Effects of ground cover management on certain abiotic and biotic interactions in peach orchard ecosystems

R. L. MEAGHER, JR* AND J. R. MEYER

Department of Entomology, Box 7626, Grinnells Lab, North Carolina State University, Raleigh, NC 27695-7626, USA

ABSTRACT. Large peach orchard blocks with three different ground cover strategies were established in North Carolina to measure the effects of abiotic and biotic variables on tree growth and peach production. Bare ground plots generally had higher soil temperature and soil moisture than the strip sod or solid sod plots. Soil nutrients, soil physical factors, and foliar nutrients were generally not different among the treatment plots. Tree growth (terminal shoot growth, trunk circumference) and fruit yield were usually higher in the bare ground plots, while the weedy plots had higher percentages of fruit injury due to feeding by hemipteran insects (catfacing). Ring nematode results were variable and no conclusions could be made with reference to treatment effects on nematode populations.

KEYWORDS: Ground cover management; abiotic/biotic interactions; peach trees; orchards; ecosystems; fruit production; North Carolina

Introduction

Over the years, a number of ground cover management strategies have been proposed for deciduous orchards. Although high-quality fruit can be produced in a variety of ways, there are distinct advantages and disadvantages to each option. Clean culture (bare ground) is a common practice in the United States because it reduces competition between weeds and trees for water and nutrients (Lord and Vlach, 1973) and provides a measure of frost protection in the early spring (Hamer, 1975). Unfortunately, bare ground also leads to compaction of the soil, increased runoff during rains, greater erosion, and poor roadability under wet conditions (Haynes, 1981b). Sod or natural sward ground covers, on the other hand, maintain better soil texture (Soong and Yap, 1976), improve absorption of water during rains, preserve roadability (the ability for intraorchard travel), and stabilize temperature fluctuations in the root zone (Dancer, 1964), but they also harbour pest populations, and compete with the trees for available water and nutrients (McMurtrie and Wolf, 1983; Powell, Forer and Stouffer, 1984).

In response to this dichotomy, many growers have adopted a modified sod management programme which allows growth of grasses or natural sward in the row middles and uses herbicides or tillage to maintain a strip of bare ground under the tree row. Although this option preserves roadability, reduces competition and offers a small degree of frost protection (Atkinson and White, 1981), it still provides a refuge for pests. We attempted to strengthen the research base for decision-making by focusing on the interactions between ground cover management strategies, growth response of the trees, water availability, orchard microclimate, and competition from pests. The objectives of this study were to compare these three ground cover management strategies in regard to several abiotic and biotic variables and to relate these variables to peach tree growth, fruit production and value, catfacing injury and ring nematode [*Criconemella xenoplax* (Raski) Luc & Raski] population density in sandy soils of North Carolina's peach-growing region.

Materials and methods

Orchard sites

Three commercial orchards and one research orchard in three North Carolina counties were studied. A 22·3 ha block in Montgomery Co. contained trees of cvs Derby, Carymac and Rubired. The orchard was divided into six ground cover management plots, two each of bare ground, strip sod, and solid sod. The bare ground was maintained by periodic

*To whom correspondence should be addressed; present address Texas Agricultural Experiment Station, Weslaco, TX 78596, USA

0261-2194/90/01/0065-08

discing, while the solid sod plots were left untreated. In the strip plots, herbicides (paraquat, diuron, and terbacil, at the grower's discretion) were applied to the areas under the trees. Variables were measured in this orchard only in 1986.

The second commercial orchard, located in Richmond Co., was used in 1986 and for a limited period during 1987. This 11·3 ha orchard, planted in 1983, contained cvs Belle of Georgia, Candor, Jefferson, Loring, Norman, Redskin and Winblo aligned in rows. In fall (autumn) 1985 the entire orchard was disced and annual rye (*Secale cereale*, cv. Aroostock) was planted in unidirectional rows in the strip plot, and in both directions in the solid sod plot. The bare ground plot was maintained by periodic discing, while the surface under the trees was freed of vegetation by herbicide (paraquat) applications.

The third orchard studied was located in the coastal plain region of North Carolina at the Horticultural Crops Research Station (HCRS) in Sampson Co. This 0·5 ha orchard planted in 1984, contained trees of cvs Biscoe and Norman and was used in 1987 and 1988. The bare ground plot was maintained by discing, the surface under the trees in the strip sod plot was freed of vegetation by paraquat applications, and the solid sod plot was untreated.

