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Agronomic and allelopathic effects of sequential cropping and tillage on tobacco and vegetable production

William Terry Kelley

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To the Graduate Council:

I am submitting herewith a dissertation written by William Terry Kelley entitled "Agronomic and allelopathic effects of sequential cropping and tillage on tobacco and vegetable production." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Plant, Soil and Environmental Sciences.

David L. Coffey, Major Professor

We have read this dissertation and recommend its acceptance:

Robert A. McLean, Charles D. Pless, Robert D. Miller

Accepted for the Council:

Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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and recommend its acceptance:

Charles D. Pless

Robert A. McLean

Accepted for the Council:

CwMinkel

Associate Vice Chancellor
and Dean of the Graduate School

AGRONOMIC AND ALLELOPATHIC EFFECTS OF SEQUENTIAL CROPPING AND TILLAGE ON TOBACCO AND VEGETABLE PRODUCTION

A Dissertation
Presented for the
Doctor of Philosophy
Degree
The University of Tennessee, Knoxville

William Terry Kelley

May, 1993

DEDICATION

Home is where the heart is. There's no place like home. Take me home, country roads. Keep the home fires burning. Home, sweet home. Other than romance and lost love, there has probably been no other topic written about, sung about, and played out in cinema and theatre than home. Thomas Wolfe wrote "You can't go home again". In many ways he was right. But in many ways you never leave. We often refer to going away from home as leaving the nest. I believe that leaving home is rarely actually leaving the nest, and most never do, or want to - entirely, at least.

Home is a sanctuary, a place of peace and comfort, a place of support and love. I know that for many, and increasingly more, that this is not the case. I am one of the lucky ones. For at home, I have been truly blessed. It would be my hope that some day all people could know the support, encouragement, guidance, advice, care, concern, freedom, and love that I have received from home over all of my years. Some feel they must sever all ties with home to gain their independence. Luckily, I have come to learn that this is not the case.

It is natural for the child to hold onto home, as it is natural for the parent to hold onto the child. But there comes a time when the parent lets go, the child begins to try his wings, and the independence is gained. But like the swallows to Capistrano, if the child, and the parents, have truly matured and grown, he/she will return to the nest for the same things that they received before their flight, only this time on a different level. For on return, the child will learn to give as well as receive. As time goes by, and the child matures and the parents age, the child becomes the caretaker, and the parents are repayed in kind for all of their labors for the child.

Just as my Granddaddy and Grandmamma Abercrombie provided for my mother and my Mamma and Papa Kelley provided for my father, they have provided for me and passed on that strong set of family values that make a home. No home is perfect, and it has been said that all homes are dysfunctional to a degree. But a good home is always possible with caring parents, or even one caring parent in single-parent homes.

Thomas Wolfe was right in one sense. You can never return to that same exact feeling you had at home when you were growing up. But would you really want to, for good? You can however, return home, and still be a part of home, and still enjoy the warmth and love of home for your entire life. That part that never left the nest will still be there if it is allowed to survive. Then it is possible to go home again. And when things are most desperate, it is such a comfort to know that you can take a page from another Thomas Wolfe book and "Look Homeward Angel" and find that no matter what the case, there is still a sanctuary of peace for you to turn.

As I travel into another phase of my life, and move a little farther away, and am less free to return to the nest as often, I hope to carry with me the valued lessons and example that I have received from home. I also hope to be able to return home on occasion and rest my wings and renew the joys I remember from there. I feel that because of my home, I am prepared to face whatever lies ahead and will have the tools to tackle it head on.

To this end, I offer this dedication to the two people responsible for making our house a home, and helping to mold my life into what it is today.

To Mom.......

I recall going to my Grandmamma and Granddaddy Abercrombie's years ago each August for the family reunion. Invariably, some silver-haired lady would ask who I was, and when she didn't recognize my name, the next question would be, "Well who's your mother?". Who is my mother? I'll tell you who she is.

She's the one standing over the kitchen sink, washing the breakfast dishes, and singing "Shall we gather at the river, where bright angel feet have trod" after she had gotten my brothers and sister off to school on the bus. Where bright angel feet have trod indeed, for those bright angel feet have trod many a step in my behalf.

Who is my mother? She's the one taking her son to Hardee's for a steak and salad bar on nights when dad was out of town. That was a treat back then. She's the one going off to work at 11 pm each night to see that her children got a college education. She's the one getting up in the middle of the night to set up a vaporizer and set by her son who could hardly breathe from the croup. She's the one running to care for her son as he screamed for her with ashes covering his burned hand when he discovered that a hairpin would fit into the light socket.

Who is my mom? She's the one sitting and crocheting those little granny squares and sewing them together into a beautiful afghan. She's the one up before anyone else on Sunday morning frying chicken and all the delicious fixin's so her family can set down to dinner soon after church. She's the one fixing a casserole to take to the circle meeting on Monday night, and the one wrapping the Christmas gift to brighten someone's day at the nursing home.

She's the one that clutches her son so tight and reassures him that everything will be alright when he has to say goodbye, first to his beloved Mamma, and then to his cherished Papa. She's the one taking charge years before when Papa cut three fingers off one hand and rushing him to the hospital while trying to calm her son and his wife. She's the one that brings strength and comfort to her family each time crisis arises. She's the one who suffers through family losses and illnesses just like everyone else, but puts away her pain to be a pillar of strength. She's the rock and foundation for her husband and her children.

She's the one going to the dogwood tree to cut a hickory to stop the bickering between her two young sons and watching them "straighten up and fly right" quickly as she walks out the door but administering punishment justly as they blame each other for starting it. She's the one seeing that homework gets done, that toys are put away, that food is on the table, shoes on the feet, clothes are clean and medication is administered when a child is ill. She's the one providing for her family every step of the way - providing love, labor, care, discipline, forgiveness, support, encouragement, character, smiles, good examples and anything else she sees we need. She's the one responsible for molding her young son into a man and letting him know she's confident he can face the future.

I hereby dedicate this work and all that it stands for to the honor of my Mother

Allie Mae Abercrombie Kelley

Thank You, Mom

To Dad.......

There was a time when I needed a friend, when I thought all hope was about to end.

What I sought, I found I already had. He was strength and peace, my best friend, my dad.

There was a time when I wanted a horse. Who provided for me? Why my dad, of course.

He gave love and shelter, showed me courage and grace. Oh, the things I see in his smiling face.

There was a time, I remember dear - the first time I saw, daddy shed a tear.

He held me tight, when Granddaddy died. There was peace in knowing, even daddys cried.

There was a time when I wrecked that night. I was wet and cold and ashake with fright.

And though we were fine and all alive, I didn't feel safe till my dad arrived.

There was a time I'll never forget, even though we could get no place to sit.

Standing room only, it was all the same. When he took me to see my first baseball game.

There was a time, I too had a dream, to go to the Series and watch my team.

My team got there, wished that I could, too. And guess who made that dream come true?

There was a time, when I wondered if, I had enough knowledge, or a talent or gift.

Whatever doubts I had wondered aloud, were gone when he said I'd made him proud.

There was a time, when I needed to learn. When I thought my dad was too hard or stern.

But as I matured, I finally understood. Everything he did was for my own good.

There were plenty of times, when I let him down. When I'm sure he had to suppress a frown.

But whatever he thought, he never let me see, that he'd ever lost his faith in me.

There was a time, of holiday joy. When Mamma first saw her new little boy.

Her best gift ever, I've heard her say. For my daddy was born on Christmas Day.

There was a time, when I was young, too. I was shaped and molded and taught as I grew.

And all that I am and become as a man, I owe it to Dad. I'm his number one fan.

I hereby dedicate this work and all that it stands for to the honor of my Father

James Donaldson Kelley

Thank You, Dad

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This work is the culmination of over 25 years of formal education. Obviously, in that time there have been many people to whom I am indebted for their support, teaching, guidance, friendship, love, and labors. As recipients of academy awards often say, I cannot possibly mention them all, but I am grateful to each and every one.

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I also offer my gratitude to David O'Dell, Blake Brown, Bruce Kirksey, Neal Denton, Jeff Herrmann, Bill Halfman and Mike Timpson for being good friends and associates, and for sharing many good times, as well as for their support and general sense of concern. I will always remember the efforts of all of these people. Thank you. I would also like to mention two people who have had a profound impact on my life during this time, and who have helped me grow and learn much through good and bad, but who nevertheless, will stay in my life for their friendship, and in my memory for all the years ahead for our associations. Thanks to Angie Moyers for her continued friendship and to Hope Barrett for the experiences we've enjoyed and endured.

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ABSTRACT

Production of vegetables and tobacco (*Nicotiana tabacum* L.) have traditionally been through monocrop, conventionally tilled systems. With the increasing importance of low input practices and conservation, and the declining number of producers, there is a need to develop reduced tillage systems and sequential cropping. This need prompted an investigation into the effects of reduced tillage and sequential cropping of tobacco, tomato (*Lycopersicon esculentum* Mill.), and broccoli (*Brassica oleracea* var. *Italica* L.) production systems. Three tillage systems (no-till, conventional till with a winter cover, and conventional till with no winter cover) and three cropping sequences (spring broccoli followed by tobacco or tomato; spring broccoli followed by tobacco or tomato, followed by fall broccoli; and tobacco or tomato followed by fall broccoli) were used in 1989 and 1990 at three locations in eastern Tennessee. Tobacco and tomato systems were evaluated separately. Also, since broccoli yields were suppressed by reduced tillage, field, greenhouse, and laboratory investigations were initiated to assess the possible allelopathic influences of wheat cover crops on the growth of tobacco, tomato, and broccoli. Field soil samples were evaluated for presence of five organic acids which are known to be allelochemicals produced from decaying wheat residue. Ferulic, p-hydroxybenzoic, p-coumaric, syringic and vanillic acids were applied to these crops individually at various concentrations. Methods of extraction and determination of concentrations of these acids from soils through high performance liquid chromatography were developed. Field samples were then evaluated for quantities of these acids. Broccoli yield and quality were reduced by minimum tillage but were not affected by cropping sequence. Tobacco was also adversely affected by reduced tillage. Tomato yield, however, was not affected by tillage, but fewer cull fruit occurred in no-till. Earlier planted tomatoes had somewhat higher yields and quality than those in later planted sequences. Allelochemicals had negligible effects on tomato and tobacco growth but retarded broccoli growth and dry weight accumulation. Greater concentrations of ferulic and p-coumaric acids were found in soils from no-till plots than from conventional till plots. Methods of extraction and analysis of organic acids were successfully developed and described in detail.

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INTRODUCTION

Production of high value crops has in the past been through a monocrop, conventionally tilled system. Although minimum tillage has been adopted in a wide range of crops, its adoption in the traditionally high value crops such as vegetables and tobacco (*Nicotiana tabacum* L.) has been slow. These crops also are generally grown as the primary crop of a particular production system with the best land in the system devoted to them.

With the increasing importance of reduced tillage, and legislation that requires erosion control practices on highly erodible land, many producers are forced to grow these high value crops with reduced or conservation tillage. Additionally, with the trend toward fewer producers and increasing food demands as well as producers' needs to increase profits, growers will be forced to get maximum production out of all their land, particularly their most productive land. This will require the use of the land to grow more than one crop in a season.

There is potential in eastern Tennessee to take advantage of many market windows in spring or fall markets, particularly in vegetable production. The addition of a spring or fall crop, or both, prior to and/or following a summer annual crop seems to be a possibility in these areas.

Tillage and sequential cropping

The production of these crops in the majority of eastern Tennessee would require the use of marginally and often highly erodible land. Thus the use of reduced tillage practices would be required. Most crops of this nature, such as tomatoes (*Lycopersicon esculentum* Mill.), tobacco, broccoli (*Brassica oleracea* L. var. *italica*), cabbage (*Brassica oleracea* L. var. *capitata*) and cauliflower (*Brassica oleracea*

L. var. *botrytis*), are not generally grown in minimum tillage systems, primarily due to the lack of research on minimum tillage practices in many of these crops. Phillips *et al.*, (1980) stated that the acreage of land that can safely be used for row crops would be increased with reduced tillage since such crops can be grown on sloping land that would be subject to erosion under conventional tillage.

Although some work has been done on sequential cropping with vegetable crops, the use of minimum tillage in these systems has basically gone uninvestigated. Vegetable growers bury debris to decrease diseases (Sumner, *et al.*, 1986). Vegetables are usually not grown on marginal land and growers prefer smooth, even seedbeds for uniform stands, which are more important in high value vegetable crops than agronomic crops (Sumner, *et al.*, 1986).

Tillage causes soil compaction, requires favorable soil moisture, can result in wind and water erosion and splatters crops with soil, decreasing quality and increasing occurrence of disease (Morrison, *et al.*, 1973a & 1973b). Weed control is the main reason for tobacco cultivation but water penetration and breaking soil crusts are also advantages even without weed problems (Hawks and Collins, 1970). Advantages of no-till tobacco include fuel and labor savings, soil moisture conservation, decreased soil erosion and elimination of tillage for planting and weed control (Wood and Worsham, 1986).

Tobacco is still a very important commodity in eastern Tennessee. While some research has been done on growing tobacco in reduced tillage systems, the practice has only begun to be implemented at the farm level. Tobacco has been grown almost exclusively in a monocrop system with the exception of small grain hay crops prior to tobacco. The addition of vegetable crops to tobacco production systems offers increased opportunities to tobacco growers, particularly since they have been faced with reduced production quotas and increased production costs over most of the last decade and need ways to supplement their income. This is an area where research has been almost nonexistent as well.

Cover crops and mulches

The use of cover crops has become a widely accepted practice on most farms over the last several years. Most farms rely on small grains such as rye (*Secale cereale* L.), wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) to provide winter cover to prevent soil erosion during the winter months and supply organic matter. Generally these crops are sown in the fall and either cut in the spring for hay or turned under prior to planting.

In much of the no-till and reduced tillage work that has occurred, the use of these species as cover crops has been followed by a burn down herbicide treatment with planting directly into the cover crop residue. Paraquat (1,1'-dimethyl-4,4'-bipyridiniumion) and glyphosate (N-(phosphonomethyl)glycine) have traditionally been used to kill these crops prior to planting (Chappell and Link, 1977).

Allelopathic implications

There has been evidence over the years that small grain cover crops exude residues either from the roots or from decaying material that can have a deleterious effect on some species (Barnes and Putnam, 1983). Use of cover crops in no-till systems was first advocated as a weed control advantage since some weed species were reduced when cover crops were used (Barnes and Putnam, 1983). There has been little evidence that cover crops have any deleterious effects on the crop plant, although such effects have been seen (Barnes and Putnam, 1983).

It is conceivable that these same residues and exudates could have a pronounced deleterious effect on the crop plant as well. DeCandolle suggested as early as 1832 that the soil sickness problem in agriculture was due to crop exudates (Rice, 1979). Since little minimum tillage work has been done in most vegetable crops, the effects of small grain covers on those crops is not widely known. Whether the cover crop is turned under or is burned down with herbicides prior to planting, residues from the cover crop will be left in the soil for the following crop.

Objectives

The first objective of these studies was to evaluate the feasibility of sequential cropping systems with reduced tillage practices. This was investigated using vegetable crops exclusively in two and three-crop systems and using both vegetable and tobacco crops in two and three-crop systems. To evaluate the likelihood of using these systems over a period of years, the growing degree days of the sequential system were compared to the growing degree days generally accumulated in any given year for a like period of time.

The second objective was to investigate the effects of cover crop residues on vegetable crops planted into them. It is known that several phenolic acids are responsible for many of the deleterious effects from cover crops on weeds and crops. The effects of these organic acids on the crops in this study were investigated in two parts. First, field samples were taken to evaluate the levels of these phenolic acids in the crop environment. Secondly, known quantities of these acids were added to these plants in the greenhouse to study the effects of individual acids on them.

Chapter 2

LITERATURE REVIEW

Little work has been done on either the use of reduced tillage in sequential cropping systems or the effects of cover crop residues on vegetable or tobacco crops. The literature on allelopathy is rather extensive and several reviews on this subject have been done (Rice, 1974 & 1979); however, more recent advances and improved techniques have outdated much of the previous work and relevant work on allelopathic effects on commercial vegetable crops is sparse. However, some relevant work on both subjects can be found.

Minimum tillage

In the most recent work on no-till burley tobacco production, no difference was found for yields (2586 lbs./Acre conventional, 2551 no-till), stand (96% conventional, 95% no-till) or value ($4066/Acre conventional, $4046 no-till) for tobacco grown in bluegrass sod or killed wheat as compared to conventionally grown tobacco (Phillips and Zeleznik, 1989). Conventional tobacco had greater growth than no-till after 30, days but no-till was greater than conventional in days 30-60.

Shilling, *et al.* (1986a) reported that there were no differences in yield of flue-cured tobacco grown with mulches of rye, wheat, oats, barley and alfalfa, but yield was only 82% of conventionally grown tobacco. Quality was not affected by rye mulch. The reduced yield was believed to be from weed competition and not due to adverse effects of the mulch. Tobacco sugar content was higher in no-till than conventional and total alkaloids were lower in no-till, but both were in the range of good quality. No-till yields were less than conventional in wetter seasons but were similar in dry years.

Similar results were found by Moschler, *et al.*, (1971) where flue-cured tobacco averaged 9.3% yield reduction in no-till plots over conventional till plots. There were no differences in value/pound but per acre value was 10.1% lower for no-till. Burley showed a 7.8% yield reduction and 6.9% less value in no-till, but the differences were not significant. No-till was found to produce thinner, more chaffy leaf. Soil and moisture conservation, elimination of tillage for planting, and weed control made no-till more desirable. There were no differences in yield with rye vs tall fescue cover. Again, no-till flue-cured tobacco had higher sugar levels.

Tobacco planted no-till into killed green rye showed reduced growth of early season pigweed (51%), lambsquarter (41%) and ragweed (73%) compared to plots with no mulch (Worsham, 1984). Crops generally showed slower growth in no-till due to cooler soils but yields were not reduced. In dry years the heavier the mulch the greater the yield increased.

Hawks and Collins (1970) found value and yields of tobacco with a herbicide and three cultivations was significantly greater than tobacco with herbicide and no cultivation. Yields and value were 2224 pounds/Acre and $1415/Acre for cultivated plots and 2007 pounds and $1292 for non-cultivated plots. Survival and uniformity of growth was greater in no-till tobacco in killed winter wheat over fescue sod (Morrison, 1975 & Shilling, *et al.*, 1986a).

Tobacco stand was reduced to 80% and 58%, respectively, by paraquat and glyphosate burndown in rye compared to conventional tillage (Chappell and Link, 1977). Yield using paraquat (3149 lbs./Acre) was greater than glyphosate (2198). Soil temperature was 25.5°C in rye and 30.9 in conventional plots but there was no plant maturity difference. In 1975 plant stands and yields were 89% and 3067 lbs./Acre (conventional), 76% and 2698 (rye + glyphosate) and 79% and 2751 (rye + paraquat). Earlier, Link (1984) reported no-till burley tobacco was equal to conventional in two of five years. No-till was significantly less the other three years. Upchurch (1987) reported the average yield of burley grown no-till to be 2860 lbs./Acre vs 2760 for conventional.

Tobacco (Maryland type) grew better on rested or idle land than when hairy vetch, crimson clover or rye was used as a soiling crop (Garner, *et al.*, 1925). Yields were poorer than controls, particularly in wet years.

Soil loss was 20 times greater in conventional till vs no-till in 1982 (121 vs 2,456 kg soil/ha) and

90 times greater in 1983 (101 vs 9,004 kg soil/ha) where a rye mulch and a Mechanical Transplanter Model MT-100 were used (Wood and Worsham, 1986). Runoff was 11.3cm in no-till vs 13.1 conventional in 1983 and 23.4 vs 20.8 for conventional in 1982. There were no significant differences in yield, value or quality index between conventional and no-till treatments.

Wheat mulch reduced sand damage to young tobacco transplants and sand contamination associated with harvested leaf (Worsham, 1985). He concluded that the technology had been developed for no-till tobacco production, and with further work on a few remaining problems, such as control of late season grasses and weeds, this method could be put into use on farms where needed.

Root density of burley tobacco in the top 15cm was greater in conventional till than no-till (Zartman, *et al.*, 1976). Plant N, root length and plant and leaf weight were also greater in conventional treatments over no-till.

Yields of tomatoes decreased with decreased tillage in an investigation comparing conventional tillage to strip-tillage and no-till production in Alabama (Doss, *et al.*, 1981). Marketable yields on complete tillage plots (29.9 MT/ha) were higher than strip-tillage plots (27.0 MT/ha) which were higher than no-till plots (26.0MT/ha). Plots with rye on them had yields 2.2 MT/ha lower than plots without rye. Percentage of large fruit was 63% of marketable tomatoes on complete tillage plots and only 56% on reduced tillage plots. Cull fruit was not affected by tillage. This agrees with the findings of Hoyt (1984) who reported decreased tomato yields when rye was used as a cover crop. Spicer (1983), however, found increased yield in strip-tilled tomatoes in Canada was due to decreased sandblasting injury. Input costs were also lower in a strip-till system. Marketable tomato yield was not affected by tillage in a three-year comparison of strip-till and conventional till (McKeown, *et al.*, 1988). Strip-till yield was lower in one year than conventional till with a rye cover crop. Increased population densities of nematodes were found in rye and strip-till plots.

Beste (1983) found tomato growth in no-till to be better when tomatoes were direct seeded into a 20 inch killed rye cover. Early seedling growth was greater in no-till, but plant height was equal at fruit set. 'Campbell 28' gave greater early no-till yield. In two of four years, no-till yield exceeded conventional and yield was equivalent the remaining years. Snapbeans produced equal yields in no-till and conventional till in four of five years and lima beans produced equal yields in 3 of 4 years. Sweet corn and pea yields were greater or equal in no-till vs conventional.

In an earlier study, tomato maturity was significantly earlier, plants grew and developed faster, and soil temperatures were higher in no-till than conventional till (Beste, 1973). When rye cover was killed with paraquat and tomatoes were direct seeded with a Planet Jr., yields were equal compared to conventional till. Cucumber yields were lower in no-till than conventional and lima bean yield was equal but early growth was greater in no-till.

Yields of early harvested number one tomatoes mulched with plastic (0.67T/Acre) were greater than tomatoes grown on bare ground (0.36T/A) (George and Utzinger, 1974). Seasonal yields of number one tomatoes were also greater on plastic (24.5T/A) than on bare ground (18.5T/A) as was total yield, but fruit size was not different.

Straw mulch applied after transplanting increased tomato yield to 68,550 kg/ha compared to a check yield of 37,341 (Estes, *et al.*, 1985). Significantly more extra large and large fruit, and less medium and number three fruit occurred in the mulched plots. The average weight per fruit was 10g greater with mulch. No difference was seen for early blight, blossom end rot or fruitworm. Annual grass control was significantly better with straw mulch.

Clear film, black film and black paper resulted in higher soil temperatures than bare soil in a comparison between clear plastic film, black film, black paper, aluminized film, grass clippings, raw leaves, and bare soil. Leaves and grass clippings lowered soil temperatures 5.6°C and 10°C, respectively, over bare soil (Hill, *et al.*, 1982). Broccoli grown on bare soil produced higher yields and larger heads than raw leaf mulch, but not as high as black film. Pepper yields with black film and raw leaves were superior to bare soil. The same was true with eggplant, in addition to aluminized film being better than bare soil. However, black film and aluminized film delayed harvest as compared to bare soil while clear film accelerated harvest. Zucchini yields with aluminized film and black film were higher than on bare soil. Grass clippings, black paper mulch and raw leaves resulted in higher tomato yields than bare soil but clear and black film were inferior to bare soil. Mulch had little effect on tomato fruit set. Clippings and leaves resulted in taller tomato plants.

Colonial bentgrass, creeping bentgrass and a Kentucky bluegrass/white clover mixture, as living mulches in strip till, reduced yields of sweet corn and cabbage (Nicholson and Wien, 1983). Yields of corn grown in red fescue and yields and head size of cabbage grown in American white clover were reduced over those grown in a bare ground control. Cabbage maturity was delayed by living mulches and marketable head yield decreased with increasing mulch dry weight. Chewing's fescue, Kentucky bluegrass and 'Kent' white clover had no effect on sweet corn or cabbage yields. Oats, rye, and perennial ryegrass as living mulches were too competitive with beets and cabbage (Hughes and Sweet, 1979).

Broccoli yields were greater in bare soil (656g/plant fresh weight) than with a leaf mulch (548g/plant), but the difference was not significant (Hankin, *et al.*, 1982). Broccoli was sensitive to even modest leaching of leaf mulch. Leaf mulch, without plastic to prevent leaching of mulch exudates, reduced broccoli yield compared to leaves with a plastic mulch.

Mulches, such as straw, resulted in yield increases under low moisture conditions for brassicas, but the crops were liable to suffer from decreased nitrate supply and additional N was recommended (Rowe-Dutton, 1957). Mulching tomatoes under dry conditions, provided soil temperatures were high enough, increased yields but delayed maturity. Although N deficiencies were possible, the practice was recommended to keep fruit off the soil and reduce soil-borne diseases.

Sumner, *et al.*, (1986) found populations of *Rhizoctonia solani* were reduced by increasing tillage, and deep plowing decreased populations of *Sclerotium rolfsii*. *Pythium* spp. and *Fusarium* spp. were not affected by tillage, nor were nematode populations.

A modified transplanter with rolling coulters, double disc openers, guage wheels, narrow press wheels, and ballast weights on the frame and press wheels was used to successfully transplant several crops (Morrison, *et al.*, 1973a, 1973b & Morrison, 1974). Tobacco, tomato and pepper plants were transplanted into chemically killed sod and cereal straw residue. The equipment worked adequately well under all conditions. Transplant survivability was lower in no-till plots due to increased insect and disease damage.

Reduction of soil erosion by wind and water, reduction of herbicide runoff, and improved quality of waterways, as well as savings of time, labor, and fuel, were all enhanced with minimum tillage (Triplett and Van Doren, 1977). Advantages of cover mulches were moisture conservation, increased intake of rainfall and maintenance of soil structure. Disadvantages included increased insect problems and weed control, which could be improved in some species but a problem in others. Minimum tillage might be undesirable in poorly drained soils due to excess moisture and low temperatures. The USDA predicted in 1975 that 90% of the U.S. crop acreage would be under reduced tillage by 2010 (Triplett and Van Doren, 1977).

Multiple cropping

Intercroppings of tomatoes and cabbage, as well as collards and muskmelon, were investigated by Brown, *et al.* (1985). Tomatoes in monocrop produced the highest net returns followed by a tomato/cabbage combination. Other combinations did not produce returns significantly different from one another. Cabbage/tomato and collard/muskmelon combinations produced yields and net returns that were comparable to either crop grown alone. Total N, plant height and yield of tomatoes were greater in one year with tomato intercropped with cabbage. When extra N was applied, there was no change in tomato yield. Production costs of tomatoes alone was greater than with tomatoes and cabbage. No differences were seen in cabbage whether intercropped or grown alone.

Tomato and broccoli gross returns were superior in sequential cropping than when either crop was grown alone (Coffey and Ramsey, 1987). Broccoli in combination with squash or pepper did not increase gross returns over pepper or squash grown alone. A spring and fall planting of broccoli with summer squash did not increase returns over squash alone. Two crops of broccoli produced greater returns than a single planting of broccoli.

Phillips *et al.*, (1980) suggested that the advantages of reduced tillage are more important in multiple cropping systems. Reduced labor and costs; reduced moisture loss at planting time ensuring stands of second and third crops under restricted rainfall; production of more than one crop per year increasing land use; reduction of soil erosion; elimination of plowing and land preparation; and time saved in planting second and third crops were all cited as increased advantages of no-till in these systems. Harvesting could be followed immediately by planting of a second crop, thus reducing lag time between crops.

Temperature sums and growth

Cabbage was shown to be mature after accumulation of 1000 to 1050°C heat units using a 10°C base (Isenberg, *et al.*, 1975). Tomatoes were shown to require 666 degree days from transplant (with a base temperature of 10°C) to reach a yield of 37.5 tons per hectare and 462 degree days to first harvest (Gray, *et al.*, 1980).

Strandberg (1979) used a minimum temperature threshold for cabbage of 0°C and a maximum of 25°C. Approximately 3300 degree days were needed to mature cabbage in winter production (Strandberg and White, 1979).

A base temperature of 43°F was best for the x-intercept method of predicting tomato harvests in direct seeded tomatoes (Warnock and Isaacs, 1969). Heat unit summations to harvest were 3636, 4044 and 4433 for three successive seasons. Harvest based on heat units was found to be better than based on days from seeding. Went (1944) found 0.1mm/day tomato growth even at 7°C.

The minimum night temperature for growth of tobacco was shown to lie between 18 and 22°C (Haroon, *et al.*, 1972). Austin and Ries (1968) studied two types of base temperatures for tomatoes. A 50°F base was evaluated vs a fluctuating base that increased in 1° intervals weekly, from 42-50°F, and 2° weekly, from 50-60°F. The constant base was best for predicting harvest of cultivars Libby C-52 and Heinz 1370.

Arnold (1959) decided the base temperature resulting in the lowest coefficient of variation of heat unit summations was the appropriate base. Procedures for correcting for minimum temperatures below the base were also reported (Arnold, 1960). Effects of location and seasonal trends were found to be sources of error. The formula for degree day accumulation was described as ((maximum + minimum temperature)/2)-base temperature.

Allelopathy

Molisch coined the term allelopathy in 1937, using it to describe plant-plant and plant-microorganism interactions, whether harmful or beneficial (Putnam and DeFrank, 1983). He also referred to detrimental effects of higher plants of one species, on the germination and growth of the recipient species (Putnam, 1985b). These phenomena were also recognized by Democritus, in the fifth century B.C., and Theophrastus, in the third century B.C. Theophrastus reported that chick pea (*Cicer arietinum*) destroyed weeds (Rice, 1987). Plinius Secundus, around 1 A.D., reported chick pea, barley and bitter vetch "scorched up" corn land, attributing the toxicity to their scents or juices (Putnam and Weston, 1986). Putnam reported in 1983 that over 1000 papers had been published on allelopathy. The first journal devoted explicitly to the topic will debut in 1993 (Anonymous, 1992).

Lovett (1982) reported that 600 papers had been published in the last decade on allelopathy. Only 14% of those described an allelochemical and only 2% described specific effects. Widespread acceptance of minimal cultivation was expected to bring about the possibility that allelochemicals from dead and decaying plant residue might enter and accumulate in the soil. One of the oldest examples of allelopathy is in juglone from black walnut (*Juglans nigra* L.), which was shown to be extremely toxic to tomato (Putnam, 1985a).

McCalla and Haskins (1964) stated that plants grown in soil are exposed normally to a tremendous variety of organic compounds from plant and animal residues in soil, or indirectly from residues through action of microorganisms, which can be innocuous, stimulatory, or inhibitory to plant growth. The presence of phytotoxic substances in plant residues and soil, and production of phytotoxic substances by microorganisms, may account in part for adverse effects of particular crops on succeeding crops, such as yield reductions associated with mulching, and plant diseases. Certain aspects of competition and allelopathy operate in all plant interactions (Rice, 1979). Allelopathy was implicated in patterning of vegetation and old-field succession.

Muller (1966) stated that allelopathy is an important influence in the operation of ecological processes and is a factor in community dynamics. Allelopathy could be a significant factor in plant succession in many kinds of vegetation. It was reported that some aromatic shrubs of southern California contain phytotoxic terpenes which volatilize and inhibit seedling establishment of a wide variety of plants at some distance from the shrubs.

Borner (1960) found that crop residues may be largely responsible for soils being toxic to subsequent crops, because they are available in large quantities, and add substantial levels of chemicals to the soil. Some soils were made poisonous to plants by organic compounds from preceding crops. However, overall growth of plants was determined more by a proper balance of growth factors than allelopathic factors. Secretion by roots was stated to be limited to the rhizosphere and in small amounts and have little direct influence on other plants.

Simple phenolic acids, coumarins, terpenoids, flavonoids, alkaloids, cyanogenic glycosides and glucosinolates have all been implicated as allelopathic agents (Putnam and Duke, 1978). Ferulic and caffeic acids were suspected to be involved in defense mechanisms against various plant pathogens. Concentration and site of action often determined allelopathic potential.

Origins and fates of plant phenolic acids

Cinnamic acid derivatives (ferulic, caffeic and coumaric acids) are derived from aromatic amino acids via the shikimic acid pathway (Putnam, 1988 & 1985b). L-phenylalanine was shown to be a precursor to cinnamic acid from which coumaric acid is derived. L-tyrosine is also a coumaric acid precursor. Caffeic acid is then formed from coumaric acid and ferulic acid is formed from caffeic (Putnam, 1988 & 1985b, Neish, 1964, Neish, 1960). Patterson (1981) also has stated that cinnamic acid is a derivative of phenylalanine in the shikimic acid pathway and is the parent compound of caffeic, coumaric and ferulic acids. Chlorogenic acid is an ester of caffeic acid and vanillic acid a derivative of benzoic acid.

Neish (1960) found tyrosine was a precursor of cinnamic acids only in *Graminae* species. Lignin was found to be a product of the shikimic acid pathway with ferulic acid as a precursor. He proposed that phenylalanine and tyrosine are precursors to shikimic acid which follows a path of cinnamic acid to phenolic cinnamic acids to lignin. The hydroxylation of cinnamic acid leads to other phenolic acids. Coumaric, caffeic and ferulic acids were reported to play central roles in the biosynthesis of lignin (Neish, 1964). Phenolic acids usually occur as esters. Ferulic acid was found to be one of the chief compounds resulting from decomposition of lignin.

Enzymatic deamination of the corresponding isomers of tyrosine formed m- and p-coumaric acids (Neish, 1961). Tyrase was found in sorghum, barley, rice, wheat, oat, corn and sugarcane but not in pea, lupine, alfalfa or white sweet clover. Tyrase catalyzes the deamination of l-tyrosine to give trans-p-coumaric acid and converts dl-m-tyrosine to m-coumaric acid. A path of l-tyrosine to coumaric acid to lignin was proposed.

Brown (1961) described the probable pathway of lignification in a similar fashion with l-tyrosine as a precursor to p-hydroxycinnamic acid, and l-phenylalanine as a precursor to cinnamic acid. Cinnamic acid then becomes p-hydroxycinnamic acid before becoming caffeic acid then ferulic acid then sinapic acid. Little lignification was found in wheat until it was ready to head out. Lignin was found to come from CO_2 and carbohydrates formed in photosynthesis. Commercial preparations of ferulic acid incubated with *Phleum pratense* produced products similar to lignin extracted from timothy shoots, supporting that ferulic acid is a precursor to lignin (Stafford, 1960).

Mendez and Brown (1971) proposed a pathway to be functioning in tomato where p-hydroxycinnamic acid can either go to benzoic or caffeic acid. Caffeic acid is then transformed to ferulic acid which can either go to vanillic or sinapic acid and sinapic to syringic acid. Vanillic, syringic, ferulic, p-hydroxycinnamic and benzoic acids were all isolated from tomato stems, leaves and roots. Vanillic and syringic acids increased with plant age. Benzoic and vanillic acids could be formed from cinnamic and ferulic acids, respectively.

Benzoic acid was formed from the shikimic acid pathway in *E. coli* (Towers, 1964). Vanillic and syringic acids were formed by ß-oxidation of ferulic and sinapic acids, respectively, or produced by hydroxylation and methylation of benzoic and protochatechuic acids. Fungi were found to convert ferulic acid to vanillic acid. Cinnamic acids were metabolically interrelated by cinnamic to p-coumaric to caffeic to ferulic to sinapic acids. *Salvia* converted each to a more complex member of the series. Coumaric, caffeic and ferulic acids occur as esters in *Salvia splendens* and follow the same pathway Towers (1964) noted and acted as intermediates in lignification (McCalla and Neish, 1959). The acids were identified by 2N NaOH extraction and paper chromatography. The pathway suggested was determined by data from formation of phenolic acids from l-phenylalanine ^{14}C. Cinnamic acid, dihydroxycinnamic acid and l-phenylalanine were good precursors of the phenolics; d-phenylalanine and l-tyrosine were not (McCalla and Neish, 1959). The fungus, *Pollystictus versicolor*, was found to hydroxylate cinnamic to p-coumaric acid (Towers, 1964). Certain bacteria were reported to be able to decompose aromatic compounds and metabolize them to various intermediates (Dagley, 1971).

Allelopathic substances were liberated from plants by rain leaching them from foliage, abscission and litter fall, volatilization from foliage, and root exudation (Tukey, 1969). Organic acids are one class of many substances that can be leached from a wide variety of plants, the quantity and quality of which are affected by a number of factors.

Allelochemicals are produced from volatilization, root exudates, leaching and decomposition of plant residues (Putnam, 1985b). The loss of membrane permeability was stated to release compounds, and microbes induced production of toxic compounds by enzymatic degradation of conjugates and polymers. Allelopathy could also occur by exudation of compounds from living roots, leaves, or fruits, or leaching from decaying residues, in which case soil microbes (fungi, bacteria and actinomycetes) play a role in synthesizing toxic agents (Putnam, 1983).

Lovett (1982) found water was critical to the release and transfer of allelochemicals. The majority of vital plant processes could be affected by allelochemicals. Aerobic conditions were critical for microorganism activity which degrades allelochemicals, and thus, they may undergo little change under anaerobic conditions.

Haider and Martin (1975) found simple phenolic compounds in concentrations up to 1000ppm were quickly utilized as C and energy sources by the soil population. Within one week, around 90% of COOH carbon of benzoic, syringic and vanillic acids evolved as CO_2, and 95% by 12 weeks. They also found that 66-85% of the ring carbon of protocatechuic, benzoic, vanillic and caffeic acids were lost after 12 weeks.

Phenolics not formed by fungi, such as lignin-derived ferulic acid, are transformed by *Epicoccum* *nigra* through introduction of further hydroxyl groups, demethoxylation, or partial degradation on an acrylic side chain (Haider and Martin, 1967). Ferulic acid was hypothesized to go to vanillic acid and then to protochatechuic acid which could be transformed to gallic acid. Ferulic acid could also be transformed to caffeic acid and then to protochatechuic acid. Transformation of p-hydroxycinnamic acid could either be to caffeic or benzoic acid which could then be transformed to protochatechuic acid. In ferulic and caffeic acids most of the carboxylic acid carbons of the side chain and the methoxyl carbon were released as CO_2 or utilized for cell synthesis, and most of the ring carbon was polymerized into humic acid or remained in solution after six weeks of growth in *E. nigrum*.

Henderson (1963) proposed the fungal metabolism of aromatic compounds from lignin by 1) aldehydes are first oxidized to corresponding acids (p-hyroxybenzaldehyde to benzoic acid, syringaldehyde to syringic acid and vanillin to vanillic acid), 2) additional hydroxy groups are added to the ring (benzoic acid to p-hydroxybenzoic acid), 3) methoxyl groups are converted to hydroxy groups (o-, m- and p-methoxybenzoic acids to o-, m- and p-hydroxybenzoic acid), and 4) oxidation of side chains (ferulic acid to vanillic acid).

Kononova (1961) found that in oxidation of phenols by microorganisms that phenols and benzoic acid are converted to intermediate aromatic compounds. A fission of the ring occurs to yield low molecular weight organic acids.

In the presence of microorganisms, ferulic acid decomposed to vanillic acid after oxidative cleavage of the side chain and double bond (Flaig, 1964). Demethylation to protochatechuic acid then occurred. Benzoic acid was oxidized to protochatechuic acid.

Regardless of the source of phenolic compounds in the soil, adsorption and desorption from soil colloids determined their solution-phase concentration (Dao, 1987). Plants synthesize phenolic acids which combine to form polymers such as lignin, flavonoids and tannins. As plants decay, phenolic polymers are attacked by fungi of several genera and also may be degraded by bacteria. Microorganisms degrade polymers by cleaving phenolic moieties. Monomeric phenolic acids released by lignin degradation are mostly cinnamic, benzoic, caffeic, vanillic and ferulic acids.

Ferulic acid was found to be metabolized quickly from decaying hackberry leaves but remained at a relatively stable concentration in the soil, approximately 30ppm (Turner and Rice, 1975). Eighteen microorganisms, mostly of the genus *Pseudomonas*, and the rest actinomycetes, were able to grow in soil with ferulic acid as their sole source of carbon. Ferulic acid was found to break down into vanillic acid and reported to continue to protocatechuic acid. Ferulic acid is commonly found in numerous plant species (Bates-Smith, 1956).

Decay and toxin release

Toussoun, *et al.*, (1968) found temperatures from 16-24°C had little effect on phytotoxin production. Toxins were detected 5-10 days after the cover crop was turned and lasted approximately 25 days, before declining. In the lab, the first toxicity was detected 7-10 days after field-grown green barley was incorportated. Levels reached a maximum at three weeks, remained high until six to seven weeks, and then declined. Inhibition by toxins on tobacco seed were seen only above a 30% moisture content of the soil-residue mixture. The toxins were from the ether-soluble fraction, which accounted for 60% of the phytotoxicity.

