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Title: Influence of Canopy Orientation on Fruiting of 'Anjou' Pears and Postharvest Urea Spray on Ovule Longevity and Fruit Set of 'Comice' Pears.

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Porter B. Lombard

The effect of canopy orientation on fruiting performance of 'Beurré d'Anjou' pears (*Pyrus communis* L.) and postharvest urea spray on ovule longevity and fruit set of 'Doyenne du Comice' pears were studied.

Hedgerows of 'Beurré d'Anjou' pear trees planted in 1969 in two orientations north-south (N-S) and east-west (E-W) were used to study the effect on pear fruiting. The trees were spaced 1.3 x 3.7 m, trained to a central leader, and mechanically pruned to a tree wall 3.7 m high and 1.8 m wide at the base with a wall angle of 17° from the vertical.

Flower density (FD), flower buds per unit branch cross-sectional area (BCSA), was lowest on the N wall of the E-W rows in 1990 and on the S wall of the same rows in 1991. In both years, N-S rows had higher FD. Fruit set (FS), fruit per flower buds, was highest on the S wall and lowest on the N wall of the E-W rows, whereas, the E and W walls of the N-S rows were intermediate. Crop

density (CD), fruit per unit BCSA, had a similar pattern as FS with more fruits on the S wall and less on the N wall of the E-W rows. However, CD was more evenly distributed between the walls of the N-S hedgerows. Differences in FS and CD between sides were corelated to different levels of sunlight interception. For instance, the mid height of the N wall of the E-W rows received less than 20% full sunlight throughout the growing season whereas the S wall received more than 35% of irradiance especially towards the equinoxes. Increased solar heating on the S and W walls late in the season led to more sunburned fruits. Fruits from E-W rows were larger and less firm.

'Doyenne du Comice' is generally considered as a commercial pear variety with highly palatable fruits. A shortcoming of this variety is, however, that its trees come into bearing late and then set a small crop. The possibility of altering ovule longevity and fruit set of this cultivar by nitrogen fertilization was investigated. Mature trees were given a single foliar application of 5% or 10% urea immediately after harvest. Ovule senescence was detected by fluorescence microscopy. Ovule longevity was extended in both treatments in comparison to control. FS was increased after a foliar application of urea when based on trunk cross sectional area. There was no effect on FD, CD, fruit fresh weight, and yield efficiency of 'Comice' trees treated with postharvest urea sprays.

Influence of Canopy Orientation on Fruiting of 'Anjou' Pears and
Postharvest Urea Spray on Ovule Longevity and Fruit Set of 'Comice'
Pears

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Habib Khemira

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_____

Head of Department of Horticulture

_____

Dean of Graduate School

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INFLUENCE OF CANOPY ORIENTATION ON FRUITING OF 'ANJOU' PEARS AND POSTHARVEST UREA SPRAY ON OVULE LONGEVITY AND FRUIT SET OF 'COMICE' PEARS

CHAPTER 1

INTRODUCTION

Pears, *Pyrus communis* L., are principally grown in western U.S.A. Ninety four percent of the of the pear production of the country are in the western coastal states : Washington, Oregon, and California. Four varieties 'Williams' (Bartlett), 'Beurré d'Anjou' (Anjou), 'Beurré Bosc' (Bosc), and 'Doyenne du Comice' (Comice) account for 99% of the total production. In Oregon, the industry is concentrated in the Rogue and Hood River Valleys and, to a lesser extent, in the Willamette River Valley.

High economic cost has greatly increased interest in better production efficiencies in the tree fruit industry. The grower has reacted to the situation by planting trees at higher densities and in better orchard designs. The aim of this strategy is to have an orchard that begin bearing quickly and consistently. Along with the increased density of orchard plantings, is the association of increased intensified orchard management. Special care is needed at every step of the production process. For instance, early in the beginning of an orchard establishment a decision should be taken concerning row orientation to maximize solar light throughout the trees. Earlier reports (Auchter et al., 1926; Heinicke, 1966; Shitt, 1937 quoted by Devyatov and Gorny, 1978) recognized the importance of sunlight

for fruit production and particularly for floral initiation of apple. The influence of row orientation on light interception by the tree canopy has recently been reanalyzed by Palmer (1989) using a light transmission model. For short hedgerows or systems with very narrow clear alleyways, row orientation has little effect on light interception, but for tall hedgrows with wide clear alleyway spacings, E-W rows intercept less light than N-S rows in mid-summer, particularly at lower latitudes (30°-50°N). At the equinoxes E-W rows intercept more light than N-S rows, although there is little difference at a latitude of 30°. Chich is basically the conclusion reached using solid models (Cain, 1972; Jackson and Palmer, 1972) and thus, emphasizes the importance of configuration factor in discontinuous canopies. Experimental evidence on the effect of row orientation on yield is contradictory, possibly because the models are dealing with light as the sole environmental variable. Lombard and Westwood (1977) found yield increases of 34% and 48% for 'Williams' and 'Beurré d'Anjou' pears in N-S rows compared to E-W in Oregon (42°N) and Christensen (1979) found similar yield increase on apple in Denmark (55.3°) of 17% with N-S rows. In contrast, Devyatov and Gorny (1978) in Minsk (53.8°N) found yield increases of apples of 16-35% with E-W rows. Therefore, further investigation of this subject seems justified.

Fruit set is another major component of the economic yield of an orchard. A large yield can only be expected if conditions for pollination and fruit set are favorable. Low fruit is recognized as a serious limiting factor for many fruit varieties. For instance, 'Doyenne du Comice' is considered the best eating winter

pear cultivar because of its juicy, buttery texture and well balanced flavor. A shortcoming of this variety is, however, that it starts bearing late in life and yields small crops. The trees form a large number of flower buds and bloom profusely but set few fruits. This has been attributed to lack of proper pollination and low self-fruitfulness (Callan and Lombard, 1978; Bini and Bellini quoted by Lombard and Richardson, 1982; Stephen, 1958), to early embryo sac degeneration and short effective pollination period (Jaumien, 1968; Lombard et al., 1971), or to the competition for nutrients between shoots and fruitlets (Nicotra et al., 1977; Van Zyl and Strydom, 1982). Crisosto et al. (1986) suggested that extension of the effective pollination period could improve fruit set. Furthermore, earlier works (Williams, 1963, 1965; Hill-Cottingham and Williams, 1967) showed that on apple trees where the nitrogen status had been raised by the use of summer or fall nitrogen the flowers were more likely to set fruit. This practice has been shown to enhance normal development of the ovules and embryo sacs of apple flowers (Williams, 1965). Ewart and Kliewer (1977) obtained similar results with grapes by a post-bloom application of ammonium nitrate. When applied late in the season, nitrogen is allocated primarily into storage structures and flower buds of the tree (Sanchez, 1990; Ystaas, 1980; Williams, 1965; Merzougui, 1986; Shim et al., 1973; Weinbaum et al., 1984). Sanchez et al. (1990) reported that a single postharvest urea spray on 'Doyenne du Comice' pear trees at 5% and 10% increased nitrogen content in one year old bark and wood and the flower buds and blossoms. Ystaas (1980) observed an immediate increase of nitrogen concentration of leaves and flower buds of

'Molke' pear after a 6% postharvest urea spray.

The purpose of this research was to compare two hedgerow orientations: north-south (N-S) and east-west (E-W) for their effect on fruiting performance of 'Beurré d'Anjou' pears and to investigate the influence of late season nitrogen on flowering and fruiting of 'Doyenne du Comice' pear trees.

Chapter 3 describes sunlight interception by 'Beurré d'Anjou' pear hedgerows oriented either N-S or E-W and relates that to flower density, fruit set, and yield.

Chapter 4 describes the effect of postharvest urea spray on ovule longevity and other yield components of 'Doyenne du Comice' pear trees.

CHAPTER 2

LITERATURE REVIEW

1. Fruit set

Fruit set (FS) is an index of the proportion of flower buds developing into fruits (Lombard et al., 1988). It is one of the most important determinants of the productivity of fruit trees (Lombard et al., 1988; Dennis, 1979). A large yield of fruit can only be expected if conditions for pollination and fruit set are favorable (Faust, 1989). This involves a complex series of events, none of which can be limiting to the overall process.

Once on the stigma, the pollen grain germinates and under the influence of the tube nucleus, a pollen tube grows down through the style into an ovule (Curtis and Barnes, 1981); at this moment fertilization of the egg takes place. A hormonal stimulus from the young developing embryo (or from elsewhere in parthenocarpy) prevents the fruit from abscising and causes the ovary and adjacent tissues to enlarge into the developing fruit (Westwood, 1978; Sedgley et al., 1977; Callan and Lombard, 1978). Simons (1974) reported that the principal morphological difference between the heavy bearing apple cultivar 'Lodi' and the other cultivars is that 'Lodi' contains more seeds. For apple, Murneck (1957) found that the fruit does not set unless fertilization has occurred in a considerable number of the 10 ovules. In this respect, it has been suggested that

seeds establish a metabolic gradient for the movement of nutrients into fruit (Crane, 1964). Therefore, fertilization is apparently necessary to initiate this gradient favoring ovary development. But it does not follow necessarily that continued seed function is required to maintain this gradient (Weinbaum and Simons, 1974). Callan and Lombard (1978) also, agree that fruit retention does not require the presence of fully developed seeds. Working with watermelon fruit Sedgley et al. (1977) showed that starch is present throughout a period of 9 days after anthesis in the integuments of the pollinated and parthenocarpic ovules but is lost from the integuments of the unpollinated ovules by day 6. Therefore, it seems here that pollination is the stimuli responsible for the establishment of the gradient. Monselise (1972) hypothesized that in seedless cultivars, fruit tissues (other than seeds) provide stimuli that establish a high metabolic gradient and divert the flow of nutrients from vegetative structures of the developing fruitlets.

In species with both a postbloom drop and a 'June' drop or preharvest drop, initial and final FS measurements are often taken (Lombard et al., 1988). After petal fall, the 'first drop' occurs - this is a general heavy shedding of undeveloped fruitlets of most species. There are presumed to be mostly from unfertilized flowers. After initial set, there may be two or three more waves of fruit shedding, after which final set is established. Final FS is used to indicate the contribution of set to yield (Westwood, 1978). Several factors have been shown to affect fruit set of trees. Among them are genotypic differences

(Lombard and Westwood, 1976), nutritional status of the tree (Williams, 1965; Deng et al., 1991), ovule longevity (Jaumien, 1968), weather conditions (Vasilakakis and Porlingis, 1985), rootstocks (Lombard and Westwood, 1977), growth regulators (Crisosto et al., 1988), and light intensity (Jackson and Palmer, 1977).

