cold injury may cause low fruit set by delaying pruning until after harvest.

In an earlier paper on tree decline (7) we showed that trees growing on old peach land and pruned in late fall or early winter had greater mortality than non pruned or trees pruned in the spring. As yields in the present study are presented as wt of peaches per area (kg/h), and fruit set per tree was not affected, the difference in the yield from time of pruning in 1972 (Table 2) reflects mostly the tree mortality. Most tree deaths occurred in the spring of 1972 in plots pruned in late fall or early winter. Therefore, the close relationship between yield and mortality of pruned trees was expected with no cold injury to blossoms.

The yield from non-pruned trees in 1972 was higher than analysis of mortality data would indicate. In addition to having less mortality than winter pruned trees (7), non-pruned trees had more bearing surface than pruned trees which contributed to the higher yield in 1972.

Mechanisms involved in reduction in tree decline by the time of pruning are not known. Although cold injury reduction has been suggested (11), it has not been established. We have previously shown an association between cold injury and tree mortality (9). Data presented in the present study show that winter pruning increases susceptibility to cold injury of blossoms which suggests strongly that it would also increase susceptibility to cold injury of the wood and thereby contribute to decline. Trees that are in a state of decline exhibit discoloration in the cambium zone which resembles cold injury. However, observations made in the cambium area after cold temperature periods during the course of this study failed to establish that winter pruning increased cold injury to the wood. Based on data obtained in this study, I suggest that a subtle type of cold injury is involved in decline which is not easily discernible by the naked eye. We have shown (8) that cold injury can result in occlusion of xylem elements in peach trees which could account for an accumulative injury. Several factors are probably involved in peach tree decline. Data obtained in the present study give further evidence that cold injury is involved at some point in the decline process.

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Effect of Short-Term High CO_2 Treatment on Storage of 'd'Anjou' Pear[1]

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Abstract. Treatment of 'd'Anjou' pears (*Pyrus communis* L.) with high CO_2 atmosphere for a short period immediately following harvest prolonged storage life, retarded ethylene production, delayed the climacteric rise in respiration, reduced loss of malic acid, suppressed increase in protein N, retained firmness, quality and the capacity to ripen after long storage. Treatment with 12% CO_2 for 2 or 4 weeks provided the best results without injury.

The use of high CO_2 atmosphere for a short period immediately following harvest to retain fruit quality has recently attracted considerable interest. Couey and Olsen (5) treated 'Golden Delicious' apples with 20% CO_2 for 10 days at the beginning of storage and found that the rapid softening was delayed and loss of titratable acidity reduced. Looney (12) reported that exposure of 'McIntosh' apples to 10% CO_2 for 6 days immediately following harvest suppressed both ethylene production and softening.

Long term storage with atmospheres containing CO_2 levels above

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3% cause a brown core disorder in 'd'Anjou' pears (9). Since data are lacking on the effect of high concn of CO_2 for short term exposures on storage and quality, this experiment was initiated to determine these relationships.

Materials and Methods

Fruit samples at optimum maturity based on a firmness test of 6.4 kg were harvested from mature 'd'Anjou' trees. Immediately following harvest, 50 to 60 pears were placed in each of a group of 19-liter glass containers and sealed with air tight lids equipped with inlet and outlet ports and tubes for supplying the desired CO_2 concn. Triplicate containers were connected by rubber tubing in series and the desired CO_2 levels were obtained by mixing gases from a CO_2 cylinder and an air pump through appropriate regulators and calibrated flow meters.