The fourth orchard was located on the Sandhills Research Station near Jackson Springs. This 4·5 ha orchard, planted in 1981, contained blocks of cvs Biscoe, Norman, Pekin and Winblo, and was used in both 1986 and 1987. The orchard was divided into three ground cover plots—bare ground, weedy, and no winter annual (NWA). The bare plot was kept clean by periodic discing; the weedy plot had no ground cover management applications except for mowing. Paraquat CL was applied in late February or early March of both years in the NWA plot to suppress growth of winter annuals over the entire floor. Regrowth of summer annuals and perennials was allowed throughout the rest of the season.

Abiotic and biotic variables

Daily maximum and minimum air temperatures were taken in the tree canopies of the Montgomery, Richmond 1986, and Sandhills 1986 orchards using Taylor dual scale maximum–minimum thermometers protected by small shelters for shade. Temperature stations located on isoclines near the centre of each plot recorded temperatures from early January through late April. Air and soil temperatures in Richmond 1987 were recorded every 10 min using Omnidata Datapods during April. Air-temperature probes were attached to branches within the tree canopy, while soil-temperature probes were placed *c*. 5 cm below the surface. Seasonal changes of air and soil temperatures were calculated by summing the daily difference between maximum and minimum temperatures throughout the recording period.

Soil moisture was measured gravimetrically from samples collected using soil corers. Samples were weighed, air-oven dried (Grieve-Hendry Laboratory Oven) for 1 h at 100°C in glass Petri dishes, cooled for 30 min, weighed again, and the percentage moisture expressed as mass of water per unit mass of dry soil (dry-weight basis) (Hunt and Pixton, 1974). Spring season (late March–late April) soil moisture was measured every 2–5 days in HCRS 1987, Richmond 1986 and 1987, and Sandhills 1987. Summer season (late June–early fall) soil moisture was measured weekly in the HCRS 1987 and Sandhills 1987 orchards. In all orchards 2–4 replications were sampled per ground cover plot.

Soil samples were collected for physical variables and plant nutrients – three in HCRS 1987, four in Montgomery, five in Richmond 1986 and Sandhills 1986, and two in Sandhills 1987. Samples were taken using soil corers, with 20–30 cores per sample, and from two to eight replications per ground cover plot, depending on orchard size. Samples were placed in small cardboard boxes and were analysed by the Agronomic Division of the North Carolina Department of Agriculture. The variables measured were humic matter (g/100 cm^3), weight per volume (g cm^{-3}), cation exchange capacity (CEC) (μg/100 cm^3), base saturation (percentage of CEC), and pH (hydrogen ion concentration). Macronutrients sampled included phosphorus and potassium, both represented as indices, and calcium and magnesium, both represented as a percentage of the CEC.

Ring nematode samples were taken in the HCRS 1987, Richmond 1987, and Sandhills 1986 and 1987 orchards. In HCRS 1987 and Sandhills 1987, early summer and late fall samples were taken; a spring sample was taken in Richmond 1987, while a late fall sample was taken in Sandhills 1986. Samples were taken using soil corers, with 20–30 cores per sample, and from two to eight replications per ground cover plot, depending on orchard size. Samples were stored in plastic bags and cardboard boxes, and nematodes were extracted by elutriation plus centrifugal flotation (Byrd *et al*., 1976) by plant pathologists at Clemson University.

Foliar nutrients in Sandhills 1986 were measured from leaf samples taken in late summer and analysed by the Plant Tissue Laboratory of the North Carolina Department of Agriculture. Samples were taken from all four cultivars in each ground cover plot. The macronutrients nitrogen, phosphorus, potassium, calcium, magnesium, and sulphur, and the micronutrients iron, manganese, zinc, copper, boron, and molybdenum were measured.

Seasonal tree growth was recorded using midwinter measurements of terminal shoot length and trunk diameter or circumference. Terminal shoots were measured in HCRS 1987 and 1988 (5 shoots/

tree, 10 trees/cultivar, 2 cultivars/ground cover plot), and Richmond 1986, Sandhills 1986, and 1987 (10 shoots/tree, 10 trees/cultivar, 4 cultivars/ground cover plot). Percentage increase in trunk diameter was measured in Richmond 1986 and Sandhills 1986 (10 trees/ground cover plot), and in trunk circumference in HCRS 1987 and 1988 (10 trees/cultivar, 2 cultivars/ground cover plot) and Sandhills 1987 (10 trees/ground cover plot).

Orchard floor surveys were conducted in all orchards during late winter or early spring to determine the vegetative content of the ground cover. Samples were taken in each ground cover treatment plot using a square-metre grid divided evenly into 25 sections. Plant species were identified (Radford, Ahles and Bell, 1976) and overall vegetative density (percentage amount of vegetation per square metre) was recorded.