Straw of barley and wheat decomposed more rapidly when buried than surface straw. Decompositon was faster with increasing temperature (Summerell and Burgess, 1989). Barley decomposed faster than wheat and the proportion of lignin, as a function of total organic matter, increased as straw decomposed.

Conditions leading to formation of high concentrations of phytotoxic substances were suggested to be more common than realized and not confined to waterlogged soils (Patrick, *et al.*, 1964). This was thought to occur despite conclusions that formation of phytotoxic decomposition products, associated with organic matter decay, occurs under poorly aerated conditions.

Coumaric acid was initially found in greater concentrations, than other phenolic acids, in non-decayed rice straw (Shindo and Kuwatsuka, 1975a). Under moist aerobic conditions, organic acids disappeared rapidly and were metabolized to CO_2. Under anaerobic flooded conditions, rapid production of organic acids occurred along with a decrease in pH. At high temperatures, even more rapid production occurred. There was no relation between organic acids and pH change in soil. High temperatures and flooded conditions caused rapid production from lignin, and degradation by microorganisms. Pathways of coumaric acid to benzoic acid to protochatechuic acid and ferulic acid to vanillic acid to protochatechuic acid were thought to occur via microorganisms. As coumaric acid decreased, benzoic acid increased in decaying rice straw. Vanillic acid increased as ferulic acid decreased. Caffeic acid was not detected. Concentrations of coumaric, ferulic and vanillic acids increased from 25 to 70 days of incubation. Phenolics were produced from lignin by hydrolysis of the ester linkage. Phenolic acids were thought to be derived rapidly under flooded, high temperature, conditions but oxidative degradation was thought to exceed aerobic production.

After rice straw was incubated for nine days, the order of phenolic acids was benzoic > coumaric > ferulic > vanillic (Shindo and Kuwatsuka, 1975b). Benzoic acid decreased less in the first three days than the others but, when added to straw together, coumaric and ferulic acids decreased less rapidly. Degradation of ferulic and coumaric acid was affected by mixtures. Degradation of vanillic and ferulic acids, which have methoxy groups, was stated to be caused by soil microorganisms. Coumaric, ferulic, vanillic and benzoic acids degraded rapidly with a half life of less than 10 days at 50°C (30ppm in water extract of decayed straw and soil). Degradation of coumaric acid produced p-methoxycinnamic acid, and degradation of ferulic acid produced 3,4-dimethoxycinnamic acid. Both were reversible reactions, transformed to benzoic and vanillic acids, respectively, and then benzoic acid was transformed to protochatechuic acid.

Allelochemical effects of grass crops and their extracts

Residues of barley, oats, rye, sorghum, sudangrass or wheat did not reduce stands of cucumber, peas or snap beans; however, all were toxic to lettuce (*Lactuca sativa* L.), particularly sorghum, oats and wheat (Putnam and DeFrank, 1983). Radish (*Raphanus sativus* L.) stand was reduced by all covers but rye. Barley (*Hordeum vulgare* L.), sorghum, sorghum x sudangrass, and wheat residues reduced stands of tomato (*Lycopersicon esculentum* Mill.). Small seeded vegetable species appeared to be the most adversely affected. Beans and peas consistently produced higher yields without tillage whether residues were present or not.

Barnes and Putnam (1982) found that rye cover, killed with glyphosate, had no effect on snapbean stand, growth or pod yield. Rye root leachates reduced dry weight of tomato more than tomato root leachates. Leachates from rye roots reduced the growth of lettuce (Barnes and Putnam, 1983). Tomato growth was not affected by rye or wheat residue, but cabbage growth was (Putnam, *et al.*, 1983).

Cotton seedling development was inhibited by aqueous extracts of wheat straw (Hicks, *et al.*, 1989). Field emergence was reduced 9% for 'Paymaster 404' and 21% for 'Acala A246' when wheat stubble residues were present in the seedbed. Lint yield was affected as a result of population densities. Planting tolerant cultivars, increasing seeding rates, and minimizing above ground residues were suggested to overcome negative effects.

The use of a winter rye (*Secale cereale*) cover crop delayed corn development and reduced corn biomass by 11% and 17% at two locations in southern Ontario (Rainbault, *et al.*, 1990). The adverse effect of rye was greater under no-till than when soil was tilled.

Weed growth at crop harvest was reduced 32% in no-till (without residues) and residues of barley, rye, or wheat in no-till reduced weed growth by 63%. Surface residues of cereal grains reduced the emergence of *Chenopodium album* L., *Portulaca oleracea*, and *Amaranthus retroflexus* (Putnam and DeFrank, 1983). Shifts of weeds to monocots instead of dicots, particularly *Gramineae*, occurred (Putnam, *et al.*, 1983). Rye, wheat and barley residues reduced weed density approximately 90%, and rye residue reduced weed seed emergence. Spring planted living rye covers, as well as fall-sown rye mulches, reduced biomass of several weed species (Barnes and Putnam, 1983) but pea yields were not reduced.

Wheat straw extracts reduced germination and seedling length of several weed species (Steinsiek, *et al.*, 1982). Inhibition of growth and germination of ivyleaf morningglory and velvetleaf were most pronounced. Ferulic acid was found to be the most toxic product produced by wheat that reduced germination and root growth of morningglory and prickly sida (Worsham, 1984).

Aqueous wheat extract reduced pitted morningglory germination and root length 27 and 66%, respectively, and ragweed root length 86%, in the dark (Liebl and Worsham, 1983). In light, morningglory germination and root length decreased 65 and 62%, respecitively. The most toxic component, and the most prevalent, was identified as ferulic acid. Ferulic acid reduced germination and root length significantly at [$5x10^{-3}$M] in morningglory, crabgrass, and prickly sida. It had no effect on ragweed, corn, or soybean germination, but reduced root growth of corn and soybean. Caffeic acid reduced germination and root length in prickly sida with carpels removed. Concentrations of $5x10^{-3}$M ferulic acid solution reduced root and shoot fresh weight of morningglory in greenhouse bioassays. A higher concentration of ferulic acid (1243ppm) was found in extracts than was used in commercial preparations (970ppm), but commercial preparations were more phytotoxic.

In no-till tobacco, rye mulch reduced the biomass of *Amaranthus retroflexus* L., *Chenopodium album* L. and *Ambrosia artemisiifolia* L. by 51, 41, and 73%, respectively (Shilling, *et al.*, 1985). Rye reduced *C. album* by 60% in both tilled and no-till tobacco. Again, ferulic acid was the most inhibitory compound, isolated from wheat straw, on morningglory and crabgrass growth and germination.

Water extracts of seeds of wheat, oats, sorghum and corn had little effect while stems of these species had the greatest inhibitory effect on wheat seedlings (Guenzi, *et al.*, 1967). Aqueous root extracts of wheat straw remained stable through the first four weeks of testing and disappeared after eight weeks of decomposition. Residues were toxic in the order of sorghum, corn, oat and wheat, with sorghum giving 77% inhibition for roots and 69% for shoots. Toxicity to wheat seedlings differed among varieties.

In an earlier study, Guenzi and McCalla (1962) found water extracts of sweetclover stems, wheat straw, soybean hay, bromegrass, oat straw, corn and sorghum stalks, and sweetclover hay were, in increasing order of toxicity, inhibitory to germination, root and shoot growth of corn, wheat, and sorghum seeds.

Elongation of wheat shoots and roots were inhibited by extracts of ryegrass, green pea, and dried pea, especially early in the rotting period (Kimber, 1973). Wheat extract had little effect on wheat growth. Toxicity was present in unrotted straw and more was present in mature straw, but toxicity was dissipated by microbial action upon rotting. Toxicity disappeared 14-21 days after rotting began.

The greatest toxicty from wheat straw was seen when rotted less than 10 days, but toxicity continued for at least 42 days (Kimber, 1967). Oat roots were more sensitive to wheat toxins than wheat roots, but wheat shoots were more sensitive. Oat and wheat growth was reduced as much as 48%. The greater the rotting and weathering of the wheat, the more inhibition was reduced. Wheat and oat growth was inhibited most from wheat straw rotted two to six days. Rotted wheat extracts inhibited germination of wheat as much as 34%.

Lentil and pea straw extracts inhibited wheat seedling root growth up to 90% (Cochran, *et al.*, 1977). No shoot inhibition was seen. Cold water or alcohol extracts of barley, rye, and wheat straw contained ferulic, coumaric, vanillic and benzoic acids, at which 10ppm inhibited wheat and rye root growth 20-30% (Borner, 1960).

Aqueous or methanol extracts of soil, from no-till wheat plots in Oklahoma, were inhibitory to wheat roots (7.35mm conventional vs 6.85mm no-till) (Cast, *et al.*, 1990). These inhibitions were found in most crop months except March and May. Extracts in February, June, July and August inhibited root growth significantly in no-till relative to the control; conventional was only inhibitory in July and August although no-till was always less than conventional for wheat root length. Shoot growth response was similar. July and August are the months right after harvest when conditions are similar for conventional and no-till in wheat fields. Stearic and palmitic acids were the major components found in the soil extracts through capillary gas chromatography-mass spectrometry analysis.

Corn germination in soil with straw mulch (44%) was lower than with no mulch (92%) with excess water, but there was no difference with optimum moisture or dry soil (McCalla and Duley, 1949). Corn seeds soaked for 48 hours with wheat straw extracts resulted in reduced germination (5%) and root length (0.3cm). McCalla and Army (1961) found plant residues contained substances, and microorganisms capable of producing substances, that affect germination and plant growth.

Subtilled soil amended with wheat straw showed periods of increased phytotoxicity to corn at 10 to 13 days and 26 to 29 days, indicating cycles of toxicity may occur (Norstadt and McCalla, 1968b). Corn seedling growth in pots was similarly affected by these cycles. Seedlings exhibited a loss of geotropism, shortened first internodes, stunting, and reduced germination. Increased numbers of *Penicillium urticae* Bainier and patulin production were detected as toxicity of the soil increased.

Extracts from rye-soil mixtures caused severe root damage, growth inhibition, absence of root hairs, and necrosis of the apical meristem of lettuce (Chou and Patrick, 1976). Vanillic, ferulic, p-coumaric and p-hyroxybenzoic acids were identified in decomposing rye residues.

Rye residues reduced emergence of lettuce (58%) and prosso millet (*Panicum miliaceum* L.) (35%) over controls in simulated no-till conditions (Barnes and Putnam, 1986). Rye shoot tissue was 52% more inhibitory than root tissue. Rye had little effect on the emergence of tomato or barnyardgrass. As distance between the seed and residue increased, phytotoxicity decreased. Inhibition of root growth was the primary effect. Results indicated that allelopathic root and shoot tissues can act together to injure sensitive species. Sufficient quantities of residue would be present under field conditions to affect plant growth.

Extracts of residue, and soil with residue of barley, rye, wheat, vetch, broccoli and sudangrass reduced the growth of lettuce seedlings over controls (Patrick, *et al.*, 1963). Soil from fields containing clumps of residue also reduced lettuce growth. Extracts of soil with barley or rye residue, decomposed for 10-25 days, gave 30-70% lettuce inhibition. Significant toxicity was seen only with plant debris. Some inhibition occurred with plant debris in soil but not with soil alone. They concluded that residues are probably not a problem in the field, except where large clumps of debris occur close to plants. The same effects were seen on broccoli, tobacco and bean seeds and seedlings.

Under saturated conditions, toxic substances extracted from decaying residues of corn, rye and tobacco inhibited the oxygen uptake of tobacco seedlings, often within one hour of exposure, but the effect was reduced at lower moisture levels (Patrick and Koch, 1958). However, extracts from soils with no residues present showed no respiration inhibition as measured by oxygen uptake. The amount of inhibition depended on the type of residue, the maturity of the decaying plant, and the length of decay time. The pH of the extract tended to decrease with increasing decomposition. Toxicity and pH were related but high toxicity remained throughout a range of pH. Addition of NaOH to the extracts precipitated the pigmented fraction of the extract and reduced its toxicity. Placement of tobacco seedlings in such extracts caused the apical meristem region to turn dark brown and also had effects on germination and growth of tobacco. Addition of crop residues to pots in the greenhouse caused stunting of the tobacco, and addition of toxic extracts caused plant wilting and root rot. No deleterious effects of crop residues left on the surface were seen in tobacco (Worsham, 1984). Germination was delayed and root growth decreased in tobacco with rye residue extracts or soil in contact with rye residue, but not with soil only, or soil and residue in field proportions. Benzoic and ferulic acids were found in these systems (Patrick, 1971).

Weight of tobacco plants was reduced by addition of timothy residue that had been decaying for four to ten weeks (Doran, 1928). Residue decaying for one to three weeks had no effect and the roots were normal. Other roots were discolored and had brown lesions from brown root rot. Residue decaying for four to seven weeks gave maximum effects. Exposure of roots of tobacco seedlings to rye or timothy toxins increased their suceptibility to black root rot (Patrick and Koch, 1963). Even resistant varieties showed susceptibility if they were exposed to the toxins prior to innoculation with black root rot.

Water soluble extracts of barley, wheat, timothy, broccoli and broadbean residues, decomposing under field conditions and highly toxic in lettuce bioassay, greatly increased the pathogenesis of *Fusarium solani* f. *phaseoli* (root rot of *Phaseolus vulgaris* L.) in lab experiments (Toussoun and Patrick, 1963). *Rhizoctonia solani* invaded only plants exposed to toxins. Injury from *Thielaviopsis basicola* was also more severe in the presence of toxins.

More phenolic acids were detected by alkaline hydrolysis than by acid hydrolysis and cinnamic acid derivatives were broken down by acid hydrolysis treatments (Guenzi and McCalla, 1966a). Residues from alkaline hydrolysis of corn, oats, wheat and sorghum yielded ferulic, p-courmaric, syringic, vanillic and p-hydroxybenzoic acids in ranges of 0-34ppm, 238-3,160ppm, 0-80ppm, 40-120ppm and 0-112ppm, respectively. Wheat and oats yielded all five phenolic acids at various concentrations. Toxicity to wheat shoot growth of vanillic and p-coumaric acids at 625ppm was similar to a response at 1,250ppm for the other three acids. Concentrations of the five acids at 1,250ppm reduced wheat root growth to 65-87% to that of controls and 63-73% of shoot controls. They estimated that there could be localized areas under field conditions where concentrations of phenolic acids could be high enough to affect plant growth.

Allelopathic effects of weeds on crops

Many weed species were identified with allelopathic potential (Putnam, 1985a). Benzoic, syringic and vanillic acids were found from a variety of plants. Plants were found to vary in production of allelochemicals depending on environment. About 90 species of weeds are believed to have allelopathic potential (Putnam and Weston, 1986). Quackgrass residue reduced cabbage plant weight to 20.6% of control in no-till and 73.3% in conventional till.

Leachates from common lambsquarters (*Chenopodium album* L.) reduced height and shoot fresh weight of tomato but had little effect on tomato dry weight (Qasem and Hill, 1989b). Concentrations of Ca and Mg in tomato were reduced by the leachates; N, P and K were not reduced, although the total amounts of all elements were decreased. Dried shoots of *C. album* mixed with soil reduced tomato shoot dry weight over controls with no mulch. Shoots decaying in the soil also reduced tomato shoot dry weight.

Extracts of western ragweed also had a negative effect on germination, shoot and root growth of several crop species, including tomato (Dalrymple and Rogers, 1983). Alfalfa and tomato had malformed root growth due to rhizome extracts. Total germination and growth of species tested were only 34.8% of that which occurred in distilled water.

Large crabgrass residue at 0.1% (w/w) reduced soybean germination 4% and biomass by 11.7% (Johnson and Coble, 1986). No effects were seen on corn, broadleaf signalgrass, or fall panicum. Fall panicum residue (0.5% w/w) reduced corn germination (17.8%) and biomass (19.9%) and stimulated broadleaf signalgrass growth (250%). Broadleaf signalgrass residue (0.25% w/w) reduced soybean (9%), broadleaf signalgrass (34%), and fall panicum (37%) growth.

Weed residues of common lambsquarters, redroot pigweed, velvetleaf and yellow foxtail reduced corn (6-20%) and soybean (2-20%) dry matter production (Bhowmik and Doll, 1983 & 1984). Incorporated residue was more inhibitory than surface residue. The effect of the residues on shoot and root dry weight of the two crops varied. Weed residues generally reduced N uptake in corn and soybeans; supplemental N did not completely overcome inhibition. All residues, except ragweed, reduced P uptake and all enhanced K uptake in corn. Incorporated residues reduced P uptake and enhanced K uptake in soybeans. The effects of the residues were allelopathic regardless of nutrient levels.

Corn radicle elongation was inhibited by water extracts of lambsquarters, fall panicum, and green, yellow, and giant foxtails in laboratory trials (Bhowmik and Doll, 1982). Redroot pigweed, fall panicum and green foxtail inhibited hypocotyl elongation in soybean. Residues of the above in addition to common ragweed, velvetleaf, and barnyardgrass inhibited corn and soybean growth in the greenhouse. In the field, residues of barnyardgrass and giant foxtail reduced corn yield. Soybean yield was reduced 14-19% by residues of lambsquarters, pigweed and sunflower. Environmental factors, such as temperature, possibly influenced inhibitory effects of weed residues on crop growth (Bhowmik and Doll, 1983). Higher temperatures reduced inhibitory effects of pigweed and yellow foxtail on corn but not on soybeans.

Jimsonweed was found to cause stunting and distruption of cabbage roots when seeds of both were germinated together (Retig, *et al.*, 1972). The average size of cortical parenchyma cells was 170μ length x 24μ width for the control vs 58μ x 33μ when grown with jimsonweed. Diameter of roots increased 200-300μ with jimsonweed. The cytoplasm of treated root cells was more granular and less vacuolated than the controls and some lateral roots were initiated. Green foxtail, mustard, and velvetleaf gave similar symptoms. Tomato roots developed larger parenchyma cells than controls with jimsonweed, and cells were disorganized and some collapsed.

Root exudates of prickly sida decreased radish root growth to 45mm vs 49 for control (Pope, *et al.*, 1985). Tomato root growth was decreased by leaf extracts of soybean (47mm) and johnsongrass (46mm) vs control (56mm). Palmer amaranth (*Amaranthus palmeri*) residue, incorporated into soil, had a greater inhibitory effect on cabbage and grain sorghum than onion and carrot seedlings (Menges, 1988). 'Grand Slam' cabbage was 17-30% more sensitive to residue than 'Sanibel'.

Allelopathic effects of one crop on another

Rhizosphere extracts from sorghum-sudangrass hybrid (*Sorghum bicolor* x *Sorghum sudanese*) significantly inhibited annual ryegrass (*Lolium multiflorum* L.) and alfalfa (*Medicago sativa* L.) at 200ppmw (H_2O weight basis) in filter-disk bioassays (Forney and Foy, 1985). In soils, 70ppmw (soil weight basis) inhibited alfalfa but not ryegrass. Treatment of the hybrid with sethoxydim increased phytotoxicity as did treatment with glyphosate and paraquat.

Aqueous extracts of asparagus (*Asparagus officinalis* L.) inhibited seed germination in tomato and lettuce but not in cucumber (Hazebroek, *et al.*, 1989). Extracts caused reductions of hypocotyl growth in lettuce, shoot growth in asparagus, and reduction of radicle elongation in barley, lettuce, and asparagus. Inhibitions were concentration dependent. Tomato and wheat seedling growth were not affected.

Brassicaceous species contain various phytotoxins, including isothiocyanates. (Ju, *et al.*, 1983). Young leaves of cabbage and beans accumulate these compounds. Tobacco plants treated with SCN^- died. Beans were more sensitive to toxins than cabbage, growing in 5mg/l SCN^- but impaired with 25mg/l, while cabbage was impaired at 100 mg/l SCN^-.

Of 526 accessions of cucumber seeded with test species, only one inhibited growth of *Penicum miliaceum* by 87%, while 25 inhibited fresh weight by > 50% (Putnam and Duke, 1974). Leachates, from two of the most inhibitory accessions, also inhibited growth of *P. miliaceum*, while noninhibitory lines did not inhibit growth, which suggested an allelopathic effect.

Encelia farinosa leaves (10g), in tomato culture, severely retarded growth, and 20g per pot killed the plant (Bonner, 1950). Ether extracts, of 50mg of *Encelia*, killed 50% of test tomatoes within one day, and 50mg/l of *Encelia* solution caused 50% inhibition of tomato growth.

Minced roots of chou moellier (*Brassica oleracea* var.) decreased marrow stem kale and white clover (*Trifolium repens*) germination from 87 to 10%, but minced stems and leaves had a lesser effect (Campbell, 1959). When clover did germinate, radicles became blackened at the tip, root hairs were sparse, and plants died within three weeks. Perennial ryegrass did germinate with chou root, but root lengths were reduced by 80% over controls.

Aqueous extracts of 23 crop and weed species, including cucumber, tomato, and wax bean, inhibited wheat germination, and growth of germinating wheat and peas (LeTourneau, *et al.*, 1956). All inhibitors were partially water soluble, and the pH of the extract had no influence on results.

Apples, pears, plums, cherries, mustard, tobacco, tomatoes and clover all exhibited reduced growth, in pot experiments, when leachates of other plants toxic to them were applied (Pickering, 1917). Plants that leached these toxins included apple, mustard, tobacco, tomatoes, two types of clovers, and 16 grasses. The receptor plants had from 6-97% growth reduction, and averaged 1/2 to 1/3 normal growth. Grass around trees caused reduced apple tree growth, even when such factors as soil moisture, nutrients, temperature, alkalinity, physical condition of the soil, alteration in CO_2, and bacterial contents were accounted for. Grass was injurious to young apple trees due to toxin produced by the grass, not necessarily from root exudates, but possibly by decay of debris from growing roots, or alteration of bacterial contents in the soil.

Phenolic effects on other plants

Tomato root and shoot dry weight were significantly reduced by vanillic, p-coumaric, chlorogenic and ferulic acids at 10^{-3}M in greenhouse experiments (Mersie and Singh, 1988). Leaf N was also reduced by the same concentration. Ferulic and p-coumaric acids, at 10^{-4}M, reduced P content.

Total leaf area and dry weight of bean, at the seedling stage, were reduced 38-48% by 1 and 2μM treatment with ferulic acid (Waters and Blum, 1987). Leaf area and dry weight, at flowering, decreased 25% one week after treatment with 2μM ferulic acid. At pod fill, 2μM caused senescence and abscission of older leaves and decreased leaf area 54%, dry weight 40%, and pod dry weight 48% within one week. Lower concentrations reduced leaf area at seedling and at flowering stages, but not at podfill. Youngest leaves at flowering had a 35% reduction in area one week after treatment, but recovered within two weeks. Biweekly exposure to 0.25-1μM ferulic acid decreased leaf area. Weekly exposure, of the same concentration, decreased leaf area 34%, leaf number 31%, and pod number 58%. As frequency of exposure increased, the concentration required to inhibit decreased.

Broccoli yield decreased due to phenolics released by decaying leaves (Hill, *et al.*, 1982). Leachates from composting maple and oak leaves decreased broccoli height (10%) in both types of leaves, and yield (12%) in maple leaves.

Williams and Hoagland (1982) suggested that germination studies should continue for at least three days in phenolic acid tests, since they found that most phenolics delayed rather than inhibited germination.

They found that corn and pigweed germination was delayed by coumaric acid. Cotton germination was decreased to 78% of controls by ferulic acid. Cantaloupe (76%), velvetleaf (87%) and sicklepod (88%) germination was reduced by caffeic acid. None of the phenolic acids affected germination of cotton, sorghum, corn, cantaloupe, velvetleaf, prickly sida, hemp sesbania, sicklepod and redroot pigweed.

"Robinson" Maryland tobacco exhibited toxic effects when grown in solutions with 5-200ppm of various amino acids, including tyrosine and phenylalanine (Steinberg, 1947). Particularly toxic was d-l-isoleucine, which duplicated frenching. Tyrosine had toxic effects on wheat seedlings at 16ppm (Shreiner and Reed, 1908). Vanillic acid, courmarin and cinnamic acid at 25ppm caused injury and at 100ppm caused death. Dihydroxystearic acid and vanillin were isolated and toxic to plants in aqueous solution (Shreiner and Shorey, 1909). Soil and fertilizer tended to neutralize toxicity. Wheat green weight was reduced to 87% and 54% of control with 20 and 200ppm, respectively, of dihydroxystearic acid. Benzoic acid at 100ppm inhibited tobacco seedling root elongation. Benzoic acid was identified as one of the toxins from barley, and was also present in cotton, soybean, and cowpea residue (Toussoun, *et al.*, 1968).

Radish germination was reduced 29% and 5% by 2.5 x 10^{-3}M vanillic and benzoic acids, respectively (Einhellig and Rasmussen, 1978). A mixture of the same concentration resulted in 52% and a mixture of 5 x 10^{-3}M gave 60% sorghum germination compared to controls. Sorhum germination was 93% with 5 x 10^{-3}M vanillic acid alone and 96% with benzoic acid alone. The mixture reduced sorghum root length more than individual treatments, and 5 x 10^{-4}M of both acids gave sorghum seedling growth equal to 5 x 10^{-3}M of either alone. Neither phenolic acid at the inhibitory concentrations caused stomatal closure in sorghum. The threshold germination inhibition was 2.5 x 10^{-3}M for radish and 5 x 10^{-3}M for sorghum. Seedling growth of sorghum was affected by 10% of the concentration needed to affect germination.

A subsequent study showed soybeans grown in 10^{-3}M and 5 x 10^{-4}M ferulic, vanillic and coumaric acids had significantly lower dry weight, chlorophyll a, chlorophyll b and total chlorophyll over untreated plants (Einhellig and Rasmussen, 1979). At 2.5 x 10^{-4}M there were no chlorophyll effects, but ferulic acid was inhibitory to growth. The same tests with sorghum had more drastic effects on growth and caused death of plants. Sorghum growth was reduced with 5 x 10^{-4}M ferulic acid, but there was no effect on chlorophyll, thus, they concluded that chlorophyll content may be a secondary response.

Patterson (1981) found similar results where caffeic, coumaric, ferulic and vanillic acids significantly decreased soybean dry matter production, leaf expansion, height, leaf production, leaf chlorophyll content, and net assimilation rate at 10^{-3}M, but not at 10^{-4}M, when grown in aerated nutrient solution. There was no effect from pH of solution on growth. At 16 hours after exposure, photosynthesis rate and stomatal conductance were decreased by caffeic (75 & 40%), coumaric (67 & 40%), ferulic (59 & 30%) and vanillic acids (62 & 40%) each; the reduction partially subsided after 40 hours.

Ferulic and coumaric acids at 0.5mM resulted in partial closure of stomates of sorghum leaves (Einhellig, *et al.*, 1985b). Those acids at 0.25mM gave sorghum leaf water potential of around -10 bars vs -5 for control. Leaf water potential change resulted from change in both osmotic potential and turgor pressure. Ferulic and coumaric acids caused reduced growth and wilting of sorghum seedlings; greater concentrations caused strongest effects. *Kochia* and cocklebur residue of 2.5%, in soil, had similar stomatal and water potential effects on sorghum seedlings.

Ferulic, benzoic, coumaric, vanillic and syringic acids, as well as a mixture of these acids, at concentrations from 25-100ppm, decreased sugarcane top and root weight with increasing concentrations. Significant reduction occurred at 50ppm (Wang, *et al.*, 1967b). Top and root weight of wheat, corn and soybeans, in nutrient solution, were decreased with increasing concentration of benzoic acid from 1-300ppm. Coumaric acid was found to be most toxic to sugarcane.

Scopoletin and chlorogenic acid, at 10^{-3}M and 5 x 10^{-4}M, resulted in stomatal closure in tobacco and sunflower within one day of treatment. Stomates stayed closed for seven days (Einhellig and Kuan, 1971). Closure correlated well with reduced growth and photosynthesis. Both chemicals were found to increase in tobacco under stress. Scopoletin at 10^{-4}M to 10^{-3}M inhibited tobacco, sunflower, and pigweed growth (Einhellig, *et al.*, 1970). Shoot to root ratio was decreased, and more scopoletin was found in shoots of tobacco. Respiration was not changed, but photosynthetic rate was reduced to as low as 34% of control, in tobacco, and 74% of control in sunflower.

Lettuce seed germination was inhibited on the order of coumaric > ferulic > caffeic acids with the latter having no significant effect on germination, and antagonizing the effects of the other two (Duke, *et al.*, 1983). Similar structures were postulated to competitively inhibit the action of ferulic and coumaric. There was no interaction between those two acids. There was no evidence that phenolics caused a water potential change, and they suggested that water stress and phenolics may inhibit germination by identical mechanisms.

The phenolic content (tannic acid), as measured by the Folin-Ciocalteu method, decreased with time in a hardwood bark compost (Yates and Rogers, 1981). Lettuce (*Lactuca sativa* L. cv. "Grand Rapids") germination increased with time in composting. Polyvinylpyrrolidone (PVP) specifically adsorbed tannins and decreased phenolic acid content.

Vanillin and benzaldehyde were harmful to several species in a water culture or nutrient solution, as well as in pots and field soils (Skinner, 1918). Vanillin was least harmful in high N solutions. Good field drainage, lime, and phosphate fertilizer were found to make fields productive again, where harmful aldehydes were present.

Allelopathic studies in cucumber

Cucumber was identified, from among several plant species, as one of the most sensitive to ferulic acid and its breakdown products (Blum, *et al.*, 1984). The pH of various concentrations of phenolic acids, changed considerably when added to petri dishes with seeds, from the intial pH for that concentration. Phenolic acids affected cell division and subsequent cell expansion of cucumber radicles, and thus, inhibition of radicle growth declined in a curvilinear response to concentration. Vanillic and ferulic acids had the most pronounced effect and were more stable than caffeic acid. Mixtures of acids produced an effect less than that for the sum of the individual acids, acting much the same as the curvalinear response to increasing concentrations of one acid alone.

Leaf area of cucumber was reduced 15 and 18% by ferulic and p-coumaric acids, respectively, (Blum, *et al.*, 1985a) and was reduced in a concentration-dependent manner. Root absorption and stability of the acids were pH dependent. Greatest inhibition was at pH 5.5, decreasing at higher pH, as the solubility increased and the acid became more negatively charged. Ferulic acid was a greater inhibitor than p-coumaric acid. Both acids reduced water utilization, when undissociated, and root membranes appeared to be more permeable to this form of both acids.

Benzoic acid uptake in cucumber was reduced 30% in the presence of ferulic acid, but benzoic acid had no effect on ferulic acid uptake (Shann and Blum, 1987). The rate of ferulic acid uptake was only influenced by its initial concentration, with the greatest uptake at pH 4 at 1mM. The effect on cucumber growth by ferulic and benzoic acids was additive. Uptake was based on depletion from nutrient solution, as measured by HPLC, as well as, ^{14}C labelling of the acids. At pH 4, most of the ferulic acid was in the undissociated form. As pH increased, more phenolics were anionic and less permeable to the cell wall and membrane. Ferulic acid uptake was 50-75% greater than benzoic acid uptake.

Ferulic acid delayed germination and radicle growth of cucumber (Blum and Dalton, 1985), and reduced leaf area and dry weight of seedlings. Although recovery from ferulic acid inhibition was noted after removal from the acid, total plant area and dry weight were reduced. Recovery depended on the concentration and the age of the seedling. Vanillic and protocatechuic acids were found in the ferulic acid treatments, apparently as breakdown products of the applied acid. Wilting from initial applications of ferulic acid suggested a water imbalance. Low level acclimation to ferulic acid did not alter the inhibitory effects of higher concentrations.

Ferulic acid and several of its metabolic products, as well as, p-coumaric and syringic acids, reduced seedling dry weight, leaf area expansion, and water utilization associated with stomatal closure in cucumber (Blum, *et al.*, 1985b). Treatments of ferulic and p-coumaric acids caused wilting, but recovery from wilting, and of transpiration rates, occurred within 48 hours. Inhibitory effects were seen when several acids produced an additive effect, equal or greater to a minimum threshold concentration of one acid. Despite recovery, the final dry weight of the seedlings was still reduced over that of the controls. Syringic, protocatechuic and p-hydroxybenzoic acids were least inhibitory, and ferulic and p-coumaric acids were most inhibitory, and reduced root dry weight as well. Cinnamic acid derivatives were more inhibitory than benzoic acid derivatives.

Ferulic acid treatments, $> 0.25mM$, decreased leaf area, root length of primary and secondary roots, average root length of primary and secondary roots, and the number of tertiary roots in cucumber (Blum and Rebbeck, 1989). Number and frequency of primary and secondary roots were not affected, but root systems were shorter, thinner, had enlarged root tips, and were more branched. Leaf area, shoot and root weight, and total and average length of primary and secondary roots at final harvest were reduced by multiple ferulic acid treatments. Photosynthesis of seedlings was inhibited 30-38% by ferulic acid treatments $> 0.25mM$. More radioactivity fixed in photosynthesis was retained by shoots than was translocated to roots. Once roots were no longer exposed to ferulic acid, leaf and root growth recovered rapidly, suggesting root water uptake is the primary limiting factor and energy fixation is secondary.

Soil acidity influenced the effect on cucumber growth in the presence of phenolic acids and mixtures of phenolic acids (Blum, *et al.*, 1989). The dosage of ferulic, p-coumaric, and vanillic acids required for 50% inhibition increased with increasing pH, with maximum inhibition at pH 5.2. Ferulic acid was more toxic than vanillic and p-coumaric acids. More phenolic acids are available for root uptake at lower pH. At lower pH, the effects of mixtures of vanillic and ferulic acid, as well as, p-coumaric and ferulic acids were antagonistic. The effects were additive for p-coumaric and vanillic acids and the other two mixtures at higher pH.

As a greater proportion of the root system of cucumber was treated with 0.5mM or 1.0mM ferulic acid, the growth rate of leaves declined (Klein and Blum, 1990b). The growth rate recovered within 24 hours after treatment. Subsequent ferulic acid treatments reduced leaf growth rate as well.

Allelopathic effects on mineral nutrition and uptake

Coumaric acid (230μM) inhibited hypocotyl growth and respiration and prevented substrate supported Ca^{++} and PO_4^{-} transport in mung bean (Demos, *et al.*, 1975). Ferulic, caffeic, benzoic, syringic and vanillic acids (all at 230μM) inhibited hypocotyl growth and vanillic acid inhibited mitochondrial Ca^{++} uptake. Protochatechuic acid had no effect.

Concentrations of benzoic and vanillic acids between 5×10^{-5} and 1×10^{-3}M inhibited P uptake and altered membrane properties in barley roots (Glass, 1973). Lipid solubility and inhibition were well correlated, thus, alteration of membrane properties was the most likely mechanism of inhibition.

In a subsequent study, phenolics were found to distribute themselves between the lipid component of the cell membrane and the aqueous incubation medium, bringing about membrane permeability alterations resulting in decreased absorption of ions and the loss of previously absorbed ions (Glass, 1974). Potassium absorption in excised barley roots was inhibited within minutes by several phenolics. The inhibition was concentration dependent and reversible. Cinnamic acids were more inhibitory than benzoic derivatives. Concentrations of 2.5 x 10^{-4}M benzoic acid gave 52% inhibition of K uptake, 99% for cinnamic, 67% for p-hydroxycinnamic and 50% for 3,4-dihyroxybenzoic acids.

Ferulic acid at 0.5mM significantly decreased P in shoots and roots of sorghum over control (Kobza and Einhellig, 1987). Also root K was 33% less than in controls. Lower Mg was found in treated roots, but Mg was greater in treated shoots than in controls. Trends for increased Ca and decreased Fe were found in ferulic acid-treated sorghum but the differences was not significant. Concentration decreases of P, K and Mg paralleled growth decreases.

Membrane potentials of barley roots were depolarized by benzoic and cinnamic acids with cinnamic acid having a greater effect (Glass and Dunlop, 1974). Inhibition of ion uptake by phenolic acids was caused by a generalized increase in membrane permeability to inorganic ions.

Salicylic acid was greater than ferulic in inhibiting K^+ absorption by oat root tissue (Harper and Balke, 1981). Inhibition was concentration and pH dependent. As pH decreased inhibition increased. Recovery was only observed at pH 7.5 but not at 4.5. As pH declined, more acids were absorbed by the tissue.

Under low nutrient conditions, coumaric (5 and 10ppm) and vanillic (25 and 50ppm) acids caused smaller barley plants and lower shoot to root ratio than untreated plants (Stowe and Osborn, 1980). Both phenolics were inhibitory when either P or N were limited.

Allelochemicals in soils

In a study comparing different cropping and tillage systems, the acids generally followed a pattern of coumaric > vanillic > benzoic > syringic > caffeic > ferulic > sinapic acids in soil samples (Blum, *et al.*, 1991). Benzoic acid derivatives were generally greater in concentration than cinnamic acid derivatives except for coumaric acid, a cinnamic acid derivative. Total phenolic content in the 0-2.5cm samples was 34% greater than in the 0-10cm samples. Individual phenolic content and total phenolic content were highly correlated. Concentration of individual phenolic acids was related to soil pH, water content and total soil C and N. Coumaric acid (2.24μg/g) was greater in wheat no-till than in soil of fallow conventional till (0.97μg/g) plots. Other cropping systems and phenolic acids were not significant. Sampling dates did, however, have a significant effect on phenolic acid content. Highest concentrations for benzoic (0.95μg/g), caffeic (0.68), syringic (0.80) and coumaric (1.80) acids occurred in late August while vanillic (1.43), sinapic (0.18) and ferulic (0.53) acids reached a maximum in mid October. Lowest concentrations occurred in late July for benzoic (0.82), caffeic (0.48), vanillic (0.94) and syringic (0.57) acids, in late August for sinapic (0.05) and ferulic (0.42) acids and in mid-October for coumaric (1.30) acid. Total phenolic acid content was 10.18μg/g for wheat no-till and 4.42 for fallow conventional till with herbicide. In the 0-2.5cm cores, total phenolic acid content was 14.09μg/g for wheat no-till, 7.18 for wheat conventional till in two-year rotation, 8.13 for wheat conventional till in four-year rotation, 4.94 for fallow conventional till with herbicide and 5.88 for fallow conventional till with cultivation. There were no clear changes over the first 109 days of the growing season for soil phenolic acids, with a maximum change of 20-30%. This slow change was expected when the source of phenolic acids was microbial action on plant litter or organic residues.

Soils extracted with NaOH and subjected to paper chromatography showed concentrations of benzoic > vanillic > coumaric acids in the soil. The quantity decreased over time (Wang, *et al.*, 1967a). These soils, with *Crotalaria juncea* and sugarcane leaf residues, were found to contain levels of benzoic acid up to 216 and 240 x $10^{-2}\mu$M/100g soil, respectively. For the two residues, levels of other acids were 0.98 and 74 for coumaric acid, 26 and 240 for vanillic acid, 14 and 28 for syringic acid, and 2 and 9 for ferulic acid, respectively, for *C. juncea* and sugarcane each. Greater amounts were found in aerobic soils with *C. juncea* than waterlogged soils; kind of soil, aeration and kind of organic matter governed the amount of phenolics found.

In another study, most soil samples tested, contained concentrations that were in the order of coumaric > benzoic > vanillic acids (Wang, *et al.*, 1967b). Ferulic acid was found less frequently and only a few samples contained syringic acid. In heavier soils, phenolics decreased with depth. In lighter soils, more phenolics were found at 50-75cm than 25-50cm. Ranges for the five phenolics, in 10^{-2} μM/100g soil extracted with NAOH and analyzed by paper chromatography, were 0-6.49 for ferulic acid, 0-30.3 for coumaric acid, 0-2.13 for syringic acid, 0-6.9 for vanillic acid, and 0-28.2 for benzoic acid.

Soil samples from Taiwan fields contained benzoic, coumaric, vanillic and ferulic acids (Wang, *et al.*, 1971). After soil was wet for four weeks in the lab, benzoic acid was still present but the others disappeared. After drying for four weeks, benzoic acid remained stable but the others were still undetectable. As the acids are liberated in the soil they were taken up by humic acid. Ferulic and syringic acids were fixed more than coumaric or vanillic acids. Labeled ^{14}C coumaric and ferulic acids confirmed fixation by humic acid.

Four contrasting soils yielded amounts of p-hydroxybenzoic, vanillic, p-coumaric and ferulic acids in the range of from 0.07 to 4.9 x 10^{-5}M in the free state from the soil organic fraction (Whitehead, 1964). Fresh moist soil was extracted with calcium oxide and water. The acids were isolated using three successive one-dimensional descending chromatographic runs with isopropanol/ammonia/water, butanol/pyridine/water and acetic acid.

