ G., MATA M., ARBONES A., SOLANS J.R., GIRONA J., MARSAL J., 2006 - *Mitigation of effects of extreme drought during stage III of peach fruit development by summer pruning and fruit thinning*. - Tree Physiol., 26: 469-477.

MARINI R.P., BARDEN J.A., 1982 - *Net photosynthesis, dark respiration, transpiration, and stomatal resistance of young and mature apple trees as influenced by summer or dormant pruning*. - J. Amer. Soc. Hort. Sci., 107: 170-174.

MARINI R.P., BARDEN J.A., 1987 - *Summer pruning of apple and peach trees*. - Hort. Rev., 9: 351-375.

MEDIENE S., JORDAN M.O., PAGÈS L., LEBOT J., ADAMOWICZ S., 2002 - *The influence of severe shoot pruning on growth, carbon and nitrogen status in young peach trees (*Prunus persica). - Tree Physiol., 22: 1289-1296.

MILLER S.S., 1982 - *Regrowth, flowering, and fruit quality of 'Delicious' apple trees as influenced by summer pruning*. - J. Amer. Soc. Hort. Sci., 107: 975-978.

MOWAT A., 1987 - *Pruning persimmons*. - HortResearch publication. New Zealand. March 28, 2011. - http://www.hortnet.co.nz/publications/science.

MYERS S.C., FERREE D.C., 1983 - *Influence of summer pruning and tree orientation on net photosynthesis, transpiration, shoot growth, and dry-weight distribution in young apple trees*. - J. Amer. Soc. Hort. Sci., 108: 4-9.

NII N., 1980 - *Current shoot and growth in Japanese persimmon,* Diospyros kaki *cv. Fuyu, in relation to the development of the tissue system in the leaf*. - J. Japan. Soc. Hort. Sci., 49: 149-159.

PARK D.S., CHOI S.T., 2000 - *Development of technology for production of high quality fruits in sweet persimmon - Studies on the method of fruit-load adjustment for high quality of fruit production*. - Rural Development Administration Report, Suwon, Korea. (in Korean with English summary).

PARK D.S., KANG S.M., CHOI S.T., LIM C.A., SONG W.D., 2003 - *Effect of secondary-shoot prunings on fruit growth and following year's fruit set of 'Fuyu' persimmon*. - J. Korean Soc. Hort. Sci., 44: 678-682.

ROM C.R., FERREE D.C., 1985 - *Time and severity of summer pruning influences on young peach tree net photosynthesis,* *transpiration, and dry weight distribution*. - J. Amer. Soc. Hort. Sci., 110: 455-461.

SONG W.D., CHOI S.T., KIM S.C., PARK D.S., KANG S.M., 2001 - *Effect of pinching on fruit set of young sweet persimmon trees during the following years*. - 2001 Annual Research Report. Gyeongsangnam-do Agr. Res. Ext. Serv. Jinju, Korea. (in Korean)

TAKANO S., 1994 - *Better branch formation by pinching adventive buds of Japanese persimmon*. - Bull. Nara Agr. Expt. Sta. J., 25: 36-37.

TAYLOR B.H., FERREE D.C., 1981 - *The influence of summer pruning on photosynthesis, transpiration, leaf abscission, and dry weight accumulation of young apple trees*. - J. Amer. Soc. Hort. Sci., 106: 389-393.

TAYLOR B.H., FERREE D.C., 1984 - *The influence of summer pruning and cropping on growth and fruiting of apple*. - J. Amer. Hort. Sci., 109: 19-24.

ULLIO L., 2003 - *Persimmon growing in New South Wales*. - Agfact H3.1.17, 3rd edition. Elizabeth Macarthur Agricultural Research Institute, Camden, Australia.

YAKUSHIJI H., NAKATSUKA A., 2007 - *Recent persimmon research in Japan*. - Japan. J. Plant Sci., 1(2): 42-62.

YAMADA M., 2008 - *Persimmon propagation, orchard planting, training and pruning in Japan*. - Adv. Hort. Sci., 22: 269-273.

YAMAMURA H., MATSUI K., MATSUMOTO T., 1989 - *Effects of gibberellins on fruit set and flower-bud formation in unpollinated persimmon (*Diospyros kaki*)*. - HortScience, 38: 77-86.

ZAMANI Z., SAIE A., TALAIE A.-R., FATAHI R., 2006 - *Effects of summer pruning on growth indices of two important Iranian apple cultivars 'Golab' and 'Shafi-Abadi'*. - Acta Horticulturae, 707: 269-274.

Adv. Hort. Sci., 2011 25(3): 170-178

Spring and summer pruning in apricot and peach orchards

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Key words: Catalonian open vase, early and late pruning, plant architecture, shoot heading back, shoot thinning.

Abstract: Spring and summer pruning are based on the possibility to manipulate the physiological control of axillary sylleptic growth and carbon allocation in the shoot through alteration of the apical dominance and light distribution in the canopy. The practical result in modern orchards is a higher flower bud differentiation for apricot and an easier training system maintenance for peach with more efficient use of labor. Cultivated apricot varieties show diverse tree architectures, habit and fruiting branches. The effect of pruning intensity at different times during spring and summer seasons is specific for the singular growth habits. Differences among the peach varieties are less evident than in the apricot. The ease with which peach water sprouts produce axillary sylleptic shoots makes the use of mechanical topping possible in the first two years of intense growth in order to train the tree as a bush and then to open it as a vase with manual pruning (Catalonian open vase). In all modern peach orchards, pruning in late summer results very useful to obtain a better light distribution in the canopy and a more efficient carbon allocation to fruiting shoots, preventing and reducing the need for winter pruning.

1. Apricot

In apricot, growth habit and fruiting behavior are strongly inter-related. Accordingly, the varieties of apricot can be classified into five groups (Guerriero and Xiloyannis, 1975 a; Bassi *et al*., 2003). Since some changes in shoot morphogenetic gradient during rest period were evident in response to dormancy and chilling (Guerriero and Scalabrelli 1982), any classification of branch habit should be strictly associated with a specific environment.

Depending on the type of bud (floral or vegetative) and shoot (sylleptic, long brindle, brindle or spur) the chilling requirement may be very different and, eventually, can be a factor in regulating branch habit and fruiting behavior (Guerriero and Xiloyannis 1975 b; Guerriero and Viti, 1997). To decide how to manage pruning, the shoot should be identified by its specific growth rate after bud break. For this purpose, its physiological behavior should be constantly monitored. There is some evidence that the emergence of sylleptic shoots is highly probable when a threshold level of growth rate is exceeded (Zucconi, 2003). This means that in some conditions apical dominance is not able to inhibit the growth of lateral meristems, which thus originate sylleptic (anticipated) shoots rather than buds (Fig. 1).

Generally, the buds (once formed) become rapidly dormant (Fig. 2) and will only grow in the following spring after a specific amount of chilling, and as a result they will originate proleptic shoots.

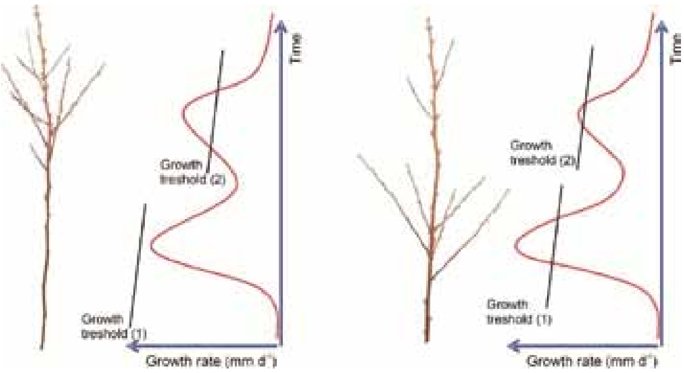

Fig. 1 - Shoot growth rate and sylleptic shoot formation in apricot. This model assumes that the growth rate threshold for inducing sylleptic growth decreases during the season. Left: the threshold was overcome only at the end of the season. Right: the critical growth rate was overcome twice in the season.

It is also possible that, depending on growing conditions, sylleptic shoot formation can take place more than once (Fig. 1) along the shoot growth. Thus buds that are formed on sylleptic shoots at different times compared to proleptic ones may have a different fruiting performance and time of flowering: this is frequently reported by growers.

Consequently the date of pruning, whether during the vegetative period (summer pruning, early or late) or during the winter before bud break, can have a strong influence in controlling the fruiting of different varieties. Moreover, the knowledge of how the shoots grow is very important

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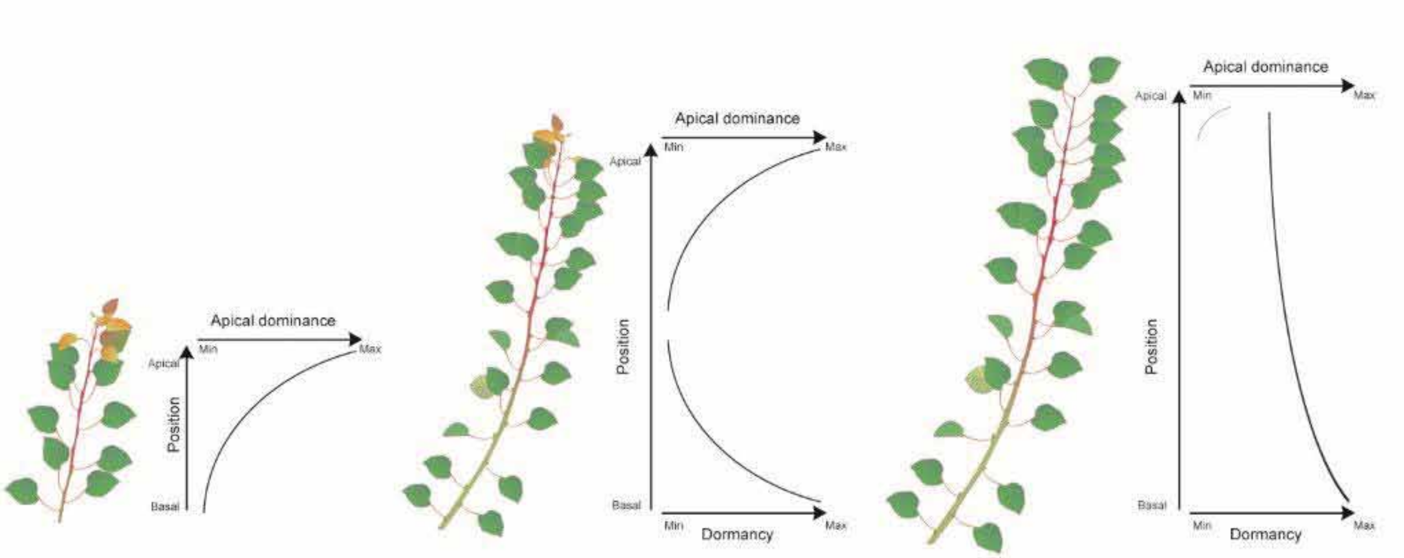

Fig. 2 - Left: apical dominance intensity along the growing shoot in early spring. Centre: apical dominance and bud dormancy intensity along the growing shoot in late spring. Right: apical dominance and bud dormancy intensity along the shoot in late summer.

for effective pruning, improving the chance of acclimatizing a cultivar that may be productive in a specific environment. Pruning for apricot should be modulated both in intensity and timing according to the interaction between the variety and its environment.

Finally, the specific shoot physiology and architectures of fruiting branches of apricot varieties will determine very dissimilar regimes for pruning. For this reason there should be in each growing area a classification of the varieties, according to their precise branch habit, fruiting behavior and need for pruning.

The most common classification in northern Italy is arranged into three groups: A - with very vigorous and spreading habit, and a tendency to fruit on spurs, brindles and sylleptic shoots; B - with less vigorous, assurgent, or semi-spreading habit, fruiting on spurs and vigorous shoots; C - with very vigorous, assurgent, or mixed spreading habit, and ability to fruit on all kinds of shoot (Neri, 2003; Pirazzini, 2004; Neri *et al*., 2010).

Therefore, for each apricot variety, it is important to predict the response (in terms of the number and type of lateral shoots) to head back pruning of shoots and branches in different periods of the spring and summer seasons. Pruning intensity and cultural techniques (fertilization, irrigation, soil management, and eventually forcing and protection conditions) play an extraordinary role in determining the final result and the possible optimal training system (Neri *et al*., 2011).

Spring shoot heading back and thinning

The intensity of head back pruning of growing shoots can be performed within these two extremes: short pruning (leaving half of the shoot or only the basal portion of it with three to five buds, as a spur) and long pruning (which reduces the apical portion of the shoot by pinching or cutting a few centimeters below the tip). Generally, these pruning techniques are limited to the spring with fast growing shoots. The time of pruning can be intended as early or late spring pruning, in which the early pruning induces the formation of long sylleptic shoots, while the latter induces nil growth or the formation of few, short, sylleptic brindles with, likely, a higher flower differentiation aptitude.

After spring heading back, shoot vigour is strongly reduced and the number of sylleptic shoots is generally increased. Short head back pruning was generally less effective than long heading back in inducing flowering brindles, with the exception of weak varieties which need to improve shoot growth. The response to pruning is always higher in fertile and irrigated soil. Apparentely the pruning in late spring induces a better response if it is limited to the terminal part of the long shoot (long pruning) (Fig. 3).

Delaying spring pruning (late spring pruning) reduces the number of sylleptic shoots per single cut and also the

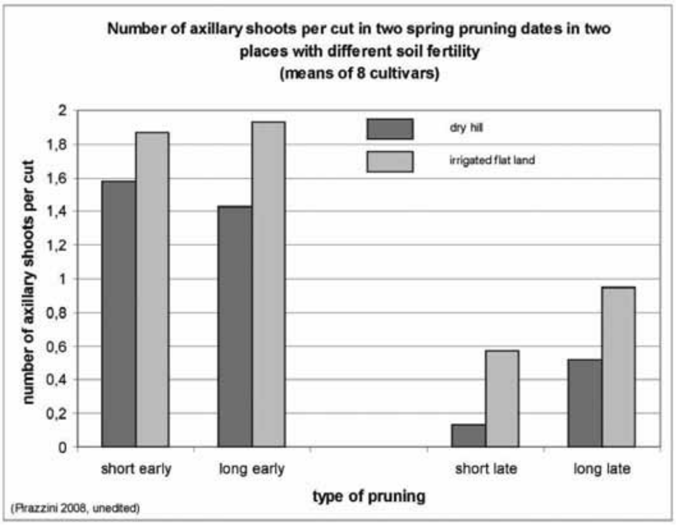

Fig. 3 - Number of sylleptic shoots per single cut in response to short and long pruning delaying the operations from early to late spring.

flowering intensity. Flowering intensity is higher when pruning is applied in early spring (May) in different varieties (Fig. 4), probably because more sylleptic brindles were produced. Apparently late pruning in June induces a better response if it is performed on the terminal part of the shoot (long pruning).

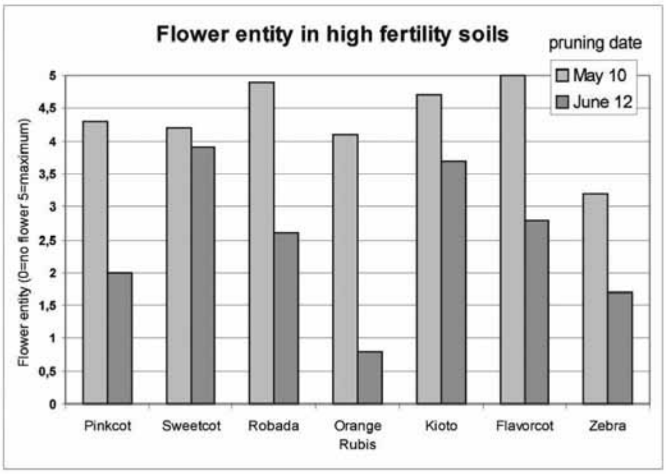

Fig. 4 - Flowering estimated entity in 8 varieties in response to pruning applied in May (early pruning), or in June.

Shoot thinning is generally carried out a few weeks before harvest to improve fruit quality in very vigorous trees. It is devoted to eliminating overcrowded and malpositioned shoots. The final goal is to have better light distribution inside the canopy and less carbon directed to water sprouts and suckers which cannot be used for fruit production in the future management of the branches.

Summer shoot heading back and thinning

Summer shoot head back pruning aims to increase flower differentiation but in apricot this is possible only if there is new shoot growth, which can be induced by water supply after summer drought or by heavy cuts such as late summer heading back.

Summer shoot thinning can be performed with the aim of improving the quality of shoots as a consequence of better light penetration and carbon allocation. This practice reduces the need for winter pruning and can be useful in areas where frost damage may challenge flowering and therefore winter pruning must be delayed until after fruit set.

Different pruning intensity is meant to stimulate more vegetative vigour when the shoot is suddenly cut very short, but to induce the formation of flowering brindles when it remains quite long (Fig. 5). Under northern Italian continental climate, the vegetative response to pruning is always greater in fertile and irrigated soils, resulting in greater shoot vigour. Finally, sylleptic shoots tended to bloom later than the rest of the plant (a very important advantage in climates where late frost is common) but to bear fruits of small size, at least in some varieties (Pirazzini, personal communication).

Varietal differences in response to spring heading back

Pinkcot. Early short heading back induces numerous, equally balanced and productive sylleptic shoots. Sylleptic shoot growth is very active when it is stimulated on vigorous shoots (water sprouts), which by the end of the season are well ramified. At blooming the number of flowers on sylleptic shoots is higher with long heading back than with short. Short heading back resulted in more uniform distribution of brindles and spurs along the original branch.

Sweetcot. Growth is greater after early shoot heading back: nevertheless only few sylleptic shoots were formed, they are not too long and the flower number is increased. In non-irrigated soils late pruning does not improve shoot ramification, while growth is short and rich in flowers**.**

Robada. In fertile soil, early pruning generally induces a few sylleptic shoots, often only one as an extension growth from the terminal bud, even though the number of flowers on all type of shoots is high. With late pruning there is a certain number of sylleptic shoots (brindles and

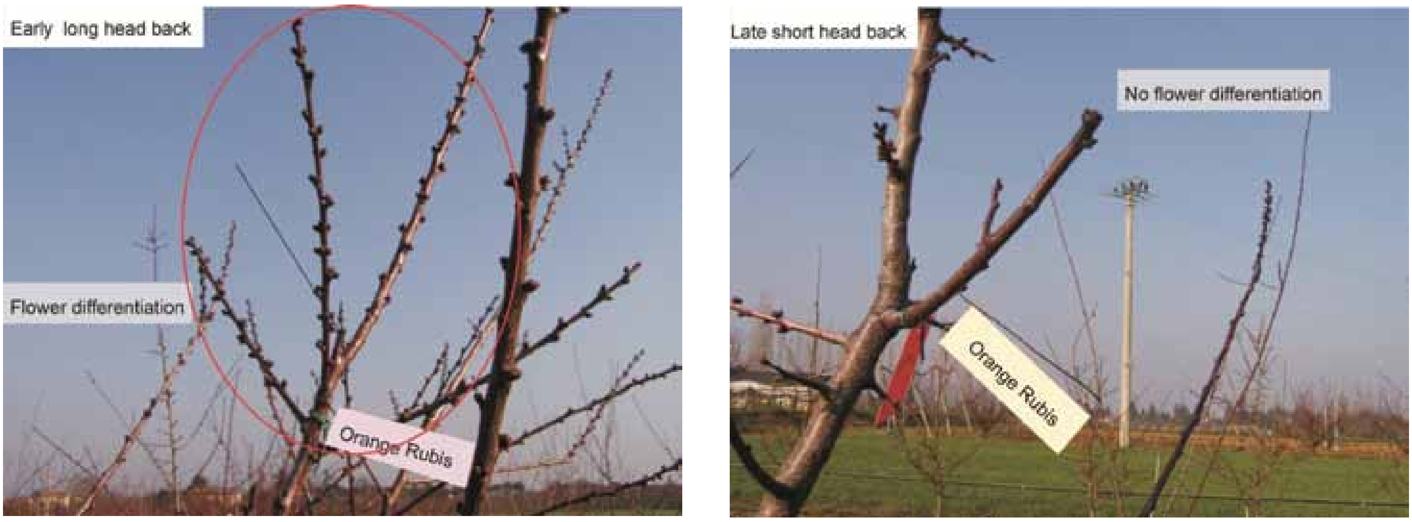

Fig. 5 - Orange Rubis forms shoots after early long-heading back (left): a high number of sylleptic shoot with good flower differentiation is formed. Shoot after late short-heading back (right): sylleptic growth and flower differentiation is visible.

spurs) but fewer flowers per shoot. In non-irrigated soil, short heading back does not induce any good growth, neither for shoots nor flowers.

Orange Rubis. Long early shoot heading back is very effective in stimulating sylleptic growth with high flower differentiation, while short heading back is useful only with weak shoots. Heading back of water sprouts, especially when late, does not favor flowering formation.