Peach yield (kg) and percentage catfacing (injury to the fruit due to feeding by hemipteran species) were measured in Sandhills 1986 and 1987. Catfacing injury was determined by randomly picking 100 fruit (2-4 replications) from all four cultivars in each ground cover plot during harvest. In 1986, yield was measured at harvest for cvs Biscoe, Norman and Winblo trees in all ground cover plots and in 1987, from eight trees per cultivar in each ground cover plot. Size was determined as small (<5·08 cm), medium (5·08–5·72 cm), medium–large (5·72–6·35 cm), or large (>6·35 cm). Fruit value was calculated based on the equation: $FV = Y[(\%sm * 0{\cdot}32) + (\%ml * 0{\cdot}37) + (\%l * 0{\cdot}41)]$, Y = yield (kg), sm = small and medium fruit, ml = medium–large fruit, and l = large fruit. The following prices were used for each size category: $0·41 kg^{-1} for large peaches, $0·37 kg^{-1} for medium–large peaches, and $0·32 kg^{-1} for small and medium peaches.

Data were analysed for the effects of ground cover management on the variables individually using a mean separation test (SAS Institute, 1982) and tested for correlation to show any relationships between single abiotic or pest variables and tree growth and peach production.

Results

Individual variables

Tree canopy temperature. No significant differences in the analysis of variance were found among ground cover plots in comparing daily maximum, minimum or range (maximum–minimum) air temperatures (*Table 1*). Ground cover appeared to have had no effect on tree canopy temperature.

Soil temperature. The bare ground plot in Richmond 1987 had significantly higher maximum mean soil temperatures (23·1 ± 1·0°C) compared with the solid and strip sod plots (19·3 ± 0·9°; 17·1 ± 0·9°). The minimum soil temperatures among plots were not different. Temperature range, as measured by the regression slopes, was higher in the bare plot (13·1) than in the other plots. The solid sod plot had the lowest temperature range slope (8·0), while the strip plot was intermediate (11·5).

Soil moisture. Soil moisture means among plots were not significantly different, but when the data were summed and analysed as a regression model to compare slopes, differences were noted in the HCRS 1987 orchard. Larger slopes correlated with generally higher soil moistures. The bare ground plot had the largest slope in the model (4·83), compared with the solid (3·97) and strip sod (3·88) plots (data not shown). There were trends for spring soil moisture to be lowest in the solid sod plots in both years in the Richmond orchard, but these differences were not significant. Also, there was a trend for summer soil

TABLE 1. Tree canopy temperatures (°C) (maximum, minimum and range) averaged over the recording period in three ground cover (GC) management plots for four peach orchards in North Carolina. All differences among plots within columns were not significantly different ($P > 0{\cdot}01$)

			Tree canopy temperatures (mean ±SE; °C)		
Location	Recording period	GC	Maximum	Minimum	Range
Montgomery	January–April (103 days)	Bare	20·3 ± 0·8	3·3 ± 0·7	16·9 ± 0·5
		Strip	19·8 ± 0·9	3·2 ± 0·7	16·5 ± 0·5
		Solid	20·2 ± 0·9	3·5 ± 0·7	16·7 ± 0·5
Richmond	January–April, 1986 (104 days)	Bare	19·9 ± 0·8	3·1 ± 0·6	16·8 ± 0·6
		Strip	20·1 ± 0·8	3·3 ± 0·6	16·8 ± 0·6
		Solid	19·6 ± 0·8	2·7 ± 0·6	16·8 ± 0·6
Sandhills	January–April, 1986 (104 days)	Bare	19·8 ± 0·9	3·2 ± 0·7	16·6 ± 0·5
		NWA[a]	19·9 ± 0·9	3·3 ± 0·7	16·6 ± 0·5
		Weedy	19·8 ± 0·8	3·3 ± 0·7	16·5 ± 0·5
Richmond	April, 1987 (23 days)	Bare	21·0 ± 1·2	6·5 ± 1·0	14·5 ± 0·9
		Strip	21·1 ± 1·2	6·4 ± 1.3	14·8 ± 0·9
		Solid	21·5 ± 1·3	6·4 ± 1·1	15·0 ± 1·0

[a] No winter annuals

moisture to be lowest in the bare ground plots in the Sandhills orchard, but again this was not significant.

Soil physical variables and nutrients. The soil physical variables and soil nutrients were generally not significantly different among ground cover treatments. The bare ground plot in three different orchards (Montgomery, Richmond 1986, and Sandhills 1987) had the highest pH, and the NWA plot in Sandhills 1987 had the lowest. Base saturation in two orchards (Richmond 1986 and Sandhills 1987) was highest in the bare ground plots and lowest in the solid sod or weedy plots. Phosphorus and manganese were different among plots, highest in the solid sod plots during both years in Richmond.