1.1 Genotype effect

In most plants not all flowers set fruit even though every flower or floret is pollinated and the plant is in good health. The extent of this natural shedding varies with species. Large-fruited types such as apple may shed 95% or more of their flowers and young fruits, while a small-fruited species like blueberry may shed only 20 to 30 percent of them (Westwood, 1978). Within the same specie, some varieties have a predisposition to set less fruits than others. For instance, 'Doyenne du Comice' pear is known to be a poor setting variety. Jaumien (1968) explained this by a genetic predisposition of its flowers towards a high proportion of embryo sacs with abnormal development or early degeneration.

Moreno et al. (1991), studying the effect of temperature on ovule longevity of two cultivars of prunes, found that at the same temperatures 'Brooks' ovules remained viable longer when compared to 'Italian'.

Another thing to take into account is the rootstock effect. Cultivars behave differently depending on their roots. For instance, *Cydonia oblonga* and *Pyrus calleryana* increase fruit set while 'Old Home' clonal stock reduces set of several pear varieties (Lombard and Westwood, 1976). Furthermore, they found that fruit set is higher on Old Home x Farmingdale (OHxF) 333 than OHxF 87 and OHxF 69 and that there is a cultivar-rootstock interaction with fruit set where rootstock differences are greater with 'Williams' (Bartlett) than 'Anjou' (Lombard and Westwood, 1977).

1.2 Nutritional status of the tree

The nutritional status of the tree will have great bearing on the ability to initiate flower buds, develop flower clusters, and set fruit. Factors which adversely affect shoot growth, leaf area, light penetration, carbohydrate assimilation and transport, or crop size would influence flower formation and fruit set. Thus, a general nutritional balance of the essential macro/ and micronutrients is important to bud development and subsequent fruit setting (Rom, 1985).

Nitrogen is the fertilizer element most needed in pear trees, but it's generally needed in relatively low amounts. Working with 'Moltke' pear trees, Ystaas (1990) showed that this cultivar has a low requirement of nitrogen and

that within the range of 1.9 - 2.4% leaf nitrogen a very satisfactory fruit set can be obtained. Sanchez (1990) observed the same thing with cultivar 'Doyenne du Comice' and attributed that to the fact pear trees recycle a substantial portion of their N content, and therefore, require little supplemental N.

In green plant material, N is shared between three main fractions : inorganic N (NO_3, NH_4^+), low molecular weight organic N compounds (free amino acids, amines, amides), and macromolecular organic N compounds (enzyme proteins, storage proteins, nucleic acids). Increasing the level of N nutrition results in an increase of the content of soluble amino compounds and to a less degree of all other fractions (Kirkby and Mengel, 1987). Recently in a study of N metabolism in developing citrus flowers Sagee and Lovatt (1991) suggested that NH_3-NH_4^+ accumulates during stress-induced flowering of 'Washington' Navel orange trees resulting in the stimulation of de novo arginine biosynthesis and in the accumulation of putrescine at an early stage of flower organogenesis, followed by rapid metabolism of these compounds during flower development. Flower bud development during the dormant season and the subsequent flower development shortly after anthesis depend exclusively on C and N reserves in the storage structures of the tree. Deng et al. (1991) suggested that abortion of pistillate flowers of a protandrous cultivar of walnut may result from transient deficiencies of C and N during the spring flush of growth, in fact, pistillate flower abortion was 26% higher in non N-fertilized trees than in N-fertilized trees. In citrus, Lovatt et al. (quoted by Sagee and Lovatt, 1991)

observed a significant increase in the number of flowers on the trees after increasing leaf NH_3-NH_4^+ content by foliar application of urea. Williams (1965) was able to increase fruit set in 'Cox' apple in England by applying N during the previous summer. He ascribed the beneficial effects of this treatment to improved ovule development. In this respect, Dorsey (1929) working with apple, first recorded a relationship existing between the longevity of embryo sacs and the quality of blossoms. The quality of the flower buds was understood in terms of mineral content, and the element most associated with fruit set was N. Trees with an appropriate N supply produce more reserve substances which enhance the chances of producing 'strong' well developed flower buds (Mishara, 1984).

Hill-Cottingham and Williams (1967) evaluated the effect of nitrogen on the differentiation of flower buds in apple. They found that ovary and pollen tetrad development occurred only if the trees were supplied with nitrogen during the summer. When N is applied in winter before bloom, as it has been conventionally, to get enough new N into flowers and leaves to increase fruit set, it has been necessary to apply high rates per acre. Studies have indicated that the pear tree actually takes-up only about 25% of the applied N (Sanchez, 1990). While this practice does appear to increase fruit set the following year, it has several unwanted side effects. Besides the high amount of minerals leaching into the ground water and domestic wells, this practice yields fruits high in N which have a predisposition towards storage disorders. However, if applied in fall, N is mainly allocated into storage structures and flower buds of the tree (Sanchez,

1990; Ystaas, 1980; Merzougui, 1986; Weinbaum et al., 1984; Williams, 1965).
With the use of concentrated solutions of urea, it is possible to decrease
substantially the amount of fertilizer applied for the same level of N recovery.

Application of N late in the season has been shown to increase N flower
bud content, ovule viability, the effective pollination period, and fruit set in
apple trees (Williams, 1965). With grapes, Ewart and Kliewer (1977) obtained
the results by a post-bloom application of ammonium nitrate. Khattab et al.
(1981) sprayed 2 and 6% urea on 'Leconte' pear trees in the fall and found
more flowers per spur. However, growers are reluctant to apply N at this time
because some reports suggested that high N trees are more susceptible to winter
damage. However, in their review of the subject, Pellett and Carter (1981) stated
that acceptance of this concept is not entirely justified. In fact, acclimation is an
active metabolic process that requires a product of photosynthesis (Chandler,
1954). Foliage should be in good condition in the fall to produce the maximum
photosynthate possible.

Another mineral element that has been closely associated with fruit set in
a number of plants is boron. Several authors (Kamali and Childers, 1970;
Thompson and Batjer, 1959) have demonstrated the importance of an adequate
level of boron for 'in vitro' pollen germination and pollen tube growth. Under
the conditions prevailing in the Northwest region, Batjer and Thompson (1949)
showed evidence that boric acid sprays significantly increase set of 'Beurre
d'Anjou' pears. They speculated that boron increases pollen germination and

pollen tube growth and stimulates formation of plant auxins during and immediately following bloom.

1.3 Ovule longevity

Williams in 1966 introduced the concept of effective pollination period (EPP). The duration of this period equals the longevity of the ovule minus the time required for pollen tubes to reach the embryo sac. In fact, after pollination it takes a certain time for the pollen tube to reach the embryo sac; and fertilization can take place only at this time. Since the mature ovule has a limited life, the effective pollination is limited to a period immediately following the opening of the flower (Faust, 1989).

In Poland, Jaumien (1968) attributed poor fruit set of 'Doyenne du Comice' pear to early embryo sac degeneration. She found 25% of ovules examined to be degenerated by 3 days after petal fall, and 95% degenerated by 12 days after. In the Southern Oregon conditions, examination of embryo sacs two days before estimated time of fertilization indicated that the percentage of malformed or aborted sacs was very low (Callan and Lombard, 1978). For almonds, Pimiento and Polito (1980) suggested that depletion of carbohydrate reserves in developing seeds is an early indication of seed abortion. Almond ovaries usually contain two ovules, one develops normally and becomes fertilized and the other aborts. At pollination, starch grains are evident in the integuments

and nucellus tissues of both ovules. However, 4 days later starch is nearly depleted from one ovule but accumulates in the one judged viable (Pimiento and Polito, 1980).

In deciduous fruit tree species, spring growth flush depends largely on the redistribution and use of C and N compounds assimilated from previous year(s) and stored over winter in perennial tissues (Deng et al., 1991). It is known that immature leaves are heterotrophic. Deng et al. (1991) postulated that the limited availability of assimilates during the transition of C availability from storage to current-year photoassimilation may contribute to the abortion of pistillate flowers of walnuts. In fact, they found that depletion of storage C and N was accentuated before maturation of pistillate flowers by the metabolic demands of many catkins, spur growth, and leaf expansion.

In the case of bean, early symptoms of abortion of ovules include rapid depletion of starch in integuments and nucellar cells, increased vacuolation, and collapse of some cells (Sage and Webster, 1990; Mirza, 1989). Mirza (1989) working with snap beans, found a marked callose deposition in the phloem of the vascular strand entering presumably aborted seeds of recently abscised flowers causing, possibly, seed starvation, abortion and ultimately pod abscission. However, Weinbaum et al. (1974) found no evidence of starch utilization either in embryo or endosperm tissue in apple fruit for three weeks after full bloom. This is supported by a previous report in which gibberellic acid (GA) was not detected in apple seeds earlier than 4 to 5 weeks after bloom. Gibberellic acid

reportedly is involved in the de novo synthesis of α-amylase which acts on starch
to liberate reducing sugars. His findings prompt the conclusion that embryo
degeneration, which has been associated with fruit abortion, occurs subsequent
to the commitment of fruit to abscise. They not support the concept of 'embryo
abortion' as a primary agent in natural fruit abscission during the post-bloom
period.

1.4 Temperature effects

Temperature appears to be a major factor limiting fruit set in several fruit
species particularly in areas in which low temperatures are frequent during
bloom time. The impact of temperature on fruit set may be through its effect on
soil nutrient uptake (Sanchez, 1990a; Kato, 1986), pollen germination and
subsequent tube growth (Lombard et al., 1972), ovule longevity (Moreno, 1991),
and pollinator insect activity (Lombard et al., 1971). Both the germination and
growth rate of compatible or partially compatible pollen are dictated by
temperature. The germination of pollen is usually not linear with temperature
and greatly depends on the variety. In contrast, pollen tube growth responds to
temperature in a much more linear fashion (Faust, 1989). Pollen germination of
'Tsakoniki' and 'Coscia' pears is reduced at temperatures below 15°C
(Vasilakakis and Porlingis, 1985). Lombard et al. (1971) found that temperature
profoundly affected the rate of pollen tube growth in pear. At 5°C, tube growth

of 'Williams' required 12 days while at 15°C, required only 2 days. They determined that pear ovules were viable for 11 days; thus at 5°C the EPP was zero, while at 15°C it was 9 days. The same phenomenon was observed in prune trees in seasons with high post-bloom temperatures (Thompson and Liu, 1973). In the case of 'Tsakoniki' and 'Coscia' pears, Vasilakakis and Porlingis (1985) observed a longer EPP at low temperature. They suggested that low temperature increases ovule longevity and thus, compensates for the reduction of pollen tube growth. Williams (1970) argues that, whereas, cool temperatures prolong ovule longevity, pollen tube growth is retarded sufficiently so that even if fertilization finally does occur, fruit set fails because ovular breakdown has already commenced.

Excessively high temperature during and after bloom decreases fruit set of several species. Kliewer (1977) reported a reduction of ovule fertility in grapes at temperatures above 35°C and attributed that partially to a decrease in organic nutrients supply.