Table 1. Influence of CO_2 treatment immediately following harvest on quality of 'd'Anjou' pears at the end of 8-month storage.[z]

Duration	Treatment	Firmness (Kg)	CO_2 injury (%)	Quality (0-36)	Ripening capacity	Protein N (mg/100gFW)	Malic acid (mg/100gFW)	Pectin (mg/100gFW)	Carbohydrates (%)	Soluble solids (%)
2 Wk	Control	5.1 ab	0	18.1 bc	Dead	46.3 b	209.4 a	254.4 ab	8.7 a	11.8 a
	12% CO_2	5.7 c	0	25.8 d	Ripened	34.5 a	266.1 b	277.1 d	9.7 cd	12.6 bc
	26% CO_2	6.0 c	29	17.9 bc	Ripened	35.6 a	280.4 c	261.9 bc	9.4 bc	12.0 a
	42% CO_2	6.0 c	83	18.5 bc	Ripened	32.3 a	285.9 cd	262.6 bc	9.6 cd	12.6 bc
4 Wk	Control	4.9 a	0	10.2 a	Dead	44.1 b	211.2 a	256.8 abc	9.1 ab	12.0 a
	12% CO_2	5.8 c	0	25.8 d	Ripened	33.5 a	279.2 c	265.7 c	9.9 d	12.8 c
	26% CO_2	5.9 c	56	15.3 b	Ripened	35.6 a	282.0 c	266.1 c	9.1 ab	12.0 a
	42% CO_2	6.0 c	100	13.9 ab	Ripened	34.0 a	287.5 cd	260.4 abc	9.3 bc	12.2 ab
6 Wk	Control	5.3 b	0	16.3 b	Dead	47.8 b	208.6 a	251.9 a	8.9 a	11.8 a
	12% CO_2	5.9 c	19	18.5 bc	Ripened	33.5 a	281.7 c	260.9 abc	9.3 bc	12.2 ab
	26% CO_2	5.9 c	87	17.8 bc	Ripened	34.1 a	284.4 cd	256.3 abc	9.5 bc	12.2 ab
	42% CO_2	6.4 d	100	14.9 ab	Ripened	32.5 a	291.7 d	255.6 ab	9.8 d	12.0 a

[z] Mean separation in columns by Duncan's multiple range test, 5% level.