Foliar nutrients. Phosphorus, magnesium, and sulphur generally were highest in leaves from the bare ground and weedy plots, and lowest in leaves from the NWA plots (*Table 2*). Nitrogen, potassium, and calcium were not different among plots, although there were trends for higher nitrogen in bare ground-plot trees, and higher potassium and calcium in weedy-plot trees. Iron, manganese, and copper were different among plots, but no trends were evident.

Tree growth measurements. In all five orchards, trees in the solid sod or weedy plots had the shortest terminal shoot growth (*Table 3*). There were significant interactions between ground cover type and cultivar in three of the orchards. In the Sandhills 1986 and 1987, this interaction was attributed to individual cultivars having either bare or NWA trees with longer shoot growths. However, in all cultivars in these orchards, the trees over weedy cover had significantly less growth. The data from Richmond 1986 are more questionable. Only one of the four cultivars (Belle of Georgia) had a significant difference among covers, although the trend was for the trees over bare ground to have the longest growth, and trees over solid sod to have the shortest. In three of the four orchards where trunk measurements were made, the weedy or solid sod plots had the smallest percentage increase, and the bare ground plots had the highest (*Table 4*). In HCRS 1988, the differences in trunk circumference among plots were not significantly different ($P = 0{\cdot}067$: bare 21·4% ± 0·3; strip 20·2 ± 0·5; solid, 16·0 ± 0·8)

Orchard floor cover. In all four orchards surveyed, cultivated plots had low percentage ground cover, ranging from 12·5% in HCRS 1987 to 1·0% in Richmond 1986. The strip and solid sod plots were similar in the amount of cover, usually >72%, except in Richmond 1986 (strip, 10%; solid, 45%), where the cover was newly established. Early spring orchard floor surveys in Sandhills 1987 suggested that there were statistically similar percentages of ground cover, but higher densities of winter annuals were found in the weedy plots. The NWA plot had 8% of its cover in henbit (*Lamium amplexicaule* L.) and 1% in bitter cress (*Cardamine hirsuta* L.), while in the weedy plot 25% of the cover was in chickweed [*Stellaria media* (L.) Cyrillo], 14% in Carolina geranium (*Geranium carolinianum* L.) and 5% in henbit.

Ring nematodes. *Criconemella xenoplax* (Raski) Luc & Raski populations were quite variable, and were only significantly different among plots in the Sand-

TABLE 2. Foliar macro- and micronutrients (means ± SE)[a] in three ground cover management plots, Sandhills Research Station, 1986

Ground cover	Macronutrients			Micronutrients		
	Phosphorus (%)	Magnesium (%)	Sulphur (%)	Iron (ppm)	Manganese (ppm)	Copper (ppm)
Bare	0·32 ± 0·005a	0·62 ± 0·02a	0·14 ± 0·004a	81·3 ± 2·1ab	64·1 ± 1·6b	6·0 ± 0·3b
Weedy	0·31 ± 0·01ab	0·60 ± 0·01a	0·14 ± 0·006a	90·5 ± 4·4a	86·8 ± 5·7a	5·9 ± 0·1b
NWA[b]	0·29 ± 0·004b	0·53 ± 0·02b	0·11 ± 0·006b	76·5 ± 1·6b	78·1 ± 4·2ab	9·0 ± 0·3a

[a] Means followed by the same letter within each orchard are not significantly different [$P < 0{\cdot}05$, Tukey's (1953) studentized range test (HSD)]; [b] no winter annuals

TABLE 3. Terminal shoot length[a] (cm; mean ± SE)[b] in three ground cover management plots for five peach orchards in North Carolina

Ground cover	Orchard				
	HCRS 1987[c]	HCRS 1988[c]	Sandhills 1986[d]	Sandhills 1987[d]	Richmond 1986[e]
Bare	170·6 ± 4·7a	203·1 ± 4·1a	50·0 ± 0·8a	95·0 ± 1·0b	48·4 ± 0·5a
Strip	155·0 ± 3·7b	188·2 ± 3·6a			46·1 ± 0·6b
Solid	128·8 ± 3·8c	158·3 ± 3·6b			45·8 ± 0·7b
NWA			46·6 ± 0·6b	99·5 ± 1·1a	
Weedy			32·7 ± 0·7c	75·3 ± 0·7c	

[a] For details of measurements see text; all terminal shoots measured were for the previous year's growth; results are combined across trees and cvs; the range of values is explicable in terms of the age of the trees, pruning practices and fruit-bearing status of the trees affecting vegetative production; [b] means followed by the same letter within each orchard are not significantly different [$P < 0{\cdot}05$; Tukey's (1953) studentized range test (HSD)]; [c] data combined from trees of cvs Biscoe and Norman; [d] data combined from Biscoe, Norman, Pekin and Winblo trees; [e] data combined from Belle of Georgia, Norman, Redskin and Winblo trees