Besides the above effects, temperature can interfere with the development of the reproductive structures of the tree and with the activity of the pollinator insects. Bees do not fly well at temperatures below 10°C; thus, cold sides of trees do not set much fruit because insects tend to work the warmest portions of trees (Westwood, 1978). Occasionally low temperatures in early spring can be detrimental for the flower buds and especially the ovaries. In some areas frost damage is the real limitation for production of many fruit

species.

1.5 Growth regulators effects

Growth regulators, both natural and synthetic, may be divided into five groups based on differences in their structures and effects: auxins, gibberellins, cytokinins, ethylene and ethylene-generators, and growth inhibitors.

Using chromatographic methods Crane, in 1964, found that the extracts of seeds and fruits contained a complex mixture of growth-regulating substances, both stimulators and inhibitors of growth as measured by various bioassays. In pear, various auxin-like promoters and gibberellins (GA) including GA_{17}, GA_{25}, and GA_{45}, have been identified in the seeds and fruit diffusate (Gil et al., 1973; Martin and Nishijima, 1978). The concentration of each of these hormones vary considerably throughout the season. For instance, in apple seeds very little gibberellin activity has been detected prior to six weeks after full bloom. Subsequently, however, there is a very rapid build up of gibberellins GA_4 and GA_7 (Luckwill et al., 1969).

The genesis of growth regulators is known to be associated with meristematic tissues (Crane, 1964). For example, the primary natural auxin, indole-3-acetic acid (IAA), is produced mainly in subapical regions of actively growing shoots, in young leaves and developing embryos. Gibberellins in trees are produced mainly in very young leaves, young embryos, fruits, and in roots;

the two latter tissues are also the primary sites of cytokinin synthesis. Ethylene is synthesized in many parts of the plant particularly under physical stress. Growth inhibitors, like abscissic acid (ABA), are mainly synthesized in mature leaves during the shortening days of late summer, but many other tissues are known to synthesize ABA in particular, under stress (Westwood, 1978). The functioning of a plant depends upon specific levels of these natural hormones, each in balance with the others. Nitsch, in his review of the subject in 1953, pointed out that fruit setting and growth were obviously under a control mechanism and presented the evidence for auxin originating in the seed as being the key factor involved.

Growth regulators are thought to control fruit set by their ability to attract assimilates and minerals (Erner, 1989). Abbott (1960) suggested that one of the main functions of the relatively high concentration of hormones found in developing seeds may be the mobilization of essential metabolites particularly carbohydrates and soluble nitrogen against the competing demands of the growing shoots. Fruits with no seeds or with only a low seed content are not, normally, able to survive this competition, though they can be made to develop if competing vegetative growth is suppressed. However, despite the fact that pollination and/or fertilization are apparently necessary to initiate a metabolic gradient favoring ovary development, it does not follow necessarily that continued seed function is required to maintain this gradient (Weinbaum and Simons, 1974). Furthermore, Monselise (1972) hypothesized that, in seedless cultivars, fruit tissues (other than seeds) provide the stimuli. For instance, a

pollen stimulus is sufficient to set fruit of seedless cultivars of citrus (Erner, 1989).

Growth regulators have been shown to influence enzymatic activity of the embryonic tissue. Kirsop and Pollack (1958) have demonstrated that there is a positive correlation between the presence of the embryo and the ß-amylase content of the endosperm, with amylolytic action falling off sharply following removal of the embryo. Paleg, in 1960, found it possible to duplicate, at least in terms of starch hydrolysis, the effect of the embryo on the endosperm by treatment of the endosperm with GA to liberate reducing sugars, providing evidence for the conclusion that GA increases the water soluble, amylolytic activity of the endosperm. Exogenous hormones and growth regulators have been shown to increase fruit set in several vegetables and fruit tree species including tomato, pepper, cucumber, egg plant, fig, orange, cranberry, pear, apple, and cherry (Crane, 1964; Crane and Hicks, 1968; Martin and Nishijima, 1978; Westwood, 1978; Monselise, 1986; Crisosto et al, 1988). In pears, several products has been shown effective, in this respect, including 2-(2,4,5-trichlorophenoxy) propionic acid (Westwood, 1978), putrescine (Crisosto et al., 1988), amino-ethoxyvinylglycine (AVG) (Lombard and Richardson, 1982), GA_3, GA_{4+7}, chlormequat, daminozide, paclobutrazol, and ethephon (Miller, 1982). Martin and Nishijima (1978) were able to get parthenocarpic fruits of 'Winter Nelis' pear that persisted until maturity after a single treatment with the gibberellin GA_3, GA_3 + $CaCl_2$ or the pear gibberellin GA_{45}.

The achievement of specific agricultural objectives, however, may depend upon the proper balance of natural and applied growth regulators. Therefore, both timing and concentration are critical in achieving these specific responses.

1.6 Effect of solar radiation

The importance of sunlight for fruit production has long been recognized. Early in this century, it was shown that severe shading of apple trees dramatically reduced flowering and fruit setting (Auchter et al., 1926; Gourley, 1920). Shading whole trees of Cox's Orange Pippin to 25 percent of full sunlight reduced yield approximately 50 percent compared to the nonshaded trees (Jackson and Palmer, 1977). Tustin et al. (1988) were able to establish a positive correlation between the photosynthetic photon flux received by apple trees and their fruit set. Furthermore, Robinson and Lakso, in 1991, found that total light interception explains most of the yield variations among different apple orchard systems. Several other researchers agree on this fact (Rom and Baritt, 1989; Christensen, 1979; Jackson and Palmer, 1977; Jackson, 1980). De Jong (1990) thinks that this relationship holds for pears also, as well as many other fruit crop. In fact, Lombard and Westwood (1977) attributed lower fruit set and yield of hedgerows of 'Williams' and 'Anjou' pear trees oriented east-west compared to others oriented north-south to the reduced solar radiation on the north side of the first ones.

Light affects fruit set through its large influence on how carbohydrates and minerals are partitioned within tree canopies (De Jong et al., 1989; Rom and Baritt, 1989); and the importance of carbohydrates for fruit set is well established. Van Zyl and Strydom (1982) investigated the factors responsible for the low fruit setting of the 'Packham's Triumph' pear in South Africa. They concluded that this problem is not due to a short EPP nor to poor development of placental tissue of ovules, but to competition between shoot and fruit in young vigorously growing trees and competition between fruit and fruit in older spur bound trees. This competition presumably results in embryo abortion followed by fruit drop.

Early development of the embryo seems to depend on carbohydrate reserves (Deng, 1991), whereas, the subsequent development is thought to depend more on current season photosynthates. For instance, Jackson and Palmer (1977b) explained the negative residual effect of very severe shading of whole apple trees for one year on fruit set in the subsequent shade-free year by depletion in reserves of carbohydrates and minerals available for translocation from storage tissue at a time when current photosynthesis is limited by the small leaf area. In the other hand, it has been recognized that fruit set is favored on leafy inflorescences, while abortion of reproductive organs is nearly complete on leafless inflorescences, during the first two months after anthesis for the most citrus (Erner, 1989). This parallels the results of Byers et al. (1984) with peach where shading of scaffold limbs from 31-41 days after full bloom caused greater

fruit abscission than earlier shading. Therefore, a good light environment late in the season will profit early development of flowers and fruitlets, and an appropriate light interception in spring is beneficial for subsequent fruit growth. In general, any improvement of the light interception (up to a certain level) and distribution in the tree canopy by a more adequate row orientation (Lombard and Westwood, 1977; Christensen, 1979; Rosati, 1978), an appropriate planting density (Sansavini, 1980; Christensen, 1979), and/or by pruning or any other cultural practice (Smart, 1985; Westwood and Bjornstad, 1974; Mika, 1968; Moreshet et al., 1975) invariably increases fruit set.

2. Flower initiation

Flower bud development is attained through transformation of the vegetative apex to a reproductive structure. The partially developed buds of the tree must receive a signal and subsequently undergo complex histological and morphological changes to become flower buds. The nature of the signal for initiation of flower bud development is unknown. In order for the vegetative bud, this shortened axis as Bijhouwer described it in 1924 (cited by Faust, 1989), to receive the induction stimulus and undergo the changes to become flower buds, it must have already developed a certain number of vegetative organ primordia (Buban and Faust, 1982). Therefore, for a given growth rate, the bud needs to grow for a certain time before being able to be induced. The time

interval between the initiation of successive leaf primordia is the plastochron. Very short plastochrons may result in the buds growing out as vegetative shoots in the current years, whereas with long plastachrons the bud never reaches the stage to be receptive to flower induction (Faust, 1989). Following initiation, the differentiation of buds occurs. Bud differenciation is influenced by the environmental conditions and the other processes of the tree occurring at the same time, for instance, fruit and leaf development (Faust, 1989).

It appears that about 30 to 40 percent full sunlight in north temperate zone regions is needed on bearing spurs to insure flower bud development in apples (Auchter et al., 1926; Cain, 1971; Jackson, 1980). This minimum light threshold probably varies between apple and pear but there is little doubt that the same general relationships exist in pear as well as apple (De Jong, 1990).

Sach, as quoted by Faust (1989), stated that a certain amount of nutrients, perhaps carbohydrates, must be available for flower bud formation activity. In fact, there is ample evidence that, within certain lower limits, the formation of flower buds is directly related to the leaf area and light on the spur leaves (Cain, 1971; Cain, 1973). The relationships between light exposure, photosynthesis, and nutrient partitioning, as will be discussed later, mean that exposed spurs or shoots will generally have greater access to carbohydrates and nutrients than those in shady positions (De Jong, 1990). It is known also that flower bud formation is inhibited on excessively vigorous or overcropping trees because flower buds early in the season are weak sinks and they can not compete with

strong sinks like growing shoots and fruitlets. In the years of abundant flowering, the foliage develops weakly during the spring. Slow growth does not shorten the plastochron to the point when differentiation can occur (Buban and Faust, 1982).

Besides their competitive effect, fruits are known to suppress flower induction by their hormones, especially within a three-week period after pollination (quoted by Tukey, 1989). Fulford (quoted by Buban and Faust, 1982) thinks that the fruit directly inhibits the older organ primordia, and that this inhibition is hormonal and not based on competition for nutrients. The inhibiting effect on flower development by hormones produces by the developing seeds of the young fruits can be attributed to gibberellins that extend the plastochron (Luckwill, 1974). The inhibiting effect of high temperature on flower initiation can also be explained in this way because more gibberellins are produced in the young leaflets at high temperatures, which lengthens the plastochron (Tromp, 1976). However, Harley et al. (1942) demonstrated that defoliating individual spurs, or one branch of forked spurs, resulted in failure to produce flowers with no effect on adjacent spurs. Therefore, it appears that flower initiation in any specific bud is dependent on the leaves in the immediate vicinity of the bud.