Kioto. The number of brindles and spurs is dramatically increased by early pruning, with very high flower differentiation along the old wood. Late pruning is positive only on vigorous lateral shoots. Flower differentiation is good in all the shoots after early pruning, and intermediate in sylleptic brindles in vigorous shoots after late pruning.

Flavorcot. Both short and long early pruning induce weak growth in comparison with the vigorous cultivars; the sylleptic shoots are limited in number and growth even in water sprouts. Late pruning does not induce good sylleptic ramification, but the flower induction is enhanced in brindles and spurs in all the plants. After early pruning, flowers are scarce in all the sylleptic shoots; after late pruning, flower production is much better in the old wood and in sylleptic brindles.

Zebra. Early long head back pruning induces positive sylleptic shoot growth; short heading back is less effective even in water sprouts; flower differentiation confirmed this result. Late heading back was negative and induced only few flowers.

Pieve. Early heading back is generally positive and, especially with long pruning, the number of sylleptic brindles is higher and flower differentiation is good. Late pruning reduces the branching of shoots, and induces a very limited number of flowers.

Pisana. For this low fertile variety, it is worth noting that the terminal shoot on the intact branch showed less growth than the second one below, as opposed to the heading back causing the terminal shoot to become the most vigorous of the branch. This means that in low fertility conditions the varieties of this group need to be stimulated by winter pruning instead of weakened by summer pruning.

Bella di Imola. This variety shows very high productivity on the one-year shoot, the terminal portion being the most productive. Growth was greater at the terminal position of the branch as well, revealing a much stronger acrotony than Pisana, and greater vigor. For this reason it is important to avoid any pruning which induces a vegetative response which is too strong. In fact in orchards with low fertilization, growth was not excessive even with winter pruning; flower differentiation was high in any case. It can be hypothesized that in more fertile soils vigor can be too strong, and so late summer pruning can be widely utilized (Neri *et al*., 2010).

Pruning in different training systems for apricot

Actual training systems for apricot are specific for each production area. The two most widely diffused training systems in the northern part of Italy are free open vase (with several variations, from delayed open vase to bush) for low density, hilly orchards and spindle for high density systems in flat fertile lands with low vigorous rootstocks.

The date and intensity of pruning effectively determines the branch architecture and fruiting potential of each cultivar. These observations lead us to conclude that for apricot, summer pruning is a basic practice in modern orchards but it must be adapted to local conditions and genetic material. Shoot physiology, theoretically modeled on the basis of growth rate, can help in choosing the best period and most effective intensity for the pruning of each new cultivar in the different training systems of a particular growing area.

We can generalize that summer pruning reduces vigor and induces greater flower production. Early long shoot heading back is more effective with high vigor varieties and fertile soil conditions, whereas short shoot and branch head back pruning is favorable for weak and spreading varieties, although the latter habit could be more easily controlled by winter pruning than the former.

Varieties of group A, such as some of the new varieties, benefit from early summer pruning (early heavy shoot heading back) in order to induce the formation of sylleptic shoots; and summer pruning (without heading back but possibly with shoot thinning) to encourage shoots to be more lignified. Group B performs best after winter pruning (shoot thinning and heading back of two- to three-year-old branches). Group C may be pruned in late summer or at the end of winter (shoot thinning, heading back the branches), depending on local growing conditions. In order to limit the development of sylleptic shoots, which only bear small fruits, it is better to carry out heading back in late summer instead of in the winter.

In any case, every pruning strategy must be tested on each variety before it is adopted throughout commercial orchards. This is due to the possible very specific influence of varietal differences in chilling requirements, and specific shoot and flower differentiation physiology.

2. Peach

In modern peach orchards, application of spring and summer pruning is increasing (from 20% up to 60% of the total amount of pruning), depending on the training system, production area and farm management (Giovannini *et al*., 2010). Peach shows good ability to form sylleptic shoots and strong epinastic control that makes the sylleptic shoot insertion angles wider moving from the top to the basal part of the shoot. These features require an appropriate shoot pruning technique and finally, if well managed, lead to dwarf the tree with the open habit of mature peach plants.

During training of modern intensive orchards, spring pruning is therefore applied more than summer pruning (and obviously of winter pruning), in order to address the inclination of vigorous growing shoots and to anticipate formation of the skeleton structure of the canopy. The removal of mal-positioned water sprouts and stimulation of a higher number of well positioned shoots (Ferree *et al*., 1984; Lanzellotti *et al*., 1998) finally dwarf the trees (Kappel and Bouthillier, 1995; Hossain and Mizutani, 2008).

The second goal of a greater use of spring and summer pruning is to reduce the vegetative unproductive phase and enhance early bearing in all new training systems (Giovannini *et al*., 2010; Neri *et al*., 2010). Summer pruning is applied to shorten the not-fruiting initial phase, improve light distribution on fruiting shoots and strengthen the future scaffold branches with a higher number of fruiting shoots (Miller, 1987).

Nevertheless, pruning time in less intensive orchards is often determined by farm organization, depending on the availability of labor and arrangement of the working schedule, rather than on the plant physiology (Chalmers *et al*., 1981; Marini and Barden, 1987; Sansavini and Neri, 2005).

Pruning can be also applied in the spring for biological reasons. In fact for some cultivars pruning intensity can be adjusted near blooming time, when flower buds enlarge and become more visible, depending on the quantity of buds that were damaged by frost during the winter. This kind of spring pruning can thus augment fruit set per tree.

If the risk of frost damage is extended to blooming time, pruning can be carried out precisely during the fruit set period. In this case "winter pruning" is completely substituted by an early spring pruning which eliminates the excess shoots, based on the rate of fruit set, by heading back two-year-old branches.

Late spring pruning is commonly used for training, but in modern orchards it is not very common to control production if trees are mature and equilibrated. Also early summer pruning, before harvest time, is used only to thin the water sprouts and to improve light distribution in the canopy, whenever the vigor is too high, to increase fruit color and quality and to prevent diseases. However when this pruning is too heavy or too early it can negatively affect fruit development.

Summer pruning after harvest can better manage excess vegetative growth and change the distribution of assimilates (Rom and Ferree, 1984; Marini, 1985; Mizutani *et al*., 1997; Hossain *et al*., 2004). It improves bud differentiation and branch hierarchy organization. During summer, shortening branches results in a more regular sprouting in the following spring, with less vigorous shoots and high quality flower buds. In some cultivars, when it is necessary to cut big branches, the summer period is useful also because it induces a more rapid and efficient wound healing. This sort of pruning can also be considered when it is necessary to mitigate severe water stress (Lopez *et al*., 2006; Marsal *et al*., 2006).

Late summer pruning in August-September is important and widespread in all environments because it contributes to reduce canopy volume and allows shoot hardening. It partially prevents winter pruning (therefore it is called pre-winter pruning) and strongly reduces the need for it. Furthermore, it is more selective than winter pruning as the best buds for fruit set are chosen in advance.

Summer pruning for peach training systems in Mediterranean climate

Depending on the training system, both spring and summer pruning are applied to favor the branch inclination of shoots through pinching or cutting the upper part of the shoot to induce sylleptic ramification (Fig. 6), also more than once per season as is done for the Catalonian vase (Monserrat and Iglesias, 2011).

Removal of excess and mal-positioned shoots is also practiced to give a regular shape to the spindle and to the small open vase (Neri *et al*., 2010). In any case, the pruning intensity is minimal and eventually some spring interventions are postponed from the first to the second year, and/or continued in the third if tree vigor is too weak.

In Mediterranean areas, with long growing season and early ripening cultivars, also vase training systems (i.e. low open vase) are commonly managed with the application of spring-summer pruning. In fact small vase formation can be improved using summer shoot cuts to direct vegetative growth to the well displaced lateral sylleptic and proleptic shoots. Modern systems derived from the vase are characterized by a low scaffold (0.5 m above ground), low tree height (2.5 m), and free growth during the first years (bush type to enhance early bearing).

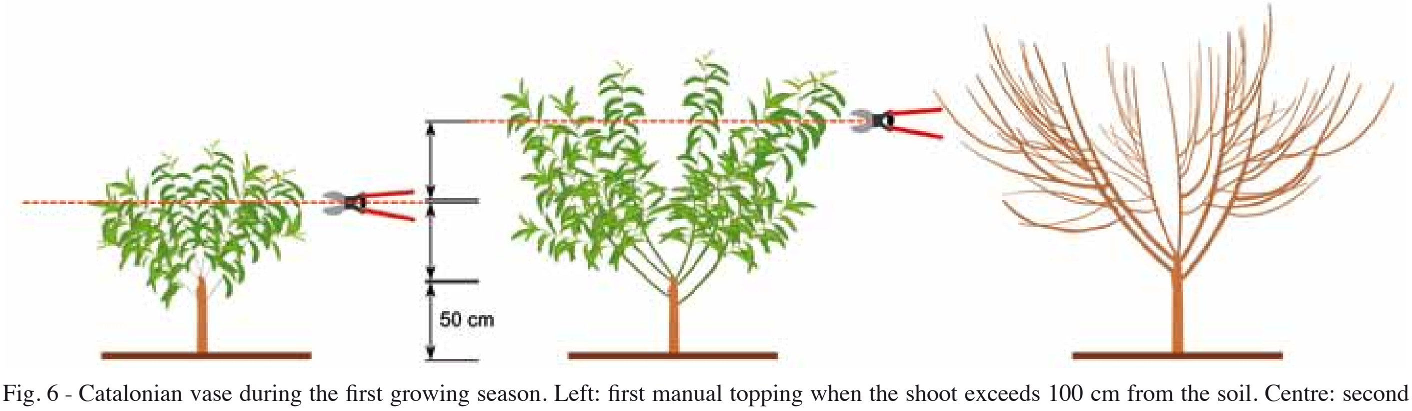

Fig. 6 - Catalonian vase during the first growing season. Left: first manual topping when the shoot exceeds 100 cm from the soil. Centre: second topping (manual or mechanical) when the shoots exceeds 150 cm from the soil. Right: the final growth at the end of the first year (redrawn from Monserrat and Iglesias, 2011).

The Catalonian vase, which originated in Spain, is the most recent and wide-spreading vase system. Spring-summer pruning is repeatedly employed to form and dwarf the trees during the first two years of training. Mechanical topping is applied every 50 cm till the final size of the plant is reached (2.5 m) at the end of second year (Figs. 6 and 7). Topping involves removing a few apical buds per shoot, thus inducing suppression of apical dominance and increasing the possibility for growth of the external sylleptic shoots. This sets off a temporary strong competition among all growing shoots, but in peach the external shoots are privileged, and thus the main shoots are naturally oriented toward the external direction. Finally, the whole plant height is lower but several shoots are well positioned to become the future branches of the vase.

During the second year, or third in the case of low fruiting cultivars, the vase shape can be completed by thinning the primary branches and cleaning the central part, mainly in late summer. In mature orchards, pruning labor in this system can require less than 100 hr/ha (60% during vegetative season), and the fruiting winter pruning (the remaining 40%) completes the late summer pre-winter pruning (Fig. 8).

Specific summer pruning is required also in the “Y” trellis system. Inclined branches with angles wider than 40-45° promote the growth of vertical shoots in the internal portion of the canopy and late spring and early summer pruning are necessary to remove them during the initial years. The high density planting of this system, the possibility to use long pruning, without eliminating shoot apex of primary branches, and the reliability of pruning during the vegetative season provide early fruiting. Nevertheless, the “Y” system is well performing only where climate conditions provide a high level of light, allowing the reduction of branch angles close to 30°, and thus reducing water sprout formation. This angle promotes a balanced vegetative growth and fruit production in all the lateral and basal portions of the two fruiting walls. “V” systems with double tree density and less vigorous rootstocks can be used to reduce further the need for spring and summer pruning. In this case, defining the two oblique productive planes is easier and more rapid but the cost of planting is very high and there is risk for overcrowding in the internal part of the canopy, which could induce an exponential increase in the need for pruning.

Spring and summer pruning in peach training systems for continental climate

In the northern part of Italy, where there are short growing seasons and high risk of frost in the spring, with midseason varieties high hedgerow systems (palmette and central leader, 4 m high) are still popular. This is because late spring frost may dramatically damage the production in the bottom part of the tree (first 2 m from the ground). In this condition pruning may be delayed after blooming (when fruit set is already complete). Thus winter pruning becomes an early spring pruning, while early summer

Fig. 8 - Catalonian vase during the fourth growing season at blooming in the Sibari area. The skeleton is completed and the plant is dwarf and equilibrated.

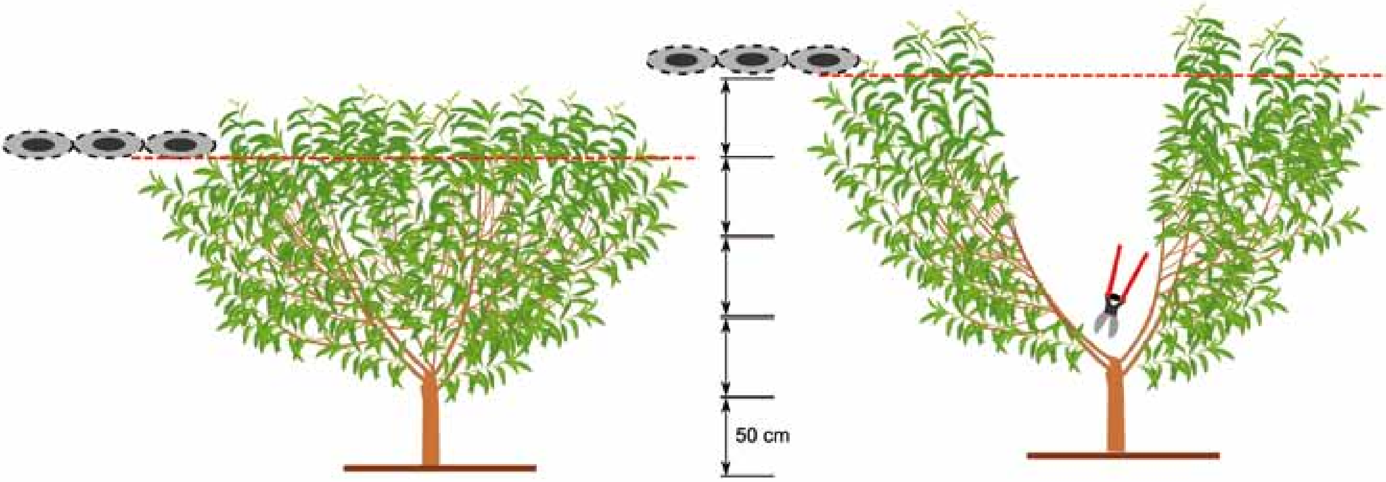

Fig. 7 - Catalonian vase during the second growing season. Left: first mechanical topping when the shoots exceed 200 cm from the soil. Right: second mechanical topping when the shoots exceed 250 cm from the soil, and manual pruning to thin the main branches down to four to five in number, opening the centre in very late summer. This last pruning is done only if the variety has a very high productivity (redrawn from Monserrat and Iglesias, 2011).

pruning is not frequent and limited to lightening the upper part of the canopy (if necessary).

During the training period to reduce shoot vigor of the mal-positioned water sprouts, turning and partially crashing them can improve their fruiting aptitude. Late summer pruning is used to maintain the shape of the trees and to increase lignification of the shoots that otherwise would be too shaded. The hedgerow made by trees trained as "U" or candelabras along the row requires less green pruning than palmette or central leaders because of less vigor of each vertical branch.

For training high density peach orchards, well feathered scions from the nursery must be used to obtain fruit production in the second year. In mature orchards, green pruning is mandatory in two specific seasons: i) in early spring before harvest to eliminate water sprouts and to induce a higher number of productive shoots in well defined positions; after fruit set it is also possible to thin the shoots proportionally to the amount of fruit set; and ii) in late summer after harvest to anticipate the winter pruning (pre-pruning). In this case the water sprouts are eliminated and the vigorous shoots on the main branches are cut only if there is excess flower differentiation; the top part of the branches can be reduced to better permit light distribution in the canopy. If the pre-pruning in late summer is well executed with light shoot thinning, winter pruning can be avoided. In this way labor can be saved and/or better organized.

In low bush open vase (delayed open vase) (Sansavini and Neri, 2005), for the first three-four years the training of the trees is free with only a few pruning cuts; green pruning is not important. Late summer pruning becomes important in the third to fourth year to cut the central leader and to open the centre of the vase. In the fourth to fifth year, the main branches are headed back and the tree is completely formed as a vase. Finally, pre-winter pruning is necessary to manage fruit shoot quality and quantity when production becomes important (starting from the third year).

Production pruning

When the tree is well mature and fully formed, spring pruning is less important and must be carried out only in very specific cases when excess vigor of the growing shoots can compete with the growing fruits, interfering with the fruit quality and flower induction for the next year.

Peach production is located on one-year shoots (brindles, fruiting shoots and in some varieties also in water sprouts) and in a very limited quantity on the spurs (these are important only in clingstone peaches and in some nectarines with low fertile shoots). Because of this specific fruiting behavior, it is very important to control shoot growth to form highly specific shoots in each variety (Day *et al.*, 1989).

If the vigor is very high (generally in early ripening varieties) it is necessary to execute the first pruning before harvest in late spring in order to eliminate mal-positioned water sprouts and to improve light distribution in the canopy. Whereas pruning in late summer is very helpful both in early and late ripening varieties to improve the quality of the fruiting shoots, favoring shoot hardening and carbon allocation. To improve light distribution in the canopy it is important to thin the shoots and to head back the branches. This pruning in late summer anticipates winter pruning, which consequently can be delayed at blooming to determine the final number of flowers per plant. Winter pruning can even be eliminated and early spring pruning after fruit set can be applied to determine more precisely the number of fruits per plant.

It is important to remember that avoiding heavy shading is important to obtain homogeneous distribution of the shoots along a branch. In fact when the shoots are shaded they can be damaged during winter and necrotize. Because peach trees do not produce adventitious meristems and do not maintain latent buds for long, winter pruning is not able to recover new adventitious shoot growth and finally the shaded area of the canopy is lost.

To avoid this dramatic loss of efficiency of the internal part of the canopy, spring- summer pruning is mandatory in modern orchards. This problem is even more accentuated in high density planting systems in which early spring pruning can be associated with fruit thinning to reduce the impact of self shading and inter shading on shoot and fruit quality. Traditional low density orchards under continental conditions are mainly pruned using precise winter pruning because once the open vase is well formed it provides high quality and constant fruit production.

3. Conclusions

In apricot each group of varieties has its own optimum season and intensity for pruning, according to fruiting aptitude and branch habit. For high density orchards, heavy late spring pruning may be used to reduce vigor and improve flower differentiation during the summer. For free open vase, use of late summer pruning only can be suggested to obtain a better carbon partitioning towards the fruiting shoots and a more uniform light distribution in the canopy.

The higher the flower differentiation aptitude, the greater the possibility to use different seasons for pruning. With low aptitude, manipulation of spring growth of the shoots and light distribution in the canopy through spring-summer pruning is mandatory.

Apricot varieties can be classified into groups characterized for different vegetative and reproductive habits, accordingly and depending on the fertility of the soil, they can be pruned in summer (if soil fertility is high) or in winter (if soil fertility is low).

Some of the new low productive varieties benefit from early summer pruning (early or late spring shoot heading back) to induce the formation of sylleptic shoots and to obtain good flower differentiation. Weak varieties perform the best after winter pruning (branch heading back). Other, very productive varieties may be pruned in late summer or at the end of winter (shoot or branch heading back) depending on local growing conditions (Pirazzini, 2004).

In peach, habit is mainly influenced by assurgent growth in low chilling varieties that are well adapted to the mild Mediterranean climate with low chill in winter, and by the widespread habit of the varieties, suitable for more continental climatic conditions with cold winters and tolerant to late frost in the spring.

Among these groups of varieties, flower aptitude is another factor which influences the type and intensity of spring and summer pruning. In modern peach orchards, late summer pruning is widely diffused as a common practice to manage light distribution and carbon allocation and finally shoot quality. This technique is applied in substitution or to reduce the amount of the winter pruning.

Late spring pruning is applied only if necessary when tree vigor is too high, while early spring pruning is used less and limited only to cases of unpredictable fruit set due to erratic climatic conditions. In any case, the labor for all kinds of pruning (spring, summer, and winter pruning) takes not more than 100 hours per hectare per year.

With some very productive varieties and appropriate training systems (delayed open vase and free spindle) it is possible to reach an amount of labor for all the manual operations during the season of about 15 hours per ton of fruit (Giovannini *et al*., 2010; Neri *et al*., 2010).

During training of Catalonian vase in the first two years, spring and summer pruning can be mechanized with a moving machine to further reduce labor. Late summer pruning may start in the second year for heavy producing varieties and in the third year for the less productive ones.

In conclusion, spring and summer pruning increase the efficiency of labor (both for the ease and speed of the work and for the capability of the tree to rapidly compensate for errors and incorrect interventions) and improve fruit quality. Late summer pruning can particularly improve modern orchard management efficiency.