Rye roots extracted with 2M NaOH revealed benzoic acid to be 0.59% of the organic matter content, coumaric acid 0.39% and ferulic acid 0.37% (Whitehead, *et al.*, 1981). In red clover roots, benzoic acid was only 0.02% of the organic matter. In a soil under permanent pasture, the concentration in water extracts of the soil solution had concentrations of 1.4μM benzoic acid, 0.11μM vanillic acid, 30nM coumaric acid and <10nM ferulic acid. Localized areas, in the field, were thought to be more concentrated and could affect plant growth. The amounts of phenolics extracted increased continuously with increasing pH, with a threshold pH of 7.5 to 10.5. Ferulic acid had the highest threshold. Comparisons, of soil extracts with beech litter extracts, suggested soil phenolics were derived from organic residues more than four years old or were a result of microbial synthesis. From pH 10 to 14 the amount of benzoics in soil were on the order of benzoic > coumaric > vanillic > ferulic acids. The influence of vegetative type on phenolics extracted was not great.

Water extracts of soil and plants gave less phenolics than alkaline extracts (Whitehead, *et al.*, 1982). The portion released by liming was extracted with $\mathrm{Ca(OH)_2}$ and 2M NaOH gave total extraction. The differences between soils tested in the amount extracted by NaOH was 34 times greater than the lowest for courmaric acid, 17 times greater for ferulic acid, six times for benzoic acid and three times for vanillic acid. The sum of phenolics extracted by 2M NaOH was 0.03-0.33% of the organic matter. Grasses yielded more ferulic and coumaric acids than other species. The difference was less in extracted soils where these plants were grown. The difference, among roots of species, for benzoic (112 times), ferulic (365 times), coumaric (202 times) and vanillic (18 times) acids was greater than the difference in soil, leading to the conclusion that soil tends to create uniformity in phenolics found, when transformed into humified organic matter. *Agropyron repens*, grown above soil, yielded water extracts of 1.16 x 10^{-6}M benzoic, 2.3 x 10^{-7}M vanillic and 1.92 x 10^{-7}M courmaric acids. A 0.05% $\mathrm{Ca(OH)_2}$ extract gave 5.8 x 10^{-5}M benzoic, 1.6 x 10^{-5}M vanillic, 6.4 x 10^{-5}M coumaric and 0.4 x 10^{-5}M ferulic acids. Liming was thought to possibly cause concentrations of phenolics high enough for adverse effects.

Benzoic acid was present in free form in soil more than vanillic, coumaric and ferulic acids (Whitehead, *et al.*, 1983). Ferulic acid had the lowest ratio of free to bound forms, where free forms were water extracts and bound forms were that portion extracted by 2M NaOH at pH 13. The water soluble portion was only a small amount of the total extracted by 2M NaOH, with water soluble benzoic acid only <0.7% of the total, vanillic acid <0.4%, courmaric and ferulic acids <0.05%. Bound and free forms of all phenolics were also found in roots.

Adsorption of phenolics by soil was greater under acid conditions, where wavelengths of 253, 306, 259, 322 and 275nm were used for spectral analysis of benzoic, coumaric, vanillic, ferulic and syringic acids, respectively (Huang, *et al.*, 1977). Noncrystalline hydroxy-Al and -Fe compounds were more reactive than clay minerals in adsorbing phenolics. Adsorption by kaolinite, illite and vermiculite was on the orders of benzoic > coumaric > ferulic > syringic > vanillic acids. More than three-fourths of added phenolics were adsorbed by Fe and Al compounds in the first half hour (Huang, *et al.*, 1977).

Patrick (1971) stated that soil toxicity, due to organic constituents, is usually associated with heavy, poorly aerated or waterlogged soils. Residues were more toxic under anaerobic conditions than lower moisture, but saturated conditions did not have to persist to produce toxicity. These conditions were thought to occur commonly in the field. When residues of several species were allowed to decompose under watterlogged conditions, toxicity began within five days of decomposition, with a maximum at three weeks and a decline after five to seven weeks. Occurrence of toxicity is often missed because of the dynamic system of clumps of organic matter and moisture, that may or may not exist, and dissipate rapidly. Microhabitats were thought to be important.

Subtillage instead of plowing stimulates general microbial activity to convert wheat straw into a favorable substrate for *Penicillium urticae* Bainier which produces patulin, an allelopathic compound that adversely affected plant growth (Norstadt and McCalla, 1968a). Subtilling, as opposed to plowing, increased total counts of bacteria and actinomycetes and total fungi. Patulin was detected in field samples at concentrations of 1.5ppm in soil, and 40-75ppm in wheat straw residue.

In comparisons between subtilled and plowed soils, twice as much ferulic acid (7.6ppm vs 3.7) was detected in subtilled soils (Guenzi and McCalla, 1966b). Levels of p-coumaric acid were also higher (14.4 vs 9.4) with syringic, vanillic and p-hydroxybenzoic acids being comparable in both. The bulk of phenolic acids were found to be combined through ester linkages to organic constituents. The amount of phenolics available to plants was regulated by mechanisms that cleave those linkages.

McCalla and Norstadt (1974) stated that toxic concentrations of phenolic acids are probably localized around fragments of the most recently returned crop residues. About 40% of all soil microorganisms isolated and studied produced organic substances that reduced plant growth. They suggested that tillage should be regulated to maintain a balance between the minimum quantity of residue needed for soil and water conservation, and the maximum amount of residue for negligible phytotoxicity.

The total phenolics left on a no-till wheat field were estimated to be 1.5 tons/acre (Waller, *et al.*, 1987). Soil extracts of Oklahoma soils had allelopathic activity against germinating wheat, with root inhibition of 4-92% and shoot inhibition of 2-49%. Conventional and no-till soils appeared to be no different in allelopathic activity since both showed inhibition.

Leaf area of cucumber and mean absolute rates of leaf expansion were reduced in plants grown in both A and B horizon soils treated with ferulic acid (Blum, *et al.*, 1987). Leaf area was 22 and 16% greater for seedlings in B than A horizon soil for 167 and 333 $\mu g/g$ treatments of ferulic acid, respectively. Leaf area, expansion and shoot dry weight were 11% lower in B horizon soil than other soils. More reversibly bound ferulic acid was found in higher clay content B horizon soils than in higher organic content A soils, where there was more microbial utilization. Recovery was decreased in A soils and higher pH soils. Uptake and adsorption by cucumber roots, and microbial utilization, were the primary factors in depletion of ferulic acid from the soil solution. Concentrations of from 10 to 70 $\mu g/g$ ferulic acid inhibited cucumber growth, showing that roots compete well with microbes for ferulic acid in the soil. Only with large amounts of ferulic acid, did clay and organic matter content affect the availability of ferulic acid.

Recovery of vanillic, p-hydroxybenzoic, p-coumaric and ferulic acids from Cecil, Portsmouth and White Store soils varied with soil type, horizon, time and functional group present on the aromatic ring (Dalton, *et al.*, 1989). Significant instantaneous sorption of all acids in all soils occurred. In A1 horizon soils, recovery decreased as organic matter increased. Greater soption occurred in A1 soils than in B1 soils and declines in recovery occurred with time in all types and horizons, with the greatest decline in recovery within 2 days of application. When methoxy groups or acrylic side chains were present on the aromatic ring of the phenolics, increased sorption in soils occurred. The order of sorption was generally p-hydroxybenzoic = vanillic < p-coumaric < ferulic acids.

Ferulic acid distribution varied with depth (Klein and Blum, 1990a). Maximum recovery was in the top soil section and declined with depth. Ferulic acid added to soil material later (day 23) disappeared faster than earlier applications (day 13), suggesting faster microbial degradation. Ferulic acid reduced cucumber seedling growth over a range of soil N concentrations, which implied that phenolic acids may exhibit allelopathic activity in both nutrient limited and nutrient sufficient environments.

When ferulic, coumaric, benzoic and vanillic acids were added to a Portsmouth soil they were used as a C source by microbes (Blum and Shafer, 1988). Bacterial and fungal populations were stimulated by those acids at less than 0.5μM/g. Greater concentrations reduced populations and the effects were greater in B1 than A1 horizon soils, due to lower organic matter in B horizons. Interactions between nutrients, phenolics, and microbial activity were found to play a vital role in allelochemical interactions. Phenolic acid metabolizing organisms increased more than other microbes when phenolics were added to the soil.

More phenolics were adsorbed in subsoil than in arable soil (Shindo and Kuwatsuka, 1976). Adsorption followed the order of protochatechuic > coumaric > benzoic > ferulic > vanillic acids. The longer the side chain (within cinnamic and benzoic derivatives) on the benzene ring, the more positive the effect on adsorption. Soil pH and clay content had little effect on adsorption of phenolics. The type of clay may have influenced adsorption in some subsoils. Greater organic matter content resulted in greater adsorption. In mineral soils, most phenolics exuded from plants or produced during decomposition, were rapidly leached with water from the surface horizon or rapidly degraded.

Mechanisms of action of allelochemicals

Mineral uptake was possibly affected by allelochemical inhibition of the plasma membrane-bound ATPases that are involved in ion transport (Rice, 1979). Mitochondrial metabolism was possibly affected by phenolics and could be an important mechanism of action. Other mechanisms of action of allelopathic agents were effects on cell elongation; hormone-induced growth; membrane permeability; mineral uptake; stomatal opening; photosynthesis; respiration; protein synthesis; lipid and organic acid metabolism; inhibition of specific enzymes; and corking and clogging of xylem elements.

Putnam (1985b) stated that allelochemicals inhibited nutrient uptake by roots, cell division, cell extension growth, photosynthesis, respiration, protein synthesis, enzyme activity and membrane permeability. Ferulic acid inhibited IAA oxidase which inactivates IAA. Phenolics were found to uncouple oxidative phosphorylation decreasing ATP formation.

Some of these same effects were stated by Leather and Einhellig (1988). Allelochemicals affected plant growth through effects on cell extension, cell division, membrane permeability, nutrient uptake, chlorophyll and protein synthesis, photosynthesis, enzyme activity, respiration, and water relations. Some effects were stated to be primary, and others secondary or tertiary results of phenolics. Some allelochemicals were inhibitory at millimolar concentrations and stimulatory at micromolar cocentrations, thus, confounding efforts to determine mechanisms of action. Effects on seed germination were thought to involve membrane alteration.

Benzoic and cinnamic acids inhibited CO_2-dependent oxygen evolution in intact spinach chloroplasts (Moreland and Novitzky, 1987). Inhibition of 50% occurred between <1 and 10mM. In thylakoids, the primary effect at low concentrations was on ATP-generating pathways, and at higher concentrations involved inhibition of electron transport. In mung bean mitochondria, the primary effect was electron transport inhibition. Inhibition of substrate oxidation were thought to be a result of alerations and perturbations in the inner mitochondrial membrane.

Effects on indole-3-acetic acid (IAA) were noted by Lee and Skoog (1965) as IAA was rapidly inactivated (38% in 15 minutes at 25°C) by crude tobacco callus extracts. Benzoic acid at 0.15-3.0mM gave 40-85% inactivation, mostly in the first 15 minutes; 2,4-dihydroxybenzoic acid gave > 70% inactivation from 0.3-3.0mM concentration. Caffeic acid inhibited the decarboxylation of IAA (Zenk and Muller, 1963). Coumaric, ferulic and benzoic acids increased IAA decarboxylation depriving the tissue of auxin and retarding growth.

Allelopathic inhibition of germination and growth typically occurred from joint action of several allelochemicals (Einhellig, 1987). One chemical below its threshold could still be active in concert with other allelochemicals. Stresses augment inhibitory effects. Suboptimal nutrients, moisture, or temperature could cause plants to be more sensitive to allelochemical effects, even when the stress is not affecting measurable growth. Allelochemicals and residual herbicides supplement each other. Activity of allelochemicals could also be tied to other stresses and pathological effects from disease organisms in the environment. Allelochemicals should be evaluated in context of what effects are in the entire environment with interaction of stresses.

Duke (1985) found that cinnamic-acid derived aromatic acids were reduced by glyphosate, which also increased accumulation of certain phenolic compounds derived from the shikimic acid pathway intermediates, and decreased synthesis of aromatic amino acid-derived secondary aromatic compounds.

Methodology on allelochemical research

In the method most similar to the one used in this study, 50g soil and 100ml deionized water were autoclaved for 45 minutes at 1.2kg/cm2 and 121°C (Blum, *et al.*, 1991). The mixture was centrifuged for 10 minutes at 27,200g and filtered through Whatman No. 42 paper, pH adjusted to 2.0 with HCl, and centrifuged an additional 10 minutes at 27,200g; pH was again adjusted to 7.0 with NaOH. Protochatechuic acid (200μl, 0.25mM, pH7) was mixed with 1.8ml of the extract and filtered through a 0.2μm Supor-200 filter. Determination of phenolic acids was with a Waters HPLC at 245nm with a model 440 absorption detector and a baseline chromatographic workstation. A Waters reverse-phase 5μm Nova-Pak C-18 column was used to isolate caffeic, ferulic, p-coumaric, p-hydroxybenzoic, protochatechuic, sinapic, syringic and vanillic acids. Mobile phases of A (2% methanol, 0.25% ethyl acetate and 0.5% acetic acid) and B (80% methanol, 1% ethyl acetate and 2% acetic acid) were used in a linear gradient of 92%A to 66%A over the first 40 minutes of a 60 minute runtime, with a flow rate of 0.5ml/minute. Caffeic and sinapic acids were reduced in concentration, but the procedure was satisfactory for extracting the other phenolic acids. Most of the phenolic acids extracted came form bound forms.

Phenolic acid concentrations were determined through High Performance Liquid Chromatography at 254nm through a μ-Bondapak C-18 column and a Waters model 440 absorbance detector (Blum, *et al.*, 1984). Isocratic elution was achieved through use of solvents consisting of 35% methanol, 1% ethyl-acetate and 2% acetic acid, using a flow rate of 2 ml/min. Separation of ferulic acid from its breakdown products was achieved with a model 660 solvent programmer (curve No. 10) with initial concentrations of 90% solvent A (2.5% methanol, 0.25% ethyl acetate and 0.5% acetic acid) and 10% solvent B (35% methanol, 1% ethyl acetate, and 2% acetic acid). Final concentrations of 20% A to 80% B were reached in 30 minutes with a flow rate of 1.8 ml/min, and a total run time of 45 minutes.

Separation of phenolic acids were acheived by binary gradient elutions, through Radial-Pak μ-Bondapak C-18 reverse phase cartridges, with a flow rate of 2.5 ml/min (Blum, *et al.*, 1985b). Solvent A (2.5% methanol, 0.25% ethyl acetate and 0.5% acetic acid) and solvent B (80% methanol, 1% ethyl acetate and 2% acetic acid) were used in gradient elutions starting with 100% solvent A for 20 minutes, and gradually increasing to 98% B over 80 minutes. Identification was made by comparing retention times and ratios of absorbance between 280 and 254nm with those of known standards.

Shilling *et al.* (1986b) dissolved residues in 15ml 35% aqueous methanol, filtered through a 0.4μm Millipore filter and analyzed on a Waters HPLC. They used a Model 6000A pumping system, Model U6K injector and a Model 480 Lambda-max LC spectrophotometer. The system was equipped with a μ-Bondapak C-18 column (7.18 x 30 cm). The solvent CH_3OH-H_2O, 35:65 was delivered isocratically at 1.5ml/min and the column effluent monitored at 350nm. A total run time of 30 minutes was used to identify ß-hydroxybutyric acid, succinic acid and ß-phenyllactic acid.

An often cited procedure was described by Hartley and Buchan (1979). The procedure included shaking 25g soil with 40ml 1M NaOH under N_2 at 20°C for 20h. The suspension was then centrifuged (1000g) and filtered through Whatman No. 1 paper. The sample was then acidified with 10ml of 12M HCl to pH 2.5, and centrifuged (1800g) to separate humic acid. An internal standard of p-anisic acid was used. Phenolics were separated with a Waters 6000A HPLC with a loop injector. A variable wavelength detector set a 275nm was used with a 10μl flow cell, recorder, and integrator. Reverse phase chromatography was conducted using a steel column (25cm X 4.6mm ID) with spherisorb C-18 bonded-phase silica. An isocratic elution with water-acetic acid-n-butanol (342:1:14) was used with a flow rate of 1.2ml/minute for benzoic, vanillic and trans- and cis-coumaric acids. Ferulic acid was separated with a 347:1:11 ratio mobile phase that was used for soil samples. Retention times of 11.1, 12.2, 14, 24.5, 31.7 and 16 minutes were found for benzoic, vanillic, syringic, trans-coumaric, trans-ferulic and cis-coumaric acids, respectively.

In comparing soil extraction procedures, Dalton *et al.* (1987) quantified ferulic acid with a Waters HPLC at 280nm with a model 440 absorbance detector. The column was 4μm particle size, with a Nova-pak C-18 Radial Pak cartridge contained in a Z-module radial compression separation system. An isocratic separation with approximately 38% MeOH was used. More ferulic acid was recovered from B1 horizons of spiked Cecil and Portsmouth soils than from A1 horizon soils. Greatest ferulic acid recovery (1038.93 mg/kg soil) was acheived with extraction with 2M NaOH and autoclaving. In A1 horizon of Cecil 2M

NaOH extracted for 24h at room temperature recovered 682.02mg/kg. Other extraction methods and recoveries included 2M NaOH for 4h at room temperature (641.81mg/kg); EDTA for 5h at room temperature (454mg/kg); 100% MeOH for 48h (323.51mg/kg); and 100% H_2O at 22-23°C (303.41mg/kg). Portsmouth soils showed similar results. NaOH gave the same ferulic acid yield under air or N2 atmospheres. More background ferulic acid was found with NaOH due to oxidation of organic matter under air than N_2. Generally, chelating extractants such as EDTA and DTPA recovered more acid over time than extraction with NaOH.

Identification of phenolic acids from higher plants have been made using two-directional paper chromatography (Ibrahim and Towers, 1960). Twenty-two phenolic acids, including the six of interest in these studies, have been identified in extracts from several plant species.

Similiar paper chromatography methods using alkaline and acid hydrolyses of ethanol-soluble extracts of wheat, confirmed the presence of ferulic, p-coumaric, vanillic, syringic and p-hydroxybenzoic acids in most wheat tissues (El-Basyouni and Towers, 1961) but revealed only traces of caffeic acid and protocatechuic acid only in roots. Chromatograms of cold alkaline hydrolyzates of the ethanol-insoluble fraction revealed only ferulic and p-coumaric acid. Hot alkaline hydrolysis revealed vanillic, syringic, p-hyroxybenzoic acids and vanillin in addition to the previous two. Concentrations of phenolic acids, determined from alkaline hydrolysis of the ethanol-soluble fraction of wheat shoots, revealed greater than 1000ppm for ferulic and p-coumaric acid but less than 100ppm for syringic and vanillic acids. Vanillic and syringic acid concentrations in wheat shoots were considerably greater at nine days than 35 days but then increased again from 47 to 57 days from germination. Ethanol-soluble ferulic and p-coumaric were highest at nine days and decreased over time, while the insoluble (cell wall) fraction showed a maximum at 25 days but remained relatively high with ferulic acid (4 mg/g) almost double p-coumaric acid (1.8 mg/g). All of the acids were found to be primarily in bound form as ester or glycosidic linkages.

Ether extracts dissolved in ethanol were used for paper, thin layer and gas chromatographic identification of phytotoxins (Chou and Patrick, 1976). Ether extracts of wheat and sugarcane native lignin (the methanol soluble fraction) in aqueous 1N NaOH on paper chromatography yielded p-hyroxycinnamic acid, as well as benzoic, vanillic, syringic and ferulic acids (Smith, 1955).

Putnam (1985b) described the steps to prove allelopathy as 1) demonstrate and quantify interference; 2) isolate, assay, characterize and synthesize toxins; 3) repeat symptoms of interference by application of toxins; and 4) show that release, movement and uptake of toxin is sufficient for observed interference.

Experimental methodologies to evaluate allelopathic plant interactions have been evaluated (Dekker, *et al.*, 1983). The use of interference studies alone have proven to be only partially successful in establishment of evidence for allelopathic events. Qasem and Hill, (1989a) found extraction studies overestimated the toxicity of allelopathic compounds. Incorporation of plant residues in soil for allelopathic studies may affect soil texture and reduce percentage of soil in the growth medium and, thus, skew results due to moisture or nutrient confounding. Microorganisms in these media, and pH changes due to soil additions, can also confound results. Difficulties on separating allelopathy from competition have been found and a lack of methods to model real situations exist. More precise and defined techniques and multiple evidence of allelopathy were suggested.

Kaminsky and Muller (1977 & 1978) suggested that alkaline extractions give phenolic artifacts or degradation products in results and were not appropriate for purposes of allelopathic studies, but may be a good way of identifying phenolics of a certain interest. A procedure was suggested using 50g soil and 25g of Na_2EDTA in 200ml of distilled H_2O, with pH adjusted to 7.5 with NaOH. This was shaken for five hours and centrifuged for 15 minutes at 3300g; pH was adjusted to 3.5 with HCl and extracted with ethyl acetate. This was centrifuged for 15 minutes at 200g and analyzed by gas chromatography. Formation of humic components were irreversibly bound by organic compounds to soil and alkaline procedures removed these. Chelating agents removed only plant available but not bound compounds. The longer the period after a rain, the lower the amount of extractable compounds. There was no evaluation of concentrations of phenolics, however, only retention times.

However, Rice (1979) stated that phytotoxins do not have to be absorbed by higher plants in order for them to have important effects on such plants, since they may also affect microorganisms. It was thus suggested that the Na EDTA procedure advocated by Kaminsky and Muller was not necessarily the only valid method.

Dalton *et al.*, (1983) studied recoveries of ferulic acid from soil. It was stated that alkaline extractions, using NaOH or EtOH at pH 11, partially solubilize the soil organic matter, introducing phenolic compounds not normally present, which could lead to overestimation of phenolics present. A neutral extraction procedure was suggested using water and a chelating agent, such as Na_2EDTA at pH 7.5, which displaces reversibly bound phenolic acids and more accurately assesses available phenolic acids in the soil system. Preliminary studies found that phenolic acids added to sterile soil controls were irreversibly lost to extraction procedures with Na_2EDTA at pH 7.5. In the recovery studies, samples were extracted with 14ml Na_2EDTA (0.03M, pH 7.5) for 30 minutes, centrifuged 10 minutes at 14,500g and passed through a 0.2 μm membrane filter. Ferulic acid was determined by a Waters HPLC at 313nm with a model 440 absorbance detector, with a μ-Bondapak C-18 column using a model 660 solvent programer. Initial concentrations of 90% solvent A (10% methanol, 1% ethyl acetate and 2% acetic acid) and 10% solvent B (80% methanol, 18% water and 2% acetic acid) were used to a final concentration of 10% A and 90% B with a 2.67% change per minute and a 2.5ml/minute flow rate. Without soil, recovery of ferulic acid was about 99%. Recovery of ferulic acid in EDTA solution was reduced significantly over time and varied with pH. The irreversible disappearance of ferulic acid in soil was more rapid at pH 7.5 than 4.5. Less ferulic acid was recovered from topsoil than subsoil, indicating that organic matter was responsible for the irreversible retention of ferulic acid. Physical and biological processes operated together to reduce concentrations of phenolic acids that interact with the biota.

Radicle elongation studies were thought to be better than seed germination studies for isolating mechanisms of action of allelochemicals (Leather and Einhellig, 1988). Seedling growth bioassays were more sensitive than germination in determining mechanisms. *Lemna* bioassays were very sensitive in assesing allelochemical phytotoxicity. Bioassays were sometimes difficult to assess, but helpful when conducted under proper conditions. Similar results were found by Lawrence and Kilcher (1962) where seedling growth of plants was more sensitive to plant root extracts than germination bioassays.

Shilling and Yoshikawa (1987) developed a bioassay to rapidly assess qualitatively and quantitatively the biological activity of pure allelopathic compounds. *Echinochloa crusgalli* (L.) Beauvois and *Sesbania exaltata* (Raf.) Cory were used in bioassay of several allelochemicals including ferulic, caffeic, benzoic, vanillic, and protocatechuic acids. Although root length was more sensitive, a modeled measurement called shoot-plus-root fresh weight, taken from total plant fresh weight, was found to be the most efficient method to use. This measurement was sufficiently accurate and was less time consuming than other methods.

Leather and Einhellig (1986) have evaluated several methods of bioassay in allelochemical studies and found that many reports of allelopathy are questionable because unsuitable bioassays were used. There was no perfect bioassay, and they suggested it might be wise to use several bioassays for each suspected allelopathic interaction. Those selected should depend on the suspected mode of action. The least sensitive bioassays were seed germination and radicle elongation.

A bioassay technique using *Lemna minor* detected inhibition (reduced dry weight) by ferulic acid as low as 250μM (Einhellig, *et al.*, 1985a). Reduced frond production was apparent by the second day with 1000μM. This bioassay was also sensitive to low concentrations of benzoic, vanillic and coumaric acids. *L. minor* was a very good bioassay species for detection of allelopathic effects.

In bioassays, at a given concentration, greater solution volume or lesser seed density increased the phytotoxin available/seed and increased inhibition observed (Wiedenhamer, *et al.*, 1987). With ferulic acid, cucumber radicle length was 70% of control with 1mM and 25 seeds/95ml, but with 25 seeds/5ml it took 2.0mM for the same inhibition. Ferulic acid lost from solution was taken up, not broken down, since the concentration was proportional to what was originally available/seed. They suggested bioassays often underestimate allelopathic potential. High plant density or small pots may overlook allelopathic potential. In the field, allelopathic effects may be more prevalent with lower plant density. Lab studies may underestimate this potential. The results were also true with caffeic and vanillic acids.

References

Anonymous, 1992. Allelopathy journal. Agron. News. June 1992:29.

Arnold, C. 1959. The determination and significance of the base temperature in a linear heat unit system. Proc. Amer. Soc. Hort. Sci. 76:430-445.

Arnold, C. 1960. Maximum-minimum temperatures as a basis for computing heat units. Proc. Amer. Soc. Hort. Sci. 76:682-692.

Austin, M.E. and S.K. Ries. 1968. Use of heat units to predict for once-over tomato harvest. HortScience 3(1):41.

Barnes, J.P. and A.R. Putnam. 1982. Weed supression with rye cover crops in vegetable cropping systems. Abst. Ann. Meeting Weed Sci. Soc. Amer. pg. 67.

Barnes, J.P. and A.R. Putnam. 1983. Rye residues contribute weed supression in no-tillage cropping systems. J. Chemical Ecology. 9(8):1045-1057.

Barnes, J.P. and A.R. Putnam. 1986. Evidence for allelopathy by residues and aqueous extracts of rye (*Secale cereale*). Weed Science. 34:384-390.

Bates-Smith, E.C. 1956. The commoner phenolic constituents of plants and their systematic distribution. Proc. Roy. Dublin. Sci. Soc. 27:165-176.

Beste, C.E. 1973. Evaluation of herbicides in no-till planted cucumbers, tomatoes and lima beans. Proc. Northeastern Weed Sci. Soc. 27:232-239.

Beste, C.E. 1983. No-tillage systems for vegetables and ornamentals. Proc. Northeastern Weed Sci. Soc. 37:52-57.

Bhowmik, P.C. and J.D. Doll. 1982. Corn and soybean response to allelopathic effects of weed and crop residues. Agron. J. 74:601-606.

Bhowmik, P.C. and J.D. Doll. 1983. Growth analysis of corn and soybean response to allelopathic effects of weed residues at various temperatures and photosynthetic photon flux densities. J. Chem. Ecol. 9:1263-1280.

Bhowmik, P.C. and J.D. Doll. 1984. Allelopathic effects of annual weed residues on growth and nutrient uptake of corn and soybeans. Agron. J. 76(3):383-388.

Blum, U., B.R. Dalton and J.O. Rawlings. 1984. Effects of ferulic acid and some of its microbial metabolic products on radicle growth of cucumber. J. Chemical Ecology. 10(8):1169-1191.

Blum, U. and B.R. Dalton. 1985. Effects of ferulic acid, an allelopathic compound, on leaf expansion of cucumber seedlings grown in nutrient culture. J. Chemical Ecology. 11(3):279-301.

Blum, U., B.R. Dalton and J.R. Shann. 1985a. Effects of ferulic and p-coumaric acids in nutrient culture of cucumber leaf expansion as influenced by pH. J. Chemical Ecology. 11(11):1567-1582.

Blum, U., B.R. Dalton and J.R. Shann. 1985b. Effects of various mixtures of ferulic acid and some of its microbial metabolic products on cucumber leaf expansion and dry matter in nutrient culture. J. Chemical Ecology. 11(5):619-641.

Blum, U., S.B. Weed and B.R. Dalton. 1987. Influence of various soil factors on the effects of ferulic acid on leaf expansion of cucumber seedlings. Plant and Soil. 98:111-130.

Blum, U. and S.R. Shafer. 1988. Enrichment of Portsmouth soil with simple phenolic acids: Effects on microbial populations and concentrations of water extractable phenolic acids in soil. Soil Biol. Biochem. 20:793-800.

Blum, U. and J. Rebbeck. 1989. Inhibition and recovery of cucumber roots given multiple treatments of ferulic acid in nutrient culture. J. Chemical Ecology. 15(3):917-928.

Blum, U., T.M. Gerig and S.B. Weed. 1989. Effects of mixtures of phenolic acids on leaf area expansion of cucumber seedlings grown in different pH portsmouth A1 soil materials. J. Chemical Ecology. 15(10):2413-2423.

Blum, U., T.R. Wentworth, K. Klein, A.D. Worsham, L.D. King, T.M. Gerig and S.-W. Lyu. 1991. Phenolic acid content of soils from wheat-no till, wheat-conventional till, and fallow-conventional till soybean cropping systems. J. Chemical Ecology. 17(6):1045-1068.

Bonner, J. 1950. The role of toxic substances in the interactions of higher plants. Bot. Rev. 16:51-65.

Borner, H. 1960. Liberation of organic substances from higher plants and their role in the soil sickness problem. Bot. Rev. 26:393-424.

Brown, J.E., W.E. Splittstoesser and J.M. Gerber. 1985. Production and economic returns of vegetable intercropping systems. J. Amer. Soc. Hort. Sci. 110(3):350-353.

Brown, S.A. 1961. Chemistry of lignification: Biochemical research on lignins is yielding clues to the structure and formation of these complex polymers. Science. 134:305-313.

Campbell, A.G. 1959. A germination inhibitor and root-growth retarder in Chou Moellier (*Brassica oleracea* var.). Nature. 183:1263-1264.

Cast, K.G., J.K. McPherson, A.J. Pollard, E.G. Krenzer, Jr. and G.R. Waller. 1990. Allelochemicals in soil from no-tillage versus conventional-tillage wheat (*Triticum aestivum*) fields. J. Chemical Ecology. 16(7):2277-2289.

Chappell, W.E. and L.A. Link. 1977. Evaluation of herbicides in no-tillage production of burley tobacco. (*Nicotiana tabacum*). Weed Science. 25(6):511-514.

Chou, C. and Z.A. Patrick. 1976. Identification and phytotoxic activity of compounds produced during decomposition of corn and rye residues in soil. J. Chemical Ecology. 2(3):369-387.

Cochran, V.L., L.F. Elliott and R.I. Papendick. 1977. The production of phytotoxins from surface crop residues. Soil Sci. Soc. Am. J. 41: 903-908.

Coffey, D.L. and P.W. Ramsey. 1987. Sequential cropping of vegetables on black plastic. Tennessee Farm and Home Science. 144:19-21.

Dagley, S. 1971. Catabolism of aromatic compounds by microorganisms. *In* A.H. Rose and J.F. Wilkinson (eds.) Advances in Microbial Physiology. Vol 6. Academic Press, London. pp. 1-46.

Dalrymple, R.L. and J.L. Rogers. 1983. Allelopathic effects of western ragweed on seed germination and seedling growth of selected plants. J. Chemical Ecology. 9(8):1073-1078.

Dalton, B.R., U. Blum and S.B. Weed. 1983. Allelopathic substances in ecosystems: Effectiveness of sterile soil components in altering recovery of ferulic acid. J. Chemical Ecology. 9(8):1185-1201.

Dalton, B.R., S.B. Weed and U. Blum. 1987. Plant phenolic acids in soils: A comparison of extraction procedures. Soil Sci. Soc. Amer. J. 51(6):1515-1521.

Dalton, B.R., U. Blum and S.B. Weed. 1989. Differential sorption of exongenously applied ferulic, p-coumaric, p-Hydroxybenzoic, and vanillic acids in soil. Soil Sci. Soc. Amer. J. 53(3):757-762.

Dao, T.H. 1987. Sorption and mineralization of plant phenolic acids in soil. *In* Allelochemicals: Role in agriculture and forestry. ed. George R. Waller. Am. Chem. Soc. Symp. Ser. No. 330. Washington, D.C. pp. 358-370.

Dekker, J.H., W.F. Meggitt and A.R. Putnam. 1983. Experimental methodologies to evaluate allelopathic plant interactions: The *Abutilon theophrasti-Glycine max* model. J. Chemical Ecology. 9(8):945-981.

Demos, E.K., M. Woolwine, R.H. Wilson and C. McMillan. 1975. The effects of ten phenolic compounds on hypocotyl growth and mitochondrial metabolism of mung bean. Am. J. Bot. 62(1):97-102.

Doran, W.L. 1928. The growth of tobacco and brown root rot of tobacco as affected by timothy infusions of different ages. J. Agr. Research. 36:281-287.

Doss, B.D., J.L. Turner and C.E. Evans. 1981. Influence of tillage, nitrogen, and rye cover crop on growth and yield of tomatoes. J. Amer. Soc. Hort. Sci. 106(1):95-97.

Duke, S.O., R.D. Williams and A.H. Markhart, II. 1983. Interaction of moisture stress and three phenolic compounds on lettuce seed germination. Ann. Bot. (Lond.) 52:923-926.

Duke, S.O. 1985. Biosynthesis of phenolic compounds: Chemical manipulation in higher plants. *In* The chemistry of allelopathy. ed. A.C. Thompson. Amer. Chem. Soc. Symp. Ser. No. 268. pp. 113-131.

Einhellig, F.A., E.L. Rice., P.G. Risser, and S.H. Wender. 1970. Effects of scopoletin on growth, CO^2 exchange rates and concentration of scopoletin, scopolin and chlorogenic acids in tobacco, sunflower and pigweed. Bull. Torrey Bot. Club 97:22-23.

Einhellig, F.A. and L. Kuan. 1971. Effects of scopoletin and chlorogenic acid on stomatoal aperture in tobacco and sunflower. Bull. Torrey Bot. Club. 98:155-162.

Einhellig, F.A., and J.A. Rasmussen. 1978. Synergistic inhibitory effects of vanillic and p-hydroxybenzoic acids on radish and grain sorghum. J. Chem. Ecol. 4(4):425-436.

Einhellig, F.A. and J.A. Rasmussen. 1979. Effects of three phenolic acids on chlorophyll content and growth of soybean and grain sorghum seedlings. J. Chem. Ecol. 5:815-824.

Einhellig, F.A., G.R. Leather and L.L. Hobbs. 1985a. Use of *Lemna minor* L. as a bioassay in allelopathy. J. Chem. Ecol. 11:65-72.

Einhellig, F.A., M.S. Muth and M.K. Schon. 1985b. Effects of allelochemicals on plant-water relationships. *In* The chemistry of allelopathy. ed. A.C. Thompson. Amer. Chem. Soc. Symp. Ser. No. 268. pp. 179-195.

Einhellig, F.A. 1987. Interactions among allelochemicals and other stress factors of the plant environment. *In* Allelochemicals: Role in agriculture and forestry. ed. George R. Waller. Am. Chem. Soc. Symp. Ser. No. 330. Washington, D.C. pp. 343-357.

El-Basyouni, S. and G.H.N. Towers. 1961. The phenolic acids in wheat I: Changes during growth and development. Canadian J. of Biochemistry. 42:203-210.

Estes, E.A., W.A. Skroch, T.R. Konsler, P.B. Shoemaker and K.A. Sorenson. 1985. Net economic values of eight soil management practices used in stake tomato production. J. Amer. Soc. Hort. Sci. 110(6):812-816.

Flaig, W. 1964. Effects of microorganism in the transformation of lignin to humic substances. Geochem. Cosmochim. Acta. 28:1523-1535.

Forney, R.D. and C.L. Foy. 1985. Phytotoxicity of products from rhizospheres of a sorghum-sudangrass hybrid (*Sorghum bicolor* x *Sorghum sudanense*). Weed Science. 33:597-604.

Garner, W.W., W.M. Lunn, and D.E. Brown. 1925. Effects of crops on the yields of succeeding crops in the rotation with special reference to tobacco. J. Agr. Res. 30(12):1095-1132.

George, W.L., Jr. and J.D. Utzinger. 1974. Effects of mulching on earliness and productivity of three fresh-market tomato cultivars grown in cages. Res. Summary 72. Ohio Agric. Res. and Dev. Center. Wooster, Ohio. pgs. 23-24.

Glass, A.D.M. 1973. Influence of phenolic acids on ion uptake. I. Inhibition of phosphate uptake. Plant Physiol. 51:1037-1041.

Glass, A.D.M. 1974. Influence of phenolic acids on ion uptake. III. Inhibition of potassium absorption. J. Exp. Bot. 25(89):1104-1113.

Glass, A.D.M. and J. Dunlop. 1974. Influence of phenolic acids on ion uptake. IV. Depolarization of membrane potentials. Plant Physiol. 54:855-858.

Gray, D., J.A. Ward and J.R.A. Steckel. 1980. Growth and development of bush tomatoes in relation to temperature. J. Agric. Sci. 95:285-292.

Guenzi, W.D. and T.M. McCalla. 1962. Inhibition of germination and seedling development by crop residues. Soil Sci. Soc. Am. Proc. 26:456-458.

Guenzi, W.D. and T.M. McCalla. 1966a. Phenolic acids in oats, wheat, sorghum, and corn residues and their phytotoxicity. Agronomy J. 58(3):303-304.

Guenzi, W.D. and T.M. McCalla. 1966b. Phytotoxic substances extracted from soil. Soil Sci. Soc. Amer. Proc. 30:214-216.

Guenzi, W.D., T.M. McCalla and F.A. Norstadt. 1967. Presence and persistence of phytotoxic substances in wheat, oat, corn, and sorghum residues. Agronomy J. 59(2):163-165.

Haider, K. and J.P. Martin. 1967. Synthesis and transformation of phenolic compounds by *Epicoccum nigrum* in relation to humic acid formation. Soil Sci. Soc. Amer. Proc. 31:766-772.

Haider, K. and J.P. Martin. 1975. Decomposition of specifically carbon-14 labeled benzoic and cinnamic acid derivatives in soil. Soil Sci. Soc. Am. Proc. 39:657-662.

Hankin, L., D.E. Hill and G.R. Stephens. 1982. Effect of mulches on bacterial populations and enzyme activity in soil and vegetable yields. Plant and Soil. 64:193-201.

Haroon, M., R.C. Long and J.A. Weybrew. 1972. Effect of day/night temperature on factors associated with growth of *Nicotiana tabacum* L. in controlled environments. Agron. J. 64:509-515.

Harper, J.R. and N.E. Balke. 1981. Characterization of the inhibition of K+ absorption in oat roots by salicylic acid. Plant Physiol. 68:1349-1353.

Hartley, R.D. and H. Buchan. 1979. High-performance liquid chromatography of phenolic acids and aldehydes derived from plants or from the decomposition of organic matter in soil. J. Chromatography. 180:139-143.

Hawks, S.N., Jr. and W.K. Collins. 1970. Effects of a herbicide and levels of cultivation on yield and value of flue-cured tobacco. Tob. Sci. 14:170-172.

Hazebroek, J.P., S.A. Garrison and T. Gianfagna. 1989. Allelopathic substances in asparagus roots; extraction, characterization, and biological activity. J. Amer. Soc. Hort. Sci. 114(1):152-158.

Henderson, M.E.K. 1963. Fungal metabolism of certain aromatic compounds related to lignin. Pure and Applied Chem. 7:589-602.

Hicks, S.K., C.W. Wendt, J.R. Gannaway and R.B. Baker. 1989. Allelopathic effects of wheat straw on cotton germination, emergence, and yield. Crop Sci. 29(4):1057-1061.

Hill, D.E., L. Hankin and G.R. Stephens. 1982. Mulches: Their effect on fruit set, timing and yield of vegetables. Bull. 805. The Conn. Agric. Exp. Sta. New Haven, Conn. pp. 1-15.

Hoyt, G.D. 1984. The effect of cover crops on strip till vegetable and tobacco production. Proc. Soil Sci. Soc. of North Carolina. 27:10-20.

Huang, P.M., T.S.C. Wang, M.K. Wang, M.H. Wu and N.W. Hsu. 1977. Retention of phenolic acids by noncrystalline hydroxy-aluminum and -iron compounds and clay materials of soils. Soil. Sci. 123:213-219.

Hughes, B. and R.D. Sweet. 1979. Living mulch: a preliminary report on grassy cover crops interplanted with vegetables. Proc. Northeastern Weed. Sci. Soc. 33:109.