Fruit size and rate of maturity, after fruit set, are generally related to the mean leaf area per fruit for the entire tree (Cain, 1973). Therefore, it seems that the importance of light here is not exclusively related to carbohydrate availability. There may be a relationship between light exposure and the kind and amount of signals and substances coming out of the leaves. In fact, it is well

established that shade affects leaf morphology and composition (Faust, 1989).

De Jong et al. (1989) showed, in a study with peach, that leaf N per unit leaf

area is directly related to leaf exposure. Leaves that are exposed to the most

light are generally thicker and have more nitrogen per unit leaf area than leaves

growing in more shaded areas of the canopy. The same phenomenon is observed

with apple, prune, and walnut. This confirms results found by Auchter et al.

(1926) with apple.

3. Light interception

If it is assumed that water and nutrients are in adequate supply, or can be

provided if deficient, and that other factors are not limiting, the interception and

utilization of sunlight then become the next most important consideration in

orchard design and management (Cain, 1972).

In a sense, a pear tree can be viewed as a massive network of solar

energy collectors. The individual solar cells are located in chloroplasts,

microscopic structures within green the leaves. In this analogy, the woody

framework of the tree can be viewed as providing the structure by which the

tree is capable of exposing maximum numbers of solar cells to the sun's rays.

Therefore, the efficiency of the pear tree as solar energy collector network

depends on the capture and the subsequent conversion of photometric energy

into chemical energy (De Jong, 1990). The orchard manager should have in

mind, then, two distinct objectives, the first is to find ways to maximize light interception by the trees and the second is to optimize light distribution within the canopy, so as to maximize the efficiency of light utilization in photosynthesis, fruit growth, flower bud formation, and fruit coloring (Jackson, 1980). Thirty percent of full sun light is considered by many horticulturists as the minimum level of irradiance to meet the above objectives (Jackson, 1980; De Jong, 1990; Cain, 1971; Rom and Barritt, 1989), with a minimum of 40% full sun for a satisfactory red color development (Faust, 1989). Apple trees, for instance, show disfinct within-canopy patterns of fruit quality, with the largest and best colored fruit near the periphery of the canopy where irradiance is high and smaller, poorer colored fruit in shadier parts of the tree, whether that shade arises from the tree itself or from neighboring trees (Palmer, 1989a). Not only do fruit vary systematically in size and color within the tree but also the fruit from the outside of the tree were more susceptible to the disorder bitter pit, had a lower calcium / potassium ratio and were more susceptible to rotting due to *Gleosporium* and soft rot fungi than fruit from the inside of the tree, which in turn were more susceptible to shrivel and core flush (Jackson et al., 1971).

Orchards are discontinuous canopies. Light transmission through the orchard canopy occurs in two ways. Light reaches the orchard floor between trees of a given geometry regardless of the leaf area index (LAI), and it also reaches the orchard floor after transmission through the canopy, that is, through the gaps between the leaves and through the leaves themselves (Faust, 1989).

Transmission through the tree is related to the density of the canopy and is high early in the season, decreases to a minimum as LAI builds up, and increases again with leaf senescence. The speed of LAI buildup depends on the cultivar, tree age, tree vigor, and crop load (Jackson, 1980). Jackson and Palmer (1980) used solid models to study the light environment in an orchard. This approach does furnish an upper limit to light interception by any system which is determined by the form of the canopy and the incoming pattern of light, which in turn depends upon latitude, time of the year and cloudiness pattern of the site. These model studies show that closer row spacings generally need lower leaf area densities within their canopies as they are increasingly affected by shading from neighboring rows (Palmer, 1989a). This upper limit of light interception can also be influenced by row orientation and this aspect has recently been re-analyzed by Palmer (1989b) using a light transmission model. For short hedgerows or systems with very narrow clear alleyways, row orientation has little effect on light interception, but for tall hedgerows with wide clear alleyway spacings, E-W rows intercept less light than N-S rows in mid-summer, particularly at lower latitudes. At the equinoxes E-W rows intercept more light than N-S rows, especially late in the growing season and at high latitudes (Ferguson, 1963), although there is little difference at a latitude of 30° (Palmer, 1989b; Cain, 1972).

Experimental evidence on the effect of row orientation on yield and quality is contradictory, possibly because the models are dealing with light as the

sole environmental variable and also because limiting factors for fruit production vary with the crop and location. Lombard and Westwood (1977) found yield increases of 34% and 48% for 'Williams' and 'Anjou' pears in N-S rows compared to E-W in Oregon (42°N) and Christensen (1979) in Denmark (55.3°N) found an average yield increase of 17% with N-S rows of apples. In contrast, Devyatov and Gorny (1978) in Minsk (53.8°N) found yield increases of apple of 16-35% with E-W rows; in this case, however, other environmental factors, which impact is related to row orientation, may have been a confounding effect.

Chapter 3

EFFECT OF CANOPY EXPOSURE ON FLOWERING AND FRUITING OF 'BEURRE D'ANJOU' PEAR TREES

Habib Khemira and Porter B. Lombard

Department of Horticulture, Oregon State University

Corvallis, OR 97331 U.S.A.

Abstract

Hedgerows of 'Beurré d'Anjou' pear (*Pyrus communis* L.) trees planted in 1969 in 2 orientations north-south (N-S) and east-west (E-W) were used to study the effect of hedgerow orientation on pear fruiting. The trees were spaced 1.2x3.7 m, trained to a central leader, and mechanically pruned to a tree wall 3.7m high and 1.8m wide at the base with a wall angle of 17° from the vertical.

Flower bud density (FD) was low in 1990 especially on the N wall of the E-W rows. In both years, N-S rows had more flower buds per unit branch cross-sectional area (BCSA). Fruit set (FS) was highest on the S wall and lowest on the N wall of the E-W rows, whereas the E and W sides of the N-S rows were intermediate. Crop density (CD) had a similar pattern than FS, with more fruits on the S wall and less on the N wall of the E-W rows. However, the crop density

was more evenly distributed between the walls on the N-S hedgerows. Differences in FS and CD between sides were related to different levels of sunlight interception. The mid height of the N wall of the E-W rows received less than 20% full sunlight throughout the growing season whereas the S wall received more than 35% of irradiance especially towards the equinoxes. Increased solar heating on the S and W walls late in the season led to more sunburned fruits. Fruits from E-W rows were larger and less firm.

Introduction

The dry matter production of many crops appears to be directly proportional to their interception of radiant energy (Jackson, 1980; De Jong, 1990). Several studies on fruit trees, especially on apples, showed the importance of sunlight not only for dry matter production (Jackson and Palmer, 1977a) but also for floral initiation and economic yield of orchards (Auchter et al., 1926; Heinicke, 1966; Jackson and Palmer, 1977a and b; Lombard and Westwood, 1977; Rom and Barritt, 1989).

Laboratory studies using solid models established mathematical equations for light transmission and interception by tree canopy and whole orchards (Cain, 1972; Jackson and Palmer, 1971, 1972). The components of these equations included leaf area index, tree density and geometry, row orientation, latitude, and time of the year. Field studies were in agreement with the theoretical studies which showed that at high latitudes more total radiation occurs in late summer when closely planted rows are oriented east-west. This set the stage for recommending east-west hedgerow orientation (Ferguson, 1960; Devyatov and Gorny, 1978; Shitt, 1937 quoted by Devyatov and Gorny, 1978) with some reservations (Christensen, 1979). At lower latitudes, Lombard and Westwood (1977) recommended north-south orientation for better solar radiation interception and better yield. In their study, they measured the irradiance received by tree walls (cal $cm^{-2}day^{-1}$) and related that to fruiting performance of

the trees. In the present study, we measured light levels received by the trees in quantum units (μmol s^{-1}m^{-2}) more commonly used to describe photosynthetically active radiation (PAR) in the 400 - 700 nm wave band (Thimijan and Heins, 1983) and related the resulting light interception patterns to variation in flowering, yield, and fruit quality among tree rows oriented differently.

Materials and Methods

Hedgerows of 'Beurré d'Anjou'/Old Home x Farmingdale 69,87, and 333 pear trees planted in 1969 in 2 orientations north-south (N-S) and east-west (E-W) were used to study the effect of hedgerow orientation on pear fruiting. The trees were spaced 1.2 x 3.7 m, trained to a central leader, and mechanically pruned to a tree wall 3.7 m high and 1.8 m wide at the base with a wall angle of 17° from the vertical.

This experiment was conducted in 1990 at the Southern Oregon Experiment Station in Medford, OR located near 42°N, 124°W latitude in high radiation and hot dry climate during the growing season. The average daily solar radiation over a 20 year period growing seasons has varied from 233 J $s^{-1}m^{-2}$ in April to 337 J $s^{-1}m^{-2}$ in July. The plot is located on a sandy loam soil.

The light exposure measurements were made 4 times during the growing season starting at mid-April over clear, sunny days. A photometer equipped with a quantum sensor (LI-188B, LI-COR Inc., Lincoln, Neb., USA) was used to measure average photosynthetic photon flux density (PPFD) in μmol $s^{-1}m^{-2}$. Measurements were taken on 2 replicates, each one included 2 rows laying in opposite directions (E-W and N-S), therefore, representing the 4 sides of the hedgerows (E,W,N, and S). The readings were done throughout a day at 3 levels of each side of the canopy: 1m, and 2m heights, and on the top, and the sensor was held horizontally at the surface of the canopy. Standard readings of the

maximum available light were taken under open sky.

Tree performance as influenced by row orientation was evaluated by flower cluster and fruit counts on limbs of measured cross-sectional area (BCSA). Flower buds were counted just before bloom when they were readily distinguished from vegetative buds and from one another. Fruits were counted after 'June' drop (end of June). Branch diameters were measured in December near the base of the unit counted at a smooth location 5 cm above the branch junction. Flower (FD) and crop densities (CD) (no./BCSA cm^2) and fruit set (FS)(no. fruit set out of 100 flower cluster) were determined. Samples of 100 fruit from each of 6 replicated blocks were used to evaluate average fresh weight and seed content of fruits. On the same fruit we measured flesh firmness using a UC firmness tester penetrometer (Western Ind. Supply, S.F.CA.) with a 7mm tip, soluble solid concentration (SSC), sun burning, and skin color. Soluble solid concentration was determined at room temperature using juice expressed from the lateral side (not exposed) of the fruit and measured using an Atago hand-held refractometer (ATAGO Optical Works Co., LTD, Japan). The fruit were also rated from 0 to 3 for sunburning, with 0 for normal looking fruits (green) and 3 for deeply sunburned fruits (deep yellow). Fruit background color was measured by placing the 8-mm-diameter measuring area of a Minolta Chroma Meter CR-200b portable tristimulus colorimeter at the mid point between the stem and calyx end on the unexposed side of the fruit. The meter was calibrated with a white standard (Minolta calibration plate CR-A43) and fruit chromaticity

measured in $L^* a^* b^*$ coordinates. In this system L^* represents the value

(lightness) of colors, it is small for dark colors and large for light colors; a^* is

negative for green and positive for red, whereas b^* is negative for blue and

positive for yellow (Singha et al., 1991). Small variations in the (-a^*:b^*) ratio

represent discernable shifts in the color of the fruit as perceived by the human

eye (Tustin et al., 1988).