TABLE 4. Percentage trunk measurement increase based on circumferences (C) or diameters (D) (means ± SE)[a] in three ground cover management plots for three peach orchards in North Carolina

Ground cover	Orchard		
	HCRS 1987 (C)	Sandhills 1986 (D)	Sandhills 1987 (C)
Bare	29·0 ± 0·5a	8·4 ± 0·5a	10·7 ± 1·1a
Strip	26·1 ± 0·4b		
Solid	20·8 ± 0·5c		
NWA		8·8 ± 0·9a	7·1 ± 0·3b
Weedy		5·1 ± 1·1b	3·9 ± 0·7c

[a] Means followed by the same letter within each orchard are not significantly different [$P < 0·05$; Tukey's (1953) studentized range test (HSD)]

hills 1986 orchard. This orchard was sampled in late fall, and the bare ground plots had more nematodes per 1000 cc [203·8 ± 45·9 (SE)] than the NWA plots (68·2 ± 14·6). The weedy plots had intermediate numbers of nematodes (134·0 ± 25·0). The other sampled orchards had lower nematode numbers.

Peach yield, size, value and catfacing. Fruit was sampled only in the Sandhills orchard during 1986 and 1987. In both years, the bare ground plots generally produced the highest yields, although the differences among ground covers were not statistically significant. In 1986 bare ground-plot trees produced 31·8 ± 1·9 kg tree^{-1}, compared with 18·9 ± 1·6 kg tree^{-1} for weedy plots. In 1987 the bare plot yield was 51·7 ± 5·0 kg tree^{-1} compared with 18·4 ± 1·7 kg tree^{-1} in weedy plots. However, there was a ground cover by cultivar interaction in 1987. The yield difference was slight for bare ground and NWA plots in cvs Biscoe and Winblo, but was much larger in Norman and Pekin trees.

The percentage of 'large' fruit was higher in the NWA plots (73·5 ± 3·3%) than in the bare ground plots (55·3 ± 5·8%) and intermediate for the weedy plots (67·6 ± 5·4%). However, there was a highly significant ground cover by cultivar interaction. Biscoe trees on bare ground produced very low percentages of large fruit (12·9%) compared with the other cultivars. Pekin peaches were larger with weedy cover, but Winblo peaches were larger with bare ground. These differences may be explained by the total amount of large fruit per cultivar. Over 91% (±1·7) of the cv. Norman peaches were large, compared with 73·8% (±3·6) of the Pekin, 52·5% (±5·5) of the Winblo and only 44·6% (±6·2) of the Biscoe fruit.

Even though the trees on the bare ground plots generally had smaller fruit, their value (a result of the yield and price per size) was the highest of the plots. Fruit on these trees averaged $20·07 (±2·00) compared with the NWA-plot trees ($12·25 ± 0·95) and weedy-plot trees ($7·39 ± 0·69). Again, a significant ground cover by cultivar interaction resulted, indicating a sharper drop in fruit value from bare ground to the NWA plots in the Norman and Pekin cultivars than the Biscoe and Winblo.

Catfacing injury during both years was higher in the weedy plots, and statistically similar in the bare and NWA plots. The weedy plot in 1986 had 8·9% (±0·8) catfacing injury compared with 2·6% (±0·4) in the NWA and 2·2% (±0·4) in the bare plots. Catfacing injury overall was higher in 1987 (weedy 28·2% ± 2·0, bare 14·4% ± 1·1, NWA 10·2% ± 1·0).

Correlation analysis

For the correlation analysis, each orchard was considered individually, and all data are recorded in *Table 5*.

Richmond 1986. The Richmond 1986 orchard had no abiotic variables that correlated with any tree growth parameters.

HCRS 1987. Soil moisture correlated well with both terminal shoot growth and trunk circumference. No other abiotic variable was significantly correlated with tree growth.

Sandhills 1986. Several abiotic variables were separately correlated with terminal shoot growth including air-temperature range, soil magnesium, and foliar potassium. Trunk diameter, however, was correlated only with foliar iron. Ring-nematode densities were negatively correlated with soil magnesium, and positively correlated with foliar calcium and molybdenum. Catfacing injury correlated with air-temperature range, soil magnesium, foliar potassium, and foliar iron. Fruit yield correlated with air-temperature range, and foliar potassium and manganese.

Sandhills 1987. Tree growth as measured by trunk circumference was negatively correlated with both mean and maximum soil moisture. Nematode density correlated with two soil variables—base saturation and magnesium. Fruit yield and value correlated with both maximum soil moisture and soil-moisture range, and the soil variables base saturation (fruit yield only), weight per unit volume, and calcium.