Ibrahim, R.K. and G.H.N. Towers. 1960. The identification, by chromatography, of plant phenolic acids. Archives of Biochemistry and Biophysics. 87:125-128.

Isenberg, F.M.R., A. Pendergrass, J.E. Carroll, L. Howell and E.B. Oyer. 1975. The use of weight, density, heat units and solar radiation to predict the maturity of cabbage for storage. J. Amer. Soc. Hort. Sci. 100(3):313-316.

Johnson III, W.C. and H.D. Coble. 1986. Effects of three weed residues on weed and crop growth. Weed Science. 34:403-408.

Ju, H., B.B. Bible and C. Chong. 1983. Influence of ionic thiocyanate on growth of cabbage, bean and tobacco. J. Chemical Ecology. 9(8):1255-1262.

Kaminsky, R. and W.H. Muller. 1977. The extraction of soil phytotoxins using a neutral EDTA solution. Soil Sci. 124:205-210.

Kaminsky, R. and W.H. Muller. 1978. A recommendation against the use of alkaline soil extractions in the study of allelopathy. Plant Soil. 49:641-645.

Kimber, R.W.L. 1967. Phytotoxicity from plant residues I. The influence of rotted wheat straw on seedling growth. Aust. J. Agric. Res. 18:361-374.

Kimber, R.W.L. 1973. Phytotoxicity from plant residues II: The effect of time of rotting of straw from some grasses and legumes on the growth of wheat seedlings. Plant and Soil. 38:347-361.

Klein, K. and U. Blum. 1990a. Effects of soil nitrogen level on ferulic acid inhibition of cucumber leaf expansion. J. Chemical Ecology. 16(4):1371-1383.

Klein, Kristofer and U. Blum. 1990b. Inhibition of cucumber leaf expansion by ferulic acid in split-root experiements. J. Chemical Ecology. 16(2):455-463.

Kobza, J. and F.A. Einhellig. 1987. The effects of ferulic acid on the mineral nutrition of grain sorghum. Plant. Soil. 98:99-109.

Kononova, M.M. 1961. Soil Organic Matter, translated by T.Z. Nowakowski and G.A. Greenwood. Pergamon Press. London. pp. 129-130.

Lawrence, T. and M.R. Kilcher. 1962. The effect of fourteen root extracts upon germination and seedling length of fifteen plant species. Canadian J. Plant. Sci. 42:308-313.

Leather, G.R. and F.A. Einhellig. 1986. Bioassays in the study of allelopathy. *In* The science of allelopathy. ed. Alan R. Putnam and Chung-Shih Tang. John Wiley & Sons. New York. pp. 133-146.

Leather, G.R. and F.A. Einhellig. 1988. Bioassay of naturally occurring allelochemicals for phytotoxicity. J. Chemical Ecology. 14(10):1821-1828.

Lee, T.T. and F. Skoog. 1965. Effects of hydroxybenzoic acids on indoleacetic acid inactivation by tobacco callus extracts. Physiol. Plant. 18:577-585.

LeTourneau, D., F.D. Failes and H.G. Heggeness. 1956. The effect of aqueous extracts of plant tissue on germination of seeds and growth of seedlings. Weeds 4:363-368.

Liebl, R.A. and A. D. Worsham. 1983. Inhibition of pitted morning glory (*Ipomoea lacunosa* L.) and certain other weed species by phytotoxic components of wheat (*Triticum aestivum* L.) straw. J. Chemical Ecology. 9(8):1027-1043.

Link, L.A. 1984. An evaluation of no-tillage culture for burley tobacco. Virginia Agric. Exp. Stn. Bull. 84-86.

Lovett, J.V. 1982. The effect of allelochemicals on crop growth and development. *In* Chemical Manipulation of Crop Growth and Development. ed. J.S. McLaren. Butterworth, London. pp. 93-110.

McCalla, T.M. and F.L. Duley. 1949. Stubble mulch studies: III. Influence of soil microorganisms and crop residues on the germination, growth, and direction of root growth of corn seedlings. Soil. Sci. Soc. Am. Proc. 14:196-199.

McCalla, D.R. and A.C. Neish. 1959. Metabolism of phenylpropanoid compounds in *Salvia* II. Biosynthesis of phenolic cinnamic acids. Can. J. Biochem. Physiol. 37:537-547.

McCalla, T.M. and T.J. Army. 1961. Stubble-mulch farming. Adv. Agron. 13:125-196.

McCalla, T.M. and F.A. Haskins. 1964. Phytotoxic substances from soil microorganisms and crop residues. Bacteril. Rev. 28:181-207.

McCalla, T.M. and F.A. Norstadt. 1974. Toxicity problems in mulch tillage. Agric. Environ. 1:153-174.

McKeown, A.W., R.F. Cerkauskas and J.W. Potter. 1988. Influence of strip tillage on yield, diseases, and nematodes in tomatoes. J. Amer. Soc. Hort. Sci. 113(3):328-331.

Mendez, J. and S.A. Brown. 1971. Phenols and coumarins in tomato plants. Can. J. Bot. 49:2097-2100.

Menges, R.M. 1988. Allelopathic effects of palmer amaranth (*Amaranthus palmeri*) on seedling growth. Weed Sci. 36(3):325-328.

Mersie, W. and M. Singh. 1988. Effects of phenolic acids and ragweed parthenium (*Parthenium hysterophorus*) extracts on tomato (*Lycopersicon esculentum*) growth and nutrient and chlorophyll content. Weed Sci. 36(3):278-281.

Moreland, D.E. and W.P. Novitzky. 1987. Effects of phenolic acids, coumarins, and flavonoids on isolated chloroplasts and mitochondria. *In* Allelochemicals: Role in agriculture and forestry. ed. George R. Waller. Am. Chem. Soc. Symp. Ser. No. 330. Washington, D.C. pp. 247-261.

Morrison, J.E., Jr. D.C. Milbocker, W.O. Atkinson, and J.H. Smiley. 1973a. Transplanter modification and survival of transplants under no-till conditions. HortScience 8:483-485.

Morrison, J.E., Jr., J.H. Smiley, W.O. Atkinson and D.C. Milbocker. 1973b. A no-tillage transplanter. Tob Sci. 17:44-46.

Morrison, J.E. 1974. No-tillage transplanting. 87th Annual Report of the College of Agric. Agric. Exp. Sta. Univ. Kent. pp. 11.

Morrison, J.E. 1975. No-tillage transplanting. 88th Annual Report of the College of Agric. Agric. Exp. Sta. Univ. Kent. pp. 8.

Moschler, W.W., G.M. Shear, M.J. Rogers and T.R. Terrill. 1971. No-tillage tobacco studies in Virginia. Tob. Sci. 15:12-14.

Muller, C.H. 1966. The role of chemical inhibition (allelopathy) in vegetational composition. Bull. Torrey Bot. Club. 93:332-351.

Neish. A.C. 1960. Biosynthetic pathways of aromatic compounds. Ann. Rev. Plant. Physiol. 11:55-80.

Neish. A.C. 1961. Formation of m- and p-coumaric acids by enzymatic deamination of the corresponding isomers of tyrosine. Phytochemistry. 1:1-24.

Neish, A.C. 1964. Major pathways of biosynthesis of phenols. *In* Biochemistry of phenolic compounds. ed. J.B. Harborne. Academic Press. New York.

Nicholson, A.G. and H.C. Wien. 1983. Screening of turfgrasses and clovers for use as living mulches in sweet corn and cabbage. J. Amer. Soc. Hort. Sci. 108(6):1071-1076.

Norstadt, F.A. and T.M. McCalla. 1968a. Microbial population in stubble mulched soil. Soil Sci. 107:188-193.

Norstadt, F.A. and T.M. McCalla. 1968b. Microbially induced phytotoxicity in stubble-mulched soil. Soil Sci. Soc. Amer. Proc. 32:241-245.

Patrick, Z.A. and L.W. Koch. 1958. Inhibition of respiration, germination, and growth by substances arising during the decomposition of certain plant residues in the soil. Can. J. Bot. 36:621-647.

Patrick, Z.A. and L.W. Koch. 1963. The adverse influence of phytotoxic substances from decomposing plant residues on resistance of tobacco to black root rot. Can. J. Bot. 41(6):747-758.

Patrick, Z.A., T.A. Toussoun and W.C. Snyder. 1963. Phytotoxic substances in arable soils associated with decomposition of plant residues. Phytopathology. 53:152-161.

Patrick, Z.A., Toussoun, T.A. and L.W. Koch. 1964. Effect of crop-residue decomposition on plant roots. Annu. Rev. Phytopathology 2:267-292.

Patrick, Z.A. 1971. Phytotoxic substances associated with the decomposition in soil of plant residues. Soil Sci. 111:13-18.

Patterson, D.T. 1981. Effects of allelopathic chemicals on growth and physiological responses of soybean (*Glycine max*) Weed Sci. 29:53-59.

Phillips, R.E., R.L. Blevins. G.W. Thomas. W.W. Frye and S.H. Phillips. 1980. No-tillage agriculture. Science. 208:1108-1113.

Phillips, R.E. and J.M. Zeleznik. 1989. Production of burley tobacco using no-tillage and conventional tillage. J. Prod. Agric. 2(4):343-346.

Pickering, S. 1917. The effect of one plant on another. Ann. Bot. 31:181-187.

Pope, D.F., A.C. Thompson and A.W. Cole. 1985. Phytotoxicity of root exudates and leaf extracts of nine plant species. *In* The chemistry of allelopathy. ed. A.C. Thompson. Amer. Chem. Soc. Symp. Ser. No. 268. pp. 219-234.

Putnam, A.R. and W.B. Duke. 1974. Biological suppression of weeds: Evidence for allelopathy in accessions of cucumber. Science 185:370-372.

Putnam, A.R. and W.B. Duke. 1978. Allelopathy in agroecosystems. Ann. Rev. Phytopathol. 16:431-451.

Putnam, A.R. 1983. Allelopathic chemicals: Natural herbicides in action. Chemical and Engineering News. 61(14):34-45.

Putnam, A.R. and J. DeFrank. 1983. Use of phytotoxic plant residues for selective weed control. Crop Protection. 2(2):173-181.

Putnam, A.R., J. DeFrank and J.P. Barnes. 1983. Exploitation of allelopathy in annual and preennial cropping systems. J. Chem. Ecol. 9:1001-1010.

Putnam, A. 1985a. Weed Allelopathy. *In* Weed Physiology Vol. 1. Reproduction and ecophysiology. ed. S.O. Duke. CRC Press, Inc. Boca Raton, Fla. pp. 131-155.

Putnam, A.R. 1985b. Allelopathic research in agriculture: Past highlights and potential. *In* The chemistry of allelopathy. ed. A.C. Thompson. Am. Chem. Soc. Symp. Ser. No. 268. pp. 1-8.

Putnam, A.R. and L.A. Weston. 1986. Adverse impacts of allelopathy in agricultural systems. *In* The science of allelopathy. ed. A.R. Putnam and C.-S. Tang. John Wiley & Sons. New York. pp. 43-56.

Putnam, A. 1988. Allelochemicals from plants as herbicides. Weed Technology. 2:510-518.

Qasem, J.R. and T.A. Hill. 1989a. On difficulties with allelopathy methodology. Weed Research. 29:345-347.

Qasem, J.R. and T.A. Hill. 1989b. Possible role of allelopathy in the competition between tomato, *Senecio vulgaris* L. and *Chenopodium album* L. Weed Research. 29:349-356.

Rainbault, B.A., T.J. Vyn and M. Tollenaar. 1990. Corn response to rye cover crop management and spring tillage systems. Agron. J. 82(6):1088-1093.

Retig, B., L.G. Holm and B.E. Struckmeyer. 1972. Effects of weeds on the anatomy of roots of cabbage and tomato. Weed Science. 20(1):33-36.

Rice, E.L. 1974. Allelopathy. Academic Press. New York.

Rice, E.L. 1979. Allelopathy-An update. Bot. Rev. 45:15-109.

Rice, E.L. 1987. Allelopathy: An overview. *In* Allelochemicals: Role in agriculture and forestry. ed. G.R. Waller. Am. Chem. Soc. Symp. Ser. No. 330. Washington, D.C. pp. 8-22.

Rowe-Dutton, P. 1957. The mulching of vegetables. Tech. Comm. No. 24. Commonwealth Bureau of Horticulture and Plantation Crops. East Malling, Maidstone, Kent. pp. 11-19, 119-146.

Shann, J.R. and U. Blum. 1987. The uptake of ferulic and p-hydroxybenzoic acids by *Cucumis sativus*. Phytochemistry. 26:2959-2964.

Shilling, D.G., R.A. Liebl and A.D. Worsham. 1985. Rye (*Secale cereale* L.) and wheat (*Triticum aestivum* L.) mulch: The supression of certain broadleaved weeds and the isolation and identification of phytotoxins. *In* The chemistry of allelopathy. ed. A.C. Thompson. Amer. Chem. Soc. Symp. Ser. No. 268. pp. 243-271.

Shilling, D.G., A.D. Worsham and D.A. Danehower. 1986a. Influence of mulch, tillage, and diphenamid on weed control, yield, and quality in no-till flue-cured tobacco (*Nicotiana tabacum*). Weed Science. 34:738-744.

Shilling, D.G., L.A. Jones, A.D. Worsham, C.E. Parker and R.F. Wilson. 1986b. Isolation and identification of some phytotoxic compounds from aqueous extracts of rye (*Secale cereale* L.) J. Agric. Food Chem. 34:633-638.

Shilling, D.G. and F. Yoshikawa. 1987. A rapid seedling bioassay for the study of allelopathy. *In* Allelochemicals: Role in agriculture and forestry. ed. G.R. Waller. Am. Chem. Soc. Symp. Ser. No. 330. Washington, D.C. pp. 334-342.

Shindo, H. and S. Kuwatsuka. 1975a. Behavior of phenolic substances in the decaying process of plants II. Changes of phenolic substances in the decaying process of rice straw under various conditions. Soil Sci. Plant Nutr. 21:215-225.

Shindo, H. and S. Kuwatsuka. 1975b. Behavior of phenolic substances in the decaying process of plants III. Degradation pathway of phenolic acids. Soil Sci. Plant. Nutr. 21:227-238.

Shindo, H. and S. Kuwatsuka. 1976. Behavior of phenolic substances in the decaying process of plants IV: Adsorption and movement of phenolic acids in soils. Soil Sci. Plant Nutr. 22(1):23-33.

Shreiner, O. and H.S. Reed. 1908. The toxic action of certain organic plant constituents. Bot. Gaz. 45:73-102.

Shreiner, O. and E.C. Shorey. 1909. The isolation of harmful organic substances from soils. U.S. Dep. Agr. Bur. of Soils Bull. No. 53. pp. 53.

Skinner, J.J. 1918. Soil aldehydes. A scientific study of a new class of soil constituents unfavorable to crops, their occurrence, properties and elimination in practical agriculture. J. Franklin. Inst. 186:735-736.

Smith. D.C.C. 1955. Ester groups in lignin. Nature. 176:267-268.

Spicer, H. 1983. Feasibility of strip-cultivation in processing tomatoes. Ont. Min. of Agr. and Food. Agdex 230/741.

Stafford, H.A. 1960. Comparison of lignin-like polymers produced peroxidatively by cinnamic acid derivatives in leaf sections of phleum. Plant Physiol. 35:612-618.

Steinberg, R.A. 1947. Growth responses to organic compounds by tobacco seedlings in aseptic culture. J. Agr. Res. 75:81-92.

Steinsiek, J.W., L.R. Oliver and F.C. Collins. 1982. Allelopathic potential of wheat (*Triticum aestivum*) straw on selected weed species. Weed Science. 30:495-497.

Stowe, L.G. and A. Osborn. 1980. The influence of nitrogen and phosphorous levels on the phytotoxicity of phenolic compounds. Can. J. Bot. 58:1149-1153.

Strandberg, J.O. 1979. Growth and phenology of cabbage in a winter production area. Proc. Fla. State Hort. Soc. 92:93-96.

Strandberg, J.O. and J.M. White. 1979. Estimating fresh market cabbage maturity dates in a winter production area. Proc. Fla. State Hort. Soc. 92:96-99.

Summerell, B.A. and L.W. Burgess. 1989. Decompositin and chemical composition of cereal straw. Soil Biol. Biochem. 21:551-559.

Sumner, D.R., E.D. Threadgill, D.A. Smittle, S.C. Phatak and A.W. Johnson. 1986. Conservation tillage and vegetable diseases. Plant Dis. 70:906-911.

Toussoun, T.A. and Z.A. Patrick. 1963. Effects of phytotoxic substances from decomposing plant residues on root rot of bean. Phytopathology. 53:265-270.

Toussoun, T.A., A.R. Weinhold, R.G. Linderman and Z.A. Patrick. 1968. Nature of phytotoxic substances produced during plant residue decomposition in soil. Phytopathology. 58:41-45.

Towers, G.H.N. 1964. Metabolism of phenolics in higher plants and microorganisms. *In* Biochemistry of phenolic compounds. ed. J.B. Harborne. Academic Press. New York.

Triplett, G.B., Jr. and D.M. Van Doren, Jr. 1977. Agriculture without tillage. Sci. Am. 236:28-33.

Tukey, H.B., Jr. 1969. Implications of allelopathy in agricultural plant science. Bot. Rev. 35:1-16.

Turner, J.A. and E.L. Rice. 1975. Microbial decomposition of ferulic acid in soil. J. Chemical Ecology. 1(1):41-58.

Upchurch, W. 1987. Growing burley tobacco without plowing. Progressive Farmer. 102:41.

Waller, G.R., E.G. Krenzer, Jr., J.K McPherson and S.R. McGown. 1987. Allelopathic compounds in soil from no-tillage vs. conventional tillage in wheat production. Plant Soil. 98:5-15.

Wang, T.S.C., S.Y. Cheng and H. Tung. 1967a. Dynamics of soil organic acids. Soil Sci. 104:138-144.

Wang, T.S.C., T.-K. Yang and T.-T. Chuang. 1967b. Soil phenolic acids as plant growth inhibitors. Soil Sci. 103:239-246.

Wang, T.S.C., K. Yeh, S. Cheng and T. Yang. 1971. Behavior of soil phenolic acids. *In* Biochemical interactions among plants. National Academy of Sciences. Wash. D.C. pp. 113-20.

Warnock, S.J. and R.L. Isaacs. 1969. A linear heat unit system for tomatoes in California. J. Amer. Soc. Hort. Sci. 94(6):677-678.

Waters, E.R. and U. Blum. 1987. The effects of single and multiple exposures of ferulic acid on the vegetative and reproductive growth of *Phaseolus vulgaris*. BBL-290. Am. J. Bot. 74:1635-1645.

Went, F.W. 1944. Plant growth under controlled conditions. II. Thermoperiodicity in growth and fruiting of tomato. Amer. J. Bot. 31:135-150.

Whitehead, D.C. 1964. Identification of p-hydroxybenzoic, vanillic, p-coumaric and ferulic acids in soils. Nature. 202:417-418.

Whitehead, D.C., H. Dibb and R.D. Hartley. 1981. Extractant pH and the release of phenolic compounds from soils, plant roots and leaf litter. Soil Biol. Biochem. 13:343-348.

Whitehead, D.C., H. Dibb and R.D. Hartley. 1982. Phenolic compounds in soil as influenced by the growth of different plant species. J. Appl. Ecol. 19:579-588.

Whitehead, D.C., H. Dibb and R.D. Hartley. 1983. Bound phenolic compounds in water extracts of soils, plant roots and leaf litter. Soil Biol. Biochem. 15:133-136.

Wiedenhamer, J.D., T.C. Morton and J.T. Romeo. 1987. Solution volume and seed number: Often overlooked factors in allelopathic bioassays. J. Chem. Ecol. 13:1481-1491.

Williams, R.D. and R.E. Hoagland. 1982. The effects of naturally occurring phenolic compounds on seed germination. Weed. Sci. 30:206-212.

Wood, S.D. and A.D. Worsham. 1986. Reducing soil erosion in tobacco fields with no-tillage transplanting. J. Soil Water Conserv. 41:193-196.

Worsham, A.D. 1984. Crop residues kill weeds: Allelopathy at work with wheat and rye. Crops and Soils. 37(2):18-20.

Worsham, A.D. 1985. No-till tobacco (*Nicotiana tabacum*) and peanuts (*Arachis hypogea*). *In* A.F. Wiese (ed.) Weed control in limited-tillage systems. Mono. Ser. No. 2, Weed Sci Soc. Am., Champaign, Ill. pp. 101-126.

Yates, N.L. and M.N. Rogers. 1981. Effects of time, temperature, and nitrogen source on the composting of hardwood bark for use as a plant growing medium. J. Amer. Soc. Hort. Sci. 106(5):589-593.

Zartman, R.E., R.E. Philips and W.O. Atkinson. 1976. Tillage and nitrogen influence on root densities and yield of burley tobacco. Tob Sci. 20:129-132.

Zenk, M.H. and G. Muller. 1963. *In vivo* destruction of exogenously applied indolyl-3-acetic acid as influenced by naturally occurring phenolic acids. Nature. 200:761-763.

Chapter 3

SEQUENTIAL CROPPING OF BROCCOLI AND BURLEY TOBACCO UNDER VARIOUS TILLAGE SYSTEMS

Abstract

The increasing need for reduced tillage and the potential for taking advantage of many vegetable market windows in eastern Tennessee prompted an investigation into the effects of different tillage and cropping systems in broccoli (*Brassica oleracea* L. var. *italica*)-tobacco (*Nicotiana tabacum* L.) production combinations. Three tillage systems (no-till, conventional with a winter cover, conventional with no cover) and three cropping sequences (broccoli-tobacco, broccoli-tobacco-broccoli, and tobacco-broccoli) were examined at three locations in 1989 and 1990. Agronomic data were taken and analyzed with mixed models. Conventional tillage systems proved to be superior to no-till systems for yield, value and quality of both tobacco and broccoli. Fall broccoli production was not successful in these studies, although weather data indicate that there are sufficient growing degree days to mature this three-crop system with timely schedules of planting and harvest. Spring broccoli can successfully be grown in combination with tobacco and can potentially increase farm revenues over tobacco alone.

Introduction

Burley tobacco has traditionally been produced through a single crop, conventionally tilled system. Although minimum tillage has been adopted in a wide range of crops, its adoption in high value crops such as vegetables and tobacco has been slow. With legislation that requires erosion control practices on erodible land, many tobacco producers will be forced to grow their crop with conservation tillage. While some research has been done on growing tobacco in reduced tillage systems, the practice has only begun to be implemented at commercially.

Since burley tobacco producers have been faced with reduced production quotas and increased production costs over most of the last decade, and with their need to increase profits, growers are forced to get maximum production out of all their land. This is particularly true of their most productive land, which is limited and has traditionally been devoted solely to tobacco. This will require use of the land to grow more than one crop in a season.

There is potential in eastern Tennessee to take advantage of many market windows in spring or fall vegetable markets. The addition of a spring or fall crop, or both, prior to and/or following a summer annual crop may be a viable possibility. The addition of vegetable crops to tobacco production systems offers great economic potential to tobacco growers.

The production of these crops in most of eastern Tennessee would be on marginally to highly erodible land making use of reduced tillage practices necessary. Tomatoes (*Lycopersicon esculentum* Mill.), tobacco and broccoli are not generally grown in minimum tillage systems. Phillips *et al.*, (1980) stated that the acreage of land that can safely be used for row crops would be increased with reduced tillage since such crops can be grown on sloping land that would be subject to erosion under conventional tillage.

Reduction of soil compaction; wind and water erosion; reduction of herbicide runoff improving quality of waterways; savings of time, labor and fuel; and increased soil moisture conservation have all been cited as advantages of reduced tillage and cover mulches (Triplett and Van Doren, 1977, Morrison, *et al.*, 1973a & 1973b, and Wood and Worsham, 1986). Cover mulches increase intake of rainfall and maintain soil structure but can increase insect and weed problems. USDA personnel have predicted that 90% of the U.S. Crop acreage will be under reduced tillage by 2010.

In much of the previous no-till research, cover crops such as rye (*Secale cereale* L.), wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) have been burned down with a herbicide treatment. Paraquat (1,1'-dimethyl-4,4'-bipyridiniumion) or glyphosate (N-(phosphonomethyl)glycine) have traditionally been used to kill these crops (Chappell and Link, 1977) prior to planting directly into the residue.

Phillips and Zeleznik (1989) found no difference in yield, stand or value of burley tobacco grown in bluegrass sod or killed wheat compared to conventionally grown tobacco. Worsham (1984) found no-till tobacco planted into killed green rye showed reduced growth of some early season weed species. He found slower growth in no-till plots but yields were not reduced in wet years and were greater in dry years. Upchurch (1987) and Wood and Worsham (1986) found similar results and the latter also found no difference for tobacco leaf quality index.

Reductions in yield, however, were reported by Shilling *et al.* (1986a) for yield of flue-cured tobacco, although no differences were found among mulches of rye, wheat, oats, barley or alfalfa. Leaf quality was not affected by rye mulch. Moschler, *et al.* (1971) found similar yield and value reductions in flue-cured and burley tobacco, with no difference between rye vs tall fescue covers. No-till tobacco produced thinner and more chaffy leaf. Tobacco stand and yield were reduced by paraquat and glyphosate burndown of rye compared to conventional tillage (Chappell and Link, 1977). Lower burley (Link, 1984) and flue-cured (Hawks and Collins, 1970) yields with reduced cultivation have also been found by other investigators.

Soil loss was found to be 20-90 times greater in conventional till vs no-till where a rye mulch was used (Wood and Worsham, 1986). They found runoff in no-till was 23.4cm vs 20.8 in conventional in 1982 and 11.3 vs 13.1 for conventional in 1983. Wheat mulch resulted in reduced sand damage to young tobacco transplants and sand contamination associated with harvested leaf (Worsham, 1985). Plant N, root length, and plant and leaf weight were also greater in conventional than in no-till treatments.

Mulches, such as straw, resulted in yield increases under low moisture conditions for Brassicas, but the crops were liable to suffer from decreased nitrate supply, and additional N was recommended (Rowe-Dutton, 1957).

A modified transplanter with rolling coulters, double disc openers, guage wheels, narrow press wheels and ballast weights on the frame and press wheels was used to successfully transplant tobacco, tomato and pepper plants into chemically killed sod and cereal straw residue. Transplant survival was lower in no-till plots than in conventional tillage plots due to increased insect and disease damage (Morrison, *et al.*, 1973a, 1973b & Morrison, 1974).

Intercroppings of tomatoes and cabbage, as well as, collards and muskmelon have been investigated (Brown, *et al.*, 1985). Net returns from tomatoes in monocrop were highest, followed by the tomato/cabbage combination. Net returns for other combinations were not significantly different. Cabbage/tomato and collard/muskmelon combinations produced yields and net returns that were generally comparable to either crop grown alone. Total yield of tomatoes was greater in one year when tomato was intercropped with cabbage. When supplemental N was applied, there was no change in tomato yield.

Tomato and broccoli sequential cropping was shown to be superior to either grown alone for gross returns (Coffey and Ramsey, 1987). Gross returns from broccoli in combination with squash or pepper were not greater than gross returns from pepper or squash grown alone. Returns were not increased from a spring and fall planting of broccoli with summer squash over squash grown alone. Two crops of broccoli produced net returns that were superior to a single planting of broccoli.

Phillips *et al.*, (1980) suggested that the advantages of reduced tillage are more important in multiple cropping systems. Reduced moisture loss at planting time ensuring stands of second and third crops under restricted rainfall; production of more than one crop per year increasing land use; elimination of plowing and land preparation; and time saved in planting second and third crops were all cited as increased advantages of no-till in these systems. Harvesting could be followed immediately by planting of a second crop thus reducing lag time between crops as well.

Materials and methods

Early maturing cultivars that are commercially available and representative of cultivars grown in eastern Tennessee were used in the study. 'Male sterile (m.s.) Ky 14 x L8' burley tobacco, which requires approximately 88 d to reach maturity, and 'Packman' hybrid broccoli, which matures in appoximately 60 d were used to facilitate early harvests.

Treatments consisted of factorial combinations of three tillage systems and three cropping sequences arranged in a strip-plot design. Sequences were stripped across tillages. The tillage systems consisted of conventionally tilled plots with no winter cover; conventionally tilled plots with a wheat winter cover; and no-till plots in which crops were transplanted directly into a wheat cover that had been burned down with paraquat prior to transplanting.

The three-crop treatment consisted of spring broccoli followed by tobacco, followed by fall broccoli. Two-crop treatments consisted of spring broccoli followed by tobacco or tobacco followed by fall broccoli. There were four replications of each treatment. Broccoli plots consisted of four-row plots with the two center rows harvested in each plot, with each row 12.8 m long. Broccoli plants were spaced 31 cm apart in rows 107 cm apart. Tobacco was planted in identical rows with plants spaced 54 cm apart.

The crops were grown at three locations in 1989 and 1990: the Plant Science Field Laboratories (PSF) at Knoxville, TN, which has an elevation of 253 m; the Tobacco Experiment Station (TES) near Greeneville, TN, which has an elevation of 402 m; and the Plateau Experiment Station (PES) near Crossville, TN, which has an elevation of 552 m. The three-crop sequences were not grown at PES due to the shorter growing season which prohibits the growth of three crops in one season.

The test was grown both years at PSF on an Etowah silt loam (fine-loamy, siliceous, thermic, Typic Paleudult); at TES on a Decatur silty clay loam (clayey, kaolinitic, thermic, Rhodic Paleudult); and at PES on a Lily loam (fine-loamy, siliceous, mesic, Typic Hapludult).

Wheat covers were seeded after fall tillage the year prior to each test. Broccoli transplants were greenhouse grown in Speedling trays (Speedling Corp., Sun City, FL). Seeding times were staggered to accommodate transplanting times. Plants were hardened in outdoor cold frames 2-3 weeks prior to transplanting. All tobacco transplants were grown at TES using normal plant bed practices. Plants were taken from TES to the other locations and transplanted the same day or the day after they were pulled.

Transplanting and harvest dates for both crops are listed in Table 3-1. Tobacco was not harvested either year at PES due to prolonged rain in 1989, which delayed transplanting beyond appropriate dates for tobacco, and severe hail in 1990, which destroyed the crop. Fall broccoli was not transplanted either year at PES or in 1990 at TES due to lateness of season. Fall broccoli was not harvested at any location since it never reached maturity.

Normal cultural practices were followed to the extent that plots could be treated similarly without

Table 3-1. Transplanting and harvesting dates for individual crops in different cropping sequences at Knoxville (PSF), Greeneville (TES), and Crossville (PES) in 1989 and 1990.

	Location					
	PSF		TES		PES	
	Plant.	Harv.	Plant.	Harv.	Plant.	Harv.
Sequence	1989					
Broccoli-BT[z]	29 Mar	29 May	13 Apr	8 Jun	19 Mar	14 Jun
Broccoli-BTB	17 Mar	18 May	28 Mar	24 May	NA[x]	NA
Tobacco-BT	1 Jun	5 Sep	26 Jun	14 Sep	30 Jun	X[y]
Tobacco-BTB	1 Jun	5 Sep	2 Jun	14 Sep	NA	NA
Tobacco-TB	1 Jun	5 Sep	2 Jun	14 Sep	30 Jun	X
Broccoli-BTB	21 Sep	X	10 Oct	X	NA	NA
Broccoli-TB	21 Sep	X	10 Oct	X	X	X
	1990					
Broccoli-BT	5 Apr	29 May	20 Apr	11 Jun	26 Apr	18 Jun
Broccoli-BTB	5 Apr	29 May	20 Apr	11 Jun	NA	NA
Tobacco-BT	6 Jun	18 Sep	14 Jun	11 Sep	20 Jun	X
Tobacco-BTB	6 Jun	18 Sep	14 Jun	11 Sep	NA	NA
Tobacco-TB	6 Jun	18 Sep	6 Jun	11 Sep	7 Jun	X
Broccoli-BTB	21 Sep	X	X	X	NA	NA
Broccoli-TB	21 Sep	X	X	X	X	X

[x] NA=not applicable. [y] X=no planting or harvest occurred. [z] BT=Broccoli/Tobacco; BTB=Broccoli/Tobacco/Broccoli; TB=Tobacco/Broccoli.

affecting tillage or sequence. Pest control followed recommended practices and was remedial except where treatments could be applied without soil incorporation. All crops were harvested at optimum maturity, with broccoli harvests never split into more than two harvests. Tobacco was harvested when > 50% of the plants were at optimum maturity.

Sequences were accomplished by following the preceding crop as soon as possible with the next crop in the sequence planted in the same plot area. Conventionally tilled plots were tilled between crops, while stubble left from no-till plots was burned down with glyphosate. Fertility for each crop was based on the recommendations for the individual crop, except in the three-crop treatments, where 67kg ha^{-1} N was added for the final broccoli crop.

Tobacco grade index was determined based on U.S. Government grades ascribed to cured leaf samples by a USDA inspector (Bowman, *et al.*, 1989). The index indicates cured leaf quality with higher numerical values denoting better quality. Analysis of leaf N content of dried leaf samples of cured tobacco and broccoli at harvest were determined using the Carlo Erba N Analyzer 1500 described by Colombo and Giazzi (1982). In broccoli, stem and head circumference measurements were taken from a subsample of five heads per plot.

Revenue data were analyzed as both a whole system and as component parts. Value of the entire cropping system (that is both or all three crops) was determined and compared to the component crops grown alone. Value for tobacco was based on USDA price supports and broccoli value was based on 11-year (1979-1989) weekly averages that matched the actual harvest weeks (Best, 1990). The total degree days accumulated for each crop, and for the entire crop sequence were determined and compared to actual degree days normally accumulated based on 30-year averages (J. Logan, personal communication) between spring and fall freezes. Degree day accumulation was based on the formula described by Arnold (1960) with base temperatures of 4 and 13°C for broccoli and tobacco, respectively (Best, 1990). Data for each crop were compared to the same crop in other sequences or under other tillage regimes. Data for yield, quality, revenue, stand, leaf N content, and broccoli head measurements were analyzed using the General Linear Mixed Model program described by Blouin and Saxton (1989). Tillage and sequence were considered to be fixed effects while replication and associated interactions were considered random. For analyses when data were combined, years, locations, and associated interactions were considered to be random. For analysis of individual locations, years and locations were not included in the model. Single-degree-of-freedom contrasts were used to make comparisons among treatments.

Results and discussion

No-till (NT) tobacco yields were significantly reduced over conventional tillage with cover (CC) and conventional tillage with no cover (CNC) at all locations except TES 1990 (Table 3-2). This is in agreement with Shilling, *et al.* (1986) and Moschler, *et al.* (1971). The conventional tillages showed no yield differences except at PSF 1989. Sequence had varying effects on yield depending on location (Table 3-2), but the tobacco-broccoli (TB) sequence tended to show lower yields than the other sequences. At locations where TB was not lowest it was not significantly different from the lowest yielding sequence. Differences among broccoli-tobacco (BT) and the three-crop sequence (BTB) varied by location and year as well, with BT producing significantly higher yields than BTB at TES 1989 and PSF 1990, but significantly lower at PSF 1989. Since planting dates for BT and BTB were almost identical, there is no plausible explanation for these differences. There was less variation among sequences at TES 1990, which had drier conditions than other environments.

Tobacco revenue was also negatively affected by reduced tillage, with lowest revenues in NT plots at all locations, except TES 1990 (Table 3-3), where there were no differences. Again this was likely due to drier conditions there than elsewhere. There was no overall difference among the conventional tillages for revenue except at PSF 1989 where CC was higher than CN as would be expected. Sequence effects on revenue were similar to those on yield. The TB sequence was generally lower, except at PSF in 1989 and TES in 1990, where differences between TB and the lowest yielding sequence were not significant.

Revenue is dictated by yield combined with quality. Yield and quality, as indicated by grade index, shows why revenues were lower under reduced tillage since no-till tobacco produced lower quality leaf in certain experiments (Table 3-4). This was true at PSF both years, but not so at TES. There were also no

Table 3-2. Mean yield of cured burley tobacco by environment and tillage combined over sequences and by environment and sequence combined over tillages.

	Environment			
Tillage (T)	PSF 1989	TES 1989	PSF 1990	TES 1990
	Yield (kg ha^{-1})			
No-Till (T1)	1970	1911	1156	2622
	135[z]	89	82	116
Conventional	2958	2153	1912	2530
(cover) (T2)	135	89	82	116
Conventional	2536	2222	1938	2638
(no cover) (T3)	135	89	82	116
Contrast	Probability > F			
T1 v T2	0.0001	0.0339	0.0001	0.5804
T1 v T3	0.0082	0.0085	0.0001	0.9252
T2 v T3	0.0400	0.5179	0.7744	0.5187
Sequence (S)				
Tobacco/Broccoli	2398	2044	1478	2634
(S1)	102	89	82	111
Broccoli/Tobacco	2402	2327	1856	2606
(S2)	102	89	82	111
Broc/Tob/Broc	2663	1914	1671	2549
(S3)	102	89	82	111
Contrast	Probability > F			
S1 v S2	0.9737	0.0150	0.0004	0.8601
S1 v S3	0.0320	0.2347	0.0394	0.5883
S2 v S3	0.0343	0.0010	0.0483	0.7140

[z] Standard error appears below each mean.

Table 3-3. Mean revenue of cured burley tobacco by environment and tillage combined over sequences and by environment and sequence combined over tillages.

	Environment			
Tillage (T)	PSF 1989	TES 1989	PSF 1990	TES 1990
	Revenue ($ ha^{-1})			
No-Till (T1)	6780	6313	3680	8894
	481[z]	349	309	498
Conventional (cover) (T2)	10372	7220	6659	8808
	481	348	309	498
Conventional (no cover) (T3)	8697	7400	6933	8803
	481	348	309	498
Contrast	------------------------Probability > F------------------------			
T1 v T2	0.0001	0.0439	0.0001	0.9029
T1 v T3	0.0114	0.0181	0.0001	0.8966
T2 v T3	0.0241	0.6684	0.4280	0.9936
Sequence (S)				
Tobacco/Broccoli (S1)	8326	6830	4886	9048
	360	348	309	421
Broccoli/Tobacco (S2)	8319	7719	6479	8652
	360	348	309	421
Broc/Tob/Broc (S3)	9203	6385	5906	8808
	360	348	309	421
Contrast	------------------------Probability > F------------------------			
S1 v S2	0.9832	0.0475	0.0002	0.4669
S1 v S3	0.0401	0.3010	0.0075	0.6578
S2 v S3	0.0384	0.0051	0.1082	0.7729

[z] Standard error appears below each mean.

Table 3-4. **Mean grade index of cured burley tobacco by environment and tillage combined over sequences and by environment and sequence combined over tillages.**

	Environment			
Tillage (T)	PSF 1989	TES 1989	PSF 1990	TES 1990
	Grade Index			
No-Till (T1)	62.94	53.33	54.27	56.63
	1.49[z]	4.45	1.29	3.42
Conventional (cover) (T2)	69.16	54.90	61.54	59.93
	1.49	4.43	1.29	3.42
Conventional (no cover) (T3)	64.63	54.87	64.65	53.53
	1.49	4.43	1.29	3.42
Contrast	------------------------Probability > F------------------------			
T1 v T2	0.0003	0.7900	0.0001	0.5023
T1 v T3	0.2351	0.7944	0.0001	0.5304
T2 v T3	0.0039	0.9955	0.0512	0.2020
Sequence (S)				
Tobacco/Broccoli (S1)	66.59	55.94	57.45	60.03
	1.49	4.30	1.29	3.42
Broccoli/Tobacco (S2)	64.83	53.81	61.42	50.56
	1.49	4.32	1.29	3.42
Broc/Tob/Broc (S3)	65.30	53.34	61.59	59.51
	1.49	4.30	1.29	3.42
Contrast	------------------------Probability > F------------------------			
S1 v S2	0.2157	0.7043	0.0158	0.0658
S1 v S3	0.3584	0.6426	0.0123	0.9160
S2 v S3	0.7374	0.9332	0.9077	0.0805

[z] Standard error appears below each mean.

differences among sequences for grade index except at PSF 1990, where TB quality was lower than both other cropping sequences.

Survival of tobacco as reflected by stand counts was not significantly altered by tillage which agrees with results of Phillips and Zeleznik (1989). Sequence had no effect on survival except at PSF where stand was higher in TB sequences (43.4 plants plot^{-1}) than BT (36.0) or BTB (36.6). Stand in BT (49.0) was also significantly higher than in TB (42.6) and BTB (41.0) at TES 1989. The differences at PSF were likely due to the moderately sloping, eroded soils on the site which were compacted, causing difficulty in transplanting tobacco following broccoli in no-till plots.

Neither, tillage nor sequence had a significant effect on tobacco leaf N content except at PSF 1989 where TB (3.80%) was significantly lower than BTB (4.13). Averages for leaf N were on the order of 4.03% (TB), 4.10 (BT) and 4.08 (BTB) for sequences. NT produced plants slightly lower in total N (4.02%) than plants from either CC (4.10) or CN (4.09).