The data were analyzed using analysis of variance for a randomized block

design. Duncan's multiple range test was used for means comparisons. FD and

FS data were transformed using a natural log before being analyzed.

Results

Flower bud density was less on the E-W rows (Table 3.1). In 1990, the lowest flower bud density occurred on the N wall, while the S wall had slightly less flowers than the E wall. This agreed with results found by Lombard and Westwood (1977). However, the values measured were below the range given for pears by Lombard et al. (1988). The following year, the E-W rows had again the lowest flower bud density and the E wall had the highest but, the S wall was the lowest and the N wall was the next lowest (Table 3.1).

Crop density as measured in the end of June, 1990 was the lowest on the N wall of E-W rows and was the highest on the S side of the same rows, but no significant difference was found between row orientations (Table 3.1).

There were significant differences in fruit set among sides but not between row orientations. The S wall set more fruits than the other sides. The E and W walls of the N-S rows were intermediate between the S and N walls of the E-W rows; the later wall had the lowest set (Table 3.1).

Fruit from the E-W rows had a greater weight than those from N-S rows and they had lower pressure values. However, there were no significant differences among either sides or orientations for SSC and seed content (Table 3.2).

Sunburning was more severe on the S wall and had least impact on the N wall. However, sunburning did not differ significantly between row orientations.

Sunburning correlated (r = 0.83) with sunlight interception late in the season. But the most exposed fruits were the most damaged by sunburning (Table 3.2).

Measurements of PPFD showed that the upper part of the trees received more than 65% of full sunlight at any time of the growing season and for both orientations (data not shown). Light intercepted above this level is of little or no value (Cain, 1972; Lakso et al., 1989). For instance, Cain (1971) found only a small decrease in flowering of 'McIntosh' and 'Macoun' apple trees resulting from a reduction from 100% to 70% sunlight interception. Therefore, we restricted our investigation to the middle part (1-2 m) of the tree walls.

At any time during the growing season light interception by the hedgerow started low early in the morning because of the mutual shading, and then increased for both row orientations (Fig. 3.1, 2, 3, 4). The PPFD on the N-S oriented trees reached a maximum late in the morning, decreased during mid-day hours, and then increased again in the afternoon then decreased at the end of the day. In the case of E-W oriented rows, light interception showed the same pattern but continued to increase until late afternoon (Fig. 3.1, 2, 3, 4). The daily PPFD on the S wall was greatest during bloom, flower bud formation, and fruit maturation than the other 3 walls, and nearly as high as the E and W walls during mid-summer, whereas the N wall was lowest during all of the growing season (Fig. 3.5). The N-S oriented rows intercepted more light during most of the growing season, but the situation was reversed in favor of the E-W rows towards the equinoxes (Fig. 3.6). This variation seems to be dictated by the

exposure of the S wall.

Discussion

In general, N-S oriented trees have a higher yield than those with an E-W orientation. Christensen (1979) in Denmark (55.3° N) found an average yield increase of 17% with N-S rows of apples. Lombard and Westwood (1977) found yield increases of 34% and 48% for 'Williams' and 'Beurre d'Anjou' pears in N-S rows compared to E-W in Medford, OR (42° N). They attributed this difference to a higher bloom density on the N-S rows since it was the only factor influenced by row orientation in their trail. They found also that trees which received more light during flower bud formation and the rest of the growing season had more flowers per unit BCSA the following year. Many horticulturists consider a minimum level of 30% full sunlight is necessary for a satisfactory cropping level (Jackson, 1980; De Jong, 1990; Cain, 1971; Rom and Barritt, 1989). It has been shown that shading not only reduces fruit quality but also depresses both fruit set and flower bud initiation and development necessary to have a crop the following year (Palmer, 1989). Aucher et al. (1926) found that artificial shade for the whole season of 'Grimes Golden' and 'Stayman Winesap' apple trees almost eliminated blossom bud formation. They also showed that this effect was local. Therefore, the effect of light in this respect maybe related, in addition to carbohydrate synthesis, to an untranslocatable endogenous factors involved in flower bud initiation and development. In our study, we did not measure total yield per tree, but there was no significant difference in CD between N-S and E-

W rows. Nevertheless, there were significant differences among the sides (Table 3.1) with the highest density of fruit on the S wall and the lowest on the N. This pattern of crop distribution was more related to fruit set ($r = 0.44$) rather than to flower density. In fact, in 1990 bloom density was similarly low on all sides but set was highest on the S side and lowest on the N side. This may be due to better conditions for pollination and fertilization during bloom of the S side of E-W rows or to a "stronger" blossoms on this side. Lombard and Westwood (1977) found that full bloom was advanced 2 days on the S wall and delayed 2 days on the N wall compared to the E and W walls. It is known that bees work less on the shaded sides of trees and in the cold and windy days (Weswood, 1978). However, apparently pollination was not responsible for the differences registered in FS since seed content of the fruit from all sides was high (Lombard et al., 1971) for this variety (Table 3.1). Environmental conditions during bloom time were very good for pollination and set. Temperature was 4.5 °C higher than the long term average for Medford, OR during that time of the year. Lombard and Westwood (1977) noted an increase of frost damage to blooms in E-W rows compared to N-S, and this can affect final fruit set of the trees. However, frost was not a problem on these trees during the 2 years of study.

More investigation on the quality of the flowers of the various walls should be continued. The quality of flowers is generally understood in terms of mineral content, and the most important nutrient, in this respect, is nitrogen. Blossoms with high nitrogen content have a longer effective pollination period

and ovule longevity and set more fruits (Williams, 1965; Khemira, 1991). Sanchez (1990) showed that leaves translocate their nitrogen preferentially to storage structures and flower buds before senescing in fall. Furthermore, leaf photosynthetic capacity and leaf nitrogen content are apparently partitioned among leaves within a plant canopy with respect to natural field light exposure (Hirose and Werger, 1987; De Jong et al., 1989; De Jong and Doyle, 1985). Therefore, the improved set (Table 3.1) observed on the more exposed regions (Fig. 3.5, 6) may be related to higher reserves availability for the flowers early in the season.

The crop was more evenly distributed between the two sides of the N-S rows compared to those of the E-W rows; this gave more homogeneous fruits in terms of weight and appearance and more stable returning bloom and set (Table 3.1).

Lombard and Westwood (1977) found no differences in maturity between either sides or orientations. However, in the present study, if we consider firmness as a reliable maturity indicator for pears, fruits from E-W rows were more mature than those from the N-S rows on the date of sampling (Sept. 8, 1990). The fruits from the E-W rows were also, bigger. The N facing side of E-W rows had bigger and firmer fruits than the other sides (Table 3.2) because of the lower CD.

The E and W walls of the N-S rows received equal sun exposure throughout the growing season. However, the E wall had more flower buds and

fruits per unit BCSA and were more yellowish but less sunburned fruits. This may be related to the early exposure of the Ė wall to sunlight during the day which can develop an early daily photosynthis saturation. The W walls had higher PPFD in the afternoons (data not presented) when temperatures are generally high and the relative humidity of the air is low. These conditions are less favorable for photosynthesis and predispose fruits to sunburning (Table 3.2).

Consideration of hedgerow orientation should be based on several factors presented in this study and others not mentioned. Generally, in areas with similar conditions to Oregon, N-S hedgerow orientation should be preferred within the orchard design used in this study. This was also the recommendation of Lombard and Westwood (1977), Cain (1972), and Jackson and Palmer (1972). However E-W orientation may be more favorable if the topography, air movement and irrigation dictate the orchard management.

Table 3.1. Influence of row orientation on flower density (FD), fruit set (FS), crop density (CD), and seed content (SC) of 'Beurre d'Anjou' pear trees, Medford, OR, 1990[z].

Orientation and sides	FD[y] (no. flower bud/cm^2 BCSA[w])		FS[y] (no. fruit/ flower bud)	CD (no.fruit/cm^2 BCSA)	SC (no.seed/fruit)
Side	1990	1991			
N	2.7 a[x]	5.0 ab	0.40 c	1.0 b	5.9 a
S	3.0 a	4.4 b	0.74 a	1.7 a	5.9 a
E	3.1 a	5.1 a	0.51 b	1.4 a	5.9 a
W	2.8 a	4.7 ab	0.52 ab	1.3 ab	6.2 a
Orientation	1990	1991			
E-W	2.9 a	4.7 b	0.56 a	1.3 a	5.9 a
N-S	3.0 a	4.9 a	0.52 a	1.3 a	6.0 a

[z]All data are from 1990 season unless indicated otherwise.
[y]FD and FS data were transformed using natural log for mean separation analysis. Actual values are presented in the table.
[x]Mean separation within columns by Duncan's multiple range test, $P = 0.05$.
[w]BCSA: branch cross-sectional area, measured 5 cm above the branch junction.

Table 3.2. Effect of hedgerow orientation on characteristics of 'Beurré d'Anjou' pear fruit. Medford, OR, 1990.

Orientation and sides	Soluble solids (°Brix)	Background color[y] ($-a^*/b^*$)	Firmness (Newton)	Wt/fruit (g)	Seed content (no./fruit)	Sunburning (0-3)[x]
Side						
N	14.1 a[z]	0.417 ab	48 b	167 a	5.9 a	0.3 c
S	14.2 a	0.407 b	52 b	160 ab	5.9 a	1.2 a
E	14.3 a	0.411 ab	51 b	148 b	5.9 a	0.5 c
W	14.2 a	0.418 a	56 a	151 b	6.2 a	0.8 b
Orientation						
E-W	14.1 a	0.415 a	50 b	164 a	5.9 a	0.7 a
N-S	14.2 a	0.412 a	54 a	150 b	6.0 a	0.6 a

[z]Mean separation within columns by Duncan's multiple range test, P = 0.05.

[y]Background color derived from the ratio of green ($-a^*$) to yellow (b^*) color of the total chromaticity of the fruit skin, measured according to the $L^* a^* b^*$ color solid system.

[x]Fruits were rated from 0 to 3: 0 green, 1 blushed, 2 light sunburning, 3 severe sunburning.