Discussion

As canopy temperatures among the three ground cover plots were similar, frost protection due to bare ground was not evident in the soil conditions and climate in this experiment. Perhaps the amount of ground cover (biomass) which was present within the strip and solid sod plots was too small to make a difference in the air temperatures. Furthermore, our data did not show significant differences among cover plots on individual nights of radiational cooling (Leyden and Rohrbaugh, 1963). The bare plots produced higher maximum soil temperatures (diurnal temperatures) and a broader soil-temperature

TABLE 5. Correlation analysis of independent (abiotic) with dependent (tree growth, pests, or fruit production) variables

Orchard	Dependent variable	Independent variable	$P > F$	Correlation coefficient
HCRS 1987	Terminal shoot growth	Soil moisture (mean)	0·017	0·89
	Trunk circumference	Soil moisture (mean)	0·016	0·90
Sandhills 1986	Terminal shoot growth	Air temperature (range)	0·003	0·96
		Soil magnesium	0·005	0·94
		Foliar potassium	0·010	0·92(−)
	Trunk diameter	Foliar iron	0·030	0·84(−)
	Nematode density	Soil magnesium	0·039	0·83(−)
		Foliar calcium	0·002	0·97
		Foliar molybdenum	0·040	0·83
	Catfacing injury	Air temperature (range)	0·016	0·90(−)
		Soil magnesium	0·008	0·93(−)
		Foliar potassium	0·010	0·92
		Foliar iron	0·015	0·90
	Fruit yield	Air temperature (range)	0·018	0·89
		Foliar potassium	0·010	0·92(−)
		Foliar manganese	0·002	0·96(−)
Sandhills 1987	Trunk circumference	Soil moisture (range)	0·038	0·84(−)
		Soil moisture (max.)	0·038	0·84(−)
	Nematode density	Base saturation	0·044	0·82
		Soil magnesium	0·005	0·94
	Fruit yield	Soil moisture (range)	0·012	0·91(−)
		Soil moisture (max.)	0·013	0·90(−)
		Base saturation	0·037	0·84
		Weight/volume	0·041	0·83
		Soil calcium	0·023	0·87
	Fruit value	Soil moisture (range)	0·033	0·85(−)
		Soil moisture (max.)	0·026	0·87(−)
		Weight/volume	0·037	0·84
		Soil calcium	0·046	0·82

range, but minimum (nocturnal) soil temperatures were not different among plots. These results are in agreement with other research (Dancer, 1964). There was no evidence that root zone microclimate affected spring flowering (unpublished data).

Soil moisture has been reported to be higher in cultivated soil than under sod or other cover (Cullinan and Weinberger, 1937; White and Holloway, 1967) but in our older, more compacted bare ground plots in the Sandhills, rainfall penetration was poor and better moisture-holding capacity was found in the grassed plots (Kenworthy, 1953; Haynes, 1981b).

In apple orchard soils, cations leach from surface soil of non-grassed plots (cultivated or herbicide-treated), and base saturation and pH decrease (Haynes, 1981a; Haynes and Goh, 1980a). Others (Shribbs and Skroch, 1986; Weller, Skroch and Monaco, 1985) found no differences in soil macronutrients, micronutrients, and other soil variables among bare ground and various ground cover systems in apple and peach. However, higher calcium, magnesium, and CEC levels were found in grassed plots in other studies (Haynes, 1981a; Haynes and Goh, 1980a, b).

Foliar analysis showed trends for nitrogen to be higher in bare-plot trees, and potassium and calcium to be higher in weedy-plot trees. Our results generally agree with those from Haynes and Goh (1980a), although we found no correlation between foliar nitrogen and tree growth that has been documented in other tree fruit studies (Shribbs and Skroch, 1986). These results are from only one sample; perhaps more sampling would have provided more differences among plots.

Most fruit tree research has documented increased tree growth with weed management or cultivation and our data support these findings (Heeney, Warren and Khan, 1981a; Welker and Glenn, 1985). Increased tree growth has been associated with improved soil moisture (Fisher, 1965) and in the HCRS 1987 orchard soil moisture was the only independent variable that was significant in relation to terminal shoot growth and trunk circumference. Soil moisture was negatively correlated to trunk diameter in Sandhills 1987, but this orchard had established covers, older trees, and lower moisture in the bare ground plots, all of which confound the relationship. Although it appears that tree growth can be vigorous on bare ground, in a mature orchard this may not be practical or economically feasible because of pruning, fruit production and thinning, or labour costs (Hibbard, 1944). Less distinct results of tree growth have been achieved in years following the initial ground cover management work (Rupp and Anderson, 1985).

Ring nematodes have been associated with peach tree short life in young trees (Nyczepir *et al.*, 1983). Some herbaceous plants have been found to be hosts for these nematodes, but the majority of orchard ground cover species are either poor hosts or non-hosts (Zehr, Lewis, and Bonner, 1986). Our results were inconclusive in deciding which ground cover management type was best for control of nematode populations.