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References

BASSI D., GUERRIERO R., GUERRIERI F., MONTELEONE P., RIZZO M., VITI R., 2003 - *Apricot*, pp. 24-49. - In: BASSI D. (ed.) *Growth habit in stone-fruit trees*. Il divulgatore, Bologna, Italy.

CHALMERS D.J., MITCHELL P.D., VAN HEEK L., 1981 - *Control of peach tree growth and productivity by regulated water supply, tree density and summer pruning*. - J. Am. Soc. Hortic. Sci., 106: 307-312.

DAY K.R., DEJONG T.M., HEWITT A., 1989 - *Postharvest and preharvest summer pruning of 'Firebrite' nectarine trees*. - HortScience, 24: 238-240.

FERREE D.C., MYERS S.C., ROM C.R., TAYLOR B.H., 1984 - *Physiological aspects of summer pruning*. - Acta Horticulturae, 146: 243-252.

GIOVANNINI D., NERI D., DI VAIO C., SANSAVINI S., DEL VECCHIO G., GUARINO F., PENNONE C., ABETI D., COLOMBO R., 2010 - *Efficienza gestionale degli impianti di pesco in un confronto Nord-Sud*. - Frutticoltura, 7/8: 16-26.

GUERRIERO R., SCALABRELLI G., 1982 - *Relationship between bud dormancy and growing and fruiting behaviour on different apricot varieties along the Tuscan coast line. A) changes of one year shoot morphogenetic gradient during rest period*. - Acta Horticulturae, 121: 85-92.

GUERRIERO R., VITI R., 1997 - *Problemi relativi alla biologia fiorale e di fruttificazione dell'albicocco*. - Italus Hortus, 4: 29-36.

GUERRIERO R., XILOYANNIS C., 1975 a - *Comportamento produttivo di alcune cultivar di albicocco nel litorale toscano*. - Proceeding of "Problemi e prospettive della coltura dell'albicocco", Imola, Italy, pp. 83-92.

GUERRIERO R., XILOYANNIS C., 1975 b - *Rapporti tra andamento climatico, dormienza habitus vegetativo e produttivo nell'albicocco*. - Proceeding of "Problemi e prospettive della coltura dell'albicocco", Imola, Italy, pp. 35-44.

HOSSAIN A.B.M.S., MIZUTANI F., 2008 - *Dwarfing peach trees and fruit quality development by using summer pruning as physiological changed dwarfing component*. - Austr. J. of Basic and Appl. Sci., 2: 844-849.

HOSSAIN A.B.M.S., MIZUTANI F., ONGUSO J.M., 2004 - *Effects of summer pruning on maintaining the shape of slender spindle bush of peach tree grafted on vigorous rootstock*. - J. of the Jap. Soc, of Agric. Tech. Manag., 11: 55-62.

KAPPEL F., BOUTHILLIER M., 1995 - *Rootstock, severity of dormant pruning, and summer pruning influences on peach tree size, yield, and fruit quality*. - Canadian J. of Plant Sci., pp. 491-496.

LANZELOTTI J., GONZALEZ B.A., BORAGNO O.A., 1998 - *Different dates of pruning in peach tree*. - Acta Horticulturae, 465: 629-635.

LOPEZ G., MATA M., ARBONES A., SOLANS J.R., GIRONA J., MARSAL J., 2006 - *Mitigation of effects of extreme drought during stage III of peach fruit development by summer pruning and fruit thinning*. - Tree Physiology, 26: 469-477.

MARINI R.P., 1985 - *Vegetative growth, yield and fruit quality of peach as influenced by dormant pruning, summer pruning and summer topping*. - J. Am. Soc. Hortic. Sci., 110: 133-139.

MARINI R.P., BARDEN J.A., 1987 - *Summer pruning of apple and peach trees*. - Horticultural Reviews, 9: 351-375.

MARSAL J., LOPEZ G., MATA M., GIRONA J., 2006 - *Branch removal and defruiting for the amelioration of water stress effects on fruit growth during Stage III of peach fruit development*. - Scientia Horticulturae, 108: 55-60.

MILLER S.S., 1987 - *Summer pruning affects fruit quality and light penetration in young peach trees*. - HortScience, 22: 390-393.

MIZUTANI F., RABBANY A.B.M.G., AMANO S., HINO A., AKIYOSHI H., KADOYA K., 1997 -*Effect of summer pruning and gibberellin application on reduction of flower bud formation in "Saotome" peach (*Prunus persica *Batsch.)*

trees grafted on P. japonica *rootstocks*. - Bulletin of the Experimental Farm College of Agriculture, Ehime University, Japan, 18: 1-8.

MONSERRAT R., IGLESIAS I., 2011 - *I sistemi di allevamento adottati in Spagna: l'esempio del vaso catalano*. - Frutticoltura, 7/8: 18-26.

NERI D., 2003 - *Ipertesto potatura*. - CRPV, Cesena, Italy.

NERI D., GIOVANNINI D., MASSAI R., DI VAIO C., SANSAVINI S., DEL VECCHIO G., GUARINO F., MENNONE C., ABETI D., COLOMBO R., 2010 - *Efficienza produttiva e gestionale degli impianti di pesco in un confronto Nord-Sud*. - Italus Hortus, 17(3): 46-62.

NERI D., MASSETANI F., GIORGI V., 2011 - *La potatura*. - Edagricole, Bologna, Italy, pp. 370.

NERI D., MORINI F., MASSETANI F. PIRAZZINI P., 2010 - *Pruning: how to manage shoot growth*. - Acta Horticulturae, 862: 355-363.

PIRAZZINI P., 2004 - *Osservazioni sulla potatura di produzione di alcune varietà di albicocco*. - Frutticoltura, 1: 36-38.

ROM C.R., FERREE D.C., 1984 - *The influence of summer pruning current season shoots on growth, floral bud development and winter injury of mature peach trees*. - HortScience, 19: 543-545.

SANSAVINI S., NERI D., 2005 - *Forme di allevamento e potatura,* pp. 115-143. - In: FIDEGHELLI C., and S. SANSAVINI (eds.) *Pesco*. Edagricole, Bologna, Italy, pp. 259.

ZUCCONI F., 2003 - *Nuove tecniche per i fruttiferi*. - Edagricole, Bologna, pp. 246.

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Summer pruning to maintain slender spindle bush type of peach trees grafted on vigorous rootstocks

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Key words: peach, pruning, shading, shoot heading back, summer shoot thinning.

Abstract: The slender spindle bush type system is commonly used for compact-sized trees, especially grafted on dwarfing rootstocks. It is difficult to apply this system to trees grafted on vigorous rootstocks by winter pruning. Such practices only cause the trees to repeat imbalanced vegetative-oriented growth every year. Therefore, in the current work summer pruning was applied to slender spindle bush type of early maturing peach trees grafted on vigorous rootstocks. Three trials were conducted: summer shoot thinning, shoot heading back trials in the field and a shoot heading back and shading trial in the pot experiment. Summer shoot thinning reduced tree growth and recovered proper balance between vegetative and reproductive growth. The following season such shoot thinning enhanced bud burst and initial growth of new shoots but the final tree growth was less in the summer-pruned trees compared with winter-pruned trees. The fruit matured earlier and soluble solids content was greater and titratable acidity was lower in the summer-pruned trees. The summer shoot heading back trial revealed that it regenerates shoots, although they bear fewer flower buds compared with winter-pruned trees. Such heading back is effective to keep alive shoots and buds near the trunk in slender spindle bush type systems. Summer shoot heading back and shading experiments in the pot showed that shading reduced the number of regenerated shoots and flower bud formation and delayed flower blooming in the following year. Thus summer shoot thinning and heading back are applicable to early maturing peach cultivars grafted on vigorous rootstocks to maintain the slender spindle bush type because thinning favors reducing tree vigor and light penetration near the trunk, and heading back keeps alive shoots and buds near the trunk which otherwise weaken or die back due to apical dominance and/or shading.

1. Introduction

Slender spindle bush types are commonly used for compact-sized fruit trees such as apple cultivars grafted on dwarfing rootstocks. Peach trees can be dwarfed and trained as slender spindle types when they are grafted on *Prunus tomentosa* and *P. japonica* (Mizutani *et al*., 1985; Yaegaki *et al*., 2008). However, these rootstocks often show graft-incompatibility for some peach scion cultivars several years after grafting (Nakano and Shimamura, 1983; Yaegaki *et al*., 2008). It is difficult to maintain trees grafted on vigorous rootstocks as slender spindle types by winter pruning. Their shoot growth is so great that the inside parts of the tree are shaded, resulting in poor growth and even death of shoots near the trunk. In relation to shading, Neri *et al*. (2003) reported that shading caused leaf wilting, necrosis and abscission earlier under water-stressed conditions. It is important to maintain shoots and buds alive near the trunk to maintain the slender spindle types. Otherwise, shoots extend outward resulting in the crown type of tree. However, when the tree vigor is so great, severe annual winter pruning only repeats imbalanced vegetative-oriented growth cycles each year. Commercial fruit production is difficult under such conditions. Many reasons have been given to support the practice of summer pruning in peach trees. It has been reported that summer pruning reduces vegetative growth, improves light penetration, enhances fruit quality, concentrates fruit maturation and increases the number of flower buds.

In general, it is considered that the time of flower bud formation in deciduous fruit trees is around late July and August in the temperate zones of the Northern Hemisphere. Thus, the time of summer pruning is very important in relation to flower bud formation, especially when heading back pruning is conducted. After summer heading back pruning, new shoots are regenerated from remaining twig parts. Even thinning out pruning sometimes enhances branching and burst of buds which otherwise remain quiescent. In relation to shoot regrowth after summer pruning, Neri *et al*. (1992) reported that it was induced only when the whole root system was well irrigated. After summer pruning the regenerated shoots are considered physiologically young compared with the spring flushes. In apple trees, the earlier the pruning time, the greater the number of flower buds (Mizutani *et al*., 2000). Apple flower buds tend to bear in the apical buds of shoots. When summer pruning is carried out earlier, new plural shoots come out and bear flower

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buds in each shoot apex resulting in greater flower bud numbers (Mizutani *et al*., 2000). However, later summer pruning diminishes such effects. It seems likely that a certain period is required for regenerated shoots to bear flower buds. Erez (1982) also reported that in the meadow orchard system of peach trees, four to five months are required for sufficient shoot regeneration and flower bud formation. Therefore he recommends that such systems are only applicable to early maturing cultivars, with a long enough growing season after fruit harvest.

Three trials (summer shoot thinning, heading back in the field, and heading back and shading in the pot) were conducted in the present work to develop new methods to maintain slender spindle bush type peach trees grafted on vigorous rootstocks.

2. Maintaining tree shapes as slender spindle bush type in peach trees grafted on vigorous rootstocks by summer shoot thinning

A. Objectives

At first we tried to maintain tree shapes as slender spindle bush type with 'AB-1' ('Akatsuki'x unknown peentao) peach trees grafted on vigorous rootstock (*Prunus persica* Batsch, wild form) by winter pruning. The trees grew well in the orchard (previously vineyard) in spite of the fact that chemical fertilizers were not applied. It was difficult to maintain tree shape as slender spindle type while producing quality fruit annually. To keep shoots and buds near the leader trunk, excessive severe winter pruning was practiced. Such practices resulted in an improper balance between vegetative and reproductive growth. The vegetative-oriented growth is represented by vigorous shoot growth, poor fruit set, much June drop and delayed fruit maturation. When the peach trees are vigorous, severe winter pruning only repeats such a tree cycle every year. Therefore, the objective of the first trial in the field was to determine whether summer shoot thinning can alter such imbalanced tree growth to the proper balance in the slender spindle type of peach trees grafted on vigorous rootstocks.

B. Materials and Methods

The orchard used in the experiment was formerly a vineyard to which chemical fertilizers had been applied according to a standard instruction in the Experimental Farm, Faculty of Agriculture, Ehime University. For the purpose of dwarfing peach trees grafted on vigorous rootstocks, we planned no application of chemical fertilizers during the course of experiments. By using nine-year-old 'AB-1' peach trees which had so far received winter pruning, we tried summer pruning to maintain the tree as slender spindle bush type. The harvest time of 'AB-1' peach is mid July. Summer pruning was conducted just after fruit harvest; most of it was conducted as thinning out methods not heading back. The weight of pruned shoots and leaves was measured. The following year new shoot growth, flowering, leaf mineral content, fruit growth and quality of harvested fruit were determined.

C. Results

Figure 1 shows summer- and winter-pruned trees just after summer pruning on 24 July. The weight of shoots removed by summer pruning was less than that removed by winter pruning (Fig. 2).

Fig. 1 - Peach trees just after summer pruning on 24 July (left: tree after summer pruning; right: tree without summer pruning)

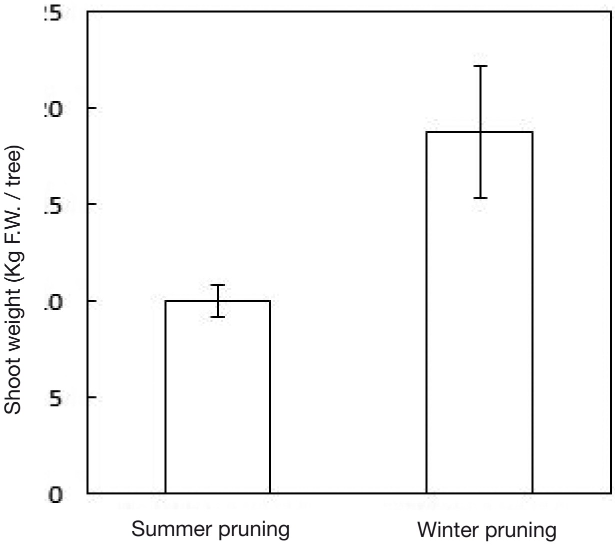

Fig. 2 - Weight of shoots removed by summer and winter pruning from peach trees. Data are presented as mean ± standard error (SE).

However, in the case of winter-pruned trees, there were no leaves at pruning time so that the actual biomass removed from the winter-pruned trees was much greater than the shoot weight pruned. Three or four days earlier bud break and flowering were observed in summer-pruned trees compared with winter-pruned trees in the following year (Fig. 3). The ovary size was greater in summer-pruned trees (Fig. 4).

The number of flowers however was less in summer-pruned trees (Fig. 3), while mineral and carbohydrate content in the new leaves and shoots was greater in the summer-pruned trees (Figs. 5 and 6). This indicates that the shoots remaining after summer pruning received enough

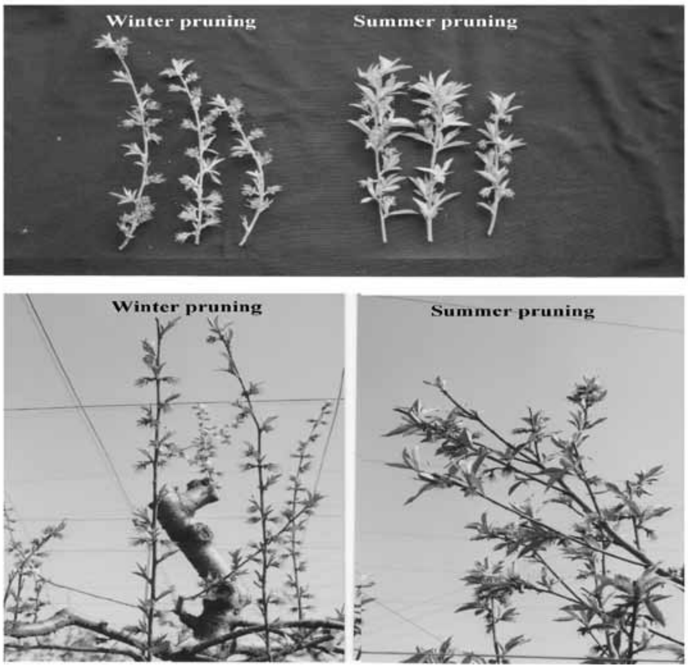

Fig. 3 - Effect of summer and winter pruning on the formation of new shoots, leaves and flowers of peach trees in the following season on April 4.

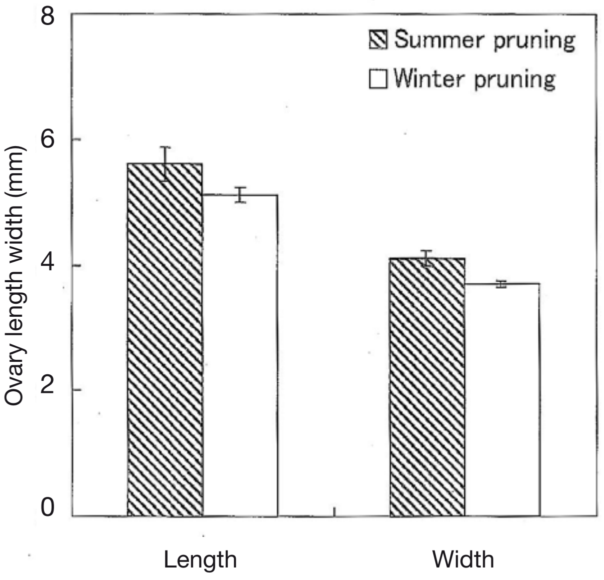

Fig. 4 - Effect of summer and winter pruning on ovary size of peach flowers on 4 April. Data are presented as mean ± standard error (SE).

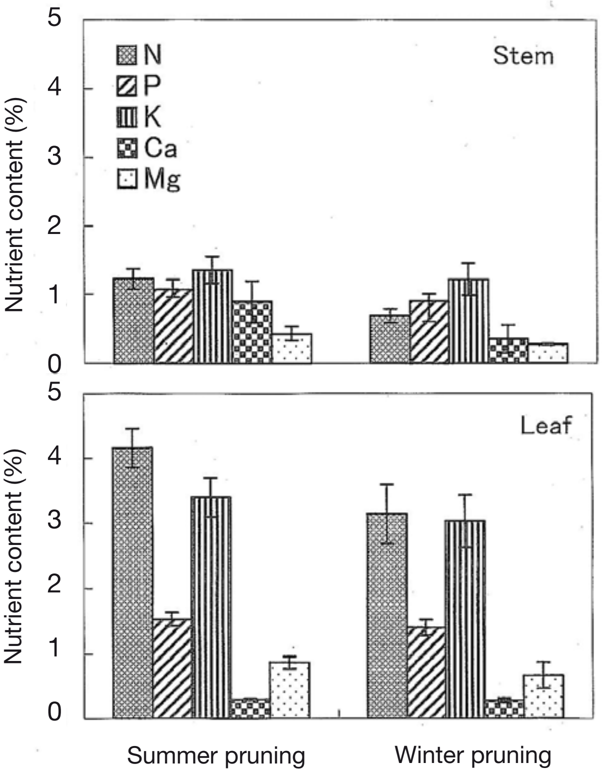

Fig. 5 - Effect of summer and winter pruning on mineral content of stems and leaves in peach trees on 4 April. Data are presented as mean ± standard error (SE).

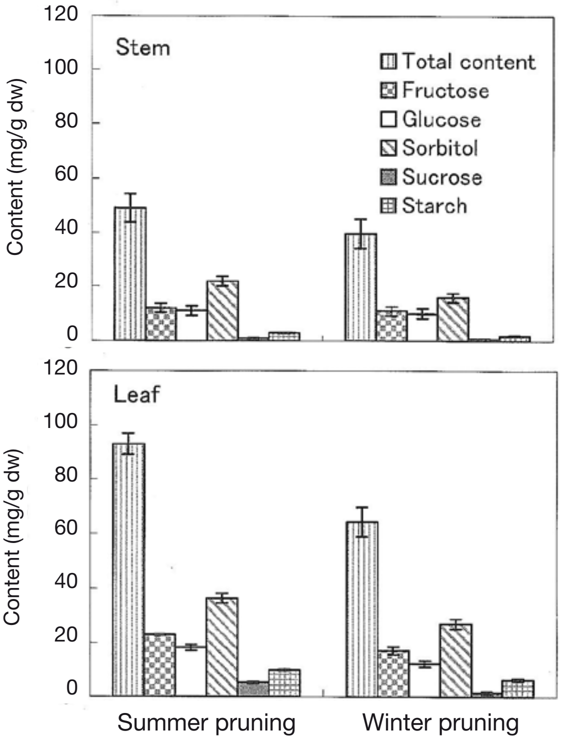

Fig. 6 - Effect of summer and winter pruning on sugar and starch content in stems and leaves in peach trees on 4 April. Data are presented as mean ± standard error (SE).

solar radiation to accumulate carbohydrate as reserves and mineral nutrient from the roots. On the other hand, in the winter-pruned trees, the shoots remaining near the trunk are supposed to have been shaded in the previous summer and fall. Although the initial tree growth was slightly enhanced in the summer-pruned trees, the shoot growth was accelerated in the winter-pruned trees in the middle growing season and final tree size became greater in the latter group (Fig. 7).