Fig. 3.1.   Light interception by the mid-canopy of E-W and N-S-oriented rows of 'Beurré d'Anjou' pear trees on the April 14, 1990 at Medford, OR. Mean separation on each date by Duncan's multiple range test, P = 0.05. Each bar represents the mean of 80 measurements.
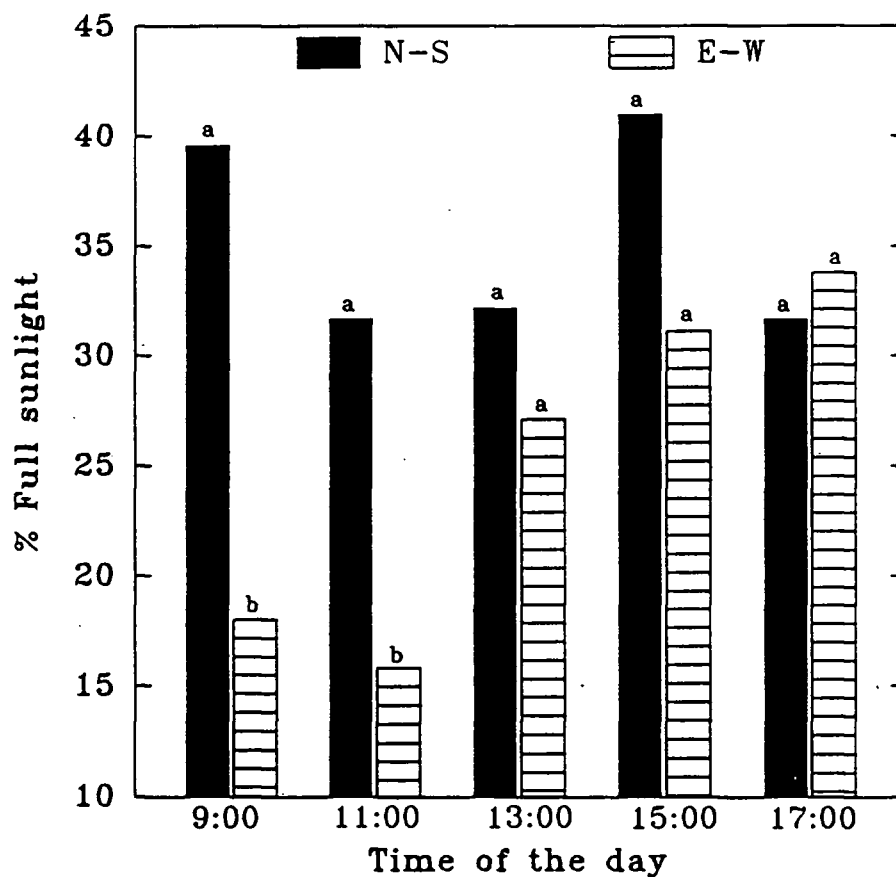
Fig. 3.2.　　Light interception by the mid-canopy of E-W and N-S-oriented rows of 'Beurré d'Anjou' pear trees on the June 16, 1990 at Medford, OR. Mean separation on each date by Duncan's multiple range test, P = 0.05. Each bar represents the mean of 80 measurements.

Fig. 3.3.   Light interception by the mid-canopy of E-W and N-S-oriented rows of 'Beurré d'Anjou' pear trees on the July 16, 1990 at Medford, OR. Mean separation on each date by Duncan's multiple range test, $P = 0.05$. Each bar represents the mean of 80 measurements.
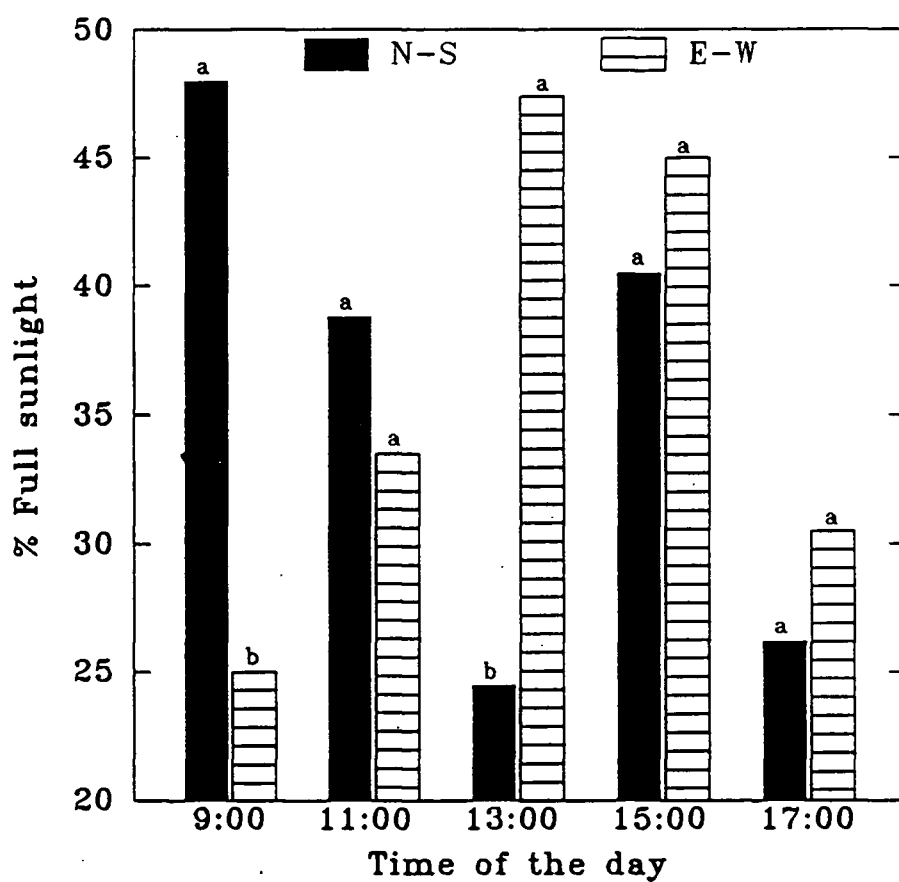
Fig. 3.4.   Light interception by the mid-canopy of E-W and N-S-oriented rows of 'Beurré d'Anjou' pear trees on the Sept. 8, 1990 at Medford, OR. Mean separation on each date by Duncan's multiple range test, P = 0.05. Each bar represents the mean of 80 measurements.

Fig. 3.5.   The daily average of sunlight intercepted by the medium part
(1-2 m) of each wall of 'Beurré d'Anjou' pear hedgerows oriented
E-W and N-S during 1990 growing season, Medford, OR.. Mean
separation on each date by Duncan's multiple range test, $P = 0.05$.
Each bar represents the mean of 200 measurements.