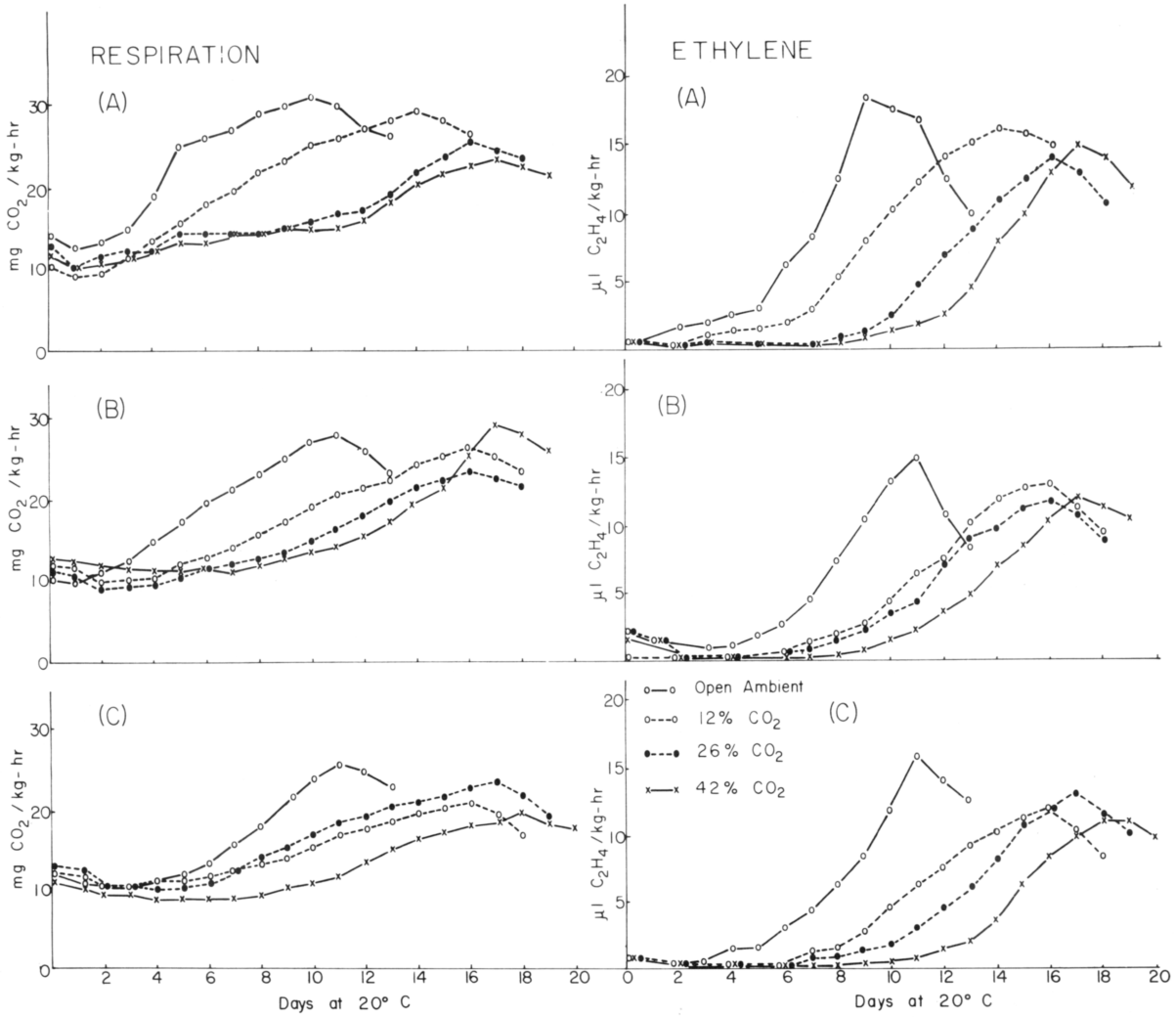

Fig. 1. Respiration and ethylene production of 'd'Anjou' pears after 5-month storage as influenced by CO_2 treatment at the beginning of storage for A) 2 wk, B) 4 wk and C) 6 wk.