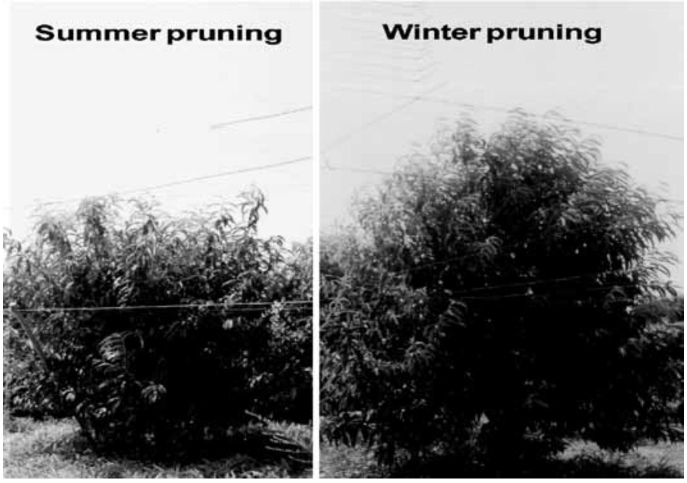

Fig. 7 - The photos show tree sizes on 24 July in the following year.

Fruit number and yield per tree were greater in the summer-pruned trees (Tables 1 and 2). Fruit weight was similar in both treatments but fruit seemed to mature earlier in summer-pruned trees. In this regard, the total soluble solids content in the juice was greater and titratable acidity was lower in summer-pruned trees. Thus, summer shoot thinning seems to be applicable to vigorous peach trees grafted on vigorous rootstocks in slender spindle bush type system to recover balanced vegetative and reproductive growth.

3. Shoot regeneration and flower bud formation after summer shoot heading back

A. Objectives

Because of apical dominant nature of shoots, the terminal shoot grows well, which retards the growth of lateral shoots. Whereas the apical part of buds on shoots burst and extend, the lower part of buds mostly remain quiescent. In the slender spindle bush type of tree it is very important to keep alive buds or shoots near the trunk. Without shoot heading back, terminal shoots extend outward, while the inside of the crown becomes shaded and shoots and buds near the trunk die back.

In the second trial in the field, we examined the effects of summer shoot heading back on shoot regeneration, leaf chlorophyll content (SPAD value), leaf drop and flower bud formation by using peach tree grafted on vigorous rootstocks.

B. Materials and Methods

Five-year-old ‘Hikawahakuho’ peach trees grafted on vigorous rootstock (*Prunus persica* Batsch, wild form) which were trained as slender spindle type were used. The harvest time of this cultivar is early July. Trees had been trained as slender spindle bush type by winter pruning before the experiment started. No chemical fertilizers were applied, as mentioned above, because the orchard was formerly a vineyard where the recommended amount of fertilizers had been applied according to the standard instruction. Tree vigor of ‘Hikawahakuho’ peach grafted on vigorous rootstocks used in this experiment was less compared with ‘AB-1’ peach described above in the previous section. Summer pruning consisted of heading back of current shoots to about 10 cm and removal of vigorous shoots, which was conducted after fruit harvest on 15 July. The number of regenerated shoots, shoot growth, flower bud formation, SPAD values and leaf drop were deter-

Table 1 - Effect of summer pruning on peach fruit yield and quality in the following season (2001)

Treatment	Fruit/tree (No.)	Yield (Kg/tree)	Fruit weight (g)	Fruit length (mm)	Fruit diameter (mm)	SSC (%)	Titratable acidity (%)
Summer pruning	136.0±36.7	13.0±3.1	102.2±5.3	59.4±0.7	62.2±0.7	9.27±0.26	0.27±0.01
Winter pruning	96.2±5.3	8.7±0.8	102.2±4.0	58.4±0.5	60.7±0.4	8.45±0.24	0.52±0.04

Data are presented as mean ± standard error (SE).

Table 2 - Effect of two-successive-year summer pruning on peach fruit yield and quality in the following season (2002)

Treatment	Fruit/tree (No.)	Yield (Kg/tree)	Fruit weight (g)	Maturity degree (Z)	SSC (%)	Titratable acidity (%)
Summer pruning	76.8±15.0	8.3±2.1	108.9±4.4	3.7±0.4	12.10±0.32	0.20±0.01
Winter pruning	66.4±8.0	6.6±1.0	103.5±3.5	2.4±0.3	9.31±0.29	0.45±0.08

(Z) For maturity degree, the score was given to green fruit=1 and ripen fruit=5.
Data are presented as mean ± standard error (SE).

mined. The following year, tree growth and fruit yield and quality were determined.

C. Results

Figures 8 and 9 show the shoot regeneration after summer pruning. There was no regrowth of shoots in winter-pruned trees. SPAD values of leaves were greater in summer-pruned trees than winter-pruned trees (Fig. 10). Leaf retention was prolonged by summer pruning (Fig. 11). Mierowska *et al*., (2002) also reported that in apple spur leaf total chlorophyll content was higher in summer-pruned than non-pruned trees. These facts indicate that regenerated shoots are physiologically young compared with spring flushes. The percent of flower buds were lower in summer-pruned trees than winter-pruned trees (Table 3); total shoot length in the following year was less in summer-pruned trees (Table 3).

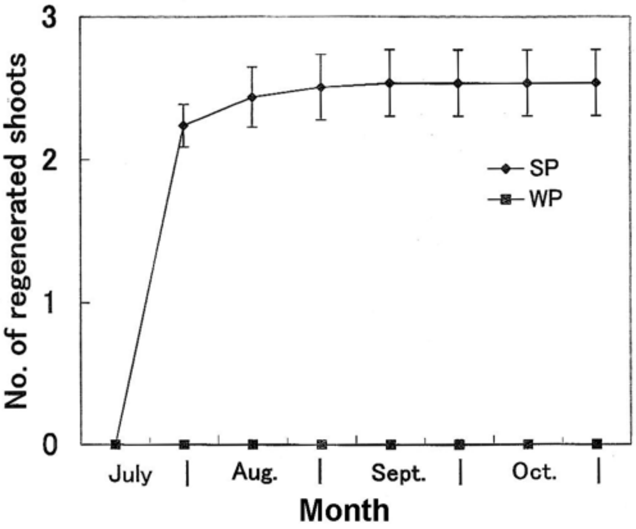

Fig. 8 - Effect of summer pruning on regenerated shoot numbers of peach trees. Data are presented as mean ± standard error (SE).

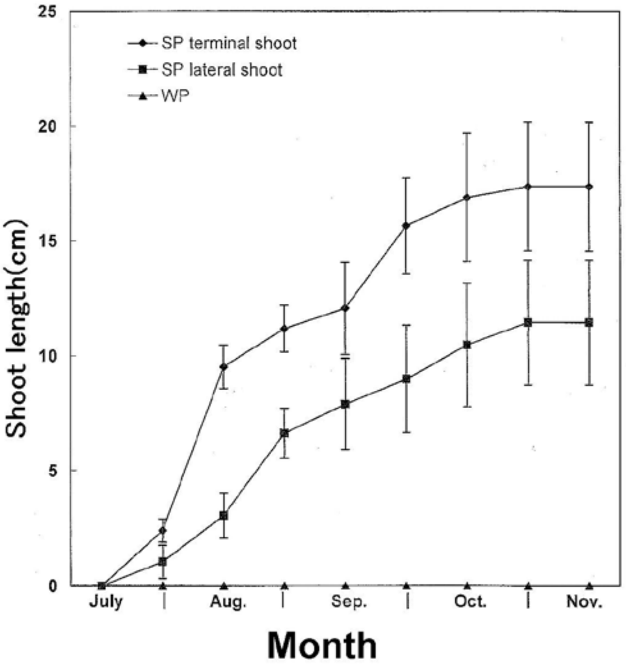

Fig. 9 - Effect of summer pruning on the regenerated shoot length of peach trees. Data are presented as mean ± standard error (SE).

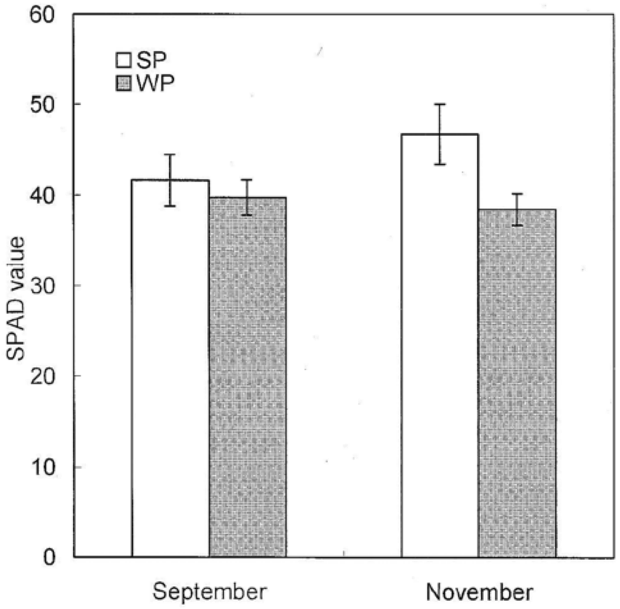

Fig. 10 - Effect of summer pruning on SPAD (chlorophyll content) in the leaves of peach trees in September and November. Data are presented as mean ± standard error (SE).

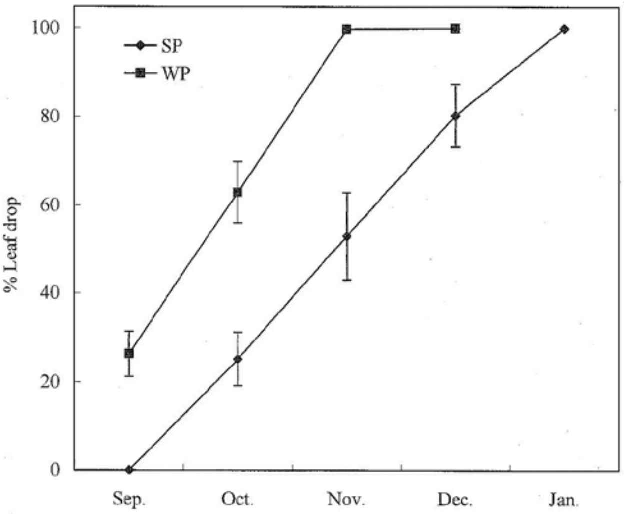

Fig. 11 - Effect of summer pruning on leaf drop in peach trees from September to late January. Data are presented as mean ± standard error (SE).

Table 3 - Effect of summer pruning on flower bud formation and total shoot length of peach trees in the following year

Treatment	Flower buds (%)	Total shoot length in the following year (m)
Summer pruning	17.2±4.5	21.8±4.9
Winter pruning	65.7±8.7	45.0±9.0

Data are presented as mean ± standard error (SE).

Therefore it can be said that the tree size of summer-pruned trees was reduced compared with winter-pruned trees. Figure 12 shows single year and two-successive-year summer pruning on the weight of shoots pruned. Two-successive-year summer pruning reduced the weight of pruned shoots. Fruit quality of harvested fruit as affected by single year and two-successive year summer pruning is presented in Table 4. Summer pruning enhanced maturation and increased soluble solids contents and reduced titratable acidity.

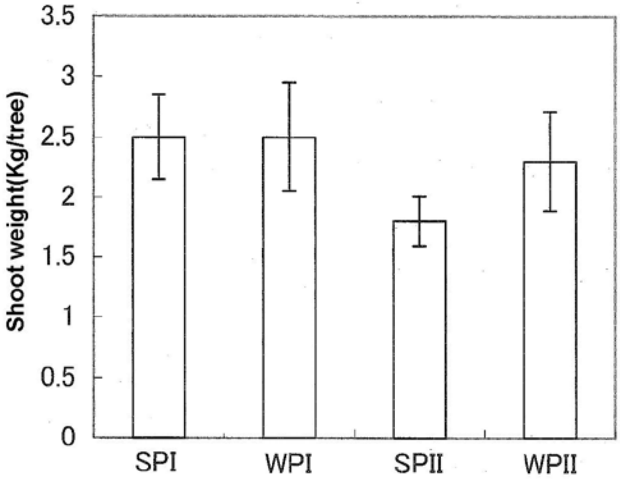

Fig. 12 - Effect of summer and winter pruning on pruned shoot weight of peach trees. Summer-pruned shoots include leaves. SPI, WPI and SPII, WPII indicate single-year and two-successive-year pruning, respectively. Data are presented as mean ± standard error (SE).

4. Shoot regeneration and flower bud formation after summer shoot heading back under shaded conditions

A. Objectives

It is important to keep alive shoots and buds near the trunk to maintain peach trees as a slender spindle type. Since shoots have apical dominance, terminal shoots extend outward so that inner parts of the crown become shaded without pruning. We further examined the effects of shading and summer shoot heading back on shoot regeneration and flower bud formation by using peach trees grafted on vigorous rootstocks in the pot trial.

B. Materials and Methods

Potted (30 cm diameter) one-year-old ‘Hikawahakuho’ peach grafted on vigorous rootstock (wild form) were used in the trial. Fertilizers (N, P_2O_5, K_2O=15%, 15%,15%) were applied at the rate of 30 g and 15 g per pot in mid March and early September, respectively. Treatments consisted of shading with white and black cheesecloth, shoot heading back (to 5 cm length from shoot base) and their combinations. Summer shoot heading back was conducted on 1 September. The number and length of regenerated shoots, leaf drop, SPAD values, flower bud formation and flowering time were determined.

C. Results

No shoot regeneration was found without summer shoot heading back under either non-shaded or shaded conditions (Fig. 13). Summer shoot heading back regenerated shoots but shading reduced their number (Fig. 13). Heavy shading (black cheesecloth) accelerated shoot growth as compared to light shading (white cheesecloth) and non-shading (Fig. 14). The number of flower buds was reduced by summer pruning and the tendency was accelerated by shading (Fig. 15). Shading tended to delay bloom in the following spring (Fig. 16). This indicates that the inner side shoots of the tree crown delayed bud burst and initial shoot growth as described in winter-pruned ‘AB-1’ peach in the previous section (Fig. 3).

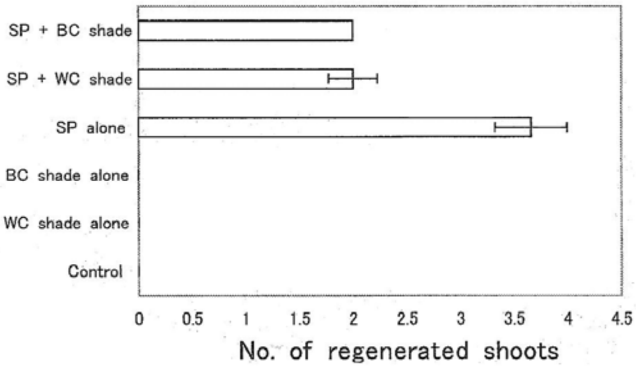

Fig. 13 - Effect of late summer pruning and shading on the number of regenerated shoots of peach trees. SP = summer pruning; WP = winter pruning, WC = white cheesecloth; BC = black cheesecloth. Data are presented as mean ± standard error (SE).

Table 4 - Effect of summer and winter pruning on fruit yield and quality in peach trees

Treatment	Fruit No./tree	Fruit weight (g)	Yield (Kg/tree)	Maturity degree (Z)	SSC (%)	Titratable acidity (%)
Summer pruning I (y)	28.1±4.1	131.0±0.5	3.7±0.7	3.5±0.4	12.8±0.2	0.27±0.03
Winter pruning I(y)	41.1±5.8	128.1±0.4	5.3±1.0	2.7±0.2	11.8±0.2	0.39±0.03
Summer pruning II	22.2±3.6	136.2±6.0	3.0±0.6	3.9±0.3	13.7±0.3	0.24±0.02
Winter pruning II	30.4±4.3	128.6±0.4	3.9±0.8	2.9±0.3	12.7±0.2	0.38±0.03

(Z) For maturity degree, the score was given to green fruit=1 and ripen fruit=5.
(Y) Indicate single-year and two-successive-year pruning, respectively.
Data are presented as mean ± standard error (SE).

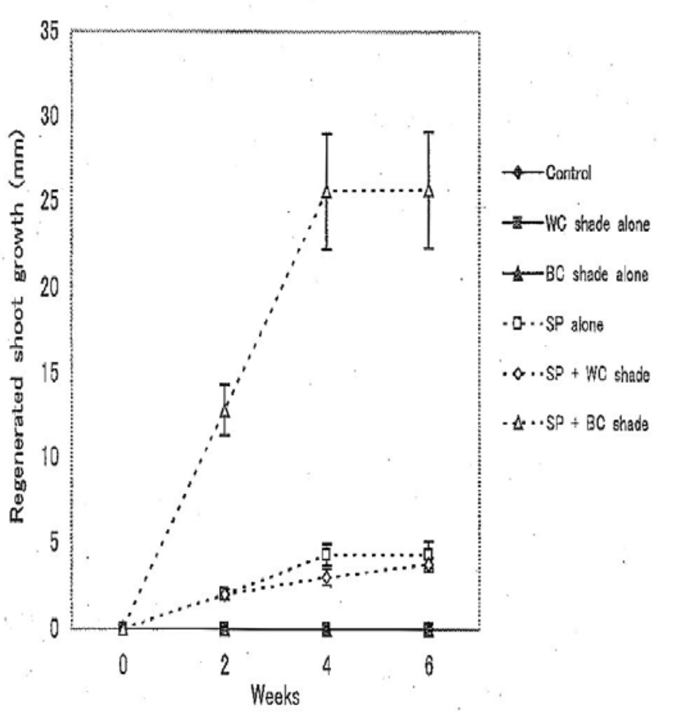

Fig. 14 - Effect of late summer pruning and shading on regenerated shoot growth of peach trees. Data are presented as mean ± standard error (SE).

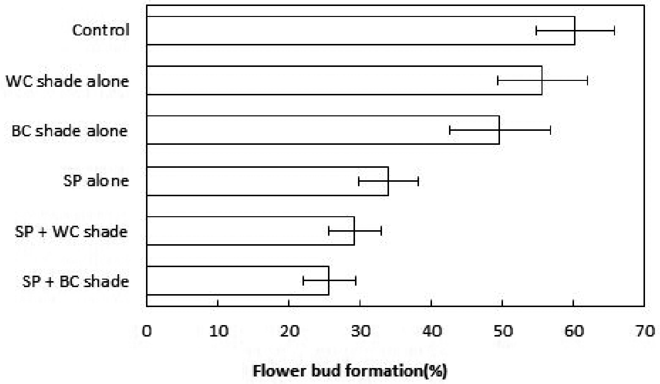

Fig. 15 - Effect of late summer pruning and shading on flower bud formation of peach trees. SP=summer pruning; WP= winter pruning; WC=white cheesecloth; BC=black cheesecloth. Data are presented as mean ± standard error (SE).

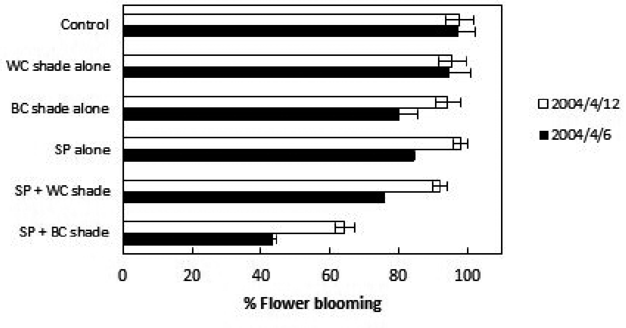

Fig. 16 - Effect of late summer pruning and shading on flower blooming of peach trees in the following year. Data are presented as mean ± standard error (SE).

5. Discussion and Conclusions

Slender spindle bush type training systems have been easily adopted in compact-sized trees grafted on dwarfing rootstocks (Mizutani *et al*., 1985). However, when this system is applied to trees grafted on vigorous rootstocks, imbalanced vegetative-oriented cycle between vegetative and reproductive growth occurs. For commercial quality fruit production, a good balance between vegetative and reproductive growth is necessary. As suggested in the present work, application of summer shoot thinning can reduce vegetative growth in such vegetative-oriented trees of spender spindle type trees grafted on vigorous rootstocks. Neri *et al*. (2010) also reported that summer pruning reduced vigor in apricot trees. To maintain the slender spindle type, it is crucial to keep alive shoots and buds near the trunk. However, shoots exhibit apical dominance by nature so that they extend outward, thus the space near the trunk becomes shaded. Shading accelerates dieback of shoots and buds inside the crown. With regard to shading, Neri *et al*. (2003) reported that shading caused leaf wilting, necrosis and abscission earlier under water-stressed conditions. Thinning of shoots is effective for the penetration of solar radiation near the trunk in the crown. Furthermore, heading back of shoots near the trunk induces shoot regeneration from the buds at the base, which are otherwise quiescent or died back. Unless heading back is conducted, the base parts of shoots become bare without alive shoots or buds. Summer shoot heading back is efficient to keep such shoots and buds near the trunk, even under shaded conditions. Readers interested in further detailed information for current work are also referred to Hossain *et al*. (2004, 2005, 2006).