Tillage effects on spring broccoli yield were similar to its effects on tobacco as in both instances yield was decreased in NT (Table 3-5). Yield was significantly lower at all locations except at PSF in 1989 and at TES in 1990. Yields in CN were also significantly higher than in CC except at TES in 1989 and 1990, and at PES in 1990. Soft rot in some broccoli heads from CN plots at TES affected marketable yields. Residue in NT plots and in CC plots appeared to suppress yields in those plots compared to those in CN plots. This could be attributed to several factors associated with no-till production and cover crop residues. There were no significant differences among sequences for broccoli yield, although BT yields tended to be slightly higher than BTB yields. This was probably due to BTB being transplanted slightly earlier than ideal for spring broccoli in eastern Tennessee. Sequence effects were consistent across locations. There were no data for fall broccoli since fall plantings were too late for broccoli to mature.

Marketable head size was also reduced in NT and followed a pattern of decreasing head size with decreasing cover (Table 3-6). NT produced consistently smaller heads at all locations except PSF in 1989. Only at TES in 1989 did CC produce larger heads than CN. Head size was not affected by sequence except at TES 1989 where BT (196g) was significantly larger than BTB (105g). There were no differences at the

Table 3-5. Mean yield of broccoli by environment and tillage combined over sequences.

	Tillage (T)			
Environment	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	Contrast/Prob. > F
	Yield (10.43 kg boxes ha^{-1})			
PSF 1989	251.3 27.7[z]	239.2 27.7	651.1 27.7	T1 v T2/0.7643 T1 v T3/0.0001 T2 v T3/0.0001
TES 1989	50.3 72.2	463.4 72.2	391.6 72.2	T1 v T2/0.0009 T1 v T3/0.0031 T2 v T3/0.4213
PES 1989	63.1 83.3	531.6 83.3	906.9 83.3	T1 v T2/0.0006 T1 v T3/0.0001 T2 v T3/0.0021
PSF 1990	553.2 42.6	722.2 42.6	851.4 42.6	T1 v T2/0.0078 T1 v T3/0.0002 T2 v T3/0.0272
TES 1990	698.8 107.8	927.2 107.8	505.1 107.8	T1 v T2/0.1682 T1 v T3/0.2359 T2 v T3/0.0218
PES 1990	163.3 52.8	512.2 52.8	636.3 52.8	T1 v T2/0.0034 T1 v T3/0.0007 T2 v T3/0.1473

[z] Standard error appears below each mean.

Table 3-6. Mean marketable head size of broccoli by environment and tillage combined over sequences.

	Tillage (T)			
Environment	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	Contrast/Prob. > F
	Marketable Head Size (g)			
PSF 1989	125.9	125.9	200.7	T1 v T2/0.9999
	6.9[z]	6.9	6.9	T1 v T3/0.0001
				T2 v T3/0.0001
TES 1989	106.6	180.9	163.3	T1 v T2/0.0032
	16.3	16.3	16.3	T1 v T3/0.0140
				T2 v T3/0.3707
PES 1989	88.5	162.2	269.9	T1 v T2/0.0079
	24.2	24.2	24.2	T1 v T3/0.0001
				T2 v T3/0.0013
PSF 1990	185.0	220.0	251.7	T1 v T2/0.0027
	10.0	10.0	10.0	T1 v T3/0.0001
				T2 v T3/0.0045
TES 1990	233.1	349.3	358.3	T1 v T2/0.0144
	27.2	27.2	27.2	T1 v T3/0.0099
				T2 v T3/0.8187
PES 1990	76.0	158.8	198.5	T1 v T2/0.0034
	9.8	9.8	9.8	T1 v T3/0.0007
				T2 v T3/0.1473

[z] Standard error appears below each mean.

other five environments. Head size as measured by weight also reflects the same results as seen in head and stem circumferences. Head circumference was significantly lower in NT except at Knoxville where it was still significantly lower than CN but was no different from CC. Overall means reflect the same results with heads from NT plots measuring 26.96cm, CC, 34.26, and CN, 38.17. Stem circumference followed the same pattern with measurements of 9.97cm (NT), 11.36 (CC), and 12.06 (CN). Sequences of BT produced slightly larger head and stem circumferences (34.94 and 11.36cm) as opposed to BTB (31.33 and 10.9cm), although the differences were significant only at TES in 1989.

NT produced less marketable broccoli overall (74% of total yield) than either CC (96%) or CN (91%), but differences were significant only at TES and PES in 1989. There were no differences for percent marketability among sequences, with both sequences producing greater than 84% marketable broccoli. Broccoli leaf total N was not significantly affected by either tillage or sequence. Total leaf N was on the order of 3.34% (NT), 3.20 (CC), and 3.44 (CN) among tillages and 2.98% (BT) and 3.68 (BTB) among sequences. NT produced significantly higher N at TES in 1989 (5.26% vs 4.36 for CC, and 4.41 for CN), and NT (4.15) and CC (4.03) were significantly lower than CN (4.55) at TES in 1990. Higher leaf N occurred in CN plots (2.53%) than either NT (1.02%) or CC (1.30%) at PES in 1989 and both CC (0.82%) and CN (0.78%) were higher than NT (0.62%) at PES in 1990.

Total combined revenues for broccoli and tobacco were also reduced in NT over both conventional systems at all environments except at TES in 1990 (Table 3-7). There were no differences between conventional systems except in 1990 where results were reversed for PSF and TES. Sequences of TB produced lower revenues than either other sequence since there was no fall broccoli revenue for this sequence. There were no differences between BT and BTB except at TES in 1989.

Actual growing degree day accumulation for crops grown in 1989 and 1990 would fall within the ranges based on 30-year averages when target planting dates are met (Table 3-8). Some tobacco sequences required more degree days than the 30-year average indicates would accumulate; however, tobacco in these experiments could have been harvested several days sooner with > 50% of plants at optimum maturity.

Table 3-7. Mean value of tobacco-broccoli cropping systems by environment and tillage combined over sequences and by environment and sequence combined over tillages.

	Environment			
Tillage (T)	PSF 1989	TES 1989	PSF 1990	TES 1990
	Value ($ ha^{-1})			
No-Till (T1)	8316	6622	7074	13168
	526[z]	585	324	835
Conventional (cover) (T2)	11834	10053	11073	14477
	526	583	324	835
Conventional (no cover) (T3)	12679	9796	12138	11891
	526	583	324	835
Contrast	------------------------Probability > F------------------------			
T1 v T2	0.0002	0.0003	0.0001	0.2822
T1 v T3	0.0001	0.0006	0.0001	0.2942
T2 v T3	0.2725	0.7379	0.0324	0.0420
Sequence (S)				
Tobacco/Broccoli (S1)	8326	6830	4886	9048
	405	558	324	635
Broccoli/Tobacco (S2)	11878	11844	12928	15203
	405	561	324	635
Broc/Tob/Broc (S3)	12622	7795	12471	15284
	405	558	324	635
Contrast	------------------------Probability > F------------------------			
S1 v S2	0.0001	0.0001	0.0001	0.0001
S1 v S3	0.0001	0.1844	0.0001	0.0001
S2 v S3	0.1262	0.0001	0.3341	0.9104

[z] Standard error appears below each mean.

Table 3-8. Growing degree days actually accumulated for crops in 1989 and 1990 and average accumulated during a similar time period over the last 30 years.[x]

Crop/ Sequence	Environment					
	PSF 1989	TES 1989	PES 1989	PSF 1990	TES 1990	PES 1990
	Degree Days Actually Accumulated					
Broc/B-T[y]	1118	1195	1191	1115	1269	1184
Broc/B-T-B	942	911	NA[z]	1115	1269	NA
Tob/B-T	1849	1585	X	2104	1717	X
Tob/B-T-B	1849	1966	NA	2104	1717	NA
Tob/T-B	1849	1966	X	2104	1827	X
Broc/B-T-B	X	X	NA	X	X	NA
Broc/T-B	X	X	X	X	X	X
	PSF		TES		PES	
	Target Planting Dates And Degree Days Usually Accumulated (30-year average)					
Broc/B-T	15 Mar	1272	20 Mar	1345	25 Mar	1198
Broc/B-T-B	1 Mar	979	10 Mar	1128	NA	NA
Tob/B-T	30 May	2438	5 June	2198	5 June	1817
Tob/B-T-B	15 May	1721	25 May	1706	NA	NA
Tob/T-B	1 May	1540	10 May	1577	15 May	1357
Broc/B-T-B	20 Aug	1793	30 Aug	1271	NA	NA
Broc/T-B	5 Aug	2331	15 Aug	1783	20 Aug	1417

[x] See table 3-1 for transplanting and harvesting dates for different cropping sequences at the respective environments. Source for 30-year averages, personal communication, J. Logan, University of Tennessee, Knoxville. [y] Broc=broccoli; Tob=Tobacco; B-T=Broccoli/Tobacco Sequence; B-T-B=Broccoli/Tobacco/Broccoli Sequence; T-B=Tobacco/Broccoli Sequence. Next crop was assumed to be planted withing one week of harvest of previous crop. Final dates for all crops were based on 50% possibility of 0°C temperatures. [z] NA=not applicable. X=not planted or harvested.

Several plots were in the field in excess of 95 days, which is outside the usual time to maturity for this 88 day cultivar.

Conclusions

Both tobacco and broccoli yields were decreased under reduced tillage systems. Numerous factors including soil compaction, moisture availability, mineral deficiencies, insect and disease pressure, or deleterious effects of cover crops could be responsible for these reductions. It was not the purpose of this study to isolate the cause, but to investigate the feasibility of reduced tillage in these systems. At present, more work is necessary to elucidate the reasons for reductions in yields in no-till systems before they can be implemented commercially, particularly in vegetable systems.

Under these experimental conditions, it was impossible to produce sequences which contained a fall broccoli crop. In systems where only one sequence is being managed, however, fall broccoli following a summer tobacco crop appears feasible. Weather data indicate that when target transplanting and harvest dates are met there are sufficient growing degree days to produce fall broccoli crops. It is definitely possible, however, to produce a spring vegetable crop follwed by a tobacco crop. Farm revenues could potentially be increased in such systems. Two-crop sequences may be easier to manage and would insure more time to produce the fall cover crop.

References

Arnold, C. 1960. Maximum-minimum temperatures as a basis for computing heat units. Proc. Amer. Soc. Hort. Sci. 76:682-692.

Best, M.J. 1990. Sequential cropping of vegetables for market windows. M.S. Thesis. Univeristy of Tennessee. Knoxville, TN.

Blouin, D.C., and A.M. Saxton. 1989. General linear mixed models user's manual version 1.0. Louisiana Agric. Exp. Stn. Tech. Report Ser. No. TR-89-001.

Bowman, D.T., R.D. Miller, A.G. Tart, C.M. Sasscer, Jr., and R.C. Rufty. 1989. A grade index for burley tobacco. Tob. Sci. 33:18-19.

Brown, J.E., W.E. Splittstoesser and J.M. Gerber. 1985. Production and economic returns of vegetable intercropping systems. J. Amer. Soc. Hort. Sci. 110(3):350-353.

Chappell, W.E. and L.A. Link. 1977. Evaluation of herbicides in no-tillage production of burley tobacco. (*Nicotiana tabacum*). Weed Science. 25(6):511-514.

Coffey, D.L. and P.W. Ramsey. 1987. Sequential cropping of vegetables on black plastic. Tennessee Farm and Home Science. 144:19-21.

Colombo, B., and G. Giazzi. 1982. Total automatic nitrogen determination. Amer. Lab. pp. 38-45.

Hawks, S.N., Jr. and W.K. Collins. 1970. Effects of a herbicide and levels of cultivation on yield and value of flue-cured tobacco. Tob. Sci. 14:170-172.

Link, L.A. 1984. An evaluation of no-tillage culture for burley tobacco. Virginia Agric. Exp. Stn. Bull. 84-86.

Morrison, J.E., Jr. D.C. Milbocker, W.O. Atkinson, and J.H. Smiley. 1973a. Transplanter modification and survival of transplants under no-till conditions. HortScience 8:483-485.

Morrison, J.E., Jr., J.H. Smiley, W.O. Atkinson and D.C. Milbocker. 1973b. A no-tillage transplanter. Tob Sci. 17:44-46.

Morrison, J.E. 1974. No-tillage transplanting. 87th Annual Report of the College of Agric. Agric. Exp. Sta. Univ. Ky. pp. 11.

Moschler, W.W., G.M. Shear, M.J. Rogers and T.R. Terrill. 1971. No-tillage tobacco studies in Virginia. Tob. Sci. 15:12-14.

Phillips, R.E., R.L. Blevins. G.W. Thomas, W.W. Frye and S.H. Phillips. 1980. No-tillage agriculture. Science. 208:1108-1113.

Phillips, R.E. and J.M. Zeleznik. 1989. Production of burley tobacco using no-tillage and conventional tillage. J. Prod. Agric. 2(4):343-346.

Rowe-Dutton, P. 1957. The mulching of vegetables. Tech. Comm. No. 24. Commonwealth Bureau of Horticulture and Plantation Crops. East Malling, Maidstone, Kent. pp. 11-19, 119-146.

Shilling, D.G., A.D. Worsham and D.A. Danehower. 1986. Influence of mulch, tillage, and diphenamid on weed control, yield, and quality in no-till flue-cured tobacco (*Nicotiana tabacum*). Weed Science. 34:738-744.

Triplett, G.B., Jr. and D.M. Van Doren, Jr. 1977. Agriculture without tillage. Sci. Am. 236:28-33.

Upchurch, W. 1987. Growing burley tobacco without plowing. Progressive Farmer. 102:41.

Wood, S.D. and A.D. Worsham. 1986. Reducing soil erosion in tobacco fields with no-tillage transplanting. J. Soil Water Conserv. 41:193-196.

Worsham, A.D. 1984. Crop residues kill weeds: Allelopathy at work with wheat and rye. Crops and Soils. 37(2):18-20.

Worsham, A.D. 1985. No-till tobacco (*Nicotiana tabacum*) and peanuts (*Arachis hypogea*). *In* A.F. Wiese (ed.) Weed control in limited-tillage systems. Mono. Ser. No. 2, Weed Sci Soc. Am., Champaign, Ill. pp. 101-126.

Chapter 4

SEQUENTIAL CROPPING OF BROCCOLI AND TOMATOES UNDER VARIOUS TILLAGE SYSTEMS

Abstract

There are many spring and fall vegetable market windows in eastern Tennessee, where most vegetables are also grown on erodible land. Thus, an investigation was initiated on the effects of different tillage systems on sequential cropping of broccoli (*Brassica oleracea* L. var. *italica*) with tomatoes (*Lycopersicon esculentum* Mill.). Three tillage systems (no-till, conventional with a winter cover, and conventional with no cover) and three cropping sequences (broccoli-tomatoes, broccoli-tomatoes-broccoli, and tomatoes-broccoli) were examined at three locations in 1989 and 1990. Yield and quality data were taken and analyzed with mixed models. Reduced tillage adversely affected broccoli yield but had no effect on tomato yield. Reduced tillage increased occurrence of No. 1 tomato fruit and decreased percentage of cull fruit. Tomatoes yielded somewhat higher when planted before than after broccoli. Sequence had little effect on broccoli yield. Although fall broccoli was not successful in these experiments, 30-year degree day data strongly suggests that it may be successful in most years if tomatoes are terminated after peak harvest.

Introduction

Single crop, conventionally tilled systems have been the traditional methods for production of high value crops. Although minimum tillage has been adopted in many crops, its adoption in vegetable crops, such as broccoli and tomatoes, has been slow. Legislation requiring erosion control practices on erodible land has forced producers to use conservation practices. With trends toward fewer producers, increasing food demands, and producers' needs to increase profits, growers are forced to get maximum production out of their most productive land. This often requires use of multiple cropping systems.

There is potential in eastern Tennessee to take advantage of many spring or fall vegetable market windows. The addition of a spring or fall crop, or both, prior to and/or following a summer annual crop may be feasible. The production of these crops in most of eastern Tennessee would be on marginally to highly erodible land where reduced tillage practices would be required. Most vegetable crops, such as tomatoes, pepper (*Capsicum annum* L.), broccoli, cabbage (*Brassica oleracea* L. var. *capitata*) and cauliflower (*Brassica oleracea* L. var. *botrytis*), are not generally grown in minimum tillage systems. Phillips *et al.*, (1980) stated that the acreage of land that can safely be used for row crops would be increased with reduced tillage since such crops can be grown on sloping land that would be subject to erosion under conventional tillage.

Vegetable growers bury plant debris to decrease disease problems. Vegetables are usually not grown on marginal land since crops require smooth, even seedbeds for uniform stands which, are more important in high value vegetable crops than in agronomic crops (Sumner, *et al.*, 1986). Tillage causes soil compaction, requires favorable soil moisture, causes wind and water erosion, and splatters crops with soil, which decreases quality and increases occurrence of disease, all which interfere with maximum production of high value crops (Morrison, *et al.*, 1973a & 1973b). Reduction of herbicide runoff; savings of time, labor and fuel; soil moisture conservation; increased rainfall intake; and maintenance of soil structure have also been cited as advantages of reduced tillage and cover mulches (Triplett and Van Doren, 1977). USDA personnel have predicted that 90% of the U.S. crop acreage will be under reduced tillage by 2010 (Triplett and Van Doren, 1977).

Many no-till researchers have utilized small grain covers such as rye (*Secale cereale* L.), wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.), which are burned down with Paraquat (1,1'-dimethyl-4,4'-bipyridiniumion) or glyphosate (N-(phosphonomethyl)glycine) prior to planting directly into the killed mulch (Chappell and Link, 1977). However, little research has been done in no-till vegetables and research has been non-existent on using reduced tillage in sequential vegetable cropping systems.

In Alabama, marketable tomato yields on complete tillage plots were higher than strip-tillage plots, which were higher than no-till plots (Doss, *et al.*, 1981). Crops from plots with rye on them tended to have lower yields than plots without rye. Percentage of marketable tomatoes considered large fruit was greater with complete tillage than with reduced tillage. Cull fruit was not affected by tillage. This agrees with the findings of Hoyt (1984), who reported decreased tomato yields when rye was used as a cover crop. Spicer (1983) disagreed, finding increased yield in strip-tilled tomatoes in Canada was due to decreased sandblasting injury. Input costs were also lower in a strip-till system. Marketable tomato yield was not affected by tillage in a three-year study of strip-till vs conventional with a rye cover (McKeown, *et al.*, 1988). Increased nematode populations were found in rye and strip-till plots.

In a study involving several vegetable crops, Beste (1983) found no-till tomato yield exceeded conventional tillage in two of four years when tomatoes were direct seeded into a 20 inch killed rye cover. Yields were equal the remaining years. Early seedling growth was greater in no-till and plant height was equal at fruit set. 'Campbell 28' produced greater early no-till yield than other cultivars. Snapbeans yielded equally in no-till and conventional in four of five years and lima beans in 3 of 4 years. Sweet corn and peas yielded greater or equally in no-till.

In an earlier study, tomato maturity was significantly earlier, plants grew and developed faster, and soil temperatures were higher in no-till than conventional tillage (Beste, 1973). When tomatoes were direct seeded with a 'Planet Jr.' into a rye cover killed with paraquat, yields were equal compared to conventional tillage. Cucumber yields were lower in no-till. Lima bean yield was equal, but early growth was greater in no-till.

Straw mulch after transplanting increased tomato yield compared to a bare check (Estes, *et al.*, 1985). In mulched plots, significantly greater numbers of extra large and large fruit were recorded, and less medium and number three fruit occurred. Average weight per fruit was greater with mulch. No difference was seen for early blight, blossom end rot, or fruitworm. Annual grass control was significantly greater with straw mulch.

Mulches such as straw were reported to give yield increases in Brassicas under low moisture conditions (Rowe-Dutton, 1957). However, the crops were liable to suffer from decreased nitrate supply and additional N was recommended. Mulching tomatoes under dry conditions, provided soil temperatures were high enough, increased yields but delayed maturity. Nitrogen deficiencies were possible but the practice was recommended to keep fruit off the soil to reduce soil-borne diseases.

A modified transplanter with rolling coulters, double disc openers, gauge wheels, narrow press wheels, and ballast weights on the frame and press wheels was used to successfully transplant tomato and pepper plants into chemically killed sod and cereal straw (Morrison, *et al.*, 1973a, 1973b & Morrison, 1974). Transplant survival was lower in no-till plots than conventional due to increased insect and disease damage.

Soil loss was 20-90 times greater in conventional till vs no-till, where a rye mulch and a Mechanical Transplanter Model MT-100 were used (Wood and Worsham, 1986). Runoff in no-till was 23.4cm vs 20.8 for conventional in 1982, and 11.3cm in no-till vs 13.1 for conventional in 1983.

Intercroppings of tomatoes and cabbage, as well as collards and muskmelon, have been investigated (Brown, *et al.*, 1985). Tomatoes in monocrop resulted in highest net returns, followed by the tomato/cabbage combination. Other combinations did not result in significantly different net returns. Cabbage/tomato and collard/muskmelon combinations produced yields and net returns that were generally comparable to either crop grown alone. Total N, plant height, and yield of tomatoes were greater in one year when tomato was intercropped with cabbage. Tomato yield was not affected when supplemental N was applied. Production costs of tomatoes grown alone were greater than when tomatoes were grown with cabbage. No differences were seen in cabbage whether intercropped or grown alone.

Gross returns in sequential crops of tomato and broccoli were superior to either grown alone (Coffey and Ramsey, 1987). Gross returns were not increased when broccoli was grown in combination with squash or pepper over pepper or squash grown alone. Spring and fall plantings of broccoli with summer squash did not increase returns over squash alone. Returns for two crops of broccoli were superior to a single planting of broccoli.

Phillips *et al.*, (1980) suggested that the advantages of reduced tillage are more important in multiple cropping systems. Reduced moisture loss at planting time ensuring stands of second and third crops under restricted rainfall; production of more than one crop per year increasing land use; elimination of plowing and land preparation; and time saved in planting second and third crops, were all cited as increased advantages of no-till. Harvesting could be followed immediately by planting of a second crop, thus reducing lag time between crops.

Materials and methods

Early maturing cultivars that are commercially available and representative of cultivars recommended for eastern Tennessee were used in the study. 'Sunny' hybrid tomatoes and 'Packman' hybrid broccoli, a cultivar which matures in approximately 60 d, were used to facilitate early harvests.

Treatments consisted of factorial combinations of three tillage systems and three cropping sequences arranged in a strip-plot design. Sequences were stripped across tillages. The tillage systems consisted of conventionally tilled plots with no winter cover; conventionally tilled plots with a wheat winter cover; and no-till plots in which crops were transplanted directly into a wheat cover that had been burned down with paraquat prior to transplanting.

The three crop treatment consisted of spring broccoli followed by tomatoes, followed by fall broccoli. Two-crop treatments consisted of spring broccoli followed by tomatoes, or tomatoes followed by fall broccoli. There were four replications of each treatment.

Broccoli plots consisted of three-row plots with the center row harvested in each plot, each row was 5.5 m long. Broccoli plants were spaced 31 cm apart in rows 137 cm apart. Tomatoes were planted in identical rows with plants spaced 45 cm apart.

The crops were grown at three locations in 1989 and 1990: the Plant Science Field Laboratories (PSF) at Knoxville, TN, which has an elevation of 253 m; the Tobacco Experiment Station (TES) near Greeneville, TN, which has an elevation of 402 m; and the Plateau Experiment Station (PES) near Crossville, TN, which has an elevation of 552 m. Only the two-crop sequences were grown at Crossville.

The test was conducted both years at PSF on an Etowah silt loam (fine-loamy, siliceous, thermic, Typic Paleudult); at TES on a Decatur silty clay loam (clayey, kaolinitic, thermic, Rhodic Paleudult); and at PES, on a Lily loam (fine-loamy, siliceous, mesic, Typic Hapludult).

Wheat covers were seeded after fall tillage the year prior to each test. Broccoli and tomato transplants were greenhouse grown in Speedling (Speedling, Corp., Sun City, FL) trays. Seeding times were staggered to accommodate transplanting times. Plants were hardened in outdoor cold frames 2-3 weeks prior to transplanting.

Transplanting and harvesting dates for both crops are listed in Table 4-1. Tomato yield data was not recorded at PES due to prolonged rain in 1989, which delayed planting too long to accommodate experimental objectives, and severe hail in 1990, which destroyed the crop. Fall broccoli was not transplanted either year at PES or in 1990 at TES due to lateness of season. Fall broccoli was not harvested at any location since it never reached maturity.

Normal cultural practices were followed to the extent that plots could be treated similarly without affecting tillage or sequence. Reccomended pest control practices were applied where treatments could be applied without soil incorporation and were otherwise remedial. Tomatoes were staked using a Florida weave system. All crops were harvested at optimum maturity, with broccoli harvests never split into more than two harvests. Tomatoes were harvested two times per week until fruit set ceased.

Sequences were accomplished by following the preceding crop as soon as possible with the next crop in the sequence planted in the same plot area. Conventionally tilled plots were tilled between crops while stubble left from no-till plots was burned down with glyphosate. Fertility for each crop was based on the recommendations for the individual crop, except in the three-crop treatments where 67 kg ha^{-1} N was added for the fall broccoli crop.

Analysis of leaf N content from dried leaf samples of tomatoes and broccoli at harvest was determined using the Carlo Erba N Analyzer 1500 described by Colombo and Giazzi (1982). In broccoli, stem and head circumference measurements were taken from a subsample of five heads per plot. Tomatoe fruits were graded into No. 1, No. 2, and culls according to USDA standards (USDA, 1976).

Value data were analyzed as both a whole system and as component parts. Value of the entire cropping sequence (that is both crops) was determined and compared to the component crops alone. Values for both crops were based on 11-year (1979-1989) weekly averages that matched the actual harvest weeks

Table 4-1. Transplanting and harvesting dates for individual crops in different cropping sequences at Knoxville (PSF), Greeneville (TES), and Crossville (PES) in 1989 and 1990.

	Location					
	PSF		TES		PES	
	Plant.	Harv.	Plant.	Harv.	Plant.	Harv.
Sequence	1989					
Broccoli-BT[z]	29 Mar	29 May	13 Apr	8 Jun	19 Apr	14 Jun
Broccoli-BTB	17 Mar	18 May	28 Mar	24 May	NA[x]	NA
Tomato-BT	23 Jun	7 Sep	26 Jun	6 Sep	30 Jun	X[y]
Tomato-BTB	23 May	31 Aug	2 Jun	6 Sep	NA	NA
Tomato-TB	10 May	31 Aug	19 May	6 Sep	30 Jun	X
Broccoli-BTB	21 Sep	X	10 Oct	X	NA	NA
Broccoli-TB	21 Sep	X	10 Oct	X	X	X
	1990					
Broccoli-BT	5 Apr	29 May	20 Apr	12 Jun	26 Apr	18 Jun
Broccoli-BTB	5 Apr	29 May	20 Apr	12 Jun	NA	NA
Tomato-BT	4 Jun	4 Sep	14 Jun	12 Sep	20 Jun	X
Tomato-BTB	4 Jun	4 Sep	14 Jun	12 Sep	NA	NA
Tomato-TB	16 May	4 Sep	23 May	12 Sep	25 May	X
Broccoli-BTB	21 Sep	X	X	X	NA	NA
Broccoli-TB	21 Sep	X	X	X	X	X

[x] NA=not applicable. [y] X=no planting or harvest occurred. [z] BT=Broccoli/Tomato; BTB=Broccoli/Tomato/Broccoli; TB=Tomato/Broccoli.

(Best, 1990). Value of No. 2 tomatoes was based on 60% of No. 1 value. The total degree days accumulated for each crop, and for the entire crop sequence, were determined and compared to actual degree days normally accumulated between spring and fall freezes based on 30-year averages (J. Logan, personal communication). Degree day accumulation was based on the formula described by Arnold (1960) with base temperatures of 4 and 13°C for broccoli and tomatoes, respectively (Best, 1990). Data for each crop were compared to the same crop in other sequences or under other tillage regimes. Data for yield, quality, revenue, stand, leaf N content, and broccoli head measurements were analyzed using the General Linear Mixed Model program described by Blouin and Saxton (1989). Tillage and sequence were considered to be fixed effects while years, locations, replication and associated interactions were considered random for analyses when data were combined across years and locations. For analysis of individual environments, years and locations were not included in the model. Single-degree-of-freedom contrasts were used to make comparisons among treatments.

Results and discussion

Yield and subsequently, value of No. 1 tomatoes was not affected by tillage, except at TES in 1989 where no-till (NT) yields were significantly lower than conventional tillage yields, and at PSF in 1989 where NT yields were higher than yields in conventional tillage with no cover (CN) (Table 4-2). Tomato-broccoli (TB) sequence produced the highest yield of No. 1 tomatoes in all environments, except PSF 1990. The differences were not significant at PSF 1990, nor different from broccoli-tomato-broccoli (BTB) at PSF in 1989 (Table 4-2). Tomatoes in the BTB sequence yielded higher in 1989 than in the broccoli-tomato (BT) sequence, but there was no difference in 1990. The TB and BTB sequences had greater yields since those plants were transplanted earlier, and nearer to the optimum time for tomato transplanting at those sites, whereas in BT sequences they were transplanted somewhat later than normal.

Percentage of cull fruit generally increased with decreasing cover except at TES 1989 (Table 4-3). Plants in NT plots produced significantly fewer cull fruit at PSF both years than those in CN tillage. There were no tillage differences at TES either year, nor between NT and conventional with cover (CC). The

Table 4-2. Mean yield of No. 1 grade tomatoes by environment and tillage combined over sequences and by environment and sequence combined over tillages.

	Environment			
Tillage (T)	PSF 1989	TES 1989	PSF 1990	TES 1990
	No. 1 Yield (11.34 kg boxes ha^{-1})			
No-Till (T1)	858	890	812	1043
	120[z]	106	100	176
Conventional	744	1461	857	1033
(cover) (T2)	120	106	100	176
Conventional	498	1349	877	1204
(no cover) (T3)	120	106	100	176
Contrast	Probability > F			
T1 v T2	0.5108	0.0007	0.7498	0.9617
T1 v T3	0.0476	0.0043	0.6495	0.4560
T2 v T3	0.1628	0.4374	0.8915	0.4282
Sequence (S)				
Tomato/Broccoli	893	2086	860	1742
(S1)	98	106	100	139
Broccoli/Tomato	369	149	874	857
(S2)	98	106	100	139
Broc/Tom/Broc	838	1465	812	680
(S3)	98	106	100	139
Contrast	Probability > F			
S1 v S2	0.0003	0.0001	0.9234	0.0001
S1 v S3	0.6489	0.0003	0.7381	0.0001
S2 v S3	0.0010	0.0001	0.6673	0.0902

[z] Standard error appears below each mean.

Table 4-3. Mean percentage by weight of cull tomatoes by environment and tillage combined over sequences and by environment and sequence combined over tillages.

	Environment			
Tillage (T)	PSF 1989	TES 1989	PSF 1990	TES 1990
	Cull Fruit (%)			
No-Till (T1)	22.0	27.0	27.7	14.9
	3.3[z]	3.7	2.0	1.3
Conventional (cover) (T2)	29.1	24.2	32.8	17.7
	3.3	3.7	2.0	1.3
Conventional (no cover) (T3)	35.2	25.3	36.3	17.8
	3.3	3.7	2.0	1.3
Contrast	------------------------Probability > F------------------------			
T1 v T2	0.1462	0.5915	0.0843	0.1605
T1 v T3	0.0113	0.7516	0.0064	0.1379
T2 v T3	0.2085	0.8245	0.2245	0.9303
Sequence (S)				
Tomato/Broccoli (S1)	23.7	28.6	35.6	17.3
	2.5	3.0	2.0	1.3
Broccoli/Tomato (S2)	38.8	15.9	30.7	18.6
	2.5	3.0	2.0	1.3
Broc/Tom/Broc (S3)	23.8	32.0	30.4	14.6
	2.5	3.0	2.0	1.3
Contrast	------------------------Probability > F------------------------			
S1 v S2	0.0001	0.0035	0.0941	0.4664
S1 v S3	0.9511	0.3762	0.0797	0.1540
S2 v S3	0.0001	0.0005	0.9294	0.0385

[z] Standard error appears below each mean.

PSF site was a continuous vegetable cropping area, whereas the TES site was on previously fallow ground. Therefore, more disease inoculum was present at PSF, which resulted in more diseased fruit from soil-borne pathogens, which were more easily splattered onto fruit from unmulched plots. Percentages of cull fruit occurring among sequences varied according to year and location. Each sequence produced largest percentages of cull fruit at least at one environment.

There were no significant differences for total tomato value (No. 1 + No. 2) among tillages except at TES 1989 where NT was lower than CN and CC (Table 4-4). Except at PSF 1989, NT produced the lowest total value among tillages. The TB sequence produced higher total value at TES than either other sequence. At PSF in 1989, BT total value was lower than TB and BTB. There were no differences among sequences at PSF in 1990. Tomatoes in BTB were transplanted earlier in 1989 than in 1990. Thus, results in 1989 reflected that these tomatoes were grown during the more optimal part of the tomato growing season. In 1989, BT tomatoes produced the lowest total value probably due to being transplanted later.

Since the largest percentages of tomatoes were always classified as No. 2 quality fruit, total value was strongly affected by yield and value of No. 2 tomatoes. Tillage and sequence means followed the same orders for yield and value of No. 2 tomatoes as they did for total value of tomatoes. Value for No. 2 tomatoes was always highest in NT (\$16,890 ha^{-1}) for TB compared to CC and CN (\$12,760 and \$15,482, respectively) and lowest for NT (\$9845) in BTB compared to CC and CN (\$12,189 and 12,792, respectively). Variations among treatments for No. 2 fruit yield and value and for total value, since it is influenced by No. 2 value, are to be expected. This is true since effects of treatments on yield of No. 1 and cull fruit do not necessarily influence yield, and thus value, of No. 2 fruit.

Percentage by weight of No. 1 fruit was not significantly affected by tillage. Plants from NT plots produced 23.4% No. 1 fruit compared to plants from CC (21.3%) and CN (19.7%). At PSF, CN plots produced fewest No. 1 fruit (15.2%) vs 19.5% and 21.4% for CC and CN, respectively. CC plots (20.9%) had fewer No. 1 tomatoes at TES compared to 23.8% and 22.0% for NT and CN, respectively. There were also no differences among sequences for percentage of No. 1 fruit with TB plots producing 23.3% vs BT (20.2%) and BTB (20.9%). Again, the same rationale follows for No. 1 fruit as for cull fruit.

Table 4-4. Mean total value of No. 1 and No. 2 grade tomatoes by environment and tillage combined over sequences and by environment and sequence combined over tillages.

	Environment			
Tillage (T)	PSF 1989	TES 1989	PSF 1990	TES 1990
	Value ($\$\ \mathrm{ha}^{-1}$)			
No-Till (T1)	19745	18046	16964	23057
	1971[z]	1746	1354	2947
Conventional (cover) (T2)	16984	24917	18347	24463
	1971	1746	1354	2947
Conventional (no cover) (T3)	14487	23255	20755	27150
	1971	1746	1354	2947
Contrast	------------------------Probability > F------------------------			
T1 v T2	0.3127	0.0123	0.4788	0.5788
T1 v T3	0.0634	0.0493	0.0631	0.1165
T2 v T3	0.3597	0.5093	0.2247	0.2934
Sequence (S)				
Tomato/Broccoli (S1)	20825	35719	19387	33239
	1531	1442	1344	2734
Broccoli/Tomato (S2)	8460	2749	19110	25179
	1531	1442	1344	2734
Broc/Tom/Broc (S3)	21934	27750	17569	16250
	1531	1442	1344	2734
Contrast	------------------------Probability > F------------------------			
S1 v S2	0.0001	0.0001	0.8852	0.0001
S1 v S3	0.4879	0.0003	0.3494	0.0001
S2 v S3	0.0001	0.0001	0.4261	0.0001

[z] Standard error appears below each mean.

Greater levels of mulch and tomatoes being in the field at a time when growing conditions are more optimal produced more good quality fruit and fewer culls. Only in one instance were there differences among sequences for percentage of No. 1 fruit. At TES in 1990, TB (28.2%) was higher than BTB (22.2%) which was higher than BT (16.3%).

There were no overall differences among tillages or sequences for average weight per No. 1 fruit. Average fruit weight was 178g in CN, and 172g and 177g in NT and CC, respectively. Weight per fruit was nearly the same in BTB (175g), TB (175g), and BT (176g). Total leaf N was also similar among tillages and sequences overall with levels of 4.37%, 4.47, and 4.53 for NT, CC, and CN respectively and 4.51%, 4.51, and 4.35 for BTB, TB, and BT, respectively. This is somewhat expected since size is a major criteria in determining grade designation.

Broccoli yield, and subsequent value, was greatest in CN at all environments (Table 4-5) and significantly greater than NT except at PSF in 1989. Also, CC was significantly greater than NT at all environments except at PSF where there was no difference in 1990 and NT was greater in 1989. There were no overall differences between the two spring broccoli sequences for yield. However, BT yields were significantly higher (420.2-10.43kg boxes ha^{-1}) than BTB (129.2) at TES 1989, but the reverse was true at PSF 1989 where BT (340.9) was lower than BTB (592.8). Broccoli in BTB was transplanted earlier in 1989 at PSF than at the other environments and did not suffer late season heat stresses.

Average marketable head weight was significantly greater in CN than NT at all environments except PSF and TES in 1989. Head weight followed a pattern of CN > CC > NT except at PSF 1989 where CC was greatest (Table 4-6). There were no significant differences between conventional tillages except at TES 1990. There were no overall differences among sequences for head size with BTB producing heads of 237g vs 215g for BT. There were differences between environments in 1989 with BTB (293g) greater than BT (140g) at PSF and BT (185g) greater than BTB (121g) at TES. There were no sequence differences in 1990. Since head and stem circumference are also indicative of head size, they followed much the same tendencies as marketable head weight. Head and stem circumference were comparable in CN (37.7 and 12.11 cm) and CC (34.3 and 11.3cm) and both were significantly greater than in NT (25.7

Table 4-5. Mean yield of broccoli by environment and tillage combined over sequences.

	Tillage (T)			
Environment	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	Contrast/Prob. > F
	Yield (10.43 kg boxes ha^{-1})			
PSF 1989	488.8	256.9	654.3	T1 v T2/0.0174
	65.7[z]	65.7	65.7	T1 v T3/0.0679
				T2 v T3/0.0008
TES 1989	87.7	340.4	395.9	T1 v T2/0.0251
	66.7	66.7	66.7	T1 v T3/0.0096
				T2 v T3/0.5689
PES 1989	7.6	812.6	952.5	T1 v T2/0.0005
	104.5	104.5	104.5	T1 v T3/0.0002
				T2 v T3/0.2842
PSF 1990	453.5	581.2	773.6	T1 v T2/0.2349
	70.9	70.9	70.9	T1 v T3/0.0109
				T2 v T3/0.0870
TES 1990	692.6	1186.6	1361.2	T1 v T2/0.0021
	128.7	128.7	128.7	T1 v T3/0.0003
				T2 v T3/0.1662
PES 1990	60.8	825.2	1008.7	T1 v T2/0.0001
	64.5	64.5	64.5	T1 v T3/0.0001
				T2 v T3/0.0616

[z] Standard error appears below each mean.

Table 4-6. Mean marketable head size of broccoli by environment and tillage combined over sequences.

	Tillage (T)			
Environment	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	Contrast/Prob. > F
	Marketable Head Size (g)			
PSF 1989	201.9 38.9[z]	243.3 38.9	203.6 38.9	T1 v T2/0.4713 T1 v T3/0.9760 T2 v T3/0.4892
TES 1989	128.5 17.0	163.3 15.9	166.7 15.9	T1 v T2/0.1733 T1 v T3/0.1394 T2 v T3/0.8835
PES 1989	40.0 40.9	246.1 34.5	288.0 34.5	T1 v T2/0.0038 T1 v T3/0.0019 T2 v T3/0.1829
PSF 1990	156.5 16.9	176.9 16.9	225.1 16.9	T1 v T2/0.4150 T1 v T3/0.0184 T2 v T3/0.0744
TES 1990	241.5 37.0	380.5 37.0	453.1 37.0	T1 v T2/0.0007 T1 v T3/0.0001 T2 v T3/0.0264
PES 1990	68.0 18.5	256.3 18.5	293.7 18.5	T1 v T2/0.0002 T1 v T3/0.0001 T2 v T3/0.1494

[z] Standard error appears below each mean.

and 10.3cm). NT broccoli head and stem circumferences were lowest at all locations, except PSF 1989 where both were significantly greater in NT (25.7 and 10.5cm, respecitively) than CC (20.8 and 9.6cm, respectively). Among sequences, head circumference in BT (34.3 cm) was significantly greater overall than BTB (30.8); but among individual environments, the difference was significant only at TES 1989. Stem circumference was significantly greater in BT (10.8cm) vs BTB (9.3) at TES 1989, but at individual environments and combined across environments there were no differences between BT (11.32 cm) and BTB (11.13).