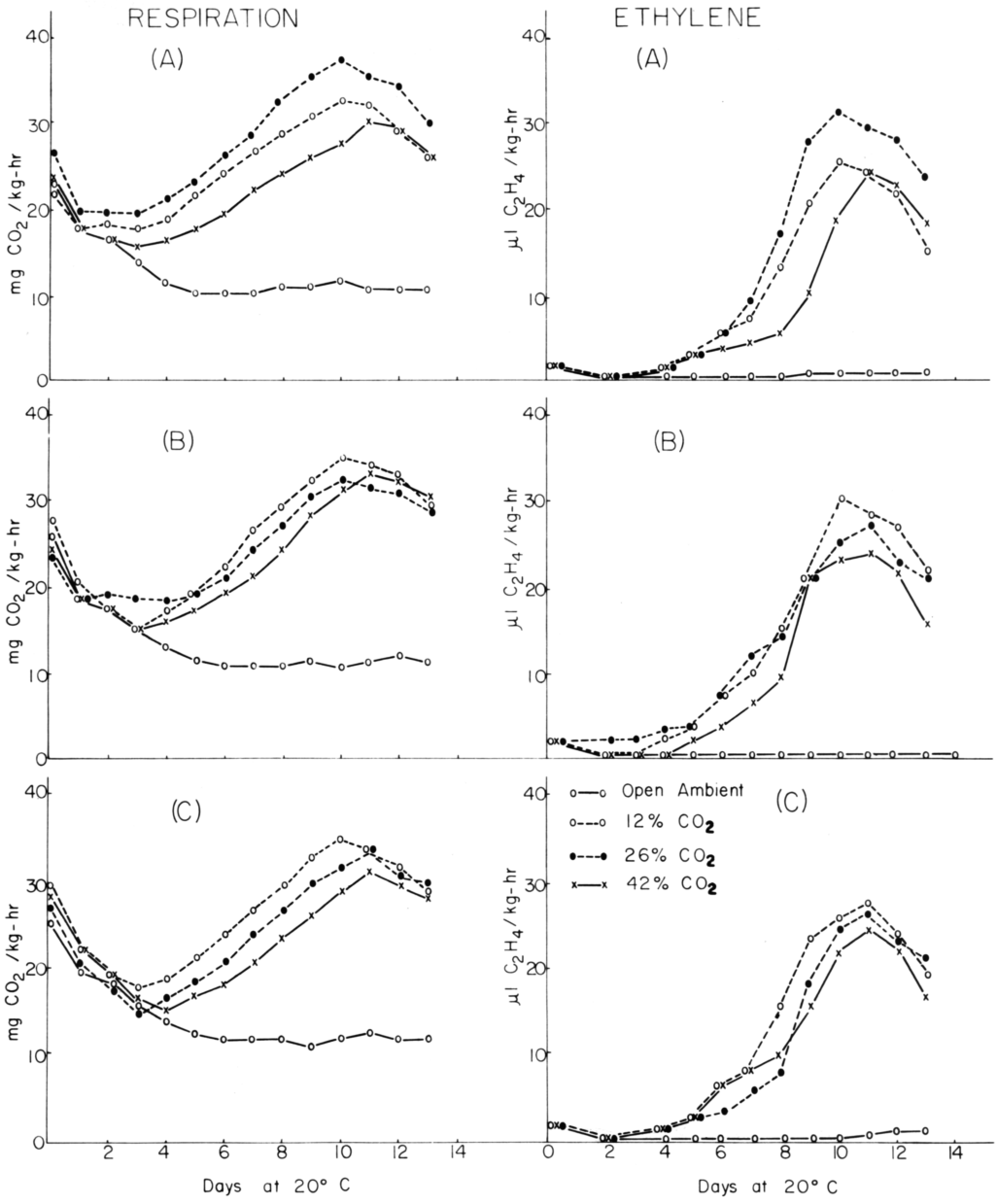

Fig. 2. Respiration and ethylene production of 'd'Anjou' pears after 8-month storage as influenced by CO_2 treatment at the beginning of storage for A) 2 wk, B) 4 wk and C) 6 wk.

In 1972, the concn of CO_2 used were 5%, 11%, and 17%; in 1973, 12%, 26% and 42%. Samples were treated for 2 weeks only in 1972, and 2 weeks, 4 weeks, and 6 weeks in 1973. The concn of CO_2 were monitored by an Orsat apparatus. In both years, control fruit was placed in open jars containing only ambient air and stored in the same room as treated fruits. The temp of the storage room was maintained at −1.1° C. At the end of the CO_2 treatment, both the treated and control fruits were transferred from the glass containers into perforated polyethylene bags and stored in wooden orchard boxes.

After 5 and 8 months of storage, samples from each treatment were measured for firmness, respiration, ethylene production, CO_2 injury, dessert quality, and ripening ability. The samples were also analyzed for contents of protein N, malic acid, pectin, carbohydrates, and soluble solids. Firmness was determined by a UC pressure tester (4) with 8 mm plunger and 3 punches per pear. Fruits for measurement of respiration and ethylene production were placed in 10-liter plexiglass chambers fitted with inlet-outlet tubes and air-tight lids. Air flow was maintained at 200 ml/min and temp at 20° C. Rates of respiration were monitored daily with a Beckman infrared CO_2 analyzer. A 5-ml air sample was collected in a gas sampling syringe from the effluent of the respiration chambers for the determination of ethylene. Ethylene production was measured daily with a Varian Aerograph Model 1200 flame ionization gas chromatograph, using a 1.5-m x 3.175-mm stainless steel column packed with Porapak Q. Flow rates for H_2, N_2, and air were 30, 40, and 350 ml/min. Temp (° C) maintained were injector 70, column 30 and detector 65. Malic acid was separated by partition column chromatography (10) and quantitatively determined with a Waters organic acid analyzer. Carbohydrate content was measured by the Anthrone reaction method (15). Soluble solids content was determined by a hand refractometer. Methods for determination of pectin and protein N have been described previously (14). Brown core was recorded as the symptom of CO_2 injury, and fruit quality was evaluated after the samples were ripened at 20° C. Quality rating included evaluation of flavor, texture, and juiciness. Scores ranged from 0 to 36 for the overall desirability with 30 to 36 being excellent, 23 to 29 being good, 15 to 22 being fair, 8 to 14 being

poor, and 1 to 7 being unsalable. A pear was classified as dead when it failed to soften properly at the ripening temperature after prolonged storage.