Tree fruit research has shown that trees under some type of weed management system (herbicides, cultivation, or mulches) generally produce larger yields and larger fruit than trees under a mowed solid sod (Atkinson and White, 1981; Heeney *et al.*, 1981a, b; Rupp and Anderson, 1985). Our data suggested that there were trends for higher yields and higher fruit value in the bare ground plots, although the degree of this improvement would depend on the individual cultivar. Differences concerning the fruiting habits among cultivars were important when fruit size and value were considered. The discrepancy among the average fruit sizes by cultivar were so variable that a generalized conclusion as to the effect of ground cover management on fruit size was not possible. It was interesting that soil moisture was negatively correlated with fruit yield in 1987. As with the tree growth data, it appears that 1987 was an unusual year for soil moisture, especially in the bare plot where the highest yield was recorded.

The relationship between winter annual plants and catfacing injury was documented by Killian and Meyer (1984). The plants provide food and shelter during late winter for catfacing insects [tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), and several stink bug species in the genera *Euschistus*, *Acrosternum* and *Nezara*]. These insects apparently migrate from the blooming winter annual plants to peach buds and flowers after the cover plants senesce.

The differences in some variables between the NWA plots and the other plots suggested that the timing and removal of certain cover species has an important effect on orchard characteristics. By mid-season, the NWA plots contained a greater variety and greater biomass of ground cover plants than the weedy plots. These plots produced trees that were almost as large as the bare-plot trees, with similar or slightly less tree growth during the season. Fruit yield and value, however, were substantially less than that of the bare plots, a result not completely understood.

An objective of this study was to differentiate the advantages and disadvantages of three primary types of ground cover management under peach-growing conditions in North Carolina. The advantages of bare ground, such as higher soil moisture and increased tree growth, fruit production and fruit value, appear to be true in younger orchards with young ground covers, but our data did not show an increase in frost protection in the spring. As an orchard and its ground cover mature, these bare ground areas can become compacted and rain runoff and erosion can be problems. Solid sod plots offer reduced soil-temperature fluctuations and, as the orchard matures, better soil absorption. However, under periods of drought, especially under sandy soils, solid sod plots may compete for this soil moisture. Furthermore, if winter annual plants become established, the grower will have to put more resources into pest control problems such as nematodes and catfacing insects. Strip sod culture offers a compromise of both management types. The type of cover plants in the row is important, and is the subject of future research.

Notes and acknowledgements

The authors are grateful to the commercial growers and the staff of the Sandhills Research Station for their assistance and use of their orchards. The authors thank F. Gould, G. House, G. Rock (North Carolina State University), and E. Zehr (Clemson University) for their critical review of an early draft of the manuscript. This research has been financed in part with funds from the USDA under agreement 85-CRSR-2-2571.

Paper no. 11991 of the Journal Series of the North Carolina Agricultural Research Service, Raleigh, NC 27695-2718, USA.

References

ATKINSON, D. AND WHITE, G. C (1981). The effects of weeds and weed control on temperate fruit orchards and their environment. In: *Pests, Pathogens and Vegetation*, pp. 415–428 (ed by J. M. Thresh). London: Pitman.

BYRD, D. W., JR, BARKER, K. R., FERRIS, H., NUSBAUM, C. J., GRIFFIN, W. E., SMALL, R. H. AND STONE, C. A. (1976). Two semiautomatic elutriators for extracting nematodes and certain fungi from soil. *Journal of Nematology* **8**, 106–112.

CULLINAN, F. P. AND WEINBERGER, J. H. (1937). Some effects of four years of cover crops in a young peach orchard. *Proceedings of the American Society for Horticultural Science* **34**, 242–246.

DANCER, J. (1964). The influence of soil moisture and temperature on the growth of apple trees. I. Some observation of moisture and temperature conditions under grass, arable and mulch. *Horticultural Research* **4**, 3–13.

FISHER, V. J. (1965). The effect of weed control by isocil and bromacil on growth of young peach and apple trees. *Proceedings of the American Society for Horticultural Science* **86**, 148–151.

HAMER, P. J. C. (1975). Physics of frosts. In: *Climate and the Orchard*, pp. 66–72. East Malling, England: Commonwealth Agricultural Bureaux.

HAYNES, R. J. (1981a). Soil pH decrease in the herbicide strip of grassed-down orchards. *Soil Science* **132**, 274–278.

HAYNES, R. J. (1981b). Effects of soil management practices on soil physical properties, earthworm populations and tree root distribution in a commercial apple orchard. *Soil Tillage Research* **1**, 269–280.