Fig. 3.6. The daily average of sunlight intercepted by the mid-canopy
(1-2 m) of 'Beurré d'Anjou' pear hedgerows oriented E-W and
N-S during 1990 growing season, Medford, OR.. Mean separation
on each date by Duncan's multiple range test, P = 0.05. Each bar
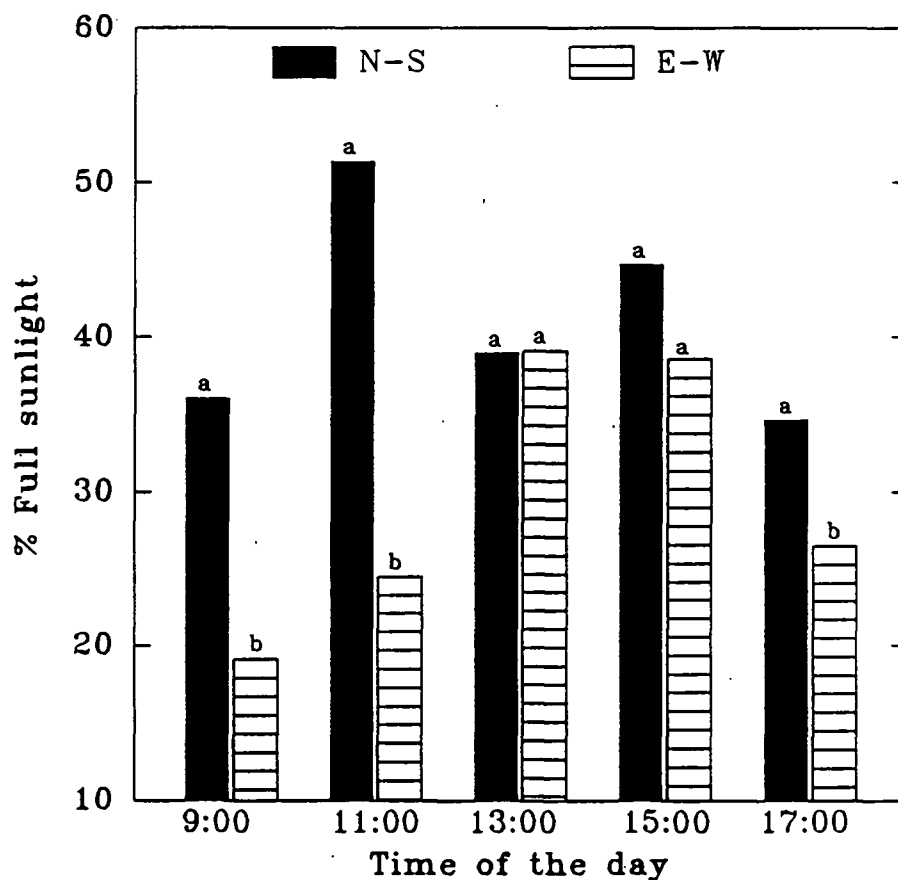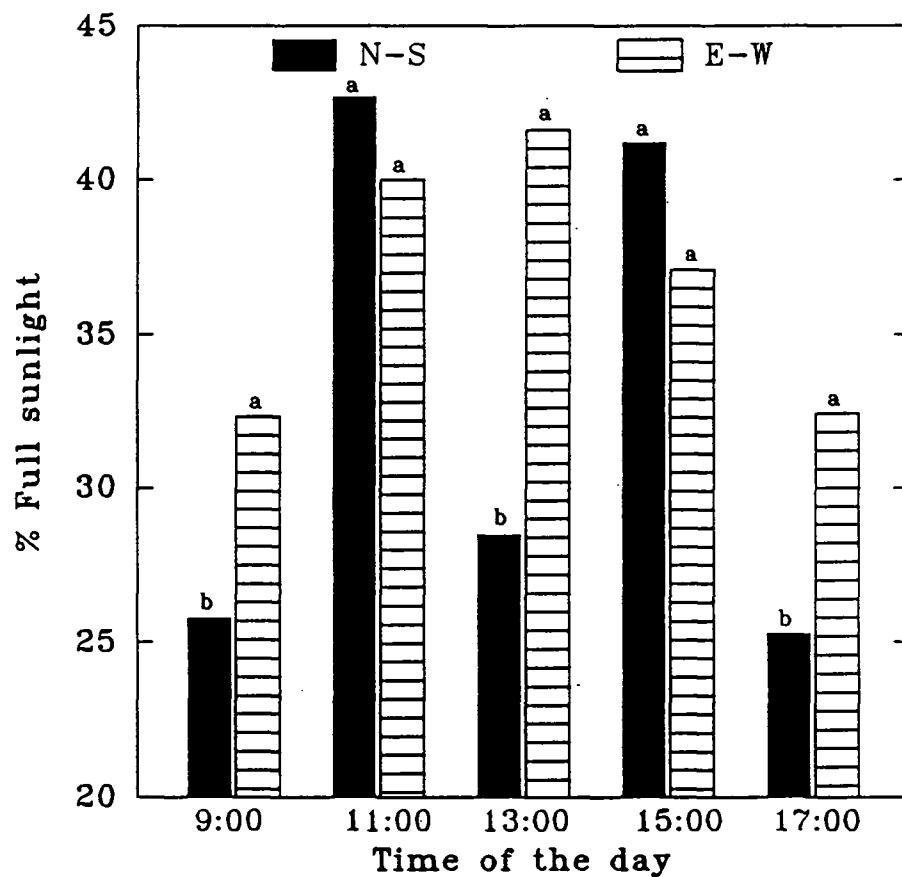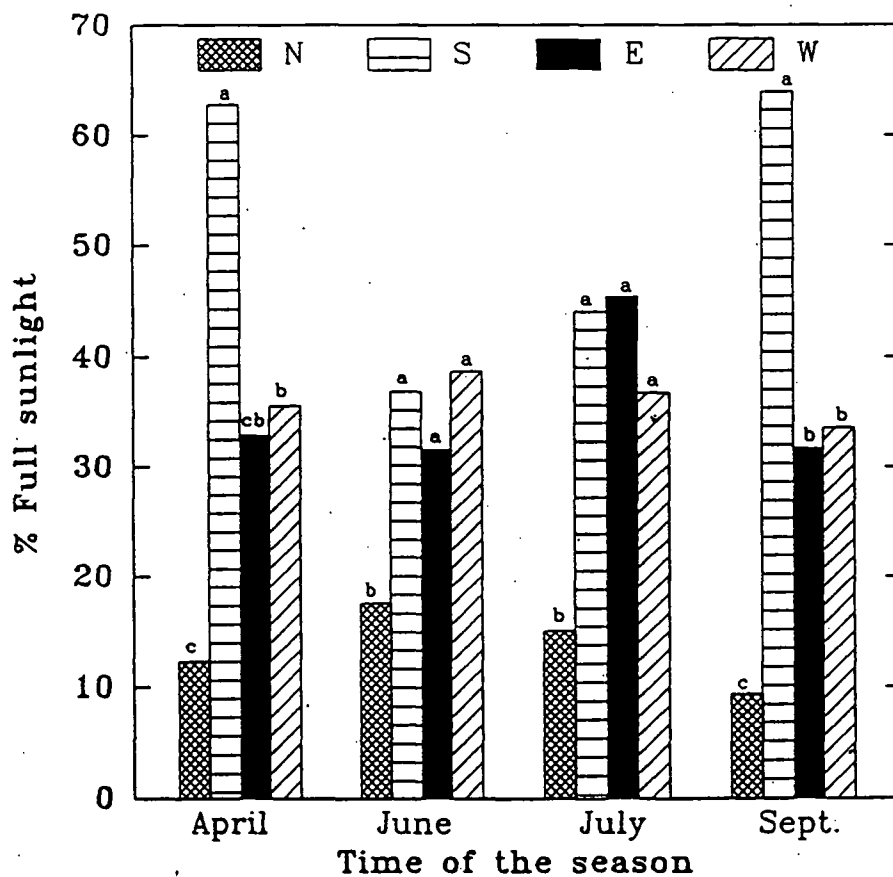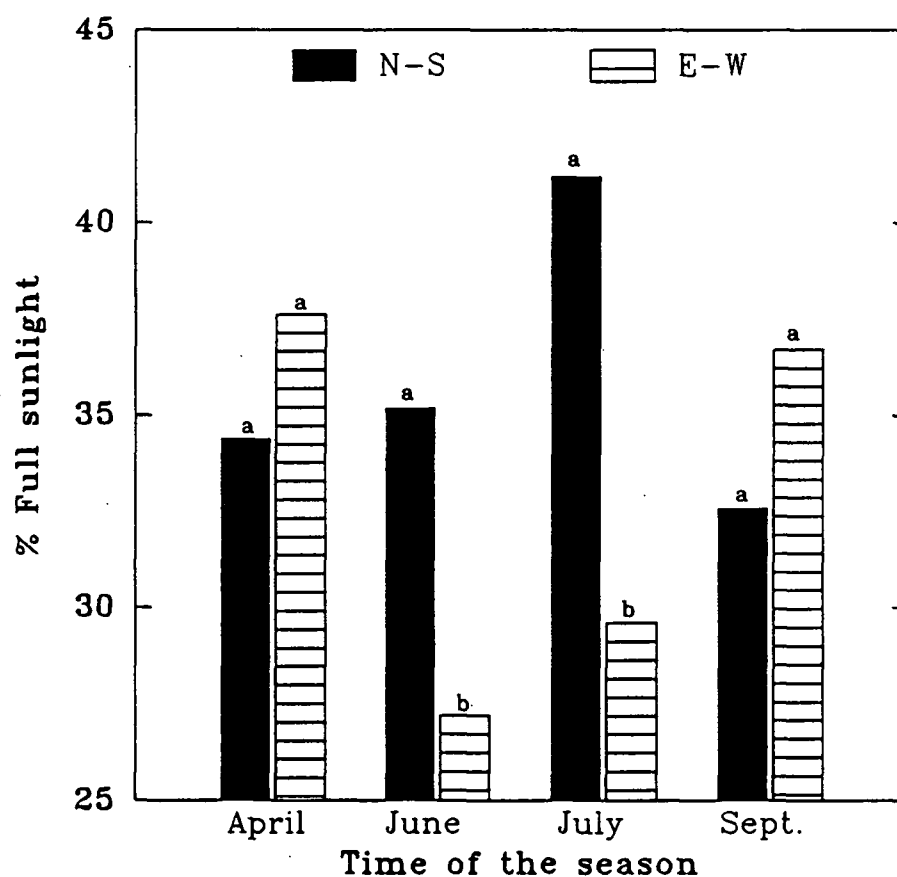represents the mean of 400 measurements.

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Chapter 4

POSTHARVEST NITROGEN APPLICATION EFFECTS ON OVULE LONGEVITY AND YIELD OF 'DOYENNE DU COMICE' PEAR TREES

Habib Khemira and Anita N. Miller

Department of Horticulture, Oregon state University

Corvallis, OR 97331 U.S.A.

Abstract

'Doyenne du Comice' pear (*Pyrus communis* L.) trees are known for low fruit set and cropping in spite of a high bloom density. A preharvest soil application or postharvest foliar application of N increased the availability of N reserves in the developing reproductive tissue of this cultivar. Mature trees were given a single foliar application of 5% or 10% urea immediately after harvest. Ovule senescence was detected by fluorescence microscopy. Ovule longevity was extended in both treatments in comparison to control. If corrected for trunk cross sectional area, fruit set was increased after a foliar application of urea. There was no effect on flower density, crop density, fruit fresh weight, and yield efficiency.

Introduction

Despite a high bloom density, 'Doyenne du Comice' pear (*Pyrus communis* L.) trees set commonly only a small crop, especially in early bearing years. This shortcoming has been attributed to lack of proper pollination and low level of self-fruitfulness (Callan and Lombard, 1978; Bini and Bellini quoted by Lombard and Richardson, 1982; Stephen, 1958), to early embryo sac degeneration and short effective pollination period (EPP) (Jaumien, 1968; Lombard et al., 1971), to the competition for nutrients between shoots and fruitlets (Nicotra et al., 1977; Van Zyl and Strydom, 1982), or to inter and/or intra-flower competition (Van Zyl and Strydom, 1982; Deng et al., 1991). EPP is the remaining period of ovule viability beyond the time required for the first pollen tube to reach and fertilize the ovule (Williams, 1966). Lombard et al. (1971) found that the EPP of 'Doyenne du Comice' flowers was 1 to 2 days at 9° to 10°C. The above factors may not be exclusive, and improving one of them may ameliorate the others. Crisosto et al. (1986) suggested that extension of the EPP could improve fruit set.

Crisosto et al. (1986) were able to increase ovule longevity and fruit set of 'Doyenne du Comice' pear trees by application of putrescine, a polyamine described as a growth promoter, at anthesis. They associated this result with an increase of foliar and flower N and B levels after fertilization.

Nitrogen is allocated primarily into storage structures and flower buds of

the tree when applied late in the season (Sanchez, 1990; Ystaas, 1980; Williams, 1965; Merzougui, 1986; Shim et al., 1973; Weinbaum et al., 1984). Sanchez (1990) reported that a single postharvest urea spray on 'Doyenne du Comice' pear trees at 5 and 10% increased N content in one year old bark and wood and the flower buds and blossoms. Ystaas (1980) observed an immediate increase of N concentration of leaves and flower buds of 'Molke' pear after a 6% postharvest urea spray. In both cases, there was no increase in fruit set. Khattab et al. (1981) sprayed 2 and 6% urea on 'Leconte' pear trees in the fall and found more flowers per spur. Fruit set did not change, but was measured on small number of spurs per treatment. An increase of flower bud N content, ovule viability, EPP, and fruit set in apple trees has been observed in response to a fall N application (Williams, 1965). With grapes, Ewart and Kliewer (1977) obtained the same results by a post-bloom application of ammonium nitrate.

The objectives of this study were to study the effects of postharvest urea sprays on ovule longevity, flowering, fruit set, and yield of 'Doyenne du Comice' pear.

Materials and Methods

The experiment was conducted in 1989 in Medford, OR at the Southern Oregon Experiment Station. 'Doyenne du Comice' pear trees grafted onto Provence quince BA29 rootstock. Trees were spaced 2.3 x 5.4 m and trained to a multiple leader.

Immediately after harvest 15 September, urea was sprayed at 5 or 10% (w/v) containing 0.1% (v/v) of non-ionic surfactant activator 90 (alkyl polyoxyethylene ether) to 10 single-tree replicates. Water containing surfactant was applied as the third treatment. Each treatment was applied to randomly selected trees in the orchard. Prior to bloom, flower buds were covered with cheesecloth bags to prevent bee pollination. Ten flowers, for each treatment, were sampled every two days from full bloom until 11 days after full bloom (DAFB). Samples were fixed in formaldehyde:propionic acid:95% ethanol (FAP) (5:5:90) until observations were made.

Flowers were removed from the FAP solution, washed in distilled water for 30 min, soaked in 1% sodium bicarbonate for 1 hr and rinsed three times in distilled water. The pistil and ovary samples were softened by autoclaving in 1% sodium sulfite for 2 min and rinsed in water. Pistils were excised, ovaries were split longitudinally and the ten ovules were removed with the aid of fine forceps. Ovules were then mounted on slides, squashed directly in 0.5% (w/v) aqueous aniline blue ('Baker Chemical Co.' C.I. 42755) in 0.15M potassium

phosphate buffer, and observed under a Carl Zeiss universal fluorescence microscope equipped for epi-illumination using near UV-excitation (Pimienta et al., 1983; Crisosto et al., 1988; Moreno et al., 1991).