Quality of broccoli was also adversely affected by NT (67.6% marketable) with plants of both CC (92.4) and CN (95.8) producing significantly higher percentages of marketable weight overall. For individual environments these differences were significant at TES in 1990 and at PES both years. At PSF in 1989, CC produced less marketable broccoli (82.6%) than either NT (98.8%) or CN (98.9%). No differences were found overall among sequences, however, as BT (86.2%) and BTB (84.3%) were comparable. Opposite results occurred in 1989 between locations for marketability among sequences with BT producing more marketable broccoli at TES (82.0% vs 58.3%), but BTB producing more at PSF (97.2% vs 89.7%). There were no differences in 1990. Broccoli leaf N content was significantly lower overall in NT (2.83%) and CC (3.06%) than CN (3.35%), but NT and CC were not different. For individual environments, NT broccoli at PES had significantly lower leaf N both years (0.87% in 1989, 0.64% in 1990) than either CC (2.00% and 1.22%) or CN (2.99% and 1.58%). Leaf N in NT (2.78%) was also lower at PSF in 1989 than CC (3.55%) or CN (3.50%). There were no differences among sequences (3.20% BT vs 2.96 BTB) overall, and only PSF 1989 had a significant difference among sequences with BT (3.91%) being greater than BTB (2.65%).

Total value of cropping systems was also affected by No. 2 tomato yield. Significantly greater total value was produced from CN plots at all environments except PSF 1989, where there were no differences among tillages (Table 4-7). Value in NT plots was lowest at all environments, except at PSF in 1989, where it was highest. There was no difference between NT and CC for value except at TES in 1989. Conventional tillages were not different at any environment. Effects of sequence on total value varied by

Table 4-7. Mean value of tomato-broccoli cropping systems by environment and tillage combined over sequences and by environment and sequence combined over tillages.

	Environment			
Tillage (T)	PSF 1989	TES 1989	PSF 1990	TES 1990
	Value (\$ ha^{-1})			
No-Till (T1)	22734	18582	19735	27291
	1875[z]	1875	1531	3339
Conventional (cover) (T2)	18555	26997	21901	31717
	1875	1875	1531	3339
Conventional (no cover) (T3)	18488	25676	25485	35472
	1875	1875	1531	3339
Contrast	------------------------Probability > F------------------------			
T1 v T2	0.1323	0.0052	0.3307	0.0956
T1 v T3	0.1266	0.0154	0.0161	0.0044
T2 v T3	0.9801	0.6241	0.1153	0.1528
Sequence (S)				
Tomato/Broccoli (S1)	20825	35719	19387	33239
	1415	1430	1531	3194
Broccoli/Tomato (S2)	11584	6602	24791	35338
	1415	1430	1531	3194
Broc/Tom/Broc (S3)	27368	28936	22941	25900
	1415	1430	1531	3194
Contrast	------------------------Probability > F------------------------			
S1 v S2	0.0001	0.0001	0.0225	0.2732
S1 v S3	0.0006	0.0005	0.1182	0.0009
S2 v S3	0.0001	0.0001	0.4042	0.0001

[z] Standard error appears below each mean.

year and location. Lowest revenues occurred in BT at both locations in 1989, but BT was highest in 1990. Again, this was affected by No. 2 tomato yield and differences in planting dates between the years due to weather conditions.

Growing degree day data indicate that, over a 30-year average, there is sufficient heat accumulation to support spring broccoli growth prior to tomatoes and fall broccoli following tomatoes (Table 4-8) when target planting dates are met. Tomatoes preceding broccoli would tend to be somewhat more difficult to grow, although the degree days actually accumulated in 1989 and 1990 are probably high since tomatoes were harvested beyond the time commercial tomato growers would continue to harvest. Termination of tomato harvest sooner would make it more likely that sequences with tomatoes before broccoli could be economically successful.

Conclusions

Broccoli yield, head size, marketability, and value were all adversely affected by reduced tillage. Although leaf N content was lower in no-till, there could be several reasons that broccoli growth declines under reduced tillage, including soil moisture, soil compaction, insect pressure, or allelopathic effects of the cover crop. In these studies it was not possible nor was it the objective to isolate the problems associated with reduced tillage, but to investigate the feasibility of the system. Tomato yield and value were not affected by tillage, although fewer cull fruit and more No. 1 quality tomatoes were produced under reduced tillage. Tomatoes planted first in the sequence resulted in more favorable yield and fruit quality than later planted tomatoes. Sequence had little effect on broccoli.

Although a fall broccoli crop was not successful under the conditions of these experiments, degree day data indicate that it is highly possible if the succeeding tomato crop is terminated after peak harvest. Where only one sequence is being managed, the possibility for a successful fall broccoli crop is even greater. Early planted broccoli prior to tomatoes was successful under the environmental conditions of this study and shows the potential for increasing total farm revenues.

Table 4-8. Growing degree days actually accumulated for crops in 1989 and 1990 and average accumulated during a similar time period over the last 30 years.[x]

Crop/ Sequence	Environment					
	PSF 1989	TES 1989	PES 1989	PSF 1990	TES 1990	PES 1990
	Degree Days Actually Accumulated					
Broc/B-T[y]	1118	1195	1191	1115	1292	1184
Broc/B-T-B	942	911	NA[z]	1115	1292	NA
Tom/B-T	1537	1428	X	1857	1735	X
Tom/B-T-B	1873	1809	NA	1857	1735	NA
Tom/T-B	1930	1985	X	1985	1970	X
Broc/B-T-B	X	X	NA	X	X	NA
Broc/T-B	X	X	X	X	X	X
	PSF		TES		PES	
	Target Planting Dates And Degree Days Usually Accumulated (30-year average)					
Broc/B-T	15 Mar	1272	20 Mar	1345	25 Mar	1198
Broc/B-T-B	1 Mar	979	10 Mar	1128	NA	NA
Tom/B-T	30 May	2438	5 June	2198	5 June	1817
Tom/B-T-B	15 May	1721	25 May	1706	NA	NA
Tom/T-B	1 May	1540	10 May	1577	15 May	1357
Broc/B-T-B	20 Aug	1793	30 Aug	1271	NA	NA
Broc/T-B	5 Aug	2331	15 Aug	1783	20 Aug	1417

[x] See table 4-1 for transplanting and harvesting dates for different cropping sequences at the respective environments. Source for 30-year averages, J. Logan, University of Tennessee, Knoxville.

[y] Broc=broccoli; Tom=Tomato; B-T=Broccoli/Tomato Sequence; B-T-B=Broccoli/Tomato/Broccoli Sequence; T-B=Tomato/Broccoli Sequence. Next crop was assumed to be planted within one week of harvest of previous crop. Final dates for fall crops were based on 50% possibility of 0°C temperatures.

[z] NA=not applicable. X=not planted or harvested.

References

Arnold, C. 1960. Maximum-minimum temperatures as a basis for computing heat units. Proc. Amer. Soc. Hort. Sci. 76:682-692.

Best, M.J. 1990. Sequential cropping of vegetables for market windows. M.S. Thesis. University of Tennessee. Knoxville, TN.

Beste, C.E. 1973. Evaluation of herbicides in no-till planted cucumbers, tomatoes and lima beans. Proc. Northeastern Weed Sci. Soc. 27:232-239.

Beste, C.E. 1983. No-tillage systems for vegetables and ornamentals. Proc. Northeastern Weed Sci. Soc. 37:52-57.

Blouin, D.C., and A.M. Saxton. 1989. General linear mixed models user's manual version 1.0. Louisiana Agric. Exp. Stn. Tech. Report Ser. No. TR-89-001.

Brown, J.E., W.E. Splittstoesser and J.M. Gerber. 1985. Production and economic returns of vegetable intercropping systems. J. Amer. Soc. Hort. Sci. 110(3):350-353.

Chappell, W.E. and L.A. Link. 1977. Evaluation of herbicides in no-tillage production of burley tobacco. (*Nicotiana tabacum*). Weed Science. 25(6):511-514.

Coffey, D.L. and P.W. Ramsey. 1987. Sequential cropping of vegetables on black plastic. Tennessee Farm and Home Science. 144:19-21.

Colombo, B., and G. Giazzi. 1982. Total automatic nitrogen determination. Amer. Lab. pp. 38-45.

Doss, B.D., J.L. Turner and C.E. Evans. 1981. Influence of tillage, nitrogen, and rye cover crop on growth and yield of tomatoes. J. Amer. Soc. Hort. Sci. 106(1):95-97.

Estes, E.A., W.A. Skroch, T.R. Konsler, P.B. Shoemaker and K.A. Sorenson. 1985. Net economic values of eight soil management practices used in stake tomato production. J. Amer. Soc. Hort. Sci. 110(6):812-816.

Hoyt, G.D. 1984. The effect of cover crops on strip till vegetable and tobacco production. Proc. Soil Sci. Soc. of North Carolina. 27:10-20.

McKeown, A.W., R.F. Cerkauskas and J.W. Potter. 1988. Influence of strip tillage on yield, diseases, and nematodes in tomatoes. J. Amer. Soc. Hort. Sci. 113(3):328-331.

Morrison, J.E., Jr. D.C. Milbocker, W.O. Atkinson, and J.H. Smiley. 1973a. Transplanter modification and survival of transplants under no-till conditions. HortScience 8:483-485.

Morrison, J.E., Jr., J.H. Smiley, W.O. Atkinson and D.C. Milbocker. 1973b. A no-tillage transplanter. Tob Sci. 17:44-46.

Morrison, J.E. 1974. No-tillage transplanting. 87th Annual Report of the College of Agric. Agric. Exp. Sta. Univ. Kent. pp. 11.

Phillips, R.E., R.L. Blevins. G.W. Thomas. W.W. Frye and S.H. Phillips. 1980. No-tillage agriculture. Science. 208:1108-1113.

Rowe-Dutton, P. 1957. The mulching of vegetables. Tech. Comm. No. 24. Commonwealth Bureau of Horticulture and Plantation Crops. East Malling, Maidstone, Kent. pp. 11-19, 119-146.

Spicer, H. 1983. Feasibility of strip-cultivation in processing tomatoes. Ont. Min. of Agr. and Food. Agdex 230/741.

Sumner, D.R., E.D. Threadgill, D.A. Smittle, S.C. Phatak and A.W. Johnson. 1986. Conservation tillage and vegetable diseases. Plant Dis. 70:906-911.

Triplett, G.B., Jr. and D.M. Van Doren, Jr. 1977. Agriculture without tillage. Sci. Am. 236:28-33.

USDA. 1976. United States standards for grades of fresh tomatoes. United States Dept. Agric., Agric. Mark. Ser. Washington, D.C.

Wood, S.D. and A.D. Worsham. 1986. Reducing soil erosion in tobacco fields with no tillage transplanting. J. Soil Water Conserv. 41:193-196.

Chapter 5

EXTRACTION OF PHENOLIC ACIDS FROM SOIL AND DETERMINATION THROUGH HIGH PERFORMANCE LIQUID CHROMATOGRAPHY

Abstract

A procedure for extraction of six phenolic acids is described and a sensitive method for determination of the acid concentrations is given. The method consists of extraction with 0.1N NaOH, centrifugation, filtration and adjustment of pH. Liquid chromatographic separation using gradient elution (with methanol, acetic acid and ethyl acetate as mobile phase components) and a C18 column, followed by UV detection at 280nm. Recoveries of six phenolic acids (ferulic, p-coumaric, caffeic, syringic, vanillic and p-hydroxybenzoic) were 58, 100, 0, 66, 83, and 123%, respectively. The limits of detection for each acid was 0.5 $\mu g\ g^{-1}$ (p-hydroxybenzoic, vanillic, and syringic), 1.0$\mu g\ g^{-1}$ (ferulic and p-coumaric). Caffeic was not detectable.

Introduction

Despite increased interest in the role of plant-produced phenolic acids as allelopathic agents, few detailed procedures on the extraction and analysis of these acids have been published. Extraction procedures have been compared (Dalton, *et al.*, 1987) and some brief descriptions of analysis procedures have occurred (Blum, *et al.*, 1991, Dalton, *et al.*, 1983 & 1987). Phenolic acids that have attracted the most attention include ferulic acid (FER), syringic acid (SYR), p-coumaric acid (COU), vanillic acid (VAN), p-hydroxybenzoic acid (BEN) and caffeic acid (CAF) (Blum, *et al.*, 1991, Dalton, *et al.*, 1983 & 1987). In this report, methodology for the simultaneous extraction and determination of five of these six phenolic acids at ppm levels using an external standard liquid chromatographic method with UV detection will be described.

Experimental

Apparatus and reagents

(a) Liquid chromatograph.-Waters automated gradient controller, Waters 484 Tunable Absorbance Detector set at 280nm, Waters 715 Ultra Wisp Sample Processor, Waters 501 HPLC Pump and Waters 740 Data Module (Millford, MA, USA).

(b) Analytical column.-25 cm X 4.6 mm id 5 um LC-C18, in-line 1 cm X 1.5 mm pellicular C18 guard column (Alltech, Chicago, IL, USA).

(c) Solvents.-LC grade (Burdick and Jackson, Muskegon, MI).

(d) Mobile phase.-Mobile phase A: methanol-water-acetic acid-ethyl acetate (2 + 97.25 + 0.5 + 0.25). Mobile phase B: methanol-water-acetic acid-ethyl acetate (80 + 17 + 2 + 1). A variable gradient at a flow rate of 0.7 mL/min was used. The gradient consisted of 70% solvent A/30% solvent B from initial to 30 minutes. Changes in the gradient occurred at: 30 minutes (50A/50B, curve 7), 35 minutes (30/70, curve 6) 38 minutes (30/70, curve 6), 40 minutes (50/50, curve 6), 42 minutes (70/30, curve 6), 50 minutes (70/30, curve 6) and 90 minutes (70/30, curve 6, 0.1mL/min flow rate).

(e) Analytical standards.-Ferulic acid, syringic acid, p-coumaric acid, vanillic acid, p-hydroxybenzoic acid, caffeic acid and protocatechuic acid all > 98% purity. (Sigma Chem. Co., St. Louis, MO, USA).

Soil medium

Soil was collected from a field plot site on which various tillage treatments in vegetable and tobacco production studies had been grown. Soil samples were collected in plastic bags and immediately stored (< 2h) in a freezer (-10°C) until processing. Since these acids naturally occur in soils with an organic fraction > 1%, it is expected the acids were present in the experimental soil material.

Extraction

The UV spectra of each of the phenolic acids was obtained using a scanning spectrophotometer

(Shimadzu, Kyoto, Japan). The sensitivity and accuracy of the analysis was examined by injection of a series of standards containing 1 to 10 ug/mL in water. Several gradient applications were examined to improve the resolution of the chromatographic peaks and to establish workable retention times for the acids.

Extraction procedures were examined using methods described in previous investigations (Dalton, *et al.*, 1987 and Blum, *et al.*, 1991). The first procedure included 50g of soil fortified with 5 ppm of each organic acid except protocatechuic, a non-fortified control soil sample, and two fortified water samples. Samples were 100ml water total including added acids in 250ml Erhlenmeyer flasks. Organic acids were removed by autoclaving for 1h at 120°C. One of the spiked water samples was not autoclaved. After returning to room temperature the samples were centrifuged for 10 minutes at 27,000g. Supernatant solutions were filtered through Whatman No. 42 filter paper and adjusted to pH 2.0 with 1N HCl and centrifuged an additional 10 minutes. This was then adjusted to pH 7.0 with 1N NaOH. The second procedure involved spiked and non-spiked soil and water treatments extracted with water in addition to treatments with spiked and unspiked soil and water using 0.5 M NaOH, 0.03 M NaEDTA and MeOH as extractants. All samples were 50g samples and all of the extractant volumes were 100mL total including 5 ppm of each of the six acids. These samples were prepared in Nalgene (Rochester, NY) bottles and shaken for two hours. The samples were then centrifuged 10 minutes at 27,000g. The supernatant was filtered through Whatman No. 42 filter paper, adjusted to pH 2.0 with 1N HCL, centrifuged an additional 10 minutes and adjusted to pH 7.0 with 1N NaOH. The third procedure was a replication of the second procedure except NaEDTA was eliminated and NaOH concentration was reduced to 0.1 M. Treatments were also examined in which samples were adjusted to a pH of 7.0 only, as well as, treatments adjusted to pH 2.0 and then back to pH 7.0. Treatments of shaking two hours versus shaking 16h were also included in the NaOH treatments. All treatments were examined using duplicates.

Results and discussion

The UV spectra of the phenolic acids showed lambda-max of 250 (VAN and BEN), 265 (SYR), and 280 (FER, COU and CAF). Injection of 50 μL of each acid produced peaks with retention times between 15.9 minutes (BEN) to 35.0 minutes (FER) (Figure 5-1a) depending on the gradient used. The gradient used was selected to optimize resolution of VAN, SYR and CAF which tended to coelute under some gradient conditions (all acids have similar parent structures, Figure 5-2) and to maximize speed at which the last acid of interest eluted. A standard curve plot was linear for each of the acids in the 1 to 10 ppm range, each with an r^2 of 0.99 (data not shown).

Recoveries of acids from the various treatments are shown in Table 5-1. Caffeic acid was not detectable using NaOH as an extractant. Extraction for 16h gave from 53.2% to 72.6% greater recovery depending on the acid. Adjustment of pH to 2.0 and back to 7.0 reduced recovery by about one-third in all acids over reduction to 7.0 pH only. Extraction with methanol was comparable to extraction with water alone and did not yield detectable concentrations of any acid. Extraction with 0.1 N NaOH was the most efficient method tested. Autoclaving destroyed some acids while water and Na_2EDTA either failed to extract or destroyed some acids (Table 5-1). Recoveries with 0.1 N NaOH ranged from 0 to 123% of added acid. The limits of detection ranged from 0.5ng/g for SYR, BEN and VAN to 1.0ng/g for FER and COU. Interference was seen from soil (Figure 5-1b). Some inherent acids were detected in unfortified soil (Figure 5-1c).

Blum, *et al.*, 1991, used similar extraction procedures, except autoclaving for 45 minutes. Centrifugation, filtration and adjustment of pH to 2.0 and back to 7.0 were similar to the methods described here. Caffeic and sinapic acids were reduced but the procedures were satisfactory for the other acids. Dalton, *et al.*, (1987) found greatest ferulic acid extraction with 2M NaOH and autoclaving. Chelating extractants such as EDTA recovered more acid than NaOH over time, but in 4-5h extraction periods, NaOH was superior, which is in agreement with the findings here. They found more background ferulic acid under air than N_2. Their findings on 100% water and methanol agreed with those here as well.

Previously Dalton, *et al.*, (1983) found phenolic acids added to soil were lost to extraction procedures with Na_2EDTA at pH 7.5. They, as well as, Kaminsky and Muller (1977) suggested that alkaline extraction procedures can overestimate plant available phenolics by giving artifacts or degradation products. Rice (1979) refuted the findings of Kaminsky and Muller and suggested Na_2EDTA was not the

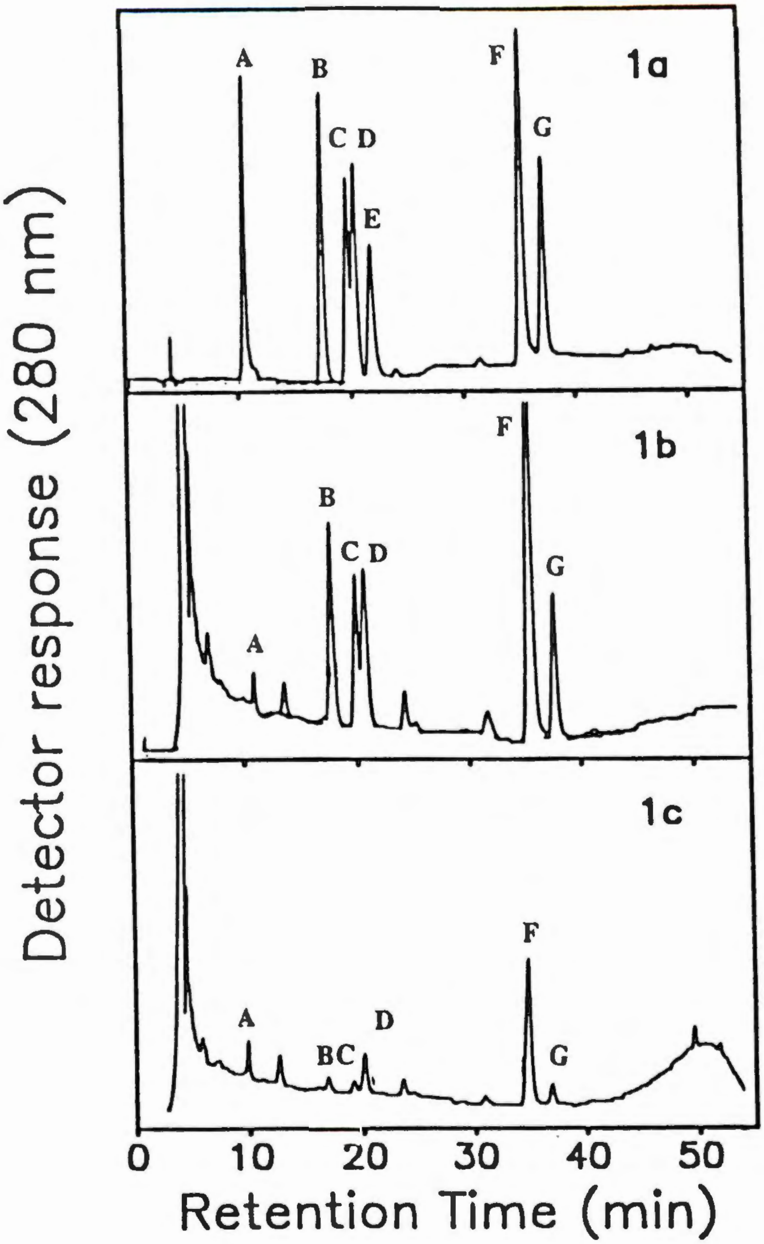

Figure 5-1. Liquid chromatograms of analytical standards and NaOH extracts of soil fortified to achieve 5 ppm concentrations of (a) protocatechuic, (b) p-hydroxybenzoic, (c) vanillic, (d) syringic, (e) caffeic, (f) coumaric and (g) p-coumaric acids: a, 5 ppm analytical standard of each acid; b, soil spiked with 5 ppm of each acid; c, non-spiked soil.

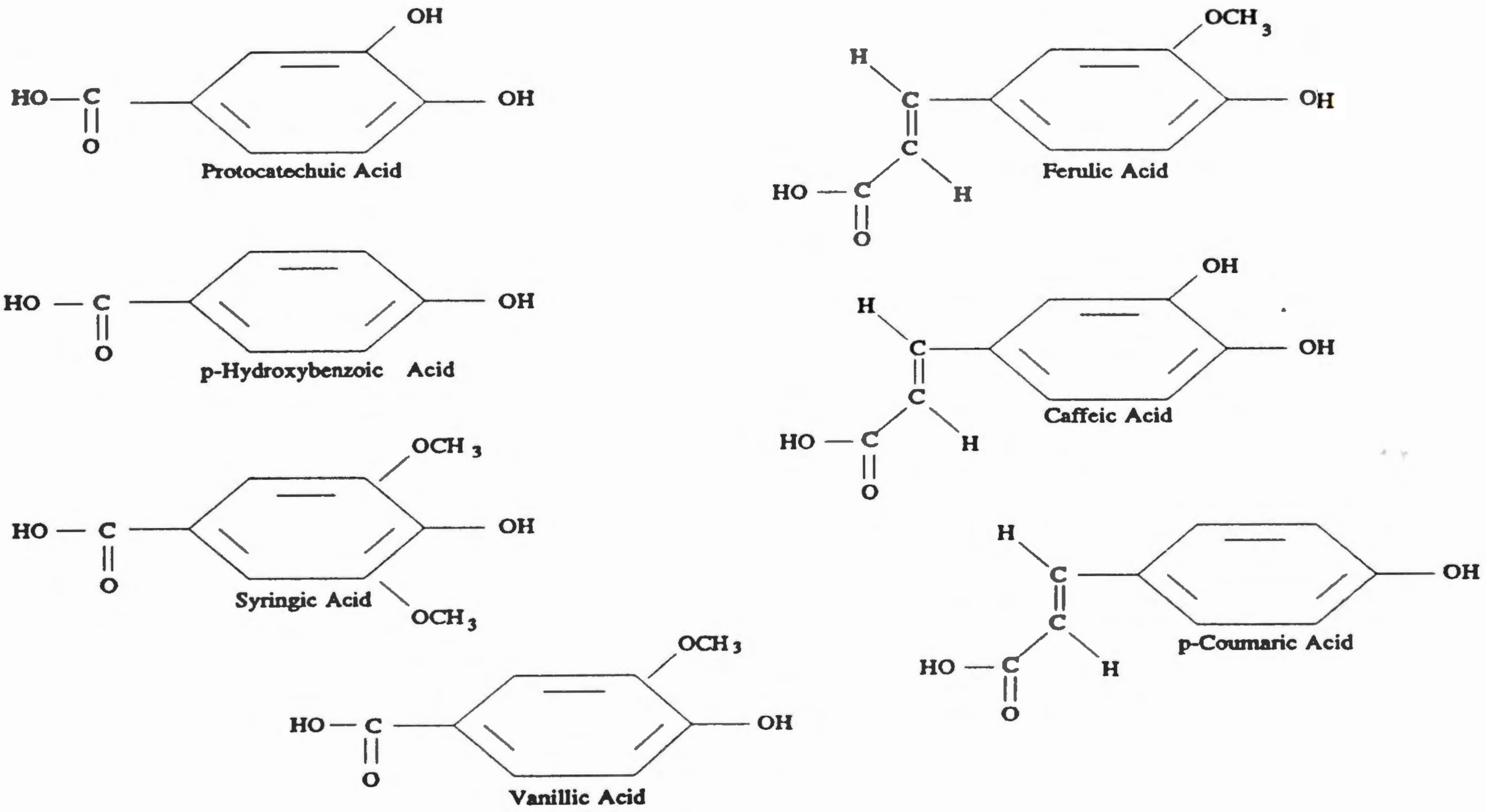

Figure 5-2. Structural representation of seven organic acids commonly found in soils. Ferulic, p-coumaric, vanillic, p-hydroxybenzoic and syringic were identified by high performance liquid chromatography.

Table 5-1. Recoveries of six phenolic acids in fortified samples from different extraction procedures.

Acid	Treatment				
	Spiked Soil Autoclaved	Autoclaved Water	Non Autoclaved Water	0.03M NaEDTA	0.1M NaOH
	Recoveries (% of added acid)				
Benzoic	80	98	3	76	123
Vanillic	39	98	0	24	83
Syringic	37	106	0	0	66
Caffeic	0	37	0	0	0
Coumaric	37	86	0	25	100
Ferulic	0	77	0	8	58

only valid extraction procedure. Kaminsky and Muller's procedure used 50g soil and 25g Na_2EDTA in 200mL distilled water, pH adjustment to 7.5 with NaOH, shaking five hours and centrifuging 15 minutes at 3300g. Another pH adjustment to 3.5 with HCl preceded extraction with ethyl acetate. Dalton, *et al.*, (1983) extracted samples with 14ml 0.3M Na_2EDTA at pH 7.5 for 30 minutes and centrifuging 10 minutes. Hartley and Buchan (1979) used an alkaline procedure, shaking 25g soil with 40mL 1M NaOH under N_2 at 20°C for 20h. The suspension was centrifuged (1000g) and filtered through Whatman No.42 paper, acidified to pH 2.5 with 12M HCl and centrifuged (1800g) again.

Blum, *et al.*, (1991) used mobile phases identical to the ones used here with determination of phenolic acids on a C18 HPLC column with a linear gradient from 92%A to 66%A over the first 40 minutes of a 60 minutes run at a flow of 0.5 mL/min and a detector set at 245nm. An internal standard of PRO, which usually naturally occurs in soils, was used. Hartley and Buchan used normal phase chromatography. Dalton, *et al.*, (1987) quantified ferulic acid at 280nm on a C18 column with an isocratic separation with approximately 38% MeOH. Earlier (1983) they quantified ferulic acid at 313nm on a C18 column. A gradient initially at 90% A (10% MeOH, 1% ethyl acetate, and 2% acetic acid) and 10% B

(80% MeOH and 2% acetic acid) was used to a final concentration of 10% A and 90% B with a flow rate of 2.5mL/min and a 2.67% change/min.

Use of the NaOH method proved to be superior to the other procedures although there was more interference than with the other methods. This interference was generally prior to the retention times of the acids of interest, however, and did not have an impact on the ability of this method to quantitate phenolic acids. Other organic components that were extracted from the soil with this method had retention times discernable from those of interest. Some extraction procedures previously identified corresponded with those used here, however, the quantification procedures identified in the literature proved not to be repeatable in our lab. Thus the procedure outlined here was determined to provide the most expedient way for identification and quantification of the acids in question.

References

Blum, U., T.R. Wentworth, K. Klein, A.D. Worsham, L.D. King, T.M. Gerig and S.-W. Lyu. 1991. Phenolic acid content of soils from wheat-no till, wheat-conventional till, and fallow-conventional till soybean cropping systems. J. Chem. Ecol. 17(6):1045-1068.

Dalton, B.R., U. Blum, and S.B. Weed. 1983. Allelopathic substances in ecosystems: Effectiveness of sterile soil components in altering recovery of ferulic acid. J. Chem. Ecol. 9(8):1185-1201.

Dalton, B.R., S.B. Weed and U. Blum. 1987. Plant phenolic acids in soils: A comparison of extraction procedures. Soil Sci. Soc. Amer. J. 51(6):1515-1521.

Hartley, R.D. and H. Buchan. 1979. High-performance liquid chromatography of phenolic acids and aldehydes derived from plants or from the decomposition of organic matter in soil. J. Chromatography. 180:139-143.

Kaminsky, R. and W.H. Muller. 1977. A recommendation against the use of alkaline soil extractions in the study of allelopathy. Plant Soil. 49:641-645.

Rice, E.L. 1979. Allelopathy-An update. Bot. Rev. 45:15-109.

Chapter 6

OCCURRENCE AND EFFECTS OF ALLELOPATHIC ORGANIC ACIDS IN NO-TILL CROP PRODUCTION

Abstract

Reduced yields in no-till broccoli field experiments (*Brassica olerace* var. *Italica* L.) prompted an investigation into the effects of residues from decaying wheat (*Triticum aestivum* L.) on no-till crop growth. Soil samples were taken from ongoing no-till vs conventional tillage studies and analyzed for concentrations of p-hydroxybenzoic, p-coumaric, ferulic, vanillic and syringic acids. Concurrent studies were conducted under greenhouse conditions in which broccoli, tomato (*Lycopersicon esculentum* Mill.), and tobacco (*Nicotiana tabacum* L.) plants were grown with additions of various concentrations of these acids. No-till soils were found to have higher levels of ferulic and p-coumaric acids while syringic, vanillic and benzoic acids did not differ significantly among tillages. Effects of acids on greenhouse broccoli growth were most pronounced, with concentration dependent decreases in shoot dry weight, plant height, and shoot to root ratio. Effects on tobacco and tomato were negligible, although both species had stimulated plant height growth when treated with greater concentrations of acids. Allelopathic interactions could be one plausible explanation for reduced broccoli yield under no-till conditions.

Introduction

Minimum tillage has been successfully implemented in many crops, although yields are occasionally reduced over conventional tillage (Guenzi and McCalla, 1966a, 1966b; Shilling, *et al.*, 1986a; Doss, *et al.*, 1981). Small grain cover crops such as wheat and rye (*Secale cereale* L.) are often used to reduce soil erosion in no-till systems. Traditionally, crops are then planted directly into residue of chemically killed covers or stubble from harvested cover crops. Even in conventional tillage, these covers are often turned under prior to planting, leaving residues in the soil. Residues and extracts of wheat and rye have been shown to have deleterious effects on the growth of several crop and weed species (Liebl and Worsham, 1983; Hicks, *et al.*, 1989; Rainbault, *et al.*, 1990; Cast, *et al.*, 1990; Guenzi and McCalla, 1962).

For many years it has been suspected that the detrimental effects of small grain residues on crop growth and yield has been due, at least in part, to allelopathic interactions (Shilling, *et al.*, 1986b; Barnes and Putnam, 1986; Putnam and Duke, 1978). Allelochemicals have been shown to inhibit nutrient uptake, cell division, cell extension, photosynthesis, respiration, protein synthesis, enzyme activity, and membrane permeability (Putnam, 1985b; Leather and Einhellig, 1988). Allelochemicals are produced from volatilization, root exudates, leaching, and decomposition of plant residues (Putnam, 1985b).

Decomposing wheat and rye produce substances toxic to plant growth (Kimber, 1967; Norstadt and McCalla, 1968b; Patrick, *et al.*, 1963). Many of these are organic acids such as caffeic, vanillic, ferulic, p-coumaric, syringic, and p-hydroxybenzoic acids, which have been identified from decaying residues of wheat and rye (Chou and Patrick, 1976; Guenzi and McCalla, 1966a). Organic acids reduced growth or germination of bean (*Phaseolus vulgaris* L.), cotton (*Gossypium hirsutum* L.), corn (*Zea mays* L.), soybean (*Glycine max* L.) and other crops (Waters and Blum, 1987; Williams and Hoagland, 1982; Einhellig and Rasmussen, 1979; and Patterson, 1981). Tomato root and shoot dry weight, and leaf N were reduced significantly by vanillic, p-coumaric and ferulic acids at a concentration of 10^{-3}M in greenhouse experiments (Mersie and Singh, 1988). Delayed germination and reduced root growth occurred in tobacco with rye residue extracts, or soil in contact with rye residue; benzoic and ferulic acids were found in these systems (Patrick, 1971). Ferulic, p-hydroxybenzoic, p-coumaric, vanillic, and syringic acids all have deleterious effects on cucumber growth. Concentrations of acids and mixtures of acids were important factors contributing to allelopathic effects (Blum, *et al.*, 1985a, 1985b, 1989; Blum and Dalton, 1985; Blum and Rebbeck, 1989).

Organic acids are found universally in plant tissue (Bates-Smith, 1956) and have all been isolated from soils (Blum, *et al.*, 1991; Wang, *et al.*, 1967a, 1967b, 1971; Whitehead, 1964; Whitehead, *et al.*, 1982, 1983). Coumaric acid and total phenolic acid content was greater in wheat no-till plots than fallow conventional tilled plots (Blum, *et al.*, 1991). Subtilled plots contained greater amounts of p-coumaric and ferulic acids than plowed soils, while there was no difference for syringic, vanillic, and p-hydroxybenzoic acids (Guenzi and McCalla, 1966b).

Although the literature on allelopathy is extensive, the emphasis in the past has been on agronomic crops such as corn and soybeans. These crops have been grown under reduced tillage for many years. With the recent emphasis on increasing minimum tillage use in vegetable and tobacco crops, there is need for investigations into the effects of organic acids occurring in minimum tillage in these crops. Thus, the first objective of this study was to quantify the concentrations of organic acids that occur in the field under various tillage conditions. A conjunctive objective was to determine the effects of known quantities of organic acids applied to broccoli, tomato, and tobacco under greenhouse conditions and compare these findings to concentrations found under field conditions.

Materials and methods

The occurrence of organic acids in the field under different tillage systems was investigated as part of another study involving sequential cropping under various tillage systems. Field concentrations of acids were compared to known concentrations applied to the same crops under greenhouse conditions, to determine if sufficient concentrations occurred in the field to affect crop growth.

Field studies

Soil samples were taken from ongoing sequential cropping and tillage studies at two locations. The field treatments consisted of factorial combinations of two cropping sequences and three tillage systems arranged in a strip-plot design. Sequences were stripped across tillages. The tillages were no-till, conventional tillage with a wheat winter cover, and conventional tillage with no winter cover. Cropping sequences were spring broccoli followed by tobacco (BT), and tobacco followed by fall broccoli (TB). Treatments were replicated four times.

The experiment was conducted in 1990 at the Plant Science Field Laboratories (PSF) at Knoxville, TN, which has an elevation of 253m; and the Tobacco Experiment Station (TES) near Greeneville, TN, which has an elevation of 402m. The test was conducted at Knoxville on an Etowah silt loam (fine-loamy, siliceous, thermic, Typic Paleudult); and at Greeneville on a Decatur silty clay loam (clayey, kaolinitic, thermic, Rhodic Paleudult).

Wheat covers were seeded after fall tillage in 1989. Soils were sampled (7.5cm diameter core) to a depth of 10cm at two locations in each plot and combined. Plots were sampled initially when conventional plots were tilled, and cover crops in no-till plots were chemically killed with paraquat (1,1'-dimethyl-4,4'-bipyridinium ion). Initial sampling was on 3 April, 1990 at PSF; and on 16 April, 1990 at TES. Final samples were taken just after broccoli harvest and tobacco transplanting. In TB plots, the cover crop was not tilled or chemically killed until just prior to tobacco transplanting. Therefore, more wheat biomass accumulated in that cropping sequence than in the BT sequence, where the cover was tilled/killed earlier in the season. Wheat on BT plots was approximately 15-20cm in height, and on TB plots was at the heading stage. Plots with no winter cover had no wheat at any time. Final sampling dates were 8 June, 1990 at PSF; and 6 June, 1990 at TES.

Samples were immediately placed in plastic bags and stored, within 2h, in a freezer (-10°C) until analyzed in the laboratory. Samples remained frozen until approximately 4h prior to processing. Samples were extracted, and concentrations of p-hydroxybenzoic (BEN), vanillic (VAN), syringic (SYR), ferulic (FER) and p-coumaric (COU) acids were determined according to the methods described in Chapter 5.

Data for concentrations of the various acids were analyzed using the General Linear Mixed Model procedures described by Blouin and Saxton (1989). For analysis of combined data tillage and sequence were considered to be fixed effects while location, replication, and associated interactions were considered random. For analysis of individual locations, years and location were not included in the model. Single-degree-of-freedom contrasts were used to make comparisons among treatments.

Greenhouse studies

Greenhouse studies were conducted in May-June, 1990 and repeated in May-June, 1991.

Greenhouse treatments consisted of factorial combinations of five acids at four concentrations each. Ferulic, p-hydroxybenzoic, p-coumaric, vanillic, and syringic acids were applied individually, at concentrations of 1000, 100, 10 and 1μM to broccoli, tobacco, and tomato plants. Solutions were made from commercial solid preparations of each acid (Sigma Chem. Co., St. Louis, MO., purity > 98%) with an initial stock solution of each at 10,000 μM, which was diluted with water to the working concentrations. Test plants were seeded in 2.5cm cell Speedling (Speedling, Corp., Sun City, FL) trays and grown to normal transplanting size (approximately 15-20cm in height). Plants were then transplanted into plastic pots (5376cc volume for tomato and tobacco, 4090cc for broccoli) which contained a mixture of 40% sand and 60% soil, which had been previously sterilized. Solution volumes of 200ml were surface applied three times weekly to each pot. Three additional pots in each replication received the same amount of water only as a check. Experiments for each crop were conducted on separate benches. Each experiment was replicated four times. Pots were not given any supplemental water since the solutions were sufficient to maintain adequate soil moisture. Greenhouse conditions were maintained at approximately 25°C with no supplemental lighting.

Initial measurements were taken of plant height, leaf number, and stem diameter. These measurements were repeated at 7-10 d intervals for the duration of the experiment. Treatments were continued for approximately 7 weeks. Crops were harvested at the conclusion of the experiment and additional data on shoot and root fresh weights were taken. After oven drying, shoot and root dry weights were determined. Analysis of leaf N was determined using the Carlo Erba N Analyzer 1500 described by Colombo and Giazzi (1982). Ratios of shoot to root fresh and dry weights were calculated, and rates of growth were calculated based on the measurements of plant height, leaf number and stem diameter.

Data were analyzed for each experiment individually, and combined across both experiments within each crop (1990 and 1991) using the Statistical Analysis Systems (SAS, 1990). Mean separation via Duncan's multiple range test was used to determine differences among all treatments. Contrasts were used to determine differences among acids across concentrations, and differences among concentrations across acids.

Results and discussion

Field results

It has been suggested that alkaline extraction procedures overestimate the amount of organic acids that are plant available in soil solution (Kaminsky and Muller, 1977; Dalton, *et al.*, 1983). However, Rice (1979) has refuted this claim, noting that the water soluble fraction is not the only plant available fraction. Therefore, the concentrations extracted from samples in this experiment can give an indication of the relative availability of organic acids that can affect plant growth.