HAYNES, R. J. AND GOH, K. M. (1980a). Some effects of orchard soil management on sward composition, levels of available nutrients in the soil, and leaf nutrient content of mature 'Golden Delicious' apple trees. *Scientia Horticulturae* **13**, 15–25.

HAYNES, R. J. AND GOH, K. M. (1980b). Some observations on surface soil pH, base saturation and leaching of cations under three contrasting orchard soil management practices. *Plant and Soil* **56**, 429–438.

HEENEY, H. B., WARREN, V. AND KHAN, S. U. (1981a). Effects of annual repeat applications of simazine, diuron, terbacil, and dichlobenil in a mature apple orchard. *Canadian Journal of Plant Science* **61**, 325–329.

HEENEY, H. B., WARREN, V. AND KHAN, S. U. (1981b). Effects of

rotation of simazine, terbacil, and dichlobenil in a mature apple orchard. *Canadian Journal of Plant Science* **61**, 407–411.
HIBBARD, A. D. (1944). The growth of young peach trees under different systems of soil management. *Proceedings of the American Society for Horticultural Science* **44**, 66–70.
HUNT, W. H. AND PIXTON, S. W. (1974). Moisture—its significance, behavior, and measurement. In: *Storage of Cereal Grains and their Products*, pp. 1–55 (ed. by C. M. Christensen). St Paul, MN: American Association of Cereal Chemists, Inc.
KILLIAN, J. C. AND MEYER, R. J. (1984). Effect of orchard weed management on catfacing damage to peaches in North Carolina. *Journal of Economic Entomology* **77**, 1596–1600.
LEYDEN, R. F. AND ROHRBAUGH, P. W. (1963). Protection of citrus trees from cold damage. *Proceedings of the American Society for Horticultural Science* **83**, 344–351.
LORD, W. J. AND VLACH, E. (1973). Responses of peach trees to herbicides, mulch, mowing, and cultivation. *Weed Science* **21** 227–229.
KENWORTHY, A. L. (1953). Moisture in orchard soils as influenced by age of sod and clean cultivation. *Michigan Quarterly Bulletin* **35**, 454–459.
MCMURTRIE, R. AND WOLF, L. (1983). A model of competition between trees and grass for radiation, water, and nutrients. *Annals of Botany* **52**, 449–458.
NYCZEPIR, A. P., ZEHR, E. I., LEWIS, S. A. AND HARSHMAN, D. C. (1983). Short life of peach trees induced by *Criconemella xenoplax*. *Plant Disease* **67**, 507–508.
POWELL, C. A., FORER, L. B. AND STOUFFER, R. F. (1984). Orchard weeds as hosts of tomato ringspot and tobacco ringspot viruses. *Plant Disease* **68**, 242–244.
RADFORD, A. E., AHLES, H. E. AND BELL, C. R. (1976). *Manual of the Vascular Flora of the Carolinas*. Chapel Hill, University of North Carolina Press. 1183 pp.
RUPP, L. A. AND ANDERSON, J. L. (1985). Growth and fruiting responses of young apple and tart cherry trees to weed control. *HortScience* **20**, 727–729.
SAS INSTITUTE (1982). *SAS User's Guide: Statistics*. Cary, NC: SAS Institute, Inc.
SHRIBBS, J. M. AND SKROCH, W. A. (1986). Influence of 12 ground cover systems on young 'Smoothee Golden Delicious' apple trees: II. Nutrition. *Journal of the American Society for Horticultural Science* **111**, 529–533.
SOONG, N. K. AND YAP, W. C. (1976). Effect of ground cover management on physical properties of rubber-growing soils. *Journal of the Rubber Research Institute of Malaysia* **24**, 145–159.
TUKEY, J. W. (1953). *The Problem of Multiple Comparisons*. Princeton, NJ; Princeton University (mimeo.)
WELKER, W. V. AND GLENN, D. M. (1985). The relationship of sod proximity to the growth and nutrient composition of newly planted peach trees. *HortScience* **20**, 417–418.
WELLER, S. C., SKROCH, W. A. AND MONACO, T. J. (1985). Common bermudagrass (*Cynodon dactylon*) interference in newly planted peach (*Prunus persica*) trees. *Weed Science* **33**, 50–56.
WHITE, G. C. AND HOLLOWAY, R. I. C. (1967). The influence of simazine or a straw mulch on the establishment of apple trees in grassed down or cultivated soil. *Journal of Horticultural Science* **42**, 377–389.
ZEHR, E. I., LEWIS, S. A. AND BONNER, M. J. (1986). Some herbaceous hosts of the ring nematode (*Criconemella xenoplax*). *Plant Disease* **70**, 1066–1069.

Received 31 January 1989
Accepted 14 July 1989