In conclusion, summer thinning is effective for reducing tree vigor and light penetration near the trunk, whereas summer heading back is essential for keeping alive shoots and buds near the trunk in slender spindle bush type peach trees grafted on vigorous rootstocks.

References

EREZ A., 1982 - *Peach meadow orchard: two feasible systems*. - HortSci., 17: 138-142.

HOSSAIN S.A.B.M., MIZUTANI F., ONGUSO J.M., 2004 - *Effects of summer pruning on maintaining the shape of slender spindle bush of peach tree grafted on vigorous rootstock*. - J. Jap. Soc. Agr. Tech. Man., 11: 55-62.

HOSSAIN S.A.B.M., MIZUTANI F., ONGUSO J.M., EL-SHEREIF A.R., 2005 - *Effects of late summer pruning and cheesecloth shades on shoot regeneration, flower bud formation and blooming time of peach trees*. - Bull. Exp. Farm Fac. Agr. Ehime Univ., 27: 11-17.

HOSSAIN S.A.B.M., MIZUTANI F., ONGUSO J.M., EL-SHEREIF A.R., RUTTO K.L., 2006 - *Effects of summer pruning on shoot growth and fruit quality in peach trees trained as slender spindle bush type*. - Mem. Fac. Agr. Ehime Univ., 51: 9-13.

MIEROWSKA A., KEUTGEN N, HUYSAMER M., SMITH V., 2002 - *Photosynthetic acclimation of apple spur leaves to summer pruning*. - Sci. Hort., 92: 9-27.

MIZUTANI F., KOGAMI T., MOON D.G., BHUSAL R.C., RUTTO K.L., AKIYOSHI H., 2000 - *Effects of summer pruning on the number of apical buds near the trunk in slender-spindle-trained apple trees grafted on semi-dwarfing rootstocks*. - Bull. Exp. Far. Coll. Agr., Ehime. Univ., 22: 1-10.

MIZUTANI F., YAMADA M., TANIGUCHI, T., KOIZUMI K., SUGIURA A., TOMANA T., KADDYA K., 1985 - *Dwarfing effect of* P. japonica *and* P. tomentosa *rootstocks on 'Ohkubo' peach trees*. - J. Jap. Soc. Hort. Sci., 54 : 327-335.

NAKANO M., SHIMAMURA K., 1983 - *Growth and yield of peaches on rootstocks of* Prunus tomentosa *and* Prunus persica. - Sci. Rep. Fac. Agr. Okayama Univ., 61: 67-75.

NERI D., CASTAGNOLI M., PONI S., CORELLI L., 2003 - *Diversified response to drought of light exposed and shaded leaves of potted grapevine, peach and pear trees*. - J. Fruit Orn. Plant Res., 11: 5-15.

NERI D., MORINI F., MASSETANI F., 2010 - *Pruning: How to manage shoot growth*. - Acta Horticulturae, 862: 355-363.

NERI D., SANSAVINI S., SUGIYAMA N., 1992 - *Summer and root pruning of split-root potted peach trees*. - Acta Horticulturae, 322: 177-189.

YAEGAKI H., INOMATA Y., MURASE S., ITO A., YOSHIOKA H., TAKATSUJI T., SUZUKI K., 2008 - *Influence of the combination of scion peach cultivars and* Prunus japonica *Thumb. and* P. tomentosa *Thumb. as a dwarfing rootstock on growth and fruit production*. - Bull. Natl. Inst. Fruit Tree Sci., 7: 1-12.

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Modern trends of *Citrus* pruning in Italy

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Key words: fruit quality, mechanical pruning, rootstock, tree habit.

Abstract: The citrus industry is at present increasingly oriented toward upgrading groves, discarding obsolete plantings and introducing new rootstock/scion combinations which are more tailored to local environmental conditions. A rise in production costs (but without a proportionate increase in profit) together with technological innovation have both led to many changes in citrus orchard management, and consequently there have been changes in cultural techniques. Many cultural and edaphic factors influence the choice of pruning frequency and intensity. The main goal of pruning is to reach a useful balance between yield and growth, and to reduce cultivation costs. Drastic pruning in young citrus trees with a vigorous vegetative habit causes an excess of shoot growth, thereby extending the juvenile stage and delaying fruiting. Adaptation of the technique to local conditions in bearing groves (species, cultivars, planting distances, etc.) is mandatory for pruning optimization. A fully mechanised approach to pruning leads to substantial changes in citrus grove management and sometimes to negative effects on yield. Functional integration of mechanical and assisted pruning seems to be the right choice for the Italian citrus industry.

1. Introduction

An increase in fruit quality is a key objective of fruit tree cultivation, while keeping in mind at the same time the relevance of production cost reduction and environmental issues. The citrus industry is increasingly oriented toward upgrading groves, discarding obsolete plantings and introducing new rootstock/scion combinations which are more tailored to local environmental conditions. Moreover, increases in production costs, without a proportionate profit increase, and innovation at the technological level have led to many changes in citrus orchard management and the updating of cultural techniques.

New plantings have been realized with regular planting distances for a fully mechanised approach to all cultural practices. In this context, technical evolution also includes pruning, essential for healthy and fruitful orchard management, but without the clear push towards mechanisation as in other countries. This cultural technique as well as all other practices, even though respecting plant physiology, has to be evaluated according to the economic impact. Furthermore, it is wise to consider the manifold factors that affect the final result, such as rootstock/scion combination, tree age and development, planting distance, soil and climate conditions.

Citrus groves in their former conception, although still present in many citrus cultivation areas in Italy, were high-density based (more than 800 plants ha^{-1}) with narrow planting distances. Citrus growers were forced to carry out frequent pruning on bearing plants, repeated in spring and at the end of summer, as the only available way for both high plant density and light penetration between and within plant canopies to coexist (Rebour, 1971). This situation led to the development of trees with high scaffold (frequently more than 1 m high), usually lacking in skirt and with poor yield.

The transition to modern citrus production, based on greater planting distance and average densities of 416 plants ha^{-1}, at least for standard grafting combinations, has led to a new concept of pruning, which in turn has meant substantial changes in the management of this technique, with sometimes substantial negative effects on citrus production (Intrigliolo, 1998).

Similarly to other fruit tree cultivations (Giacalone *et al.*, 2004; Neri and Sansavini, 2004; Peano and Giacalone, 2004; Ventura and Sansavini, 2005), pruning practices in citriculture are important to support plant health and reduce stress in order to reach an acceptable balance between vegetative and reproductive activities, a key factor in many stages of citrus grove development.

Citrus bearing trees in semi arid environments have main shoot growth flushes during the year (spring, summer and autumn flush), with growth stasis periods overlapped with periods of higher and lower temperatures. Only for lemon (*C. limon* (L.) Bern) does flowering occur during all growth flushes, whereas for other citrus species flowering is mainly bound to spring flush.

Flowers, solitary or in inflorescence, can be terminal or axillary and are normally produced on one-year

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shoots. In young citrus trees shoots are normally vegetative, since the productive stage begins with flower emission mainly on lateral drooping shoots. In *Citrus* species, like in other tree fruit species, bud differentiation occurs in response to chilling temperatures and mainly depends on interactions at physiological and nutritional level (Garcia-Luis *et al*., 1995).

Drastic pruning in young citrus trees with a vigorous vegetative habit causes an excess of shoot growth, thereby extending the juvenile stage and delaying the beginning of fruiting. In adult trees heavy pruning of branches, twigs and leaves means the removal of reserve substances (i.e. carbohydrates, nitrogen), thus leading to serious reductions in plant growth and overall development. Furthermore, in this way pruning in adult trees favors excessive sucker production especially in upright-growing species. On the contrary, in senescent or declined trees light or even hard thinning may be useful to promote growth and healthy fruitwood.

2. Pruning of young trees

It is essential to take care of citrus trees during the juvenile stage to obtain a balanced scaffold with three to four principal branches developing at 30-50 cm from the collar (Fig. 1).

Fig. 1 - Young 'Tarocco' orange tree.

If citrus trees are correctly managed in the nursery (cut back or headed) they require little pruning once in the field. Trees will grow naturally and they will take the growth habit typical of the species or cultivar. In this case trees assume a drooping shape, ranging from spheroid to ellipsoid (Fig. 2).

Fig. 2 - 'Navelate' orange tree with drooping canopy and full skirt.

At this stage the most common and severe mistakes are the removal of apical or more drooping branches. In such cases the development of both upper and lower part (the first to produce) of the tree are limited. However, pruning during the first period should be limited to removing an occasionally unwanted branch or buds on the rootstock, to regulate the final scaffold and reduce future severe cuts.

3. Pruning mature trees

For many years after transplanting citrus trees require no relevant pruning. It is not easy to determine a general rule for the beginning and frequency of regular pruning since this practice depends on many factors: species, cultivar, planting distance, soil and climate conditions and, more relevant, growth status (crowding, presence of deadwood in the internal part, upright shoots exhaustion) and its balance with fruitfulness.

Pruning frequency can be annual or long-standing, with frequency and severity closely linked. Longer time intervals imply more drastic pruning, with wider wounds and a subsequent massive influence on plant growth.

In a field trial on full-bearing trees of Tarocco orange (*Citrus sinensis* Osbeck) the effects of hand pruning with annual, biennial and quadrennial frequency were evaluated (Calabretta *et al*., 2008). Quadrennial frequency of pruning showed a decline of fruit quality parameters (above all for average fruit weight), even though they were linked to higher yield and shortening of work time. Biennial frequency of pruning showed the best balance as far as work time (costs), yield and fruit quality were concerned. In the case of aged trees, low in vigor or presenting other problems, it is wise to increase the frequency (Intrigliolo, 1984; Intrigliolo, 1998).

For wider planting distances progressive exhaustion of the internal part of the canopy can be balanced by lateral and vertical expansion, without any influence on yield. Therefore in these conditions pruning initially plays a minor role and it could be delayed. On the contrary if pruning is carried out at maturity stage of the orchard, in conjunction with the right fulfillment of all other cultural practices, it becomes necessary to sustain growth vigor, high yield and fruit quality standards. It is not easy to choose the right time to start regular pruning. In the case of a delayed start, the citrus orchard could grow old prematurely, while the opposite case could cause an increase in costs and severe yield reduction (Intrigliolo, 1998).

Another important factor is the timing of pruning. Intervention is often undertaken without distinction from January to June, and sometimes is repeated at the end of August or beginning of September to eliminate vigorous upright suckers, due to severe spring cuts. In any case, the right pruning time is extremely variable, depending on species, variety, climate conditions and severity of the previous treatment. Early varieties are usually pruned before late ones, either because of earlier harvest times or because of an absence of frost risk. Frosts are the main deterrent to early pruning (Fisher, 1977; Phillips, 1980 b; Cutuli, 1985; Intrigliolo, 1986 b). As a matter of fact, the removal of the outer part of foliage makes trees more subject to frost injuries since it stimulates the emission of new soft shoots that can be easily damaged by low temperatures. Severe treatments should be properly scheduled and deferred until after the juvenile stage: moderation is still the key word. Light pruning is advisable to provide deadwood removal and to increase light interception in the internal part of the canopy and between rows. This improves yield and fruit quality, especially fruit size, thus making other cultural techniques easier and less expensive (Intrigliolo, 1984; Calabretta *et al*., 2008).

Studies on pruning timing showed the positive effects of early treatments (end of winter to early spring) in comparison with late summer ones (Cameron and Hogdson, 1943; Milella, 1967; Turpin, 1973; Fisher, 1977; Fucik, 1979). If pruning takes place before spring flush, removal of new vegetation is prevented (Turpin, 1973). Early pruning is thus highly recommended for skeletonisation and as a general rule for trees low in vigor or weakened by biotic or environmental stresses (Cameron and Hogdson, 1943; Bevington and Bacon, 1976; Phillips, 1980 a, 1980 b). Vigorous trees, on the other hand, will react improperly with extra shooting and will lose fruit bearing surface, as reported by Bevington and Bacon (1976). Phillips (1980 a) reported that light pruning in July and August implied useful fruit thinning, with the consequence of increased fruit size, especially in case of top dressing. As far as yield is concerned, Fucick (1979) reported higher levels in Texas with grapefruit (*C. paradisi* Macfadyen) resulting from December treatment, whereas in Australia Bevington and Bacon (1976) and Bevington (1980), working with Valencia late oranges, found similar levels comparing summer and autumn treatments.

Tree phenological stage as well as scion/rootstock combination and species/variety habit are decisive factors in determining pruning effects. ‘Moro’ in the bloody group and many accessions in the navel group represent low vigor orange cultivars; low vigor trees are found among a few lemon cultivars, most bergamot (*C. bergamia* Rissi) and citron (*C. medica* L.) (Fig. 3) cultivars. Given the vegetative habit of these genotypes, pruning has the main function of increasing air and light penetration in the internal part of the canopy, avoiding back-cuts that would thicken the tree and preferring a balanced thinning. In the case of mandarin (*C. reticolata* Blanco) (Fig. 4) and its hybrids these treatments are essential, the canopy being extremely dense due to huge branch production.

Fig. 3 - ‘Navelina’ orange tree.

Fig. 4 - ‘Avana’ mandarin tree.

Satsumas (*C. unshiu* Marcovitch) and many clementines (*C. clementine* Hort.) (Fig. 5) show an intermediate growth habit. Expanded growth habit is normally shown by bloody orange 'Sanguinello' and 'Tarocco' clones, with a tendency to upright growth habit in nucellar lines (Fig. 6) and in triploids, such as 'Tacle' and 'Alcantara'.

Fig. 5 - Clementine tree.

Fig. 6 - 'Tarocco' clone NL 57-E-1 orange tree.

With the aim of obtaining virus-free and viruslike-free accessions, nucellar progeny strategy has been largely adopted in breeding projects in Italy. These lines are characterized by their large size (although with some exceptions) thus conditioning plant spacing and orchard management. In this situation concerns arise about the extremely reduced density and about pruning practices, that should be reduced in number and intensity. Branches shortening cuts should be preferred mainly in the first years after planting, even though this practice induces very vigorous growth reactions and delay of productive stage. These effects are linked to the increase of costs for future pruning, harvest and other cultural practices. In order to increase yield and reduce the costs of cultural practices (especially pruning), recovery strategies based on micrografting technique should be encouraged, as well as the adoption of new rootstocks able to reduce tree vigor (Russo *et al.*, 2011).

'Femmiminello' lemon trees are characterised by upright irregular shoots (Fig. 7), with pronounced apex dominance; young trees show long, thin shoots which are weak and easily prone to breakage. For these trees it is necessary to shorten the branches to reduce plant height, favoring their strength and thus their stability. In late summer, pruning treatments play a prominent role in the eradication of *Phoma tracheiphila* (Kanc et Ghik) infections, making clear the necessity for tree removal in extreme situations.

Fig. 7 - 'Femminello' lemon tree.

More extensive pruning (i.e. Skeletonisation) is essential in cases of old, decadent trees or in case of damage due to environmental or biotic stresses. In these situations removal of deadwood is useful or absolutely necessary for tree rejuvenate, thus leading to normal growth and production conditions.

4. Mechanical pruning

In citrus orchard management, pruning is increasingly oriented toward greater levels of mechanization with the aim of combining cost reduction with a proper balance between yield and plant growth.

Research activity in this field started in Italy at the end of 1970s with several experiences of mechanical pruning (Giuffrida *et al.*, 1979; Blandini *et al.*, 1981; Raciti *et al.*, 1981; Intrigliolo *et al.*, 1986) with the integration of internal thinning of deadwood and upright shoot removal, and aided pruning by means of pneumatic saws and clippers (Intrigliolo and Barbagallo, 1987; Schillaci, 1988).

Experiments carried out in Italy on mechanic pruning in citrus (Giuffrida *et al*., 1979; Blandini *et al*., 1981; Raciti *et al*., 1981; Giametta, 1983; Spina *et al*., 1984; Intrigliolo, 1986 a; Intrigliolo *et al*., 1986; Intrigliolo *et al*., 1988; Intrigliolo and Giuffrida, 1990; Raciti *et al*., 1991) gave largely positive results. Trials were carried out on several species and cultivars under different environmental and cultivation conditions, utilizing different equipment and operating systems mainly associated with a traction engine. Up till now, however, hand pruning seems to be the most widespread approach in Italy and in other advanced citrus cultivation areas like Spain (Agustì, 2003).

Frequency and intensity of mechanical pruning represent the key choices to attain high yields and delayed tree senescence (Zaragoza-Adriaensens and Alonso - Cabo, 1981; Intrigliolo, 1986 b; Raciti and Intrigliolo, 1989). Results of a two-year trial on ‘Tarocco’ orange trees mechanically pruned with the same intensity in April, June and August, showed that full summer treatments were useful to control plant growth, whereas early treatments stimulated the spring flush (Intrigliolo and Giuffrida, 1990). Yield and fruit quality were only slightly influenced by treatment time.

The main purposes of fully mechanized pruning are the fulfillment of the tree’s physiologic demand and the massive reduction of production costs. Mechanical pruning is not a selective or thinning practice, but it follows rigid patterns by cutting trees back vertically (hedging) (Fig. 8) or removing their tops (topping) (Fig. 9) and it is adapted to wide planting distances. Thus, the grove is sufficiently open for the passage of equipment for spraying and other cultural practices, reducing shady areas and removing dead or decadent wood (Intrigliolo, 1986 b).

Pneumatic tools reduce the physical effort of workers, amplifying their performance both by replacing hand pruning with traditional tools and complementing mechanical pruning. The economic convenience of pneumatic tool utilization increases as the time needed for the intervention increases. Assisted pruning loses its economic convenience in comparison to traditional pruning (Intrigliolo and Barbagallo, 1987). The reduction of working time accounts for up to 30-40% for assisted pruning, 90% for mechanical pruning and an average of 60-70% when integrated with the latter (Fig. 10) (Intrigliolo, 1986 a, 1998).

Fig. 8 - Mechanical hedging and topping done at the same time.

Fig. 9 - Mechanical topping.

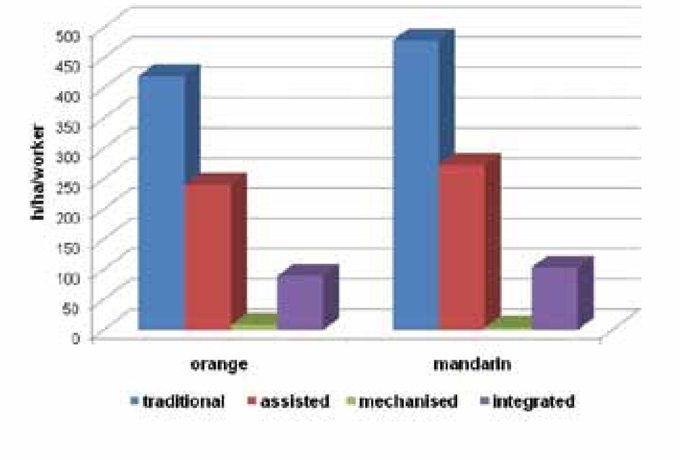

Fig. 10 - Work time in different kinds of pruning.

The functional integration of mechanical and assisted pruning could be the best way to achieve useful results, hopefully in economic and agronomic terms, at least until further profit loss forces growers toward full mechanizaten. Even though experimental results with fully mechanized pruning have to date shown limited effects, it seems that in the near future it will spread to large- and medium-sized citrus orchards. In the traditional Italian citrus industry, with terrace cultivation and small-sized farms, for many years pruning has been carried out using pneumatic tools permitting workers to use their own judgment in terms of frequency and limiting costs.

References

AGUSTÌ M., 2003 - *Citricultura*. - Mundi-Prensa, Madrid, Spain, pp. 422.

BEVINGTON K.B., 1980 - *Response of Valencia orange trees in Australia to hedging and topping*. - Proc. Fla. State Hort. Soc., 93: 65-66.

BEVINGTON K.B., BACON P.E., 1976 - *Response of Valencia orange trees to hedging*. - Australian Citrus News, 52: 2.

BLANDINI G., PETRONE F., SISINNA S., 1981 - *Trials of mechanical pruning machines in Italian citriculture*. - Proc. Int. Soc. Citric., Vol. I: 180-185.

CALABRETTA M.L., GIUFFRIDA A., INTRIGLIOLO F., 2008 - *La periodicità della potatura, fattore determinante per la qualità delle arance*. - Rivista di Frutticoltura e di Ortofrutticoltura, 70(1): 2-5.

CAMERON S.H., HODGSON R.W., 1943 - *Effect of time of pruning on the rate of top regeneration of Valencia orange trees*. - Proc. Am. Soc. Hort. Sci., 42: 280-282.

CUTULI G., 1985 - *Potatura*, pp. 423-451. - In: SPINA P. (ed.) *Trattato di agrumicoltura*. Edagricole, Bologna, Italy, pp. 552.