Ovule longevity was based on the differential intensity of ovule fluorescence after staining with aniline blue, with ovules showing very intense fluorescence considered non-viable or senescent (Polito and Pimienta, 1982; Stösser and Anvari, 1982). Each flower was rated for the number of viable (non-fluorescing) ovules per ovary. The mean number of viable ovules per flower were calculated for the 10 replicate flowers.

For all the trees, flower buds and fruits were counted and yield and trunk cross-sectional area (TCSA) were measured. Flower density (FD = no. of flower buds per cm^2 of TCSA), fruit set (FS = fruit no./ flower bud no.), crop density (CD = no. of fruits per cm^2 of TCSA), yield efficiency (YE = yield per cm^2 of TCSA), and fruit fresh weight were determined.

Data were analyzed using SAS General Linear Models procedure (SAS Institute, Cary, N.C.). FS data were corrected for tree size by dividing by TCSA and then subjected to a natural log transformation [Log(FS/TCSA)]. For YE mean separation, FD was introduced as a covariate.

Results and Discussion

Flowers from untreated 'Doyenne du Comice' pear trees had 32% of

their ovules in process of degeneration at full bloom (Table 4.1). This is in

agreement with observations of Jaumien (1968) on the same variety. She found

that at the time of full bloom the flowers have embryo sacs at different stages

of development, and degeneration of particular elements and even of the whole

sac has started in as much as 20% of the ovules. This early ovule degeneration

had a tendency to decrease with application of urea in fall ($P\geq$ 0.13) especially

with the 10% concentration (Table 4.1). Similar results were found with apple

(Hill-Cottingham and Williams, 1967). The meristematic activity in the nucellar

tissue of 'Lord Lambourne' apple trees given no N ceased as early as the first

day after anthesis (Hill-Cottingham and Williams, 1967) indicating the onset of

senescence of the ovules (Williams, 1965).

The longevity of the ovules from N treated trees was extended. The rate

of their senescence was slower when compared with the control treatment (Fig.

4.1). At anthesis, flowers from untreated trees had 68% of their ovules viable,

nine days later three fourths of the ovules were dead. However, flowers of

urea-treated trees had up to 80% of their ovules viable at full bloom. Nine

days later, the flowers from the 10% urea treatment still have 58% of their

ovules viable. It appears that with the foliar N applications, more ovules are

able to complete their development by anthesis time and a higher percentage

of them are able to remain viable for a longer period of time. In their experiment with 'Lord Lombourne' apple, Hill-Cottingham and Williams (1967) found that ovules from unfertilized trees showed obvious signs of degeneration by the fourth day, whereas, ovules from trees given a fall application of N do not senesce until 8 days after anthesis. Therefore, this practice can be used to extend the EPP and to increase set. In this respect, N supply may had altered the quality and/or the availability of the substrate. Increasing the level of N nutrition results in an increase of the content of soluble amino compounds and to a lesser degree other compounds (Kirkby and Mengel, 1987). On the other hand, it is well established that early embryo and flower bud development depends on carbohydrate reserves (Auchter et al., 1926; Van Zyl and Strydom, 1982; Deng et al., 1991; Erner, 1989). De Jong et al. (1989) showed that peach leaves with a high N content photosynthesize more carbohydrates, and he think that this holds also for pear leaves (De Jong, 1990).

Flower density was very low (up to 0.33 cluster per cm^2 of trunk cross sectional area) compared to the limits given by Lombard et al. (1988) for pears (6 - 10)(Table 4.1). This may explain the high fruit set observed during the year of study on these trees (110% on untreated trees). No differences were found between treatments in FD and FS (Table 4.2). If FS percentages are corrected for tree size by dividing by the trunk cross sectional area (TCSA) and with a logarithmic transformation (Log(FS/TCSA)), the 10% urea application increased FS.

The temperatures during bloom were 4°C higher than the long term average of 10°C for Medford,OR during that period of the year. It's generally accepted that warm temperatures during bloom enhance pollen tube growth and pollinator activity, extend the EPP, and increase fruit set (Lombard et al., 1971). The uncommon high fruit set observed on unfertilized trees may be a result of warm temperatures prior to bloom that advanced root activity and enabled new absorbed N to reach the flowers thereby decreasing their dependence on tree reserves. Therefore, the effect of N foliar application in the previous season could have become negligible (Sanchez, 1990). White and Beinbaum (1984) found that heating the root-zone of calceolaria plants increases the tissue concentration and total uptake of N. Therefore, the non-response of the trees to the fall N application, in terms of flowering and set, could be expected if we keep in mind that pear trees have a low requirement of N (Sanchez, 1990; Ystaas, 1990). A yield decrease was registered in 'Molke' pear trees after 2.2% leaf N (percent of dry matter)(Ystaas, 1990).

Crop densities were similar for the three treatments and they were lower than the minimum given by Lombard et al. (1988) for pears. Fruit fresh weight averages were also similar for all treatments and were within the range of this variety. Trees that received more urea had a tendency to be more yield efficient. The differences are more obvious when the FD is introduced in the analysis of variance as a covariate (Table 4.2).

Fall foliar urea application to 'Doyenne du Comice' pear trees increased

the proportion of viable ovules per flower at any time during the first 11 days following full bloom. There was a tendency of the fertilized trees towards a better fruit set and a higher yield efficiency. Flower density, crop density, and fruit fresh weight were not affect by fall urea application.

Table 4.1. Effect of postharvest urea sprays on ovule longevity of 'Doyenne du Comice' pear, Medford, OR, 1990.

	Viable ovules / ovary					
	Days after full bloom					
Treatment	0	2	4	7	9	11
10% urea	8.0 a^z	7.7 a	7.6 a	6.2 a	5.8 a	3.9 a
5% urea	7.7 a	7.5 a	6.6 a	5.9 ab	5.1 a	2.8 ab
control	6.8 a	6.7 a	5.6 b	3.5 b	2.5 b	2.2 b

^{z}Mean separation within columns by Duncan's multiple range test, P = 0.05. Each value is a mean of 10 flowers.

Table 4.2. Effect of urea applications after harvest on 'Doyenne du Comice' yield components, Medford, OR, 1990[z].

Treatment	F D (cluster no. cm^{-2})	FS[y]	CD (fruit no. cm^{-2})	YE[x] (g cm^{-2})	Fresh wt. (g)
Control	0.30	1.10 b	0.29	66 b	240
5% urea	0.33	1.15 b	0.32	65 b	216
10% urea	0.31	1.31 a	0.36	83 a	232

FD = Flower density = no. flower buds/trunk cross-sectional area (TCSA); FS = Fruit set = no. fruits/no. flower buds;

CD = Crop density = no. fruits/TCSA; YE = Yield efficiency = yield per tree/TCSA.

[z]Mean separation in these columns by Duncan's multiple range test, $P = 0.05$.

[y]For mean separation analysis, data were transformed by dividing by TCSA and taking the natural log, Log(FS/TCSA).

[x]For mean separation analysis, FD was introduced as a covariate.
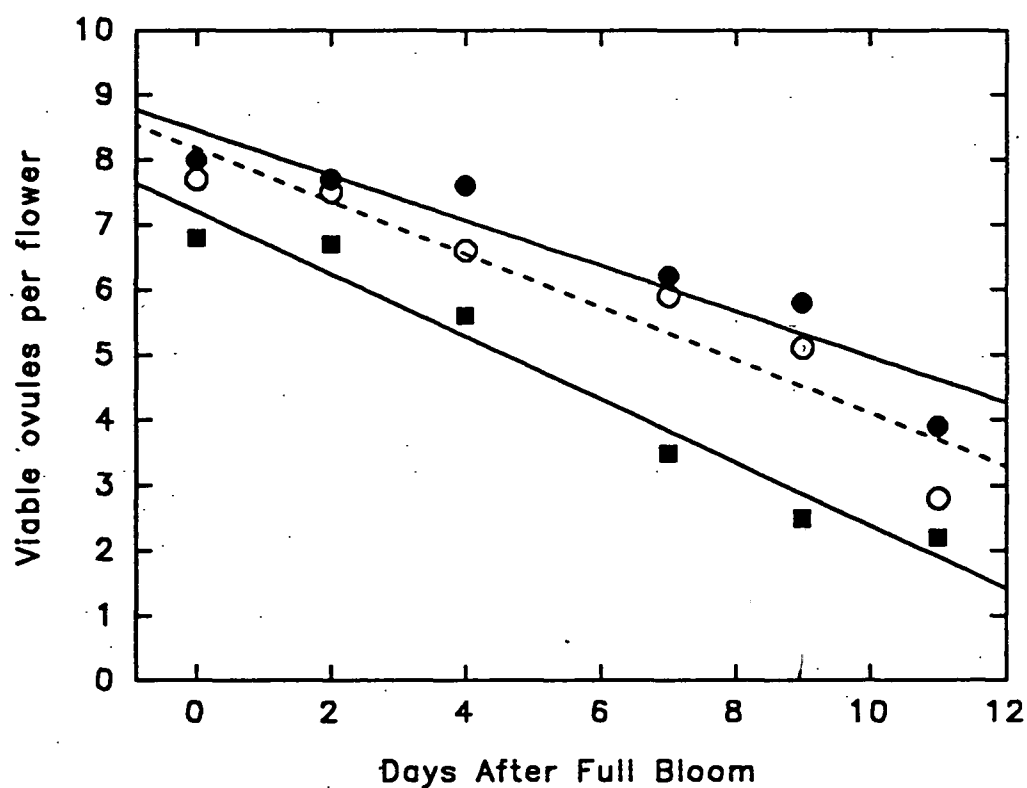
Fig. 4.1.   Relationship between the number of days after full bloom and the number of viable ovules per ovary in flowers of fall-urea sprayed (5% or 10%) or unsprayed 'Doyenne du Comice' pear trees, Medford, OR, 1990.(●) 10% urea; (O) 5% urea; (■) control. Each point represents the mean of 10 observations. Equations of lines of best fit are (●—●) y = 8.5 - 0.35x, r^2 = 0.89;(O--O) y = 8.2 - 0.41x, r^2 =0.89; (■—■) y = 7.2 - 0.48x, r^2 = 0.96.

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APPENDIX

Appendix A

The daily average percentage of full sunlight intercepted by the middle part (1-2 m) of each wall and each row of 'Beurre d'Anjou' pear trees, Medford, OR, 1990.

Orientation and walls	Time of the growing season			
	14 April	16 June	16 July	8 Sept.
Wall				
N	12 c^z	18 b	15 b	9 c
S	63 a	37 a	44 a	64 a
E	33 cb	32 a	45 a	32 b
W	36 b	39 a	37 a	34 b
Orientation				
E-W	38 a	27 a	30 b	37 a
N-S	34 a	35 a	41 a	33 a

^{z}Mean separation within columns by Duncan's multiple range test, $P = 0.05$.