Results and Discussion

In 1972 'd'Anjou' pears treated with 11% CO_2 for 2 weeks had an average quality rating of 24.0, which was the highest for any treatment. Quality ratings of 5% and 17% CO_2 treated fruits were 14.4 and 21.6, respectively. The control samples scored 12.0. No CO_2 injury developed in any treatment.

In 1973, brown core was detected in fruits treated with 26% CO_2 for 2 weeks (Table 1). The disorder became more severe with increasing CO_2 concn and exposure time. Retention of firmness is one of the most obvious benefits obtained from the CO_2 treatment. All CO_2 treatments showed significantly higher pressure test than the ambient control at the end of 8 months' storage (Table 1).

Most control fruits failed to ripen and remained firm even when transferred to a temp favorable for ripening. Quality ratings were based on juiciness, texture and flavor. Some control fruits were rated as fair due to their juiciness and moderate flavor even though they failed to soften. Although all CO_2-treated fruits softened and ripened normally, the quality ratings were low except for treatments of 12% CO_2 for 2 or 4 weeks (Table 1). The higher quality of these 2 treatments was related to freedom from CO_2 injury and higher acid content.

Decrease of malic acid, the predominant organic acid in 'd'Anjou' pear (11), was markedly inhibited by the CO_2 treatment. The initial value of 302.8 mg/100 g F. W. at harvest declined to approximately 210 mg in the control fruits, but ranged from 266.1 mg to 291.7 mg in treated fruits sampled after 8 months' storage (Table 1).

Protein synthesis is required for normal ripening in pears and the enzymes required for ripening are proteins synthesized early in the ripening process (7). During storage, the control fruits accumulated higher protein levels than the CO_2-treated fruits (Table 1), but failed to ripen. The enzymes synthesized during storage could either be qualitatively different from those synthesized during normal ripening or may have been inactivated by the prolonged cold exposure as proposed by Li and Hansen (11). CO_2 treatment tended to suppress protein synthesis and to maintain the normal capacity for ripening after prolonged storage periods.

Although samples treated with CO_2 showed slightly higher pectin, carbohydrates, and soluble solids contents than the control fruits, the differences were not consistently significant (Table 1).

High CO_2 environment was found to inhibit the activities of respiratory enzymes in pears and apples (8, 13). Suppression of metabolic activities by CO_2 is implicated by the delay of the climacteric rise in respiration and by the retardation of ethylene production (Fig. 1). Following 8 months' storage, control fruits failed to complete the climacteric phenomenon and the ethylene production stayed at a low level (Fig. 2). This may relate to the loss of the ripening capacity after prolonged cold storage.

CO_2 has been suggested as an effective antagonist to ethylene action (1, 2). High CO_2 treatment probably retarded some of the metabolic reactions which are associated with ripening and senescence and which are readily promoted by ethylene. The differences in respiration, ethylene production, protein N, malic acid, and ripening capability between high CO_2 treated and ambient fruits were still evident after 8 months' storage. This indicates that the initial suppressing effect on metabolism by CO_2 persisted throughout the cold storage period.

CO_2 injury is always a potential problem, and a limiting condition in this type of experiment. Several factors which influence the susceptibility of the fruit need to be considered in order to arrive at the best combination and to attain the most effective results. These include maturity (3, 9), low O_2 concn, and tree vigor (6, 9). It is also possible that factors such as seasonal growing conditions and the time of CO_2 treatment following harvest could influence the effectiveness. Nevertheless, the short term high CO_2 treatment appears to have promising potential for improving storage and quality of 'd'Anjou' pears. Further study is required to establish guide lines for commercial application.

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