FISHER I.E., 1977 - *Hedging and topping*. - The Citrus Industry, 57: 6-12.

FUCIK I.E., 1979 - *Long term responses of Texas grapefruit trees to hedging and topping*. - The Citrus Industry, 59: 25-27.

GARCIA-LUIS A., FORNES F., GUARDIOLA J.L., 1995 - *Leaf carbohydrates and flower formation in* Citrus. - J. Amer. Soc. Hort. Sci., 120(2): 222-227.

GIACALONE G., LA IACONA T., VITTONE G., 2004 - *Valutazione di parametri produttivi e qualitativi in impianti di melo condotti con differenti metodi di potatura*. - Proc. VII Giornate Scientifiche SOI, pp. 763-765.

GIAMETTA G., 1983 - *Prove sperimentali di potatura meccanica degli agrumi*. - Macchine e motori agricoli, 7: 7-20.

GIUFFRIDA A., MELITA E., ROMEO M., 1979 - *Prove di potatura meccanica degli agrumi*. - Rivista di Frutticoltura, 41: 23-28.

INTRIGLIOLO F., 1984 - *La potatura degli agrumi*. - L'Informatore Agrario, 40(22): 49-53.

INTRIGLIOLO F., 1986 a - *La potatura meccanica e agevolata in agrumicoltura*. - L'Informatore Agrario, 42(9): 93-105.

INTRIGLIOLO F., 1986 b - *Potatura meccanica e tradizionale a seguito di danni da gelo su arancio cv. 'Sanguinello moscato'*. - Proc. 'Il recente contributo della ricerca allo sviluppo dell'agrumicoltura italiana', Cagliari 29 April-3 May, pp. 267-277.

INTRIGLIOLO F., 1998 - *Differenti frequenze di potatura meccanica su piante di arancio*. - Atti Giornate Scientifiche SOI, 1: 157-158.

INTRIGLIOLO F., BARBAGALLO A., 1987 - *Confronto in diverse condizioni di campo fra potatura tradizionale ed agevolata in agrumicoltura*. - L'Informatore Agrario, 43(25): 69-72.

INTRIGLIOLO F., GIUFFRIDA A., 1990 - *Interventi di potatura meccanica sull'arancio cv. 'Tarocco' effettuati in diverse epoche*. - Frutticoltura, 52(5): 91-95.

INTRIGLIOLO F., RACITI G., SCUDERI A., 1988 - *Mechanical and aided pruning combined with tree removal of nucellar 'Tarocco' orange*. - Proc. Sixth Int. Citrus Congress, Vol. II: 947-952.

INTRIGLIOLO F., RACITI G., SCUDERI A., GIUFFRIDA A., 1986 - *Prove quadriennali di potatura meccanica sul mandarino cv. 'Avana'*. Proc. 'Il recente contributo della ricerca allo sviluppo dell'agrumicoltura italiana', Cagliari 29 April-3 May, pp. 297-307.

MILELLA A., 1967 - *Un quadriennio di osservazioni sull'epoca di potatura dell'arancio*. - Studi Sassaresi, Sez. III, Ann. Fac. Agraria, 1: 1-15.

MILELLA A., 1980 - *Potatura*. - In: *Gli Agrumi*, REDA, pp. 165.

NERI D., SANSAVINI S., 2004 - *Attualità della potatura nella frutticoltura intensiva*. - Rivista di Frutticoltura, 1: 14-23.

PEANO C., GIACALONE G., 2004 - *Potatura del melo: dalla taille longue all'extinction*. - Proc. VII Giornate Scientifiche SOI, pp. 196-198.

PHILLIPS R.L., 1980 a - *Hedging and topping practices for Florida Citrus*. - The Citrus Industry, 55: 5-10.

PHILLIPS R.L., 1980 b - *Rejuvenation pruning of* Citrus. - Citrus and Vegetable Magazine, 44: 6-22.

RACITI G., CUTULI G., INTRIGLIOLO F., GIUFFRIDA A., 1991 - *Indagine sull'influenza delle tecniche colturali sul mal secco degli agrumi. 2a nota: conduzione del terreno e potatura*. - L'informatore Agrario, 47(22): 47-49.

RACITI G., INTRIGLIOLO F., 1989 - *Nuovi orientamenti sulla potatura degli agrumi*. - Rivista di Frutticoltura, 51(1): 25-30.

RACITI G., SPINA P., SCUDERI A., INTRIGLIOLO F., 1981 - *Three years of mechanical pruning of citrus in Italy*. - Proc. Int. Soc. Citriculture, Vol I: 175-180.

REBOUR H., 1971 - *Gli agrumi*. - Edagricole, Bologna, Italy, pp. 371.

RUSSO G., REFORGIATO RECUPERO G, RECUPERO S., INTRIGLIOLO F., 2011 - *La scelta dei nuovi portinnesti i risultati delle ricerche*. - Rivista di Frutticoltura, 73(1-2): 62-64.

SCHILLACI G., 1988 - *La potatura agevolata in agrumicoltura*. - Macchine e motori agricoli, 4: 55-64.

SPINA P., GIUFFRIDA A., MELITA E., 1984 - *Comparative trials of mechanical and aided pruning*. - Proc. Int. Soc. Citriculture, Vol. I: 106-109.

TURPIN I.W., 1973 - *The place of hedging in the management of Citrus orchards*. - Australian Citrus News, 49: 6-7.

VENTURA M., SANSAVINI S., 2005 - *Tipologia di rami a frutto e qualità delle mele cvs Braeburn, Golden Delicious e Jonagold*. - Rivista di Frutticoltura, 67(11): 52-60.

ZARAGOZA-ADRIAENSENS S., ALONSO-CABO E., 1981 - *La frecuencia de la poda manual de los agrios. Primeros resultados*. - Anales del Instituto nacional de Investigaciones Agrarias. Serie: Agrìcola, Nùm. 15, Separata nùm. 11.

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Intensive plum orchard with summer training and pruning

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Key words: canopy structure, fruiting biology, mechanical harvesting, plums, pruning, *Prunus domestica*, training.

Abstract: An intensive plum orchard model was created for two types of fruit harvesting: by hand and with a self-propelled straddle harvester working in continuous motion. Six plum cultivars grafted on semi dwarfing rootstock 'Prune Wangenheim' (*Prunus domestica*) were planted at three densities (1000, 1250 and 1666 trees/ha). A new training system - central leader spindle - was applied. The leader was not headed after planting and summer training treatments were performed. From the third year onward renewal pruning was done after fruit harvesting. The new training and pruning system resulted in very rapid tree growth, much young wood, fruit bud formation on young wood and early bearing. Trees appeared to be suitable for hand and mechanical harvesting within four years from planting.

1. Introduction

In Western Europe plums are grafted on Myrobalan B, St. Julien A, Marianna and other vegetatively propagated rootstocks (Nicotra and Moser, 1995). In Eastern Europe it is difficult to propagate dwarfing and semi dwarfing rootstocks for plums and prunes because of long and hard winters. Stool beds are often damaged by winter frost and hard-wood cuttings are not properly rooted because of low temperatures in autumn and spring. Mother plants in stool beds are also threatened by plum pox. Very few nurseries produce trees grafted on St. Julien A and GF 655/2. Most plum and prune trees are grafted on seedlings of selected types of *Prunus divaricata*. Such trees are planted at 4x3 to 5x5 m and trained to open centre form. In Poland about 20% of trees are grafted on seedlings of 'Prune Wangenheim' (*Prunus domestica*). This cultivar is self-pollinated, so seed trees grown in isolation produce seedlings with uniform grow habit (Sitarek *et al*., 2001). 'Prune Wangenheim' is compatible with all European plums and prunes. Cultivars grafted on 'Prune Wangenheim' are semi dwarf, tolerant to arid soils common in Poland and very productive (Sitarek *et al*., 2001). Such trees should be suitable for dense plantings in intensive orchards. In Germany, Zahn (1986, 1994) and Brunner (1990) introduced central leader spindle and free spindle (without shoot bending) for dwarf and semi dwarf, densely planted plums and prunes. These systems were tested in Belgium (Wustenberghs and Keulemans, 1996) with 825 and 1250 trees per ha and appeared to be very economical in yielding and harvesting.

The goal of the present work was to elaborate an intensive plum orchard suitable for both hand and mechanical fruit harvesting with combined self propelled straddle harvester working in continuous motion, as is used in Poland to harvest sour cherries. The harvester requires densely planted trees with central leader up to 3 m high and young flexible shoots coming out of the leader. For this purpose new methods of summer training and pruning were introduced to plum trees. Studies were also undertaken on the intensity of tree growth of six cultivars grafted on 'Prune Wangenheim', their growth habit, canopy structure, fruit bud formation in relation to wood age, quality of flower clusters, fruit set, sun irradiation and distribution and yield. These studies enabled to precise the pruning method of trees in full bearing age.

2. Materials and Methods

One-year-old feathered trees of 'Cacanska Rana', 'Cacanska Lepotica', 'Cacanska Najbolja', 'Diana', 'Katinka', and 'Silvia' grafted on semi dwarf seedling rootstock 'Prune Wangenheim' were planted in autumn 2004 on a 0.5 ha plot, on sandy-loam soil at the Research Institute of Pomology, Skierniewice, Poland. To estimate optimum planting density, trees were spaced 4 m between rows and at various densities in the row: 1.5; 2.0 and 2.5 m (1666; 1250 and 1000 trees/ha). Each cultivar was planted in two rows (each consisting of 36 trees): one for hand harvesting, the other for mechanical harvesting. In each row the trees were arranged in three randomized blocks with four trees per plot. In the second year after planting the inter-rows were grassed down with frequent grass mowing in

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conjunction with the maintenance of 1.5-m-wide herbicide strips along the row. A drip irrigation system was installed from the first year. This was necessary because yearly precipitation at Skierniewice is around 500 mm whereas plums grown in central Poland require 700 mm of rainfall. Fertilizers were applied according to the standard recommendation for commercial plum orchards. Eight to ten sprayings were essential to control pests and diseases.

A new training system with summer pruning was introduced to obtain central leader trees suitable for mechanical harvesting and hand picking (Fig. 1). Trees having central leaders 1.7 m high at planting time were not headed after planting and side shoots were shortened lightly. Subordination of the side branches to the central leader was obtained by summer pruning. At the end of May or beginning of June (depending on the growing season) new shoots that appeared at the top of the central leader were thinned leaving only one to extend the leader. This treatment resulted in numerous short side shoots along the leader most of them setting flower buds in the first growing season. Any side shoots growing upright were bent to horizontal position by fixing (clips) pinches to the leader above shoots. These treatments were repeated in the second year. In spring of the third year, trees were nearly 3 m high with at least 1.5 m of canopy diameter and they were able to give the first crop. Further training was not necessary. From the fourth year onward, renewal pruning introduced in Poland by Czynczyk *et al.* (1976) was performed after fruit harvesting. Each branch over three years of age was cut off near the central leader leaving a 10-30 cm stub to ensure new shoot growth (Fig. 2). Light shoot thinning was carried out as necessary. Effect of cultivars and planting distance on tree growth, canopy structure, relation between shoot age and fruit bud formation, and fruit setting was stud-

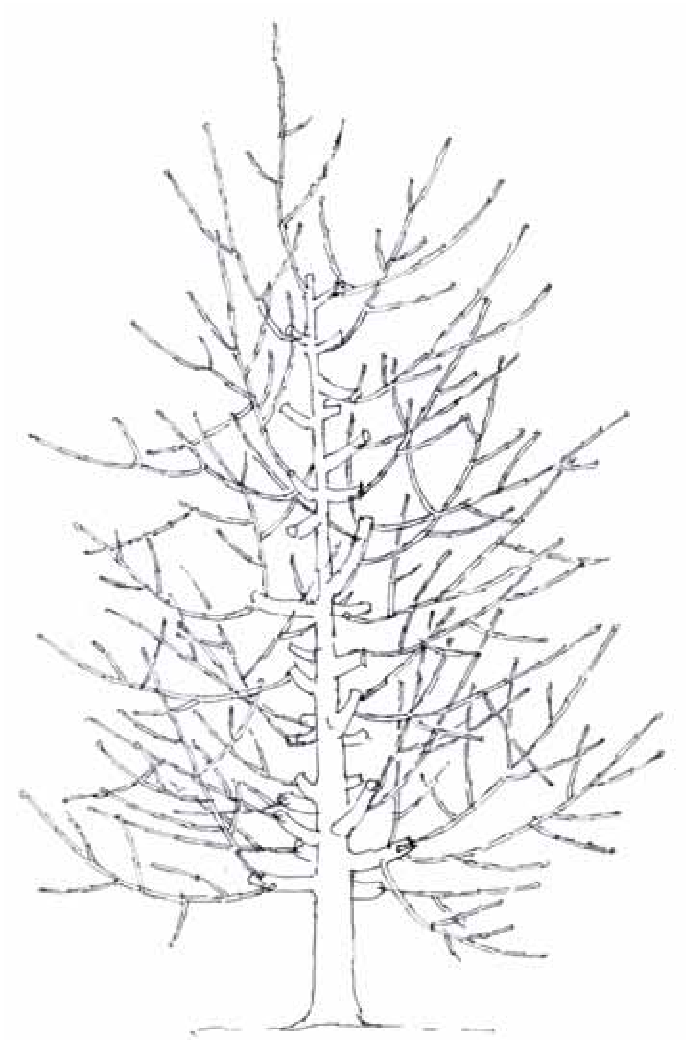

Fig. 2 - Plum tree pruning by renewal method done after harvesting. Old branches are removed to stumps and mainly one-, and two-year-old twigs are left.

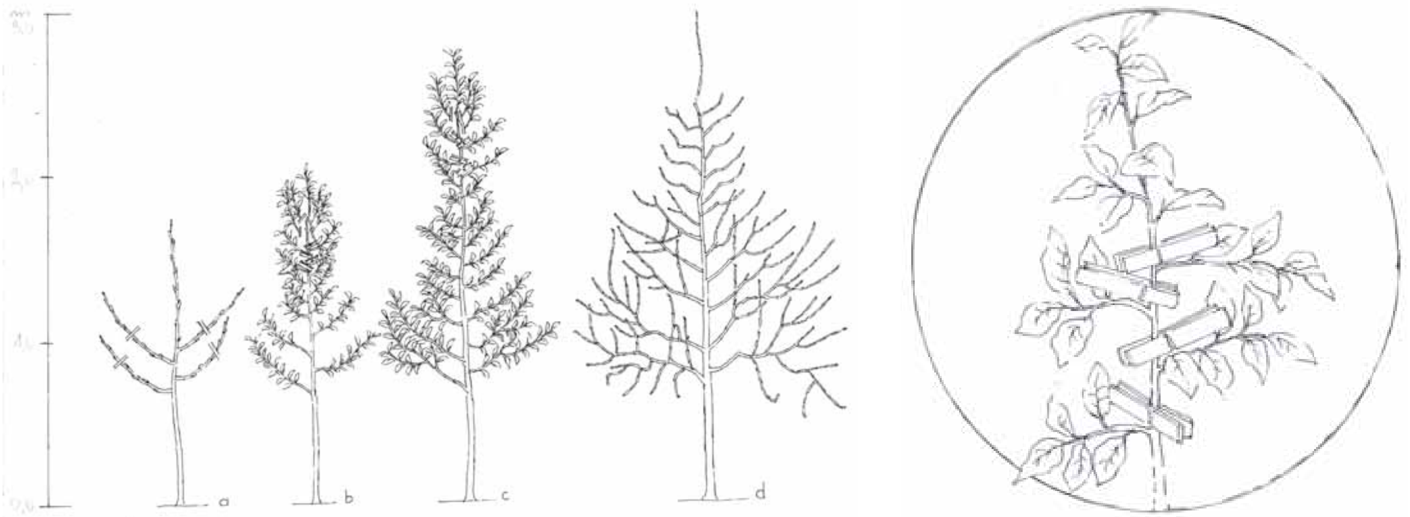

Fig. 1 - Plum tree training with summer pruning: a) planted feathered tree is left with unheaded central leader and lightly headed side shoots; b) in May side shoots appearing at top of the leader are cut off except for one left for leader prolongation, some lower shoots are bent with clips; c) treatments at top of the leader are repeated in May of the second year; d) tree with fruiting ability in spring of the third year; e) shoot bending with a clip.

ied. To estimate light interception, the irradiation intensity was measured at ground level in rows and interrows with a Delta T Tube Solarimeter TSL and with a light sensor mounted above trees (Anderson, 1964). Light interception was calculated by subtracting the light intensity at ground level from light intensity above trees and was expressed as percentage of light intercepted by the canopy. Light distribution was measured across tree rows on three levels: 0.8; 1.6 and 2.4 m with Sun Scan Probe type SS -1 (Delta-T Devices Ltd, Burwell, Cambridge, England). Harvesting efficiency with a combine harvester was recorded. Fruit quality of hand-picked fruit against mechanically harvested fruit was compared.

3. Results and Discussion

In the sixth year after planting (2010) the growth of trees, expressed by trunk cross sectional area (Table 1), showed significant differences between cultivars and also significant differences between the most dense tree spacing in the row compared to the two larger spacing treatments. The large differences in growth intensity among cultivars indicate that this factor should be considered in designing intensive plum orchards. Treatment in the most densely spaced rows resulted in a dwarfing effect on tree growth. When the orchard is managed over a long period, such dwarfing effect leads to a smaller crop from smaller trees, as is often observed in intensive apple orchards (Mika and Piskor, 1996). The new applied methods of tree training resulted in rapid vertical growth. All the trees (except for cv. 'Katinka') reached the required height (3.0-3.5 m) in the fourth year after planting (Table 2). In the subsequent years tree height had to be restricted by pruning to coincide with gap required by the harvester. For this reason strong shoots appearing on the top of trees were removed from the fourth year on trees for both machine and hand harvesting. Canopy spread (Table 3) increased until the sixth year from planting. Trees of cv. 'Silvia' created the most spread whereas 'Katinka' formed compact trees which were significantly smaller than the other cultivars. Some influence of planting density on canopy spread was evident but the differences were not significant. In renewal pruning method, old branches are cut out and replaced by young shoots. Due to that, trees are kept in a constant spread. Canopy structure is favourable for fruiting because most of new shoots are short, in range 5-10 cm. (Table 4). Such shoots are able to form fruit buds on one-year-old wood (Table 4). There were no significant differences between cultivars and planting density treatments. Spur number per tree was also estimated in the fourth year after planting. In spite of renewal pruning, which forced young wood to grow, numerous spurs were present in the tree

Table 1 - Influence of cultivars and spacing on tree growth expressed by trunk cross sectional area in the sixth year from planting (2010)

Influence of cultivars	Trunk cross sectional area (TCSA) (cm^2)
'Cacanska Rana'	46.6 bc
'Cacanska Najbolja'	52.9 d
'Cacanska Lepotica'	35.0 a
'Diana'	42.8 b
'Katinka'	33.3 a
'Silvia'	51.7 cd
Influence of spacing (m)	
4 x 1.5	40.7 a
4 x 2.0	45.6 b
4 x 2.5	44.8 b

Different letters indicate significant differences separately for cultivars and spacing at P=0.05.

Table 2 - Influence of cultivars and spacing on tree growth expressed by tree height in the fourth year from planting (2008)

Influence of cultivars	Tree height (m)
'Cacanska Rana'	3.08 b
'Cacanska Najbolja'	3.26 b
'Cacanska Lepotica'	3.20 b
'Diana'	3.44 b
'Katinka'	2.50 a
'Silvia'	3.62 c
Influence of spacing (m)	
4 x 1.5	3.20 a
4 x 2.0	3.17 a
4 x 2.5	3.20 a

Different letters indicate significant differences separately for cultivars and spacing at P=0.05.

Table 3 - Influence of cultivars and spacing on tree growth expressed by tree spread in the fourth year from planting (2008)

Influence of cultivars	Tree spread (m)
'Cacanska Rana'	2.47 b
'Cacanska Najbolja'	2.33 b
'Cacanska Lepotica'	2.50 b
'Diana'	2.44 b
'Katinka'	1.74 a
'Silvia'	2.67 c
Influence of spacing (m)	
4 x 1.5	2.49 a
4 x 2.0	2.38 a
4 x 2.5	2.40 a

Different letters indicate significant differences separately for cultivars and spacing at P=0.05.

Table 4 - Influence of cultivars and spacing on canopy structure (% of shoots in three classes of length) in the fourth year from planting (2008)

Influence of cultivars	Class 5-50 cm	Class 51-90 cm	Class 91-150 cm
'Cacanska Rana'	73.5 ij	18.7 cde	6.6 ab
'Cacanska Najbolja'	62.1 hi	30.2 ef	4.8 a
'Cacanska Lepotica'	60.4 gh	13.8 bcd	24.7 def
'Diana'	48.3 g	34.2 f	14.0 bcd
'Katinka'	74.6 j	14.6 bcd	10.2 abc
'Silvia'	54.1 gh	22.7 def	21.7 def
Influence of spacing (m)			
4 x 1.5	61.1 c	21.2 b	15.0 ab
4 x 2.0	62.1 c	22.5 b	12.4 a
4 x 2.5	64.1 c	22.1 b	11.0 a

Different letters indicate significant differences separately for cultivars and spacing at P=0.05.

canopy (Table 5). Significant differences among cultivars suggests that some variation in pruning methods may be needed in future for cultivars producing a small number of spurs. Bare wood, typical for plums under traditional pruning, did not appear. The significant differences between cultivars show the variation in the growth habit of the chosen cultivars.