Concentrations of the organic acids isolated were on the order of COU > FER > VAN > BEN > SYR, which differed slightly from the findings of Blum, *et al.* (1991), who found COU > VAN > BEN > SYR > FER; and from Whitehead, *et al.* (1982), who found BEN > COU > VAN > FER. Initial concentrations of COU did not differ among tillage systems at PSF (Table 6-1), but both tillages with wheat residues were significantly greater than without wheat residue at TES initially. The same was true at final sampling except that only no-till (NT) and conventional with no cover (CNC) differed significantly at Greeneville (Table 6-1). In all cases, except conventional with cover (CC) at PSF, the amount of COU acid decreased with increasing residue. Generally, concentrations increased from first to last sampling, which would be expected, since the acids are released upon decay (Dao, 1987). There were no differences among cropping sequences in this regard. Increased biomass of wheat in the TB sequence did not necessarily result in increased levels of coumaric acid.

Results were similar in FER, where generally concentrations of FER decreased with increasing residue (Table 6-2). Overall, concentrations of FER in NT were significantly higher than CNC at initial sampling. There were no differences at final sampling, except at TES where NT had higher concentrations of FER than CC and CNC. Again, there were no differences among sequences, except at TES at last sampling where NT was significantly greater than CC or CNC.

There were no significant differences among tillages or cropping sequences for amount of total organic acids (FER + COU + VAN + SYR + BEN) (Table 6-3). As expected, there was a tendency for greater concentration of total acids in plots which contained more residue. This was particularly true at

Table 6-1. Mean field concentration of p-coumaric acid at first and last sampling by tillage combined over sequence and by sequence combined over tillage for Knoxville, TN (PSF) and Greeneville, TN (TES) and combined over locations.

	Location					
	PSF		TES		Combined	
	Sampling Date					
Tillage (T)	First	Last	First	Last	First	Last
	Concentration ($\mu g\ g^{-1}$)					
No-Till	7.20	7.32	11.23	11.66	9.36	9.58
(T1)	1.26[y]	1.84	0.73	1.14	0.86	0.96
Conv. (cover)	6.93	9.33	10.61	9.61	8.66	9.19
(T2)	1.16	1.96	0.82	1.14	0.87	0.98
Conv. (no cover)	6.79	7.95	6.97	7.34	6.84	7.83
(T3)	1.16	1.79	0.73	1.13	0.86	0.97
Sequence (S)						
Tb/Br[z]	6.35	8.44	9.55	10.52	7.92	9.35
(S1)	0.97	1.65	0.58	0.99	0.77	0.85
Br/Tb	7.60	7.96	9.67	8.55	8.66	8.38
(S2)	0.97	1.65	0.58	0.99	0.77	0.85
Contrast	Prob. > F					
T1 V T2	0.8707	0.3670	0.6106	0.1664	0.4636	0.7295
T1 v T3	0.8058	0.7066	0.0010	0.0075	0.0092	0.1195
T2 v T3	0.9238	0.5080	0.0102	0.1202	0.0571	0.2339
S1 v S2	0.3272	0.7396	0.8942	0.0980	0.3150	0.2789

[y] Standard error appears below each mean. [z] Tb=Tobacco, Br=Broccoli.

Table 6-2. Mean field concentration of ferulic acid at first and last sampling by tillage combined over sequence and by sequence combined over tillage for Knoxville, TN (PSF) and Greeneville, TN (TES) and combined over locations.

	Location					
	PSF		TES		Combined	
	Sampling Date					
Tillage (T)	First	Last	First	Last	First	Last
	Concentration ($\mu g\ g^{-1}$)					
No-Till	5.77	5.05	4.53	4.93	5.12	4.92
(T1)	0.66[y]	0.85	0.59	0.62	0.39	1.37
Conv. (cover)	4.84	5.65	3.82	2.45	4.33	3.99
(T2)	0.60	0.93	0.67	0.62	0.40	1.37
Conv. (no cover)	3.78	4.69	2.69	3.04	3.27	3.99
(T3)	0.60	0.82	0.60	0.61	0.39	1.37
Sequence (S)						
Tb/Br[z]	4.97	5.76	4.19	4.79	4.62	5.12
(S1)	0.48	0.72	0.47	0.53	0.31	1.34
Br/Tb	4.62	4.50	3.17	2.16	3.86	3.48
(S2)	0.48	0.72	0.47	0.53	0.31	1.34
Contrast	Prob. > F					
T1 V T2	0.3404	0.6217	0.4685	0.0079	0.1806	0.1648
T1 v T3	0.0558	0.7112	0.0398	0.0282	0.0021	0.1580
T2 v T3	0.2212	0.4099	0.2666	0.4503	0.0688	0.9962
S1 v S2	0.6244	0.1419	0.1624	0.0011	0.0913	0.0036

[y] Standard error appears below each mean. [z] Tb=Tobacco, Br=Broccoli.

Table 6-3. Mean field total concentration of organic acids at first and last sampling by tillage combined over sequence and by sequence combined over tillage for Knoxville, TN (PSF) and Greeneville, TN (TES) and combined over locations.

	Location					
	PSF		TES		Combined	
	Sampling Date					
Tillage (T)	First	Last	First	Last	First	Last
	Concentration ($\mu g\ g^{-1}$)					
No-Till	17.36	17.17	22.07	25.24	19.72	21.22
(T1)	2.15^{y}	2.82	2.46	3.13	2.77	1.91
Conv. (cover)	16.47	20.59	20.47	16.87	18.55	18.48
(T2)	1.97	3.05	2.79	3.15	2.77	1.94
Conv. (no cover)	14.91	17.05	17.99	18.18	16.36	17.84
(T3)	1.97	2.72	2.49	3.08	2.75	1.93
Sequence (S)						
Tb/Br^{z}	16.24	20.15	19.52	22.25	17.90	20.84
(S1)	1.61	2.43	1.96	2.54	2.62	1.61
Br/Tb	16.25	16.39	20.83	17.94	18.52	17.52
(S2)	1.61	2.43	1.96	2.54	2.62	1.61
Contrast	Prob. > F					
T1 V T2	0.7682	0.3781	0.6968	0.0848	0.5807	0.2893
T1 v T3	0.4231	0.9669	0.2454	0.1271	0.1051	0.1873
T2 v T3	0.5555	0.3331	0.5501	0.7682	0.2868	0.8044
S1 v S2	0.9957	0.1528	0.6545	0.2466	0.6941	0.1112

^{y}Standard error appears below each mean. ^{z}Tb=Tobacco, Br=Broccoli.

initial sampling. There were no differences among tillages for either BEN, VAN, or SYR at initial or final sampling (Tables 6-4, 6-5 and 6-6). There were however, significantly higher concentrations of VAN overall at both sampling dates in the TB sequence than the BT sequence (Table 4-5). The same was true for BEN, but only at PSF (Table 4-4). Concentrations of SYR were higher in BT at first sampling at TES, but were higher in TB at last sampling at PSF (Table 4-6). The percentage of total acids that were present as COU and FER remained stable from initial to final sampling dates. There were no sequence by tillage interactions for any acid. The findings for all acids generally agree with those of Blum, *et al.* (1991) and Guenzi and McCalla (1966b).

Greenhouse results

Shoot dry weight is indicative of dry matter accumulation, and thus, is the most appropriate indicator of growth among the parameters tested in the greenhouse experiments. Field data on yield and quality of broccoli, tobacco, and tomatoes had indicated that broccoli yields were most affected by reduced tillage systems. Therefore, the possible allelopathic effect of organic acids on broccoli was the primary emphasis of this study. It was not surprising then to find that the greatest effect of organic acids on crop growth in the greenhouse was on broccoli shoot dry weight. All acids had a concentration dependent effect on broccoli shoot dry weight, with increased concentrations causing decreased dry weight accumulation (Figure 6-1). FER and BEN had the most pronounced effect, although all five acids showed similar results.

In light of those findings, it was expected that the dry shoot to root ratio of broccoli was affected in a similar manner (Figure 6-2). As acid concentration increased the shoot to root ratio declined. The most dramatic effect was seen with COU, although all acids produced significant results. The effects on broccoli plant height at harvest were not as pronounced, however, similar declines in plant height with increased concentrations occurred (Figure 6-3). Shoot fresh weight was also significantly less at 1000μM concentrations (23.08g) than at either of the other concentrations (100μM-24.21g, 10μM-26.31g, 1μM-25.79g) when combined across acids. Overall only FER and BEN were consistent with that trend overall. All acid treatments resulted in decreased shoot fresh weight with increased concentration in 1991. Ferulic acid treated plants produced the lowest shoot fresh weight among acids.

Table 6-4. Mean field concentration of p-hydroxybenzoic acid at first and last sampling by tillage combined over sequence and by sequence combined over tillage for Knoxville, TN (PSF) and Greeneville, TN (TES) and combined over locations.

	Location					
	PSF		TES		Combined	
	Sampling Date					
Tillage (T)	First	Last	First	Last	First	Last
	Concentration ($\mu g\ g^{-1}$)					
No-Till	1.01	1.03	2.30	3.43	1.55	2.20
(T1)	0.12[y]	0.14	0.91	1.11	1.37	1.09
Conv. (cover)	1.00	1.24	2.03	1.59	1.67	1.46
(T2)	0.11	0.15	1.03	1.12	1.37	1.09
Conv. (no cover)	0.94	0.99	3.56	3.08	2.22	2.01
(T3)	0.11	0.13	0.92	1.09	1.36	1.09
Sequence (S)						
Tb/Br[z]	1.11	1.27	1.86	2.51	1.49	1.84
(S1)	0.09	0.10	0.73	0.89	1.34	1.05
Br/Tb	0.85	0.90	3.41	2.88	2.13	1.95
(S2)	0.09	0.10	0.73	0.89	1.34	1.05
Contrast	Prob. > F					
T1 V T2	0.9410	0.3551	0.8674	0.2776	0.8556	0.3344
T1 v T3	0.6288	0.8215	0.3293	0.8267	0.3058	0.7994
T2 v T3	0.6366	0.2419	0.3328	0.3637	0.4019	0.4768
S1 v S2	0.0245	0.0335	0.1668	0.7800	0.2147	0.8528

[y] Standard error appears below each mean. [z] Tb=Tobacco, Br=Broccoli.

Table 6-5. Mean field concentration of vanillic acid at first and last sampling by tillage combined over sequence and by sequence combined over tillage for Knoxville, TN (PSF) and Greeneville, TN (TES) and combined over locations.

	Location					
	PSF		TES		Combined	
	Sampling Date					
Tillage (T)	First	Last	First	Last	First	Last
	Concentration ($\mu g\ g^{-1}$)					
No-Till	2.64	3.14	2.23	2.82	2.46	2.94
(T1)	0.39[y]	0.42	0.38	0.50	0.25	0.32
Conv. (cover)	3.00	3.47	2.19	1.61	2.58	2.57
(T2)	0.36	0.46	0.44	0.50	0.26	0.32
Conv. (no cover)	2.93	2.87	2.61	2.87	2.77	2.88
(T3)	0.36	0.39	0.39	0.49	0.25	0.32
Sequence (S)						
Tb/Br[z]	3.08	3.78	3.10	3.32	3.10	3.51
(S1)	0.29	0.32	0.31	0.42	0.20	0.26
Br/Tb	2.64	2.53	1.58	1.55	2.11	2.08
(S2)	0.29	0.32	0.31	0.42	0.20	0.26
Contrast	Prob. > F					
T1 V T2	0.5430	0.6391	0.9566	0.0942	0.7417	0.3970
T1 v T3	0.6319	0.6355	0.4755	0.9369	0.3781	0.8754
T2 v T3	0.8791	0.3682	0.5195	0.0767	0.5953	0.4916
S1 v S2	0.3140	0.0203	0.0049	0.0058	0.0014	0.0003

[y] Standard error appears below each mean. [z] Tb=Tobacco, Br=Broccoli.

Table 6-6. Mean field concentration of syringic acid at first and last sampling by tillage combined over sequence and by sequence combined over tillage for Knoxville, TN (PSF) and Greeneville, TN (TES) and combined over locations.

	Location					
	PSF		TES		Combined	
	Sampling Date					
Tillage (T)	First	Last	First	Last	First	Last
	Concentration ($\mu g\ g^{-1}$)					
No-Till	0.71	0.61	1.77	2.44	1.17	1.56
(T1)	0.11[y]	0.17	0.52	0.70	0.92	0.94
Conv. (cover)	0.70	0.91	1.79	1.71	1.33	1.29
(T2)	0.10	0.19	0.59	0.71	0.92	0.94
Conv. (no cover)	0.48	0.57	2.15	1.72	1.30	1.12
(T3)	0.10	0.16	0.52	0.69	0.92	0.94
Sequence (S)						
Tb/Br[z]	0.73	0.93	0.81	1.15	0.75	1.01
(S1)	0.08	0.14	0.41	0.56	0.90	0.91
Br/Tb	0.54	0.46	3.00	2.76	1.78	1.64
(S2)	0.08	0.14	0.41	0.56	0.90	0.91
Contrast	Prob. > F					
T1 V T2	0.9690	0.2374	0.9786	0.4893	0.7323	0.5923
T1 v T3	0.1837	0.8349	0.6030	0.4833	0.7652	0.3921
T2 v T3	0.1412	0.1590	0.6858	0.9883	0.9557	0.7570
S1 v S2	0.1350	0.0133	0.0033	0.0708	0.0051	0.1356

[y] Standard error appears below each mean. [z] Tb=Tobacco, Br=Broccoli.

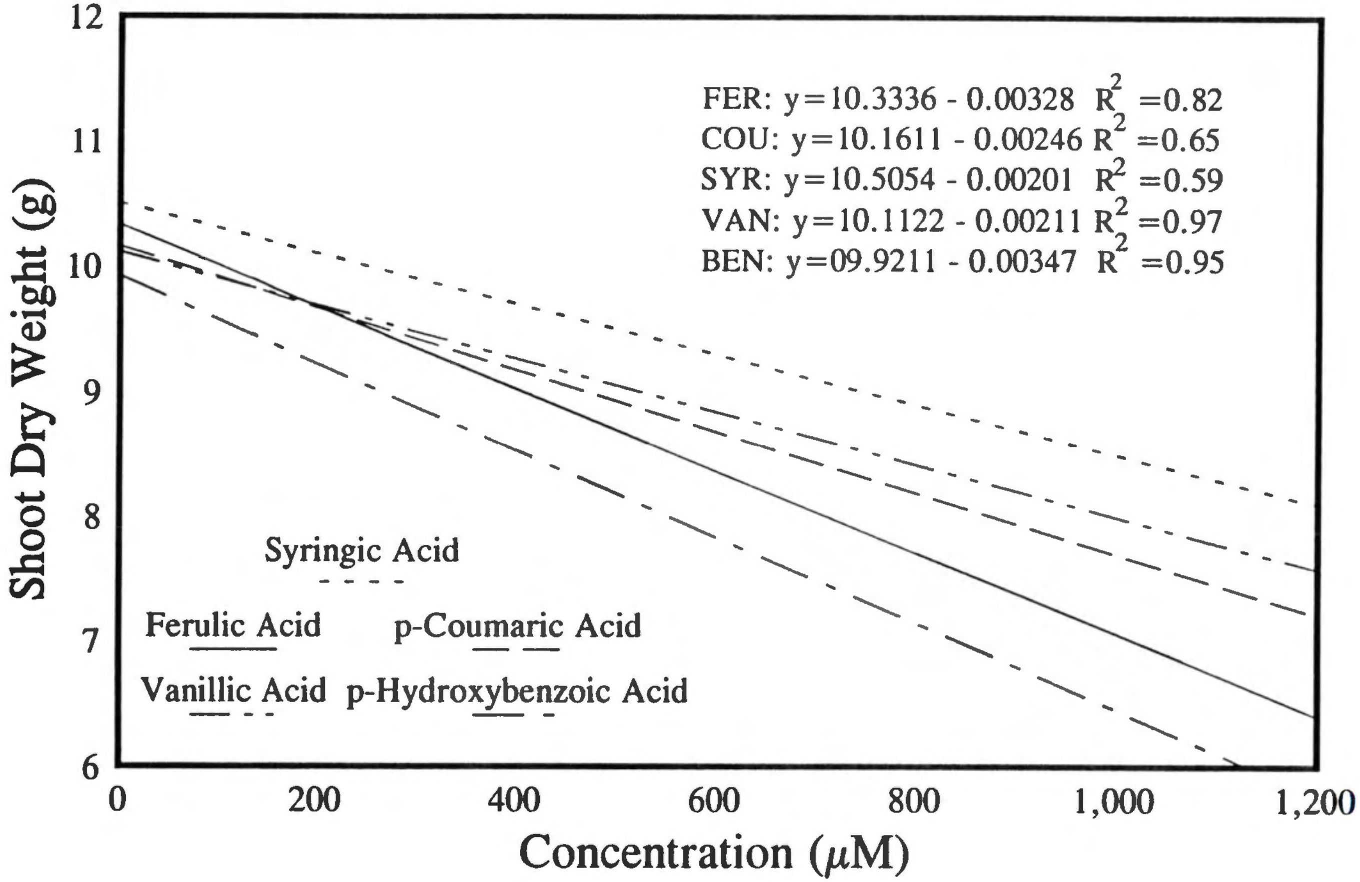

Figure 6-1. Shoot dry weight of greenhouse broccoli treated with various concentrations of p-hydroxybenzoic, vanillic, syringic, ferulic, and p-coumaric acids combined across experiments in 1990 and 1991.

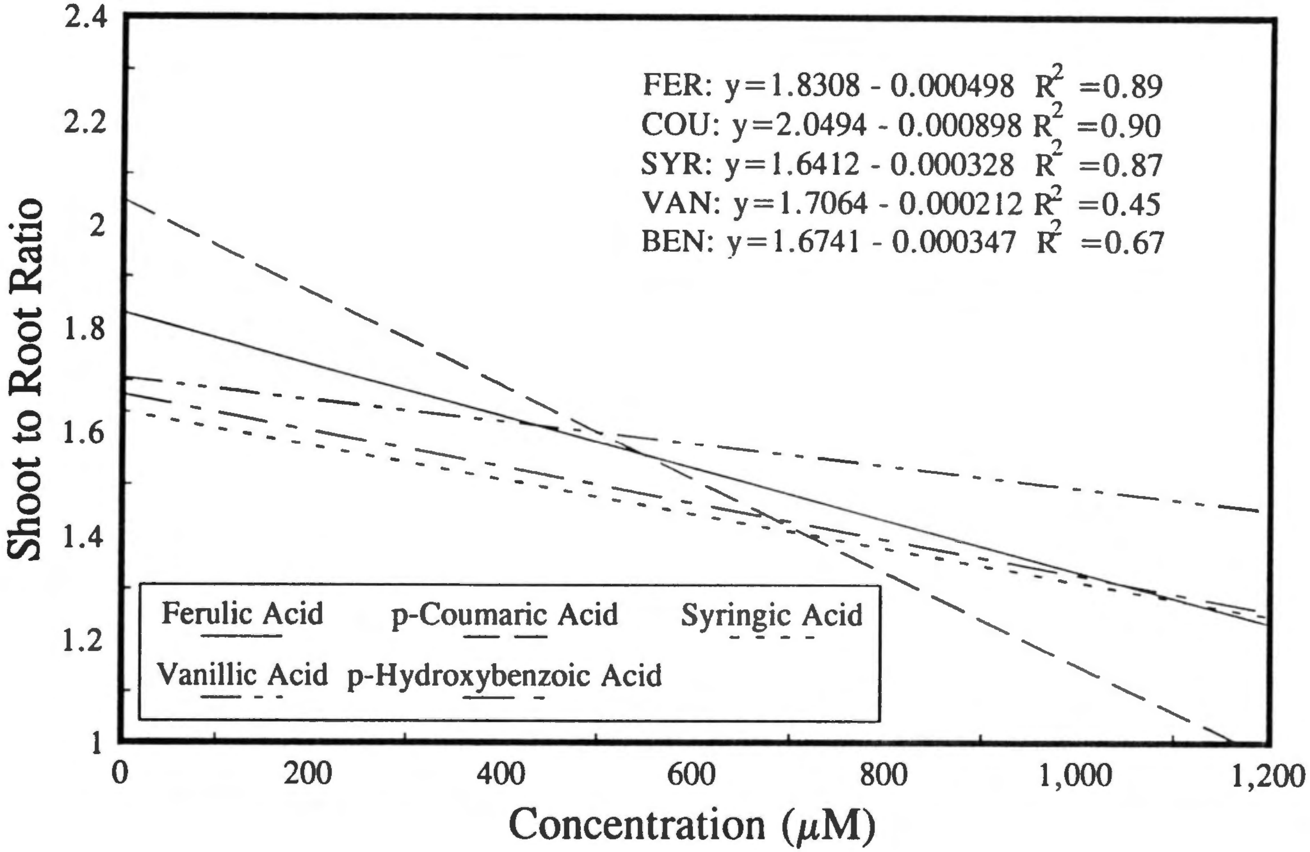

Figure 6-2. Shoot to root ratio of oven dried greenhouse broccoli plants treated with various concentrations of p-hydroxybenzoic, vanillic, syringic, ferulic, and p-coumaric acids combined across experiments in 1990 and 1991.

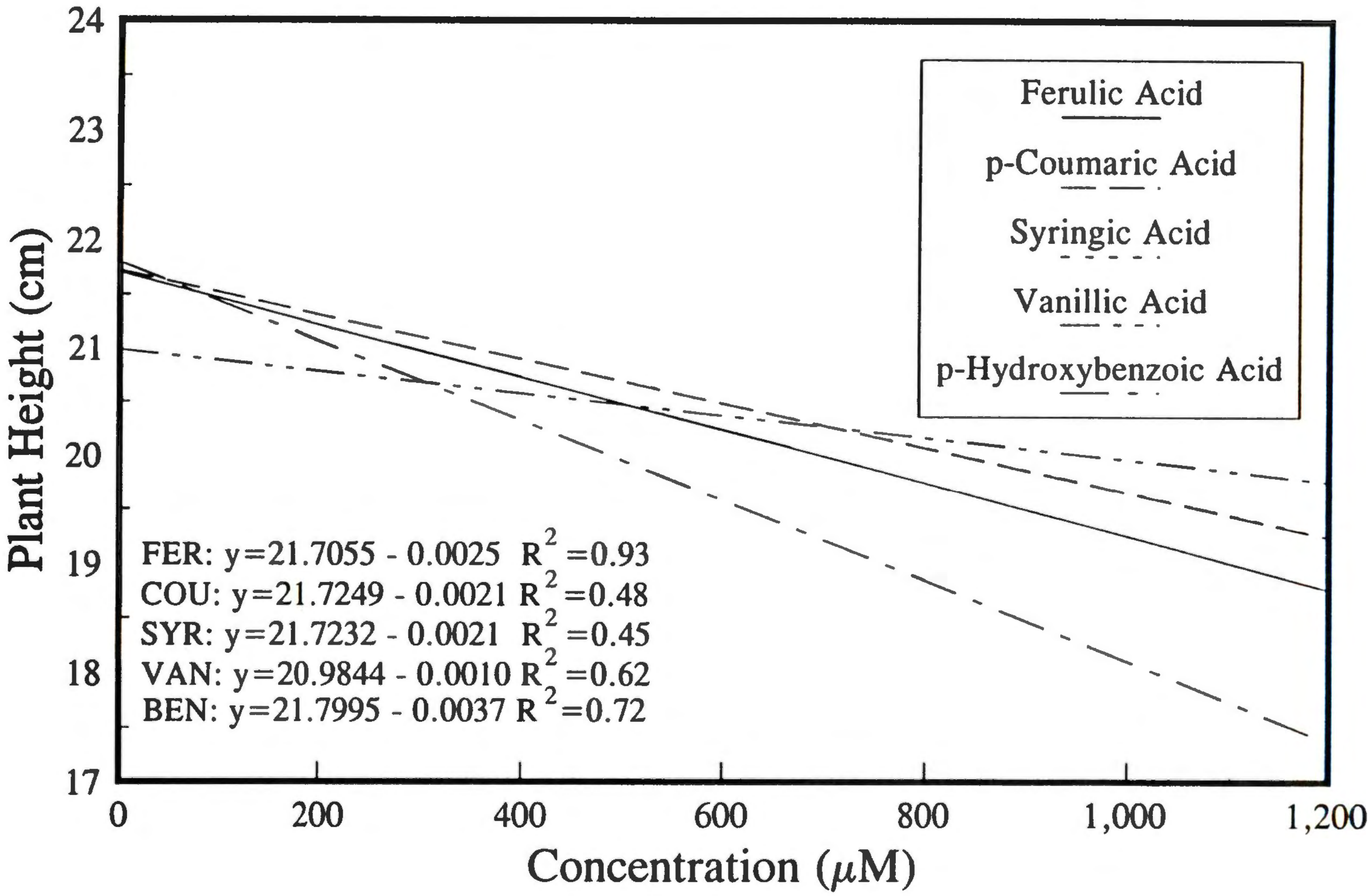

Figure 6-3. Plant height at harvest of greenhouse broccoli plants treated with various concentrations of p-hydroxybenzoic, vanillic, syringic, ferulic, and p-coumaric acids combined across experiments in 1990 and 1991.

There were no differences among acids in broccoli for either shoot dry weight, dry shoot to root ratio, final plant height, shoot fresh weight, leaf N content, leaf number or stem diameter, nor in growth in plant height, stem diameter or leaf number over the duration of the experiment. FER (9.48g) and COU (9.24) resulted in lower root fresh weights than the other three acids, but only significantly less than SYR (11.44). Root dry weight and fresh shoot to root ratio was similar. In root dry weight COU (4.59g) and SYR (5.09) differed significantly.

There were no effects among concentrations for root fresh weight, root dry weight, fresh shoot to root ratio, or leaf N content, nor in plant height or leaf number growth over time. There were however, concentration dependent decreases in leaf number (11.1 for 1000μM; 11.9 for 100μM; 12.4 for 10μM; and 12.2 for 1μM), stem diameter (5.78, 6.06, 6.32, and 6.62mm) and growth per day in stem diameter (0.06, 0.07, 0.08, and 0.08mm). SYR and BEN had the greatest effect on leaf number, while all acids affected stem diameter. There was a decrease in leaf N content with greater concentrations of BEN (1000μM-0.78%; 100μM-0.87%; 10μM-0.88%; and 1μM-0.94%).

Tomato plants showed fewer effects than broccoli among either acids or concentrations, although there were a few notable differences. Highest concentrations actually seemed to stimulate tomato shoot fresh weight (42.38g at 1000μM vs 37.51 at 1μM). This was true with COU, VAN and BEN. The opposite was true of root fresh weight (1000μM-8.4g vs 1μM-10.59). This was consistent for all acids except BEN. Shoot dry weight decreased with increasing concentrations of FER, SYR and VAN. Combined across acids, there were significant shoot dry weight differences between concentrations of 1000μM (8.88g) and both 100μM (10.51) and 1μM (10.28).

Root dry weight was lowest (2.10g) at highest concentrations, but only significantly different from 100μM (3.21). The reverse was true in dry shoot to root ratio. Treatment with FER resulted in significantly higher (5.53) dry shoot to root ratio than SYR (4.08) and BEN (4.24). Plant height of tomatoes was stimulated by higher concentrations (69.6cm and 65.1, for 1000 and 100μM, respectively) over lower concentrations (63.6cm and 63.3cm, for 10 and 1μM, respectively). This effect was most pronounced in SYR. Plant height growth over time was similarly affected. There were no effects among acids for shoot fresh weight, root fresh weight, shoot dry weight, root dry weight, plant height, leaf number, stem diameter or plant height and leaf number rate of growth. There were no concentration effects for leaf N content, leaf number, stem diameter, or leaf number and stem diameter rate of growth.

The effects on tobacco were not dramatic either. SYR produced lower leaf N content (1.57%) than VAN (1.92%). There were also slight, but not significant, increases in tobacco plant height with higher concentrations of acids, though not significantly. This was true with all acids except VAN which showed a reversed trend. This effect in tobacco and tomato was probably a result of increased internode length. Growth rate in leaf number was greater at 1μM (0.21mm d^{-1}) than at higher concentrations (0.18). There were no other significant effects of either acid or concentration on tobacco.

Conclusions

Concentration of acids detected in soils of this study are indicative of the relative amounts of organic acids that are plant available and that can affect growth of the respective test species. There were greater concentrations of organic acids, particularly COU and FER, under reduced tillage, and in conventional tillage where a wheat cover had been turned under. The same was generally true for total organic acids, although the difference was not significant. There were no differences among tillages for BEN, SYR or VAN. The presence of greater residue in the later planted sequence did not necessarily translate into greater amounts of acids.

The greatest effect of acids on growth of plants in the greenhouse was on broccoli dry weight accumulation. This correlated with decreased field broccoli yields. The effects on tobacco and tomato were not nearly as pronounced. The concentrations detected in the field are well within the range of acids tested in the greenhouse. In light of this fact, the concentrations which produced decreased broccoli growth in the greenhouse could also produce decreased broccoli growth in the field, and at least partially explain why field broccoli yields under no-till production are reduced. Obviously, other factors such as soil moisture and compaction, N availability, microclimate, and root penetration could also have effects on broccoli yield. These results indicate that allelopathic interactions could be operating in broccoli no-till systems.

References

Barnes, J.P. and A.R. Putnam. 1986. Evidence for allelopathy by residues and aqueous extracts of rye (*Secale cereale*). Weed Science. 34:384-390.

Bates-Smith, E.C. 1956. The commoner phenolic constituents of plants and their systematic distribution. Proc. Roy. Dublin. Sci. Soc. 27:165-176.

Blouin, D.C., and A.M. Saxton. 1989. General linear mixed models user's manual version 1.0. Louisiana Agric. Exp. Stn. Tech. Report Ser. No. TR-89-001.

Blum, U. and B.R. Dalton. 1985. Effects of ferulic acid, an allelopathic compound, on leaf expansion of cucumber seedlings grown in nutrient culture. J. Chemical Ecology. 11(3):279-301.

Blum, U., B.R. Dalton and J.R. Shann. 1985a. Effects of ferulic and p-coumaric acids in nutrient culture of cucumber leaf expansion as influenced by pH. J. Chemical Ecology. 11(11):1567-1582.

Blum, U., B.R. Dalton and J.R. Shann. 1985b. Effects of various mixtures of ferulic acid and some of its microbial metabolic products on cucumber leaf expansion and dry matter in nutrient culture. J. Chemical Ecology. 11(5):619-641.

Blum, U. and J. Rebbeck. 1989. Inhibition and recovery of cucumber roots given multiple treatments of ferulic acid in nutrient culture. J. Chemical Ecology. 15(3):917-928.

Blum, U., T.M. Gerig and S.B. Weed. 1989. Effects of mixtures of phenolic acids on leaf area expansion of cucumber seedlings grown in different pH portsmouth A1 soil materials. J. Chemical Ecology. 15(10):2413-2423.

Blum, U., T.R. Wentworth, K. Klein, A.D. Worsham, L.D. King, T.M. Gerig and S.-W. Lyu. 1991. Phenolic acid content of soils from wheat-no till, wheat-conventional till, and fallow-conventional till soybean cropping systems. J. Chemical Ecology. 17(6):1045-1068.

Cast, K.G., J.K. McPherson, A.J. Pollard, E.G. Krenzer, Jr. and G.R. Waller. 1990. Allelochemicals in soil from no-tillage versus conventional-tillage wheat (*Triticum aestivum*) fields. J. Chemical Ecology. 16(7):2277-2289.

Chou, C.-H. and Z.A. Patrick. 1976. Identification and phytotoxic activity of compounds produced during decomposition of corn and rye residues in soil. J. Chemical Ecology. 2(3):369-387.

Dalton, B.R., U. Blum and S.B. Weed. 1983. Allelopathic substances in ecosystems: Effectiveness of sterile soil components in altering recovery of ferulic acid. J. Chemical Ecology. 9(8):1185-1201.

Dao, T.H. 1987. Sorption and mineralization of plant phenolic acids in soil. *In* Allelochemicals: Role in agriculture and forestry. ed. George R. Waller. Am. Chem. Soc. Symp. Ser. No. 330. Washington, D.C. pp. 358-370.

Doss, B.D., J.L. Turner and C.E. Evans. 1981. Influence of tillage, nitrogen, and rye cover crop on growth and yield of tomatoes. J. Amer. Soc. Hort. Sci. 106(1):95-97.

Einhellig, F.A. and J.A. Rasmussen. 1979. Effects of three phenolic acids on chlorophyll content and growth of soybean and grain sorghum seedlings. J. Chem. Ecol. 5:815-824.

Guenzi, W.D. and T.M. McCalla. 1962. Inhibition of germination and seedling development by crop residues. Soil Sci. Soc. Am. Proc. 26:456-458.

Guenzi, W.D. and T.M. McCalla. 1966a. Phenolic acids in oats, wheat, sorghum, and corn residues and their phytotoxicity. Agronomy J. 58(3):303-304.

Guenzi, W.D. and T.M. McCalla. 1966b. Phytotoxic substances extracted from soil. Soil Sci. Soc. Amer. Proc. 30:214-216.

Hicks, S.K., C.W. Wendt, J.R. Gannaway and R.B. Baker. 1989. Allelopathic effects of wheat straw on cotton germination, emergence, and yield. Crop Sci. 29(4):1057-1061.

Kaminsky, R. and W.H. Muller. 1978. A recommendation against the use of alkaline soil extractions in the study of allelopathy. Plant Soil. 49:641-645.

Kimber, R.W.L. 1967. Phytotoxicity from plant residues I. The influence of rotted wheat straw on seedling growth. Aust. J. Agric. Res. 18:361-374.

Leather, G.R. and F.A. Einhellig. 1988. Bioassay of naturally occurring allelochemicals for phytotoxicity. J. Chemical Ecology. 14(10):1821-1828.

Liebl, R.A. and A.D. Worsham. 1983. Inhibition of pitted morning glory (*Ipomoea lacunosa* L.) and certain other weed species by phytotoxic components of wheat (*Triticum aestivum* L.) straw. J. Chemical Ecology. 9(8):1027-1043.

Mersie, W. and M. Singh. 1988. Effects of phenolic acids and ragweed parthenium (*Parthenium hysterophorus*) extracts on tomato (*Lycopersicon esculentum*) growth and nutrient and chlorophyll content. Weed Sci. 36(3):278-281.

Norstadt, F.A. and T.M. McCalla. 1968b. Microbially induced phytotoxicity in stubble-mulched soil. Soil Sci. Soc. Amer. Proc. 32:241-245.

Patrick, Z.A., T.A. Toussoun and W.C. Snyder. 1963. Phytotoxic substances in arable soils associated with decomposition of plant residues. Phytopathology. 53:152-161.

Patrick, Z.A. 1971. Phytotoxic substances associated with the decomposition in soil of plant residues. Soil Sci. 111:13-18.

Patterson, D.T. 1981. Effects of allelopathic chemicals on growth and physiological responses of soybean (*Glycine max*) Weed Sci. 29:53-59.

Putnam, A.R. and W.B. Duke. 1978. Allelopathy in agroecosystems. Ann. Rev. Phytopathol. 16:431-451.

Putnam, A.R. 1985b. Allelopathic research in agriculture: Past highlights and potential. *In* The chemistry of allelopathy. ed. A.C. Thompson. Am. Chem. Soc. Symp. Ser. No. 268. pp. 1-8.

Rainbault, B.A., T.J. Vyn and M. Tollenaar. 1990. Corn response to rye cover crop management and spring tillage systems. Agron. J. 82(6):1088-1093.

SAS Institue Inc. 1990. SAS/Stat User's Guide, Version 6, Fourth Edition. SAS Institue Inc. Cary, N.C.

Shilling, D.G., A.D. Worsham and D.A. Danehower. 1986a. Influence of mulch, tillage, and diphenamid on weed control, yield, and quality in no-till flue-cured tobacco (*Nicotiana tabacum*). Weed Science. 34:738-744.

Shilling, D.G., L.A. Jones, A.D. Worsham, C.E. Parker and R.F. Wilson. 1986b. Isolation and identification of some phytotoxic compounds from aqueous extracts of rye (*Secale cereale* L.) J. Agric. Food Chem. 34:633-638.

Wang, T.S.C., S.Y. Cheng and H. Tung. 1967a. Dynamics of soil organic acids. Soil Sci. 104:138-144.

Wang, T.S.C., T.-K. Yang and T.-T. Chuang. 1967b. Soil phenolic acids as plant growth inhibitors. Soil Sci. 103:239-246.

Wang, T.S.C., K. Yeh, S. Cheng and T. Yang. 1971. Behavior of soil phenolic acids. *In* Biochemical interactions among plants. National Academy of Sciences. Wash. D.C. pp. 113-20.

Waters, E.R. and U. Blum. 1987. The effects of single and multiple exposures of ferulic acid on the vegetative and reproductive growth of *Phaseolus vulgaris*. BBL-290. Am. J. Bot. 74:1635-1645.

Whitehead, D.C. 1964. Identification of p-hydroxybenzoic, vanillic, p-coumaric and ferulic acids in soils. Nature. 202:417-418.

Whitehead, D.C., H. Dibb and R.D. Hartley. 1982. Phenolic compounds in soil as influenced by the growth of different plant species. J. Appl. Ecol. 19:579-588.

Whitehead, D.C., H. Dibb and R.D. Hartley. 1983. Bound phenolic compounds in water extracts of soils, plant roots and leaf litter. Soil Biol. Biochem. 15:133-136.

Williams, R.D. and R.E. Hoagland. 1982. The effects of naturally occurring phenolic compounds on seed germination. Weed. Sci. 30:206-212.

APPENDICES

APPENDIX A
TOBBACO/BROCCOLI FIELD DATA

Table A-1. Mean yield, revenue and grade index of burley tobacco in 1989 by tillage and sequence combined over two locations.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Yield (kg ha^{-1})			
Tb/Br[y] (S1)	1886 232[z]	2389 232	2388 232	2221 207
Br/Tb (S2)	2000 234	2672 232	2418 232	2363 207
Br/Tb/Br (S3)	1931 232	2605 232	2332 232	2289 207
$\bar{X}$	1939 212	2556 212	2379 212	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0001	0.0031	0.0243	0.2214	0.5533	0.5189

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Revenue (\$ ha^{-1})			
Tb/Br (S1)	6491 934	8126 934	8116 934	7578 852
Br/Tb (S2)	6592 941	9322 934	8124 934	8013 853
Br/Tb/Br (S3)	6538 934	8939 934	7906 934	7795 852
$\bar{X}$	6541 870	8796 869	8050 869	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0001	0.0048	0.1398	0.2816	0.5863	0.5869

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Grade Index			
Tb/Br (S1)	63.15 6.47	59.44 6.47	61.21 6.47	61.27 5.81
Br/Tb (S2)	54.10 6.48	65.41 6.47	58.69 6.47	59.40 5.82
Br/Tb/Br (S3)	57.39 6.47	61.24 6.47	59.34 6.47	59.32 5.81
$\bar{X}$	58.21 5.82	62.03 5.82	59.75 5.82	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.1914	0.5951	0.4293	0.5158	0.4975	0.9777

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-2. Mean yield, revenue and grade index of burley tobacco in 1990 by tillage and sequence combined over two locations.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Yield (kg ha^{-1})			
Tb/Br[y] (S1)	1865	2088	2216	2056
	221[z]	221	221	188
Br/Tb (S2)	1999	2379	2315	2231
	221	221	221	188
Br/Tb/Br (S3)	1803	2196	2332	2110
	221	221	221	188
$\bar{X}$	1889	2221	2287	
	200	200	200	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0440	0.0172	0.6756	0.0994	0.6003	0.2503

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Revenue (\$ ha^{-1})			
Tb/Br (S1)	6168	7203	7529	6965
	1612	1612	1612	1553
Br/Tb (S2)	6546	8247	7904	7566
	1612	1612	1612	1553
Br/Tb/Br (S3)	6150	7751	8168	7356
	1612	1612	1612	1553
$\bar{X}$	6289	7734	7867	
	1573	1573	1573	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0166	0.0095	0.8143	0.1133	0.2956	0.5739

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Grade Index			
Tb/Br (S1)	55.61	60.81	59.79	58.74
	3.49	3.49	3.49	2.60
Br/Tb (S2)	52.55	58.95	56.46	55.99
	3.49	3.49	3.49	2.60
Br/Tb/Br (S3)	58.18	62.45	61.03	60.55
	3.49	3.49	3.49	2.60
$\bar{X}$	55.45	60.74	59.09	
	2.24	2.24	2.24	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0408	0.1507	0.5102	0.4214	0.5950	0.1866

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-3. Mean yield, revenue and grade index of burley tobacco at Greeneville, TN by tillage and sequence combined over 1989 and 1990.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Yield (kg ha^{-1})			
Tb/Br[y] (S1)	2341	2220	2455	2338
	274[z]	274	274	256
Br/Tb (S2)	2406	2617	2379	2467
	274	274	274	256
Br/Tb/Br (S3)	2054	2186	2456	2232
	274	274	274	256
$\bar{X}$	2267	2342	2430	
	258	258	258	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.4783	0.1277	0.4015	0.1800	0.2618	0.0178

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Revenue (\$ ha^{-1})			
Tb/Br (S1)	8074	7600	8139	7939
	1022	1022	1022	950
Br/Tb (S2)	7778	8924	7852	8186
	1025	1022	1022	950
Br/Tb/Br (S3)	6958	7516	8314	7598
	1022	1022	1022	950
$\bar{X}$	7605	8013	8102	
	960	960	960	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.3417	0.2499	0.8368	0.4892	0.3386	0.1056

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Grade Index			
Tb/Br (S1)	62.43	56.23	55.30	57.98
	4.50	4.50	4.50	2.93
Br/Tb (S2)	46.29	57.69	51.85	51.94
	4.56	4.50	4.50	2.94
Br/Tb/Br (S3)	55.49	58.34	55.45	56.43
	4.50	4.50	4.50	2.93
$\bar{X}$	54.73	57.42	54.20	
	2.61	2.60	2.60	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.4401	0.8774	0.3547	0.1571	0.7101	0.2898

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-4. Mean yield, revenue and grade index of burley tobacco at Greeneville, TN in 1989 by tillage and sequence.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Yield (kg ha^{-1})			
Tb/Br[y] (S1)	1947 138[z]	1979 138	2206 138	2044 89
Br/Tb (S2)	2093 140	2564 138	2327 138	2327 89
Br/Tb/Br (S3)	1693 138	1917 138	2134 138	1914 89
$\bar{X}$	1911 89	2153 89	2222 89	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0339	0.0085	0.5179	0.0150	0.2347	0.0010

	Revenue ($ ha^{-1})			
Tb/Br (S1)	6713 543	6387 543	7390 543	6830 348
Br/Tb (S2)	6610 550	8828 543	7719 543	7719 349
Br/Tb/Br (S3)	5619 543	6444 543	7094 543	6385 348
$\bar{X}$	6313 349	7220 348	7400 348	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0439	0.0181	0.6684	0.0475	0.3010	0.0051

	Grade Index			
Tb/Br (S1)	63.58 7.07	48.18 7.07	56.08 7.07	55.94 4.30
Br/Tb (S2)	44.98 7.18	61.95 7.07	54.50 7.07	53.81 4.32
Br/Tb/Br (S3)	51.43 7.07	54.58 7.07	54.03 7.07	53.34 4.30
$\bar{X}$	53.33 4.45	54.90 4.43	54.87 4.43	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.7900	0.7944	0.9955	0.7043	0.6426	0.9332

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-5. Mean yield, revenue and grade index of burley tobacco at Greeneville, TN in 1990 by tillage and sequence.