Table 5 - Influence of cultivars and spacing on fruiting spurs per tree in the fourth year from planting (2008)

Influence of cultivars	Number of fruiting spurs
'Cacanska Rana'	238.8 b
'Cacanska Najbolja'	260.8 b
'Cacanska Lepotica'	136.6 a
'Diana'	285.7 c
'Katinka'	146.1 a
'Silvia'	265.8 b
Influence of spacing (m)	
4 x 1.5	216.8 a
4 x 2.0	-
4 x 2.5	219.6 a

Different letters indicate significant differences separately for cultivars and spacing at P=0.05.

In the fifth year from planting, trees of three cultivars planted at distances of 1.5 and 2.0 m created dense structures in the bottom part of the canopy; for this reason leaf area index (LAI), light interception and light distribution at three planting distances were estimated. This very laborious study was performed only on vigorously growing Silvia cultivar having the most regular canopy structure (Table 6). The results reveal that LAI, expressed as ratio of total canopy leaf area to ground area under tree (m^2/m^2), achieved a value of 2.5 at planting distance 4 x 1.5 m. This was close to the optimum value (2-3) suggested by Jackson (1996) for intensive apple orchards. Trees spaced 4 x 2.5 m were far from that value. Light interception (Table 7) was at an acceptable level at planting distance 4 x 1.5 and 4 x 2.0 m but still insufficient as required for an intensively planted orchard; according to Jackson (1996) the value should be 60-70%. Light interception at planting distance 4 x 2.5 m was very poor. In a number of studies it has been found that light interception is correlated with fruit production per ha (Jackson, 1980). In apple orchards, production increases with light interception up to about 70% available light. Light distribution within the fruit tree canopy was acceptable in the upper and middle parts of the trees. In the bottom part (0.7 m above ground) it was critical at the 1.5 x 4 m planting distance, low at 4 x 2 m and sufficient at 4 x 2.5 m planting distances. These results show that the most densely planted trees (1.5 m) require more heavy pruning in the fifth year from planting than trees spaced 2 and 2.5 m in the row.

The relationship between the age of wood and percent of cluster fruit bud setting was studied in three years

Table 6 - Influence of spacing on leaf area, leaf area index (LAI), and light interception of 'Silvia' cultivar in the fifth year from planting (2009)

Spacing (m)	Leaf area (m^2)	LAI	Insolation on ground level ($Watt/m^2$)*	% of light interception
4 x 1.5	15.16 a	2.52 c	168.0	44.6 b
4 x 2.0	14.20 a	1.78 b	176.3	46.8 b
4 x 2.5	14.75 a	1.48 a	105.5	28.0 a

Mean insolation above trees 376.7 Watt.

Table 7 - Influence of spacing on % light distribution in three canopy levels of 'Silvia' cultivar in the fifth year from planting (2009)

Spacing (m)	Canopy level from the ground		
	0.8 m	1.6 m	2.4 m
4 x 1.5	7.7 a	18.8 bc	48.0 d
4 x 2.0	19.5 bc	29.2 c	48.1 d
4 x 2.5	10.5 ab	32.4 c	49.5 d

(2008-2010). There were no significant differences between years. Table 8 shows the results in the sixth year from planting on fully-grown trees. Many differences were found in the ability of the cultivars to set fruit buds on young wood. In spite of this, most cultivars were able to set 60 to 80% of cluster fruit buds on one-year-old and two-year-old wood. The rest (20-40%) was set on three-year-old wood. These results indicate that trees treated with renewal pruning produce enough fruiting wood and the pruning method does not have adverse effects on tree yielding. Bare wood observed on trees with traditional regulated pruning was not observed in this experiment. Detailed studies on flower bud formation revealed that cluster fruit buds on one-year-old wood consist of, on average, fewer flowers than clusters on older wood (Table 9). For this reason one can expect that young wood may set less fruit than older wood. However this was not proven. Most of the cultivars set 5 to 10% fruit out of 100 flowers (Table 10). As the result, the percent of fruit on one- and two-year-old wood was similar to the percent of cluster flower buds (60-80).

Table 8 - Influence of cultivars and spacing on % of spur fruit buds on young wood in the fourth year from planting (2008)

Influence of cultivars	1-year-old	2-year-old	3-year-old
‘Cacanska Rana’	34.4 efg	42.4 ghi	21.4 bcd
‘Cacanska Najbolja’	50.0 i	30.1 def	19.5 bc
‘Cacanska Lepotica’	37.5 fgh	25.9 cde	39.4 fghi
‘Diana’	11.9 a	48.2 hi	39.2 fghi
‘Katinka’	40.8 fghi	37.5 fgh	20.6 k
‘Silvia’	16.5 ab	44.5 ghi	38.2 fgh
Influence of spacing (m)			
4 x 1.5	28.2 ab	40.4 e	31.2 abcd
4 x 2.0	29.0 abc	36.7 de	32.0 bcd
4 x 2.5	35.6 cde	36.7 de	24.8 a

Different letters indicate significant differences separately for cultivars and spacing at P=0.05.

Table 9 - Influence of cultivars and shoot age on number of flowers in one spur fruit bud in the fourth year from planting (2008)

Influence of cultivars	Number of flowers in one spur fruit bud
‘Cacanska Rana’	4.3 d
‘Cacanska Najbolja’	1.9 b
‘Cacanska Lepotica’	1.9 b
‘Diana’	2.9 c
‘Katinka’	1.3 a
‘Silvia’	1.3 a
Influence of shoot age	
1-year-old	1.9 a
2-year-old	2.1 b
3-year-old	2.5 c

Different letters indicate significant differences separately for cultivars and shoot age at P=0.05.

Table 10 - Influence of cultivars and spacing on yield (kg/tree) in the fourth and sixth years from planting (2008 and 2010 [z])

Influence of cultivars	2008 kg/tree	2010 kg/tree
‘Cacanska Rana’	9.7 a	16.5 c
‘Cacanska Najbolja’	28.6 c	4.9 a
‘Cacanska Lepotica’	11.4 ab	16.1 c
‘Diana’	14.5 b	17.1 c
‘Katinka’	15.0 b	11.7 b
‘Silvia’	9.0 a	11.1 b
Influence of spacing (m)		
4 x 1.5	13.8 a	12.7 a
4 x 2.0	14.3 b	12.2 a
4 x 2.5	16.0 c	13.9 a

Different letters indicate significant differences separately for cultivars and spacing at P=0.05.

(z) Yields in 2007 and 2009 were affected by spring frosts.

Trees came to blossom in the second year after planting and produced about 0.3 kg of plums per tree. In the third year, blooming was very abundant but spring frost in the first days of May killed all the flowers. For this reason the first yield was obtained in the fourth year after planting. Most of the trees produced from 8 to 30 kg per tree. The most productive was ‘Cacanska Najbolja’, the poorest was ‘Katinka’. There were many differences within cultivar and little differences within planting distances. Only ‘Cacanska Najbolja’ and ‘Diana’ gave a greater crop when planted at the greater distance. In the fifth year again spring frost in May reduced the crop to less than one kg per tree. Acceptable yield was obtained in the sixth year after planting (2010) (Table 11) when most trees yielded 15-18 kg per tree. There were again very large differences in tree productivity among cultivars but none in terms of planting distance. This suggests that when renewal pruning is performed trees can be spaced at even 1.5 m in the row. The good yield, calculated per hectare, varied from 13.9 tons at the largest planting distance to 23 tons at the closest spacing.

In the fourth and sixth years after planting fruits were harvested by hand and by self-propelled straddle harvester. Harvesting was begun when the forces between fruit and stem were 6-8 N, fruit firmness 5 kg/cm, and TSS 12-14%.

Table 11 - Calculated yield in 2008 and 2010 (t/ha)

Influence of spacing (m)	2008	2010
4 x 1.5	23.0	21.2
4 x 2.0	17.9	15.3
4 x 2.5	16.0	13.9

The effectiveness of mechanical harvesting was about 95%, with 5% fruit left on the tree or lost on the ground. Labour efficiency was 150 kg/8-hour-day at hand picking and 15 ton/day with mechanical harvesting. After grading fruit harvested by machine did not differ visually from that picked by hand. When put in cold storage at temperatures close to 0°C the fruit remained in good condition for five to seven days. The fruits were excellent for processing, but rather poor quality as dessert fruit.

References

ANDERSON M.C., 1964 - *Light relations of terrestrial plant communities and their measurement*. - Biol. Rev., 39: 425-486.

BRUNNER T., 1990 - *Pruning with bending effect on the basis of inducing hypotonic ramification. Physiological fruit tree training for intensive culture*. - Akademiai Kiado, Budapest, pp. 81-97.

CZYNCZYK A., MIKA A., CHLEBOWSKA D., 1976 - *Progress report on 12 years of experimentation with established spur, renewal and regulated pruning of apple trees*. - Fruit Sci. Rep., 3(2): 25-28.

JACKSON J.E., 1980 - *Light interception and utilization by orchard systems*. - Hortic. Rev., 2: 208-267.

JACKSON J.E., 1996 - *Light interception and canopy characteristics at low latitudes in relation to orchard system design*. - Acta Horticulturae, 451: 417-425.

MIKA A., PISKOR E., 1996 - *Growth and cropping of dwarf 'Jonagold' ('Jonica') apple trees planted at the density ranged from 2000 to 10000 per ha and trained as slender spindle, super spindle and V system*. - Acta Horticulturae, 451: 473-477.

NICOTRA A., MOSER L., 1995 - *Orientamenti per la scelta dei portinnesti del susino*. - L'Informatore Agrario, 32: 43-45.

SITAREK M., GRZYB Z.S., KOŁODZIEJCZAK P., 2001 - *Effect of rootstocks on growth and yield of plum trees*. - J. of Fruit and Ornam. Plant Res., IX(1-4): 19-24.

WUSTENBERGHS H., KEULEMANS J., 1996 - *A comparison of 3 plum tree training systems during the first five years of growth*. - Acta Horticulturae, 451: 625-631.

ZAHN F.G., 1986 - *Intensivierung von Steinobstanlagen durch stärkenbezogene Schnittbehandlung*. - Erwerbsobstbau, 28: 124-140.

ZAHN F.G., 1994 - *Hohengerechter Pflanzabstand durch Stärkenbezogene Baumbehandlung*. - Erwerbsobstbau, 36: 213-220.

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Summer pruning of apple: impacts on disease management

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Key words: apple scab, black rot, canopy management, cultural control, fire blight, *Malus* x *domestica*, microclimate, Nectria canker, powdery mildew, sanitation, sooty blotch and flyspeck, white rot.

Abstract: Pruning, including summer pruning, of apples can have a positive impact on disease management in two basic ways: through removal of dead tissue and inoculum, and through alteration of the canopy microclimate. Summer pruning can also increase diseases if it is done when disease risk is high. However summer pruning is used almost exclusively as a horticultural tool to improve fruit quantity and quality. As orchard planting and training systems have moved from semi-dwarf trees to high-density, fully-dwarf trees, very few summer pruning studies have looked at impacts related to disease, yet summer pruning in high-density systems may have important disease management effects. Growers should avoid summer pruning practices which will increase disease risks, and use those that offer both horticultural and disease management benefits. More research in this area is needed, as cultural components of apple disease management will become increasingly important in sustainable production systems. This review looks at important apple diseases, including apple scab, fire blight, sooty blotch and flyspeck, black rot, white rot, Nectria canker and powdery mildew, and uses dormant pruning studies plus knowledge of the epidemiology of the diseases to suggest ways that summer pruning would be expected to impact disease management.

1. Introduction

Summer pruning of apples (*Malus* x *domestica*) is a practice used primarily to enhance fruit quality through the manipulation of tree physiology and alteration of the canopy environment, particularly light. The majority of studies of summer pruning in apple have focused on physiological impacts such as photosynthate partitioning, winter hardiness, return bloom, fruit coloring and post-harvest quality. However, summer pruning can have impacts on apple diseases, because it alters canopy microclimate, can remove diseased tissue, improves deposition of fungicides and other chemicals, and in altering tree physiology may change resistance to disease. Summer pruning may enhance disease management, but in some cases may increase the risk of disease. Of the few studies that have investigated interactions between summer pruning and apple diseases, most were done on semi-dwarf trees, and very few have looked at high-density systems.

In semi-dwarf trees, summer pruning offered both horticultural and disease management benefits. This is illustrated by an example from the mid-1980's in the northeastern US, where summer pruning was used to compensate for the loss of daminozide in commercial apple production (Autio and Greene, 1990). The predominant cultivar produced in the region at that time was 'McIntosh', which frequently drops fruit to the ground before they are sufficiently colored for harvest. Daminozide (Alar®) prevented this premature fruit drop, allowing development of full fruit color. When the manufacturers of daminozide removed the registration for apple use, it created potentially devastating crop loss through premature drop in 'McIntosh'. As a response, growers were encouraged to summer prune, primarily to accelerate development of fruit color through increased light penetration in the canopy. The practice was successful, to a large extent compensating for daminozide treatments. It also had a side-benefit, in that incidence of the summer disease complex sooty blotch and flyspeck (SBFS) decreased in summer-pruned trees, primarily as the result of reduced humidity and improved fungicide penetration in the canopy (Cooley *et al*., 1997).

At this time, the most recent major review of summer pruning was written 25 years before this review, focusing exclusively on effects on tree growth, yield, flowering, and fruit development (Saure, 1987). Since then, commercial apple production has seen wide-spread adoption of high-density planting systems in which the methods and impacts of summer pruning would be expected to differ substantially from those used in semi-dwarf (e.g. M.7, ca. 5 m tall) trees, but few studies have examined the impacts of summer pruning on apple diseases in high-density trees. In larger, semi-dwarf trees, summer pruning does not have an impact on the tree scaffold, but focuses on small branches and is largely intended to increase light penetration and

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air circulation, beneficial to both fruit quality and disease management. However, in modern high-density production systems a primary goal is light penetration, and overall tree training maintains a relatively small, open canopy. In such trees, summer pruning may not significantly increase air circulation, improve drying in the canopy, or improve pesticide deposition, and it is unclear whether it has benefits in terms of disease management. Instead, pruning cuts during the growing season may increase the risk of infection. Alternatively, pruning and removing diseased tissue, sanitation, may reduce disease impacts and future risks, but such cuts may conflict with desired tree architecture in a high-density system. Yet as restrictions on chemical use in plant disease management increase, cultural controls such as sanitation and inoculum destruction become more important. Much of this review must extrapolate from studies on semi-dwarf trees, dormant pruning, and the epidemiology of apple diseases to identify potential benefits and risks of summer pruning related to disease. It outlines types of summer pruning used in high-density systems, and then looks at important apple diseases that may be impacted by summer pruning and how pruning for sanitation may be useful.

2. Impacts on tree growth, yield, flowering and fruit development

Summer pruning can take on various forms from simple watersprout removal only to significant reductions in canopy density. Much study of summer pruning came from an interest in enhanced light penetration into the summer canopy, thus improving fruit color development. Vincent (1917), Preston and Perring (1974), Stiles (1980), Lord and Greene (1982), Marini and Barden (1982), Morgan *et al.* (1984), Autio and Greene (1990), Schupp (1992), and Ystaas (1992) all showed increased fruit redness as a result of summer pruning. Decreases in fruit size, however, have also been reported in some studies (Stiles, 1981; Marini and Barden, 1982; Greene and Lord, 1983; Myers and Ferree, 1983) but not all and not consistently. Li *et al.* (2003) modeled tree physiology as a result of summer pruning and found reductions in carbohydrates, potentially leading to a carbohydrate shortage after summer pruning. The potential for shortage was greater as the intensity of summer pruning increased. Fruit size impacts of that shortage can be mediated by improved water status resulting from reduced transpiration. Additionally, varying responses may be partially explained by the location of the summer-pruning treatment. Greene and Lord (1983) suggested that, as the severity of pruning increased or as the distance between the cut and the fruit decreased, the potential for a size reduction is enhanced.

Timing of summer pruning also is an important consideration. In general, regrowth during the period following summer pruning is greater the earlier the summer pruning is performed. Autio and Greene (1990) showed a linear decrease in the amount of regrowth as the pruning was performed from early (~45 days after full bloom) to late summer (~105 days after full bloom). Zamani *et al.* (2006) described a similar response from summer pruning from 30 to 90 days after full bloom.

Such data indicate that summer pruning acts as a stress on apples. If a stress is severe enough it can predispose woody plants to disease particularly from canker pathogens, but plants will recover from light to moderate stress (Schoeneweiss, 1981). At the same time, abiotic stresses can induce disease resistance in plants, including apples, though the physiological mechanisms behind induced resistance are not well understood (Hammerschmidt, 1999; Poupard *et al.*, 2003). Developing a better understanding of the detrimental and positive impacts of pruning stress at the physiological level is an area in need of more research.

3. Impacts on disease

Pruning apple trees, including summer pruning, can impact disease in several ways: by altering microclimate and architecture of the canopy, by removing inoculum and infected tissue, and by creating wounds that pathogens can invade. In their experiment in an organic orchard, Simon *et al.* (2006) observed that centrifugal training decreased apple scab and key insect pests in an organic orchard, and listed five explanatory hypotheses: 1) removal of inoculum and arthropods with the removal of fruiting spurs; 2) change in canopy microclimate, particularly better aeration; 3) decreased shoot density and increased distance between growing shoots slowing transmission; 4) changes in tree physiology inducing resistance or otherwise changing tissue susceptibility; 5) decreased canopy density improving pesticide penetration and deposition.

Pruning for sanitation is specifically designed to remove inoculum, thereby delaying or slowing epidemics and decreasing disease incidence and severity. For example, pruning removes primary inoculum of apple powdery mildew and fire blight, and is routinely recommended as part of the management programs for these diseases (Covey and Fischer, 1990; Xu, 1999; Steiner, 2000; Holb, 2005). However, pruning for sanitation often requires pruning cuts that do not conform to horticultural goals, and in most cases is performed in winter or early spring rather than summer. Summer pruning may remove inoculum, though it is not the primary purpose of the practice.

Changing the canopy density alters microclimate thereby impacting infection and disease development. Microclimate factors, particularly those related to moisture, have a major effect on plant diseases (Huber and Gillespie, 1992), and altering canopy density, as summer pruning does, influences canopy drying and disease (Gubler *et al.*, 1987; Cooley *et al.*, 1997; Sentelhas *et al.*, 2005; Batzer *et al.*, 2008). Leaf wetness duration (LWD) is a particularly important factor in plant disease epidemics and is often used in disease forecast models (Gleason *et al.*, 2008). For example, LWD has a major impact on whether or not apple scab (*Venturia inaequalis*) infections occur (Mills, 1944;

MacHardy and Gadoury, 1989; Stensvand *et al*., 2005; Xu and Robinson, 2005). High humidity and LWD also increase disease incidence and severity of SBFS (Cooley *et al*., 2011), cedar-apple rust (*Gymnosporangium juniperi-virginianae*) (Aldwinckle *et al*., 1980), black rot (*Botryosphaeria obtuse*) (Arauz and Sutton, 1989), white rot or Bot rot (*Botryosphaeria dothidea*) (Sutton and Arauz, 1991), Nectria canker (*Nectria galigena*) (Krahmer, 1981; Xu *et al*., 1998), and fire blight (*Erwinia amylovora*) (Steiner, 2000). Of these diseases, apple scab, SBFS, black rot, white rot and bitter rot drive most of the fungicide applications made in the eastern US, and account for substantial fungicide use in many apple production areas around the world (Cooley, 2009). By maintaining an apple canopy that dries relatively quickly, LWD periods are shortened, which may allow decreases in fungicide use.

The relationship between plant growth and the rate of an epidemic is complex, depending on tissue susceptibility, existing infections and the density of susceptible tissue, among other factors (Ferrandino, 2008). For apple scab, the relative risk of infection is affected by the amount of leaf tissue available for infection interacting with increasing ontogenic resistance and inoculum availability, which all change over time (Ficke *et al*., 2002). Summer pruning removes target tissue as well as sources of inoculum, and hence should slow development of apple scab epidemics. The timing of tissue removal should affect disease, and in general removal early in the growing season should reduce disease more than mid- or late-season removal. Still the interaction between pruning and the different epidemiological factors is complex. In the scab example, if early pruning stimulates vegetative growth, the rapid development of relatively large amounts of young, susceptible tissue may erase any early-season disease suppression. Holb *et al*. (2004) observed that heavy winter pruning suppressed foliar scab, but the impact on fruit at harvest was not significant.

For fire blight, it is recommended that flower clusters be removed from non-bearing trees before bloom, because the flowers are an important infection court for *E. amylovora* (Steiner, 2000). Pruning relatively non-productive flower clusters, as in centrifugal training, may reduce risk of fire blight.

Pruning also usually improves penetration of fungicides and other disease controlling chemicals (Sutton and Unrath, 1984; Travis *et al*., 1987; Cooley *et al*., 1997; Cross *et al*., 2003). Both summer (Cooley *et al*., 1997) and winter pruning (Ocamb-Basu *et al*., 1988; Holb, 2005) have been shown to improve spray penetration relative to non-pruned trees, though a comparison between two high density pruning methods in which centrifugal training reduced scab relative to original solaxe pruning did not show a difference in spray deposition (Simon *et al*., 2006).

Apple scab

Scab is probably the most important diseases threatening apples in humid production regions, but only one published study has been done on the impacts of summer pruning on the disease. Disease incidence in apple scab is strongly related to the duration of wetting periods and the amount of inoculum available in an orchard, with longer wetting periods and more inoculum increasing disease incidence and severity (MacHardy, 1996). Simon *et al*. (2006) showed a decrease in scab in high-density plantings pruned using centrifugal pruning relative to original solaxe pruning. They suggested that centrifugal pruning shortened wetting periods in the canopy thereby reducing the number and/or intensity of infection periods, though they do not present data on canopy microclimate.

A study by Holb (2005) looked at different levels of winter pruning on scab in high-density organic orchards, and concluded that heavy pruning significantly reduced the area under the disease progress curve for foliar and fruit scab on susceptible cultivars. They hypothesized that suppression of scab epidemics were caused by a reduction of inoculum overwintering in apple buds, improved fungicide deposition in pruned trees, and modification of the in-canopy microclimate, though microclimate factors did not consistently vary among pruning regimens.

Fire blight

Fire blight is an increasingly serious disease of apples worldwide. The disease affects all apple tissues, but is most damaging when it migrates from primary infections, commonly in blossoms and young shoots, to limbs and trunks. Scaffold limb and trunk infections are particularly damaging, cutting production over several seasons and often killing trees (Van der Zwet and Beer, 1995; Steiner, 2000; Thomson, 2000). Primary infections may also occur when trees are damaged mechanically by hailstones or other means, allowing the bacterial pathogen to enter the plant.

In the case of fire blight, pruning for horticulture purposes also may provide entry points for the pathogen. An early study of effects of summer pruning on fire blight in apple showed that it markedly increased infections (Lake *et al*., 1975). Hence pruning when fire blight models (e.g. (Steiner and Lightner, 1996; Smith, 1999) indicate risk of infection is high should be avoided if possible, or a treatment of streptomycin or other chemical prior to pruning be made if it is not. For example, mechanical hedging as practiced in fruiting walls would be expected to open multiple sites to fire blight infection for several days, and would be analogous to a hailstorm in terms of generating risk of infection from fire blight.

Fire blight epidemics often force growers to prune in an attempt to stop the progress of infections and remove inoculum. Recommendations for such pruning generally suggest cutting back to a healthy branch union approximately 25 cm below visible infections; disinfection of pruning tools with alcohol or bleach between cuts may also be recommended (Van der Zwet and Beer, 1995; Steiner, 2000; Toussaint and Philion, 2008). In apples it has generally been recommended diseased tissue be pruned out as soon as symptoms are observed, and pruning continued at frequent intervals thereafter in order to slow and stop epidemics (Covey and Fischer, 1990; Steiner, 2000; Toussaint and Philion, 2008). Shtienberg *et al*. (2003) found that factors related to the host, pathogen and environment should all be taken into account when determining whether and how to prune fire blight in pears, and elements of this approach may be useful in apples.

Sooty blotch and flyspeck

Summer pruning has been shown to decrease SBFS in apples, primarily because it reduces relative humidity and improves fungicide penetration and coverage in the canopy (Cooley *et al*., 1997). This study was conducted on free-standing semi-dwarf apple trees approximately 5 m tall by 3 m diameter. It is not known whether similar results would be obtained in systems using fully dwarf trees in dense plantings. However a trial in the US showed that it took over 450 hours LWD for SBFS symptoms to develop in fully-dwarf, well-maintained trees while large trees with dense canopies developed signs at 225 hours LWD (Ellis *et al*., 1999). The extent to which fully-dwarf trees in high-density systems may benefit from summer pruning has not be studied. Mummified fruit have been shown to harbor inoculum for SBFS pathogens, and removing these mummies can reduce disease incidence (Gleason *et al*., 2011).

Black rot and white rot

Black rot and white rot are fungal diseases that can attack fruit, foliage and woody tissue of apples. Sutton (1981) showed that much of the inoculum for these diseases comes from prunings in or near production blocks, and it is recommended that prunings be removed or chopped so that they rapidly disintegrate so as to remove inoculum from the orchard. Removing mummified fruit is also recommended as a cultural control. In that rates of these diseases on fruit is related to wetness duration and can be controlled with fungicides, pruning that reduces canopy humidity and improves fungicide coverage would be expected to enhance their management (Sutton, 1981; Arauz and Sutton, 1989; Arauz and Sutton, 1990; Sutton and Arauz, 1991; Parker and Sutton, 1993).

Nectria canker

Nectria can cause infections on fruit and woody tissue in apple. Pruning wounds are susceptible to the disease, and hence summer pruning can have an impact on canker incidence (Krahmer, 1981; Xu *et al*., 1998). Studies have consistently shown that new wounds, including pruning cuts, are readily colonized by *N. galigena*. While this is another example of a disease that can be exacerbated by summer pruning, unlike fire blight, there are no forecast models to predict when summer pruning is less risky. There are fungicidal chemicals that can be very effective in reducing canker incidence if applied right after pruning, including the organically accepted slaked lime (Heijne *et al*., 2005).

Powdery mildew

Since the early 20th century, dormant pruning has been recommended as a control measure against powdery mildew (Fisher, 1920). More recent studies from eastern Europe suggest that summer pruning that targets infected shoots can significantly reduce the disease, and even eliminate the disease (e.g. Berbekov *et al*., 2006; Holb and Abonyl, 2007). Disease reduction is probably primarily the result of inoculum removal, though reduction in canopy humidity may play some role as well (Xu, 1999).

4. Conclusions

While the role of summer pruning in modern high-density apple orchards is not disease management, the practice does alter the canopy architecture in ways that may reduce moisture levels and wetting period duration. For some diseases, notably fire blight and Nectria canker, summer pruning can increase the risk of infection by causing wounds. While some recent studies show that summer pruning can reduce risk for major apple diseases, such as scab and powdery mildew, virtually no studies have been done outside Europe. There is a need to assess the horticultural and disease management benefits and costs of summer pruning across a broader range of climates and high-density production systems, in order to determine whether summer pruning can be an element in economically and environmentally sustainable apple production.

References

ALDWINCKLE H.S., PEARSON R.C., SEEM R.C., 1980 - *Infection periods of* Gymnosporangium juniperi-virginianae *on apple*. - Phytopathology, 70: 1070-1073.

ARAUZ L.F., SUTTON T.B., 1989 - *Temperature and wetness duration requirements for apple infection by* Botryosphaeria obtusa. - Phytopathology, 79: 440-444.

ARAUZ L.F., SUTTON T.B., 1990 - *Protectant and after-infection activity of fungicides against* Botryosphaeria obtusa *on apple*. - Plant Disease, 74: 1029-1034.

AUTIO W.R., GREENE D.W., 1990 - *Summer pruning affects yield and improves fruit quality of McIntosh apples*. - J. Am. Soc. Hortic. Sci., 115: 356-359.

BATZER J.C., GLEASON M.L., TAYLOR S.E., KOEHLER K.J., MONTEIRO J., 2008 - *Spatial heterogeneity of leaf wetness duration in apple trees and its influence on performance of a warning system for sooty blotch and flyspeck*. - Plant Disease, 92: 164-170.

BERBEKOV V.N., BYASTRAYA G.V., YAGUBYAN S.K., 2006 - *Summer apple shaping and pruning as a method for decreasing damage done by powdery mildew (Russian)*. - ANO Redaktsiya Zhurnala Sadovodstvo i Vinogradarstvo, pp. 8-10.

COOLEY D.R., 2009 - *Biorational approaches to disease management in apples*, pp. 214-252. - In: LESKEY T.C., M. ALUJAH, and C. VINCENT (eds.) *Biorational tree fruit pest management*. Commonwealth Agricultural Bureau International, Oxfordshire, UK.

COOLEY D.R., GAMBLE J.W., AUTIO W.R., 1997 - *Summer pruning as a method for reducing flyspeck disease on apple fruit*. - Plant Disease, 81: 1123-1126.

COOLEY D.R., ROSENBERGER D.A., GLEASON M.L., KOEHLER G., COX K., CLEMENTS J.M., SUTTON T.B., MADEIRAS A., HARTMAN J.R., 2011 - *Variability among forecast models for the apple sooty botch/flyspeck disease complex*. - Plant Disease, 95(9): 1179-1186.

COVEY R.H., FISCHER W.R., 1990 - *Timely cutting of fire blight infections reduced losses*. - Acta Horticulturae, 273: 351-353.

CROSS J.V., WALKLATE P.J., MURRAY R.A., RICHARDSON G.M., 2003 - *Spray deposits and losses in different sized apple trees from an axial fan orchard sprayer: 3. Effects of air volumetric flow rate*. - Crop Prot., 22: 381-394.

ELLIS M.A., MADDEN L.V., WILSON L., 1999 - *Evaluation of an empirical model for predicting sooty blotch and flyspeck of apples in Ohio*. - Ohio State University Research Bulletin, Research Circular, pp. 1-6.

FERRANDINO F.J., 2008 - *Effect of crop growth and canopy filtration on the dynamics of plant disease epidemics spread by aerially dispersed spores*. - Phytopathology, 98: 492-503.

FICKE A., GADOURY D.M., SEEM R.C., 2002 - *Ontogenic resistance and plant disease management: A case study of grape powdery mildew*. - Phytopathology, 92: 671-675.

FISHER D.F., 1920 - *Control of apple powdery mildew*. - U.S. Department of Agriculture, Farmer's Bulletin, no. 1120.

GLEASON M.L., BATZER J.C., SUN G., ZHANG R., ARIAS M.M.D., SUTTON T.B., CROUS P.W., IVANOVIC M., MCMANUS P.S., COOLEY D.R., MAYR U., WEBER R.W.S., YODER K.S., DEL PONTE E.M., BIGGS A.R., OERTEL B., 2011 - *A new view of sooty blotch and flyspeck*. - Plant Disease, 95: 368-383.

GLEASON M.L., DUTTWEILER K.B., BATZER J.C., TAYLOR S.E., SENTELHAS P.C., MONTEIRO J., GILLESPIE T.J., 2008 - *Obtaining weather data for input to crop disease warning systems: leaf wetness duration as a case study*. - Sci. Agric., 65: 76-87.

GREENE D.W., LORD W.J., 1983 - *Effects of dormant pruning, summer pruning, scoring, and growth regulators on growth, yield, and fruit quality of 'Delicious' and 'Cortland' apple trees*. - J. Am. Soc. Hortic. Sci., 108: 590-595.

GUBLER W.D., MAROIS J.J., BLEDSOE A.M., BETTIGA L.J., 1987 - *Control of* Botrytis *bunch rot of grape with canopy management*. - Plant Disease, 71: 599-601.

HAMMERSCHMIDT R., 1999 - *Induced disease resistance: how do induced plants stop pathogens*? - Physiol. Mol. Plant Pathol., 55: 77-84.

HEIJNE B., DE JONG P.F., WENNEKER M., JANSONIUS P.J., 2005 - *Slaked lime against European fruit tree canker: efficacy and introduction into practice*. - ISOFAR, Prooceedings of the Conference "Researching Sustainable Systems", 21-23 September, Adelaide, South Australia.

HOLB I.J., 2005 - *Effect of pruning on apple scab in organic apple production*. - Plant Disease, 89: 611-618.

HOLB I.J., ABONYL F., 2007 - *Control of apple powdery mildew in integrated and organic production*. (Hungarian - English summary). - *Növényvédelem,* 43: 247-252.

HOLB I.J., HEIJNE B., JEGER M.J., 2004 - *Overwintering of conidia of* Venturia inaequalis *and the contribution to early epidemics of apple scab*. - Plant Dis., 88: 751-757.

HUBER L., GILLESPIE T.J., 1992 - *Modeling leaf wetness in relation to plant disease epidemiology*. - Annual Review of Phytopathology, 30: 553-577.

KRAHMER H., 1981 - *Regeneration of pruning wounds of apple trees and their susceptibility to infections by* Nectria galligena. - Angew. Bot., 55: 429-439.

LAKE C.F., STUSHNOFF C., KENNEDY W., 1975 - *Fire blight infection on summer-pruned apples*. - Plant Disease Reporter, 59: 620-622.

LI K.T., LAKSO A.N., PICCIONI R., ROBINSON T., 2003 - *Summer pruning effects on fruit size, fruit quality, return bloom and fine root survival in apple trees*. - J. Hortic. Sci. & Biotechnology, 78: 755-761.

LORD W.J., GREENE D.W., 1982 - *Effects of summer pruning on the quality of McIntosh apples*. - Hortscience, 17: 372-373.

MACHARDY W.E., 1996 - *Apple scab: biology, epidemiology and management*. - APS Press, St. Paul, MN, USA, pp. 545.

MACHARDY W.E., GADOURY D.M., 1989 - *A revision of Mills criteria for predicting apple scab infection periods*. - Phytopathology, 79: 304-310.

MARINI R.P., BARDEN J.A., 1982 - *Yield, fruit size, and quality of three apple cultivars as influenced by summer or dormant pruning*. - J. Am. Soc. Hortic. Sci., 107: 474-479.

MILLS W.D., 1944 - *Efficient use of sulfur dusts and sprays during rain to control apple scab*. - N.Y. Agr. Exp. Sta. Ithaca Ext., Bull. No. 630, pp. 4.

MORGAN D.C., STANLEY C.J., VOLZ R., WARRINGTON I.J., 1984 - *Summer pruning of 'Gala' apple: The relationships between pruning time, radiation penetration, and fruit quality*. - J. Am. Soc. Hortic. Sci., 109: 637-642.

MYERS S.C., FERREE D.C., 1983 - *Influence of time of summer pruning and limb orientation on yield, fruit size, and quality of vigorous 'Delicious' apple trees*. - J. Am. Soc. Hortic. Sci., 108: 630-633.

OCAMB-BASU C.M., SUTTON T.B., NELSON L.A., 1988 - *The effects of pruning on incidence and severity of* Zygophiala jamaicensis *and* Gloedes pomigena *infections of apple fruit*. - Phytopathology, 78: 1004-1008.

PARKER K.C., SUTTON T.B., 1993 - *Effect of temperature and wetness duration on apple fruit infection and eradicant activity of fungicides against* Botyosphaeria dothidea. - Plant Disease, 77: 181-185.

POUPARD P., PARISI L., CAMPION C., ZIADI S., SIMONEAU P., 2003 - *A wound- and ethephon-inducible PR-10 gene subclass from apple is differentially expressed during infection with a compatible and an incompatible race of* Venturia inaequalis. - Physiol. Mol. Plant Pathol., 62: 3-12.

PRESTON A.P., PERRING M.A., 1974 - *The effect of summer pruning and nitrogen on growth, cropping and storage quality of Cox's Orange Pippin apple*. - J. Hortic. Sci. & Biotechnology, 49: 77-83.

SAURE M.C., 1987 - *Summer pruning effects in apple - a review*. - Sci. Hortic., 30: 253-282.

SCHOENEWEISS D.F., 1981 - *The role of environmental stress in diseases of woody plants*. - Plant Disease, 65: 308-314.

SCHUPP J.R., 1992 - *Effect of root pruning and summer pruning on growth, yield, quality, and fruit maturity of McIntosh apple trees*. - Acta Horticulturae, 322: 173-175.

SENTELHAS P.C., GILLESPIE T.J., BATZER J.C., GLEASON M.L., MONTEIRO J., PEZZOPANE J.R.M., PEDRO M.J., 2005 - *Spatial variability of leaf wetness duration in different crop canopies*. - International Journal of Biometeorology, 49: 363-370.

SHTIENBERG D., ZILBERSTAINE M., OPPENHEIM D., LEVI S., SHWARTZ H., KRITZMAN G., 2003 - *New considerations for pruning in management of fire blight in pears*. - Plant Disease, 87: 1083-1088.

SIMON S., LAURI P.E., BRUN L., DEFRANCE H., SAUPHANORE B., 2006 - *Does manipulation of fruit-tree architecture affect the development of pests and pathogens? A case study in an organic apple orchard*. - J. Hortic. Sci. & Biotechnology, 81: 765-773.

SMITH T.J., 1999 - *Report on the development and use of Cougarblight 98C - A situation-specific fire blight risk assessment model for apple and pear*. - Acta Horticulturae, 489: 429-436.

STEINER P.W., 2000 - *Integrated orchard and nursery management for control of fire blight*, pp. 339-358. - In: VANNESTE J.L. (ed.) *Fire Blight: The Disease and Its Causative Agent,* Erwinia amylovora. - CABI, Oxon, Wallingford, UK, pp. 370

STEINER P.W., LIGHTNER G.W., 1996 - *Maryblyt^{TM} 4.3. A predictive program for forecasting fire blight disease in apples and pears*. - University of Maryland, College Park, MD, USA.

STENSVAND A., EIKEMO H., GADOURY D.M., SEEM R.C., 2005 - *Use of a rainfall frequency threshold to adjust a degree-day model of ascospore maturity of* Venturia inaequalis. - Plant Disease, 89: 198-202.

STILES W.C., 1980 - *Pruning, growth regulator, and nutrition studies with apples*. - Maine State Pomo. Soc. Ann. Rep., pp. 25-34.

STILES W.C., 1981 - *Summer pruning and growth regulator effects on 'McIntosh' apples*. - Maine State Pomo. Soc. Ann. Rep., pp. 26-29.

SUTTON T.B., 1981 - *Production and dispersal of ascospores and conidia by* Physallospora obtusa *and* Botryosphaeria dothidea *in apple orchards*. - Phytopathology, 71: 584-589.

SUTTON T.B., ARAUZ L.F., 1991 - *Influence of temperature and moisture on germination of ascospores and conidia of* Botryosphaeria dothidea. - Plant Disease, 75: 1146-1149.

SUTTON T.B., UNRATH C.R., 1984 - *Evaluation of the tree-row-volume concept with density adjustments in relation to spray deposits in apple orchards*. - Plant Disease, 68: 480-484.

THOMSON S.V., 2000 - *Epidemiology of fire blight*, pp. 9-36. - In: VANNESTE J.L. (ed.) *Fire blight: The disease and its causative agent,* Erwinia amylovora. - CABI, Oxon, Wallingford, UK, pp. 370.

TOUSSAINT V., PHILION V., 2008 - *Natural epidemic of fire blight in a newly planted orchard and effect of pruning on disease development*, pp. 313-320. In: JOHNSON K.B., and V.O. STOCKWELL (eds.) *Proceedings of the Eleventh International Workshop on Fire Blight*. International Society Horticultural Science, Leuven 1, Belgium.

TRAVIS J.W., SKROCH W.A., SUTTON T.B., 1987 - *Effect of canopy density on pesticide deposition and distribution in apple trees*. - Plant Disease, 71: 613-615.

VAN DER ZWET T., BEER S.V., 1995 - *Fire blight - its nature, prevention, and control: a practical guide to integrated disease management*. - Cornell University, USDA Agricultural Information Bull. no. 631, pp. 91.

VINCENT C.C., 1917 - *Winter versus summer pruning of apple trees*. - Idaho Agric. Expt. Sta. Bul. University of Idaho, USA.

XU X.M., 1999 - *Modelling and forecasting epidemics of apple powdery mildew (*Podosphaera leucotricha). - Plant Pathology, 48: 462-471.

XU X.M., BUTT D.J., RIDOUT M.S., 1998 - *The effects of inoculum dose, duration of wet period, temperature and wound age on infection by* Nectria galligena *of pruning wounds on apple*. - Eur. J. Plant Pathol., 104: 511-519.

XU X.M., ROBINSON J., 2005 - *Modelling the effects of wetness duration and fruit maturity on infection of apple fruits of Cox's Orange Pippin and two clones of Gala by* Venturia inaequalis. - Plant Pathology, 54: 347-356.

YSTAAS J., 1992 - *Effects of summer pruning on yield, fruit size, and fruit quality of the apple cultivar 'Summerred'*. - Acta Horticulturae, 322: 277-282.

ZAMANI Z., SAIE A., TALAIE A., FATAHI, R., 2006 - *Effects of summer pruning on growth indices of two important Iranian apple cultivars 'Golab' and 'Shafi-Abadi'*. - Acta Horticulturae, 707: 269-274.