Sequence (S)	Tillage (T)					
	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$		
	Yield (kg ha^{-1})					
Tb/Br[y] (S1)	2736	2462	2704	2634		
	192[z]	192	192	111		
Br/Tb (S2)	2716	2672	2430	2606		
	192	192	192	111		
Br/Tb/Br (S3)	2414	2456	2779	2549		
	192	192	192	111		
$\bar{X}$	2622	2530	2638			
	116	116	116			
Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.5804	0.9252	0.5187	0.8601	0.5883	0.7140
	Revenue ($ ha^{-1})					
Tb/Br (S1)	9438	8813	9000	9048		
	729	729	729	421		
Br/Tb (S2)	8949	9020	7986	8652		
	729	729	729	421		
Br/Tb/Br (S3)	8299	8591	9534	8808		
	729	729	729	421		
$\bar{X}$	8894	8808	8803			
	498	498	498			
Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.9029	0.8966	0.9936	0.4669	0.6578	0.7729
	Grade Index					
Tb/Br (S1)	61.28	64.28	54.53	60.03		
	5.92	5.92	5.92	3.42		
Br/Tb (S2)	49.05	53.43	49.20	50.56		
	5.92	5.92	5.92	3.42		
Br/Tb/Br (S3)	59.55	62.10	56.88	59.51		
	5.92	5.92	5.92	3.42		
$\bar{X}$	56.63	59.93	53.53			
	3.42	3.42	3.42			
Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.5023	0.5304	0.2020	0.0658	0.9160	0.0805

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-6. Mean yield, revenue and grade index of burley tobacco at Knoxville, TN by tillage and sequence combined over 1989 and 1990.

Sequence (S)	Tillage (T) No-Till (T1)	 Conventional (cover) (T2)	 Conventional (no cover) (T3)	 $\bar{X}$
		Yield (kg ha^{-1})		
Tb/Br[y] (S1)	1409	2257	2149	1939
	191[z]	191	191	171
Br/Tb (S2)	1599	2434	2354	2129
	191	191	191	171
Br/Tb/Br (S3)	1681	2615	2208	2167
	191	191	191	171
	1564	2435	2237	
$\bar{X}$	174	174	174	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0001	0.0001	0.1198	0.0905	0.0439	0.7236

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
		Revenue ($ ha^{-1})		
Tb/Br (S1)	4584	7729	7506	6607
	682	682	682	601
Br/Tb (S2)	5377	8645	8176	7398
	682	682	682	601
Br/Tb/Br (S3)	5730	9174	7763	7556
	682	682	682	601
	5229	8514	7815	
$\bar{X}$	619	619	619	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0001	0.0001	0.1440	0.0508	0.0211	0.6903

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
		Grade Index		
Tb/Br (S1)	56.34	64.03	65.70	62.02
	3.06	3.06	3.06	2.79
Br/Tb (S2)	59.40	66.68	63.30	63.13
	3.06	3.06	3.06	2.79
Br/Tb/Br (S3)	60.08	65.35	64.91	63.45
	3.06	3.06	3.06	2.79
	58.60	65.35	64.64	
$\bar{X}$	2.86	2.86	2.86	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0002	0.0006	0.6525	0.3520	0.2321	0.7853

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-7. Mean yield, revenue and grade index of burley tobacco at Knoxville, TN in 1989 by tillage and sequence.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Yield (kg ha^{-1})			
Tb/Br[y] (S1)	1826	2800	2569	2398
	177[z]	177	177	102
Br/Tb (S2)	1916	2782	2509	2402
	177	177	177	102
Br/Tb/Br (S3)	2168	3294	2530	2663
	177	177	177	102
$\bar{X}$	1970	2958	2536	
	135	135	135	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0001	0.0082	0.0400	0.9737	0.0320	0.0343

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Revenue ($ ha^{-1})			
Tb/Br (S1)	6269	9868	8845	8326
	623	623	623	360
Br/Tb (S2)	6612	9816	8526	8319
	623	623	623	360
Br/Tb/Br (S3)	7457	11434	8719	9203
	623	623	623	360
$\bar{X}$	6780	10372	8697	
	481	481	481	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0001	0.0114	0.0241	0.9832	0.0401	0.0384

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Grade Index			
Tb/Br (S1)	62.73	70.70	66.35	66.59
	2.03	2.03	2.03	1.49
Br/Tb (S2)	62.75	68.88	62.88	64.83
	2.03	2.03	2.03	1.49
Br/Tb/Br (S3)	63.35	67.90	64.65	65.30
	2.03	2.03	2.03	1.49
$\bar{X}$	62.94	69.16	64.63	
	1.49	1.49	1.49	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0003	0.2351	0.0039	0.2157	0.3584	0.7374

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-8. Mean yield, revenue and grade index of burley tobacco at Knoxville, TN in 1990 by tillage and sequence.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Yield ($kg\ ha^{-1}$)			
Tb/Br[y] (S1)	993 119[z]	1714 119	1729 119	1478 82
Br/Tb (S2)	1282 119	2087 119	2199 119	1856 82
Br/Tb/Br (S3)	1194 119	1936 119	1885 119	1671 82
$\bar{X}$	1156 82	1912 82	1938 82	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0001	0.0001	0.7744	0.0004	0.0394	0.0483

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Revenue ($\$\ ha^{-1}$)			
Tb/Br (S1)	2900 459	5590 459	6168 459	4886 309
Br/Tb (S2)	4140 459	7474 459	7825 459	6479 309
Br/Tb/Br (S3)	4004 459	6911 459	6805 459	5906 309
$\bar{X}$	3680 309	6659 309	6933 309	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0001	0.0001	0.4280	0.0002	0.0075	0.1082

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Grade Index			
Tb/Br (S1)	49.95 1.97	57.35 1.97	65.05 1.97	57.45 1.29
Br/Tb (S2)	56.05 1.97	64.48 1.97	63.73 1.97	61.42 1.29
Br/Tb/Br (S3)	56.80 1.97	62.80 1.97	65.18 1.97	61.59 1.29
$\bar{X}$	54.27 1.29	61.54 1.29	64.65 1.29	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0001	0.0001	0.0512	0.0158	0.0123	0.9077

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-9. Mean yield, revenue and grade index of burley tobacco by tillage and sequence combined over years and locations.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Yield (kg ha^{-1})			
Tb/Br[y] (S1)	1875 228[z]	2239 228	2303 228	2138 215
Br/Tb (S2)	2003 228	2526 228	2367 228	2298 215
Br/Tb/Br (S3)	1867 228	2401 228	2332 228	2200 215
$\bar{X}$	1915 218	2388 218	2333 218	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0001	0.0001	0.5792	0.0324	0.4030	0.1820

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Revenue (\$ ha^{-1})			
Tb/Br (S1)	6331 794	7664 794	7822 794	7272 741
Br/Tb (S2)	6583 796	8783 794	8013 794	7793 741
Br/Tb/Br (S3)	6345 794	8346 794	8037 794	7575 741
$\bar{X}$	6420 758	8265 758	7958 758	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0001	0.0001	0.4176	0.0513	0.2502	0.4096

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Grade Index			
Tb/Br (S1)	59.38 4.33	60.13 4.33	60.50 4.33	60.00 3.91
Br/Tb (S2)	52.92 4.33	62.18 4.33	57.58 4.33	57.56 3.91
Br/Tb/Br (S3)	57.78 4.33	61.84 4.33	60.18 4.33	59.94 3.91
$\bar{X}$	56.69 3.85	61.38 3.85	59.42 3.85	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0150	0.1509	0.2980	0.2742	0.9761	0.2873

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-10. Mean stand, leaf nitrogen concentration and crop index of burley tobacco in 1989 by tillage and sequence combined over two locations.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Stand (plants plot^{-1})			
Tb/Br[y] (S1)	47.8 2.7[z]	42.4 2.7	39.8 2.7	43.3 2.1
Br/Tb (S2)	39.0 2.7	45.9 2.7	43.1 2.7	42.7 2.1
Br/Tb/Br (S3)	43.3 2.7	38.4 2.7	42.0 2.7	41.2 2.1
$\bar{X}$	43.3 1.9	42.2 1.9	41.6 1.9	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.5021	0.3087	0.7230	0.7739	0.3510	0.5168

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Nitrogen (%)			
Tb/Br (S1)	3.90 0.19	4.07 0.19	4.14 0.19	4.04 0.16
Br/Tb (S2)	4.09 0.19	4.09 0.19	4.01 0.19	4.06 0.16
Br/Tb/Br (S3)	4.23 0.19	4.26 0.19	4.22 0.19	4.24 0.16
$\bar{X}$	4.07 0.16	4.14 0.16	4.13 0.16	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.5606	0.6587	0.8874	0.8050	0.0694	0.1137

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Crop Index			
Tb/Br (S1)	106.4 24.3	131.0 24.3	130.9 24.3	122.8 22.5
Br/Tb (S2)	96.7 24.4	156.8 24.3	127.3 24.3	126.9 22.5
Br/Tb/Br (S3)	100.4 24.3	147.2 24.3	125.5 24.3	124.4 22.5
$\bar{X}$	101.2 22.9	145.0 22.9	127.9 22.9	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0005	0.0234	0.1356	0.6220	0.8504	0.7597

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-11. Mean stand, leaf nitrogen concentration and crop index of burley tobacco in 1990 by tillage and sequence combined over two locations.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Stand (plants plot^{-1})			
Tb/Br[y] (S1)	38.9	36.4	39.0	38.1
	3.9[z]	3.9	3.9	2.3
Br/Tb (S2)	34.0	38.1	34.1	35.4
	3.9	3.9	3.9	2.3
Br/Tb/Br (S3)	29.3	35.5	37.4	34.0
	3.9	3.9	3.9	2.3
$\bar{X}$	34.0	36.7	36.8	
	2.3	2.3	2.3	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.4085	0.3797	0.9579	0.4034	0.2091	0.6652

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Nitrogen (%)			
Tb/Br (S1)	3.86	3.99	4.23	4.03
	0.35	0.35	0.38	0.32
Br/Tb (S2)	4.08	4.05	4.27	4.13
	0.35	0.35	0.35	0.31
Br/Tb/Br (S3)	3.91	4.15	3.69	3.92
	0.36	0.35	0.35	0.32
$\bar{X}$	3.95	4.06	4.06	
	0.32	0.31	0.32	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.4720	0.4937	0.9990	0.5232	0.4872	0.1703

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Crop Index			
Tb/Br (S1)	98.5	115.2	114.9	109.5
	22.0	22.0	22.0	20.4
Br/Tb (S2)	90.9	123.8	115.5	110.1
	22.0	22.0	22.0	20.4
Br/Tb/Br (S3)	94.1	122.7	125.0	114.0
	22.0	22.0	22.0	20.4
$\bar{X}$	94.5	120.6	118.5	
	20.7	20.7	20.7	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0214	0.0331	0.8463	0.9510	0.6155	0.6590

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-12. Mean stand, leaf nitrogen concentration and crop index of burley tobacco at Greenville, TN by tillage and sequence combined over 1989 and 1990.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	X̄
	Stand (plants plot^{-1})			
Tb/Br[y] (S1)	35.0	40.9	38.1	38.0
	5.1[z]	5.1	5.1	4.7
Br/Tb (S2)	45.4	41.1	40.0	42.2
	5.1	5.1	5.1	4.7
Br/Tb/Br (S3)	40.3	33.6	42.1	38.7
	5.1	5.1	5.1	4.7
X̄	40.2	38.5	40.1	
	4.7	4.7	4.7	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.4002	0.9480	0.4358	0.0569	0.7527	0.1063

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	X̄
	Nitrogen (%)			
Tb/Br (S1)	4.29	4.25	4.35	4.30
	0.13	0.13	0.14	0.08
Br/Tb (S2)	4.27	4.26	4.26	4.26
	0.13	0.13	0.13	0.07
Br/Tb/Br (S3)	4.23	4.46	4.23	4.31
	0.13	0.13	0.13	0.07
X̄	4.26	4.32	4.28	
	0.08	0.08	0.08	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.5578	0.8738	0.6730	0.7329	0.9270	0.6616

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	X̄
	Crop Index			
Tb/Br (S1)	130.8	114.0	119.3	121.4
	17.9	17.9	17.9	15.3
Br/Tb (S2)	100.5	134.4	110.1	115.0
	17.9	17.9	17.9	15.3
Br/Tb/Br (S3)	103.1	115.4	122.4	113.6
	17.9	17.9	17.9	15.3
X̄	111.5	121.3	117.3	
	15.4	15.3	15.3	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.3198	0.5530	0.6828	0.5093	0.4205	0.8835

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-13. Mean stand, leaf nitrogen concentration and crop index of burley tobacco at Greeneville, TN in 1989 by tillage and sequence.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Stand (plants plot^{-1})			
Tb/Br[y] (S1)	43.0	43.0	41.8	42.6
	1.9[z]	1.9	1.9	1.1
Br/Tb (S2)	49.5	48.8	48.8	49.0
	1.9	1.9	1.9	1.1
Br/Tb/Br (S3)	45.0	36.0	42.0	41.0
	1.9	1.9	1.9	1.1
	45.8	42.6	44.2	
$\bar{X}$	1.1	1.1	1.1	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0576	0.3117	0.3363	0.0007	0.3234	0.0001

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Nitrogen (%)			
Tb/Br (S1)	4.30	4.26	4.26	4.27
	0.19	0.19	0.19	0.11
Br/Tb (S2)	4.05	4.22	4.19	4.15
	0.19	0.19	0.19	0.11
Br/Tb/Br (S3)	4.50	4.44	4.09	4.35
	0.19	0.19	0.19	0.11
	4.28	4.31	4.19	
$\bar{X}$	0.13	0.13	0.13	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.8979	0.5798	0.4950	0.3895	0.6176	0.1824

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Crop Index			
Tb/Br (S1)	110.0	85.8	109.9	101.9
	15.9	15.9	15.9	9.6
Br/Tb (S2)	84.5	141.7	114.2	113.4
	16.0	15.9	15.9	9.6
Br/Tb/Br (S3)	78.2	93.6	104.7	92.2
	15.9	15.9	15.9	9.6
	90.9	107.0	109.6	
$\bar{X}$	9.6	9.6	9.6	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.2201	0.1582	0.8420	0.3758	0.4542	0.1118

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-14. Mean stand, leaf nitrogen concentration and crop index of burley tobacco at Greeneville, TN in 1990 by tillage and sequence.

Sequence (S)	Tillage (T) No-Till (T1)	 Conventional (cover) (T2)	 Conventional (no cover) (T3)	 $\bar{X}$
	Stand (plants plot^{-1})			
Tb/Br[y] (S1)	27.0 4.1[z]	38.8 4.1	34.5 4.1	33.4 2.4
Br/Tb (S2)	41.5 4.1	33.5 4.1	31.3 4.1	35.4 2.4
Br/Tb/Br (S3)	35.5 4.1	31.3 4.1	42.3 4.1	36.3 2.4
$\bar{X}$	34.7 2.6	34.5 2.6	36.0 2.6	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.9642	0.7203	0.6872	0.5327	0.3658	0.7739

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Nitrogen (%)			
Tb/Br (S1)	4.28 0.17	4.24 0.17	4.48 0.19	4.33 0.11
Br/Tb (S2)	4.49 0.17	4.31 0.17	4.33 0.17	4.37 0.10
Br/Tb/Br (S3)	3.96 0.17	4.48 0.17	4.36 0.17	4.27 0.10
$\bar{X}$	4.24 0.10	4.34 0.10	4.39 0.11	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.4564	0.2930	0.7350	0.7725	0.6347	0.4350

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Crop Index			
Tb/Br (S1)	151.6 16.2	142.3 16.2	128.7 16.2	140.9 9.3
Br/Tb (S2)	117.8 16.2	127.2 16.2	106.0 16.2	117.0 9.3
Br/Tb/Br (S3)	127.9 16.2	137.1 16.2	140.1 16.2	135.0 9.3
$\bar{X}$	132.4 10.4	135.5 10.4	124.9 10.4	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.8348	0.6183	0.4816	0.0697	0.6430	0.1624

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-15. Mean stand, leaf nitrogen concentration and crop index of burley tobacco at Knoxville, TN by tillage and sequence combined over 1989 and 1990.

Sequence (S)	Tillage (T)					
	No-Till (T1)		Conventional (cover) (T2)		Conventional (no cover) (T3)	$\bar{X}$
	Stand (plants plot^{-1})					
Tb/Br^y (S1)	51.6		37.9		40.6	43.4
	3.4^z		3.4		3.4	2.5
Br/Tb (S2)	28.0		42.9		37.3	36.0
	3.4		3.4		3.4	2.5
Br/Tb/Br (S3)	32.3		40.3		37.3	36.6
	3.4		3.4		3.4	2.5
	37.3		40.3		38.4	
$\bar{X}$	2.5		2.5		2.5	
Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.2166	0.6560	0.4226	0.0050	0.0087	0.8235
	Nitrogen (%)					
Tb/Br (S1)	3.48		3.81		3.97	3.75
	0.22		0.22		0.24	0.16
Br/Tb (S2)	3.89		3.88		4.03	3.93
	0.22		0.22		0.22	0.15
Br/Tb/Br (S3)	3.95		3.95		3.68	3.86
	0.23		0.22		0.22	0.15
	3.77		3.88		3.89	
$\bar{X}$	0.16		0.15		0.16	
Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.5146	0.4840	0.9481	0.2762	0.5025	0.6690
	Crop Index					
Tb/Br (S1)	74.1		132.2		126.4	110.9
	13.2		13.2		13.2	11.5
Br/Tb (S2)	85.5		146.1		132.8	121.5
	13.2		13.2		13.2	11.5
Br/Tb/Br (S3)	91.5		154.6		128.1	124.7
	13.2		13.2		13.2	11.5
	83.7		144.3		129.1	
$\bar{X}$	12.1		12.1		12.1	
Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0001	0.0001	0.1089	0.1188	0.0444	0.6241

^{y}Tb=Tobacco, Br=Broccoli. ^{z}Standard error appears below each mean.

Table A-16. Mean stand, leaf nitrogen concentration and crop index of burley tobacco at Knoxville, TN in 1989 by tillage and sequence.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Stand (plants $plot^{-1}$)			
Tb/Br[y] (S1)	52.5 2.9[z]	41.8 2.9	37.8 2.9	44.0 1.7
Br/Tb (S2)	29.5 2.9	43.0 2.9	37.5 2.9	36.7 1.7
Br/Tb/Br (S3)	41.5 2.9	40.8 2.9	42.0 2.9	41.4 1.7
$\bar{X}$	41.2 1.8	41.8 1.8	39.1 1.8	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.7967	0.4245	0.2949	0.0050	0.2745	0.0529

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Nitrogen (%)			
Tb/Br (S1)	3.50 0.16	3.88 0.16	4.02 0.16	3.80 0.90
Br/Tb (S2)	4.10 0.16	3.97 0.16	3.84 0.16	3.97 0.90
Br/Tb/Br (S3)	3.96 0.16	4.09 0.16	4.35 0.16	4.13 0.90
$\bar{X}$	3.86 0.10	3.98 0.10	4.07 0.10	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.3840	0.1383	0.5184	0.1985	0.0177	0.2183

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Crop Index			
Tb/Br (S1)	102.8 12.3	176.3 12.3	151.9 12.3	143.7 7.1
Br/Tb (S2)	107.1 12.3	171.9 12.3	140.5 12.3	139.8 7.1
Br/Tb/Br (S3)	122.6 12.3	200.8 12.3	146.3 12.3	156.5 7.1
$\bar{X}$	110.8 10.0	183.0 10.0	146.2 10.0	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0001	0.0217	0.0177	0.6016	0.0935	0.0334

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-17. Mean stand, leaf nitrogen concentration and crop index of burley tobacco at Knoxville, TN in 1990 by tillage and sequence.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Stand (plants plot^{-1})			
Tb/Br^y (S1)	50.8 5.3^z	34.0 5.3	43.5 5.3	42.8 3.5
Br/Tb (S2)	26.5 5.3	42.8 5.3	37.0 5.3	35.4 3.5
Br/Tb/Br (S3)	23.0 5.3	39.8 5.3	32.5 5.3	31.8 3.5
$\bar{X}$	33.4 3.5	38.8 3.5	37.7 3.5	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.1911	0.3006	0.7732	0.0824	0.0129	0.3699

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Nitrogen (%)			
Tb/Br (S1)	3.45 0.36	3.74 0.36	3.86 0.49	3.68 0.26
Br/Tb (S2)	3.67 0.36	3.79 0.36	4.21 0.36	3.89 0.23
Br/Tb/Br (S3)	3.98 0.41	3.82 0.36	3.01 0.36	3.60 0.24
$\bar{X}$	3.70 0.28	3.78 0.27	3.69 0.29	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.8130	0.9839	0.8032	0.4536	0.7783	0.2765

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Crop Index			
Tb/Br (S1)	45.5 7.9	88.1 7.9	101.0 7.9	78.2 5.4
Br/Tb (S2)	64.0 7.9	120.3 7.9	125.1 7.9	103.1 5.4
Br/Tb/Br (S3)	60.4 7.9	108.4 7.9	109.9 7.9	92.9 5.4
$\bar{X}$	56.6 5.4	105.6 5.4	112.0 5.4	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0001	0.0001	0.2848	0.0004	0.0203	0.0940

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-19. Mean head and stem circumference and total leaf N concentration of broccoli in 1989 by tillage and sequence combined over two locations.

	Tillage (T)			
Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Head Circumference (cm)			
Br/Tb[y] (S2)	21.03	33.55	39.53	31.37
	1.96[z]	1.96	1.96	1.52
Br/Tb/Br (S3)	18.41	22.63	30.07	23.70
	2.32	2.32	2.32	1.79
$\bar{X}$	19.72	28.09	34.80	
	1.78	1.79	1.79	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0006	0.0001	0.0034	0.0008
	Stem Circumference (cm)			
Br/Tb (S2)	9.10	10.62	11.57	10.43
	0.50	0.50	0.50	0.42
Br/Tb/Br (S3)	8.41	9.60	10.87	9.96
	0.55	0.55	0.55	0.45
$\bar{X}$	8.75	10.11	11.22	
	0.48	0.48	0.48	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0082	0.0001	0.0251	0.0190
	N (%)			
Br/Tb (S2)	3.32	3.15	3.40	3.29
	0.39	0.39	0.39	0.36
Br/Tb/Br (S3)	3.87	3.58	3.78	3.74
	0.47	0.47	0.47	0.44
$\bar{X}$	3.60	3.37	3.59	
	0.33	0.33	0.33	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.3966	0.9779	0.4116	0.4228

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-20. Mean head and stem circumference and total leaf N concentration of broccoli in 1990 by tillage and sequence combined over two locations.

Sequence (S)	Tillage (T)			
	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Head Circumference (cm)			
Br/Tb[y] (S2)	33.70	39.90	41.92	38.51
	2.22[z]	2.22	2.22	1.97
Br/Tb/Br (S3)	34.28	41.00	41.37	38.89
	2.38	2.22	2.22	2.05
	33.99	40.45	41.65	
$\bar{X}$	2.16	2.16	2.16	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0011	0.0003	0.4623	0.6985
	Stem Circumference (cm)			
Br/Tb (S2)	11.14	12.79	12.93	12.28
	0.48	0.48	0.48	0.37
Br/Tb/Br (S3)	11.22	12.58	12.84	12.21
	0.51	0.51	0.51	0.39
	11.18	12.68	12.88	
$\bar{X}$	0.47	0.47	0.47	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0100	0.0045	0.6956	0.7571
	N (%)			
Br/Tb (S2)	2.51	2.58	2.92	2.67
	0.45	0.45	0.45	0.44
Br/Tb/Br (S3)	2.68	2.52	2.78	2.66
	0.45	0.45	0.45	0.44
	2.59	2.55	2.85	
$\bar{X}$	0.45	0.45	0.45	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.7229	0.0515	0.0259	0.8932

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-21. Mean head and stem circumference and total leaf N concentration of broccoli at Greeneville, TN by tillage and sequence combined over 1989 and 1990.

Sequence (S)	Tillage (T)			
	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Head Circumference (cm)			
Br/Tb[y] (S2)	30.37	43.65	43.67	39.23
	4.67[z]	4.67	4.67	4.44
Br/Tb/Br (S3)	28.16	35.78	36.52	33.48
	4.67	4.67	4.67	4.44
$\bar{X}$	29.26	39.71	40.09	
	3.32	3.32	3.32	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0001	0.0001	0.8402	0.3751
	Stem Circumference (cm)			
Br/Tb (S2)	10.92	12.09	12.10	11.71
	0.56	0.56	0.56	0.49
Br/Tb/Br (S3)	10.29	11.19	11.70	11.06
	0.56	0.56	0.56	0.49
$\bar{X}$	10.61	11.64	11.90	
	0.43	0.43	0.43	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0252	0.0072	0.5351	0.3486
	N (%)			
Br/Tb (S2)	4.59	4.19	4.42	4.40
	0.27	0.27	0.27	0.23
Br/Tb/Br (S3)	4.82	4.20	4.55	4.52
	0.27	0.27	0.27	0.23
$\bar{X}$	4.71	4.20	4.48	
	0.25	0.25	0.25	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0322	0.3127	0.2047	0.4203

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-22. Mean head and stem circumference and total leaf N concentration of broccoli at Greeneville, TN in 1989 by tillage and sequence.

Sequence (S)	Tillage (T)			
	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Head Circumference (cm)			
Br/Tb[y] (S2)	18.83	37.29	38.05	31.39
	2.47[z]	2.47	2.47	1.74
Br/Tb/Br (S3)	13.74	20.21	23.56	19.17
	2.47	2.47	2.47	1.74
	16.28	28.75	30.81	
$\bar{X}$	1.94	1.94	1.94	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0003	0.0001	0.3629	0.0001
	Stem Circumference (cm)			
Br/Tb (S2)	9.52	11.91	11.16	10.86
	0.47	0.47	0.47	0.27
Br/Tb/Br (S3)	8.15	9.91	10.15	9.40
	0.47	0.47	0.47	0.27
	8.83	10.91	10.65	
$\bar{X}$	0.35	0.35	0.35	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0023	0.0050	0.6189	0.0032
	N (%)			
Br/Tb (S2)	4.89	4.35	4.17	4.47
	0.26	0.26	0.26	0.15
Br/Tb/Br (S3)	5.64	4.38	4.65	4.89
	0.26	0.26	0.26	0.15
	5.26	4.36	4.41	
$\bar{X}$	0.21	0.21	0.21	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0135	0.0174	0.8782	0.0434

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-23. Mean head and stem circumference and total leaf N concentration of broccoli at Greeneville, TN in 1990 by tillage and sequence.

Sequence (S)	Tillage (T)			
	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Head Circumference (cm)			
Br/Tb^y (S2)	41.91 2.21^z	50.01 2.21	49.29 2.21	47.07 1.28
Br/Tb/Br (S3)	42.58 2.21	51.35 2.21	49.47 2.21	47.80 1.28
$\bar{X}$	42.25 1.56	50.68 1.56	49.38 1.56	
Contrast Prob. > F	T1 v T2 0.0041	T1 v T3 0.0104	T2 v T3 0.5703	S2 v S3 0.6947
	Stem Circumference (cm)			
Br/Tb (S2)	12.33 0.29	12.28 0.29	13.05 0.29	12.55 0.17
Br/Tb/Br (S3)	12.43 0.29	12.46 0.29	13.25 0.29	12.71 0.17
$\bar{X}$	12.38 0.21	12.37 0.21	13.15 0.21	
Contrast Prob. > F	T1 v T2 0.9736	T1 v T3 0.0282	T2 v T3 0.0267	S2 v S3 0.5217
	N (%)			
Br/Tb (S2)	4.29 0.14	4.04 0.14	4.66 0.14	4.33 0.08
Br/Tb/Br (S3)	4.01 0.14	4.02 0.14	4.45 0.14	4.16 0.08
$\bar{X}$	4.15 0.11	4.03 0.11	4.55 0.11	
Contrast Prob. > F	T1 v T2 0.4256	T1 v T3 0.0205	T2 v T3 0.0054	S2 v S3 0.1104

^{y}Tb=Tobacco, Br=Broccoli. ^{z}Standard error appears below each mean.

Table A-24. **Mean head and stem circumference and total leaf N concentration of broccoli at Knoxville, TN by tillage and sequence combined over 1989 and 1990.**

Sequence (S)	Tillage (T)			
	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Head Circumference (cm)			
Br/Tb[y] (S2)	30.96	31.30	37.40	33.22
	3.07[z]	3.07	3.07	2.89
Br/Tb/Br (S3)	28.51	29.90	36.25	31.55
	3.07	3.07	3.07	2.89
	29.74	30.60	36.83	
$\bar{X}$	2.99	2.99	2.99	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.5789	0.0004	0.0011	0.0708
	Stem Circumference (cm)			
Br/Tb (S2)	11.36	11.55	12.44	11.78
	0.44	0.44	0.44	0.39
Br/Tb/Br (S3)	10.86	11.19	12.26	11.44
	0.44	0.44	0.44	0.39
	11.11	11.37	12.35	
$\bar{X}$	0.41	0.41	0.41	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.3449	0.0004	0.0025	0.0626
	N (%)			
Br/Tb (S2)	3.34	3.35	3.41	3.37
	0.21	0.21	0.21	0.16
Br/Tb/Br (S3)	2.94	2.94	2.79	2.89
	0.21	0.21	0.21	0.16
	3.14	3.15	3.10	
$\bar{X}$	0.16	0.16	0.16	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.9769	0.8147	0.7924	0.0322

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-25. Mean head and stem circumference and total leaf N concentration of broccoli at Knoxville, TN in 1989 by tillage and sequence.

	Tillage (T)			
Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Head Circumference (cm)			
Br/Tb^y (S2)	27.76	28.06	37.15	30.99
	1.97^z	1.97	1.97	1.14
Br/Tb/Br (S3)	24.68	24.38	35.13	28.06
	1.97	1.97	1.97	1.14
$\bar{X}$	26.22	26.22	36.14	
	1.62	1.62	1.62	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.9992	0.0019	0.0019	0.0513
	Stem Circumference (cm)			
Br/Tb (S2)	10.65	10.29	11.45	10.79
	0.40	0.40	0.40	0.24
Br/Tb/Br (S3)	9.94	10.04	11.52	10.50
	0.40	0.40	0.40	0.24
$\bar{X}$	10.29	10.16	11.48	
	0.33	0.33	0.33	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.7838	0.0293	0.0185	0.3043
	N (%)			
Br/Tb (S2)	4.06	3.82	3.49	3.79
	0.21	0.21	0.21	0.12
Br/Tb/Br (S3)	2.65	3.01	2.48	2.71
	0.21	0.21	0.21	0.12
$\bar{X}$	3.35	3.41	2.98	
	0.16	0.16	0.16	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.7793	0.1316	0.0833	0.0001

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-26. Mean head and stem circumference and total leaf N concentration of broccoli at Knoxville, TN in 1990 by tillage and sequence.

Sequence (S)	Tillage (T)			
	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Head Circumference (cm)			
Br/Tb[y] (S2)	34.17 1.16[z]	34.55 1.16	37.66 1.16	35.46 0.67
Br/Tb/Br (S3)	32.34 1.16	35.42 1.16	37.38 1.16	35.04 0.67
$\bar{X}$	33.25 0.93	34.98 0.93	37.52 0.93	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.2207	0.0100	0.0855	0.6175
	Stem Circumference (cm)			
Br/Tb (S2)	12.08 0.29	12.80 0.29	13.43 0.29	12.77 0.19
Br/Tb/Br (S3)	11.78 0.29	12.35 0.29	12.99 0.29	12.37 0.19
$\bar{X}$	11.93 0.22	12.58 0.22	13.21 0.22	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0396	0.0010	0.0437	0.1052
	N (%)			
Br/Tb (S2)	2.63 0.20	2.89 0.20	3.33 0.20	2.95 0.12
Br/Tb/Br (S3)	3.24 0.20	2.88 0.20	3.09 0.20	3.07 0.12
$\bar{X}$	2.93 0.17	2.88 0.17	3.21 0.17	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.8348	0.2900	0.2134	0.3458

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-27. Mean head and stem circumference and total leaf N concentration of broccoli by tillage and sequence combined over years and locations.

Sequence (S)	Tillage (T) No-Till (T1)	 Conventional (cover) (T2)	 Conventional (no cover) (T3)	 $\bar{X}$
	Head Circumference (cm)			
Br/Tb[y] (S2)	27.36	36.72	40.72	34.94
	5.01[z]	5.01	5.01	4.93
Br/Tb/Br (S3)	26.56	31.80	35.62	31.33
	5.09	5.09	5.09	4.98
	26.96	34.26	38.17	
$\bar{X}$	4.97	4.97	4.97	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0001	0.0001	0.0053	0.0063
	Stem Circumference (cm)			
Br/Tb (S2)	10.12	11.70	12.25	11.36
	1.14	1.14	1.14	1.12
Br/Tb/Br (S3)	9.81	11.02	11.86	10.90
	1.15	1.15	1.15	1.13
	9.97	11.36	12.06	
$\bar{X}$	1.14	1.14	1.14	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0002	0.0001	0.0398	0.0313
	N (%)			
Br/Tb (S2)	2.92	2.87	3.16	2.98
	0.29	0.29	0.29	0.27
Br/Tb/Br (S3)	3.77	3.54	3.72	3.68
	0.34	0.34	0.34	0.33
	3.34	3.20	3.44	
$\bar{X}$	0.24	0.24	0.24	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.3361	0.4938	0.1053	0.0887

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-28. Mean yield and value of broccoli in 1989 by tillage and sequence combined over two locations.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Yield (10.43-kg boxes ha^{-1})			
Br/Tb[y] (S2)	138.3	468.7	731.6	446.1
	59.7[z]	59.7	59.7	39.3
Br/Tb/Br (S3)	114.6	274.7	424.6	271.3
	72.0	72.0	72.0	47.4
$\bar{X}$	126.5	371.7	578.1	
	52.1	52.1	52.1	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0028	0.0001	0.0088	0.0057
	Value ($ ha^{-1})			
Br/Tb (S2)	1269	4298	6709	4092
	547	547	547	361
Br/Tb/Br (S3)	1051	2518	3894	2488
	660	660	660	435
$\bar{X}$	1160	3408	5301	
	478	478	478	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0028	0.0001	0.0088	0.0057

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-29. Mean yield and value of broccoli in 1990 by tillage and sequence combined over two locations.

Sequence (S)	Tillage (T)			
	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Yield (10.43-kg boxes ha^{-1})			
Br/Tb[y] (S2)	486.4 102.5[z]	706.4 102.5	662.1 102.5	618.3 90.1
Br/Tb/Br (S3)	464.3 106.2	753.5 106.2	653.4 106.2	623.8 91.7
$\bar{X}$	475.4 102.9	730.0 102.9	657.8 102.9	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0076	0.0424	0.3916	0.8533
	Value ($ ha^{-1})			
Br/Tb (S2)	4460 940	6478 940	6071 940	5670 827
Br/Tb/Br (S3)	4258 974	6910 974	5992 974	5720 841
$\bar{X}$	4359 930	6694 930	6032 930	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0076	0.0424	0.3916	0.8533

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-30. Mean yield and value of broccoli at Greeneville, TN by tillage and sequence combined over 1989 and 1990.

Sequence (S)	Tillage (T)			
	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Yield (10.43-kg boxes ha^{-1})			
Br/Tb[y] (S2)	380.2	795.7	570.6	582.2
	217.2[z]	217.2	217.2	206.5
Br/Tb/Br (S3)	368.8	595.1	326.1	430.0
	217.2	217.2	217.2	206.5
	374.5	695.4	448.4	
$\bar{X}$	213.1	213.1	213.1	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0086	0.4935	0.0338	0.0226
	Value ($ ha^{-1})			
Br/Tb (S2)	3485	7296	5231	5338
	1992	1992	1992	1894
Br/Tb/Br (S3)	3381	5456	2991	3942
	1992	1992	1992	1894
	3433	6378	4113	
$\bar{X}$	1954	1954	1954	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0086	0.4935	0.0338	0.0226

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-31. **Mean yield and value of broccoli at Greeneville, TN in 1989 by tillage and sequence.**

Sequence (S)	Tillage (T)			
	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Yield (10.43-kg boxes ha^{-1})			
Br/Tb[y] (S2)	55.8	684.4	609.4	449.9
	85.5[z]	85.5	85.5	59.1
Br/Tb/Br (S3)	44.7	242.5	173.8	153.7
	85.5	85.5	85.5	59.1
	50.3	463.4	391.6	
$\bar{X}$	72.2	72.2	72.2	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0009	0.0031	0.4213	0.0003
	Value ($ ha^{-1})			
Br/Tb (S2)	512	6276	5588	4125
	784	784	784	541
Br/Tb/Br (S3)	410	2224	1594	1409
	784	784	784	541
	461	4250	3591	
$\bar{X}$	662	662	662	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0009	0.0031	0.4214	0.0003

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-32. Mean yield and value of broccoli at Greeneville, TN in 1990 by tillage and sequence.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Yield (10.43-kg boxes ha^{-1})			
Br/Tb[y] (S2)	704.6 113.4[z]	907.1 113.4	531.8 113.4	714.5 65.4
Br/Tb/Br (S3)	693.0 113.4	947.6 113.4	478.4 113.4	706.3 65.4
$\bar{X}$	698.8 107.8	927.3 107.8	505.1 107.8	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.1682	0.2359	0.0218	0.8445
	Value (\$ ha^{-1})			
Br/Tb (S2)	6461 1039	8318 1039	4876 1039	6552 600
Br/Tb/Br (S3)	6355 1039	8690 1039	4387 1039	6477 600
$\bar{X}$	6407 989	8504 989	4632 989	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.1682	0.2359	0.0218	0.8446

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-33. Mean yield and value of broccoli at Knoxville, TN by tillage and sequence combined over 1989 and 1990.

Sequence (S)	Tillage (T)			
	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Yield (10.43-kg boxes ha^{-1})			
Br/Tb[y] (S2)	443.8	445.1	748.3	545.8
	73.4[z]	73.4	73.4	65.6
Br/Tb/Br (S3)	362.7	516.3	754.2	544.4
	73.4	73.4	73.4	65.6
	403.3	480.7	751.3	
$\bar{X}$	69.3	69.3	69.3	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.1112	0.0001	0.0001	0.9622
	Value ($ ha^{-1})			
Br/Tb (S2)	4069	4083	6862	5004
	673	673	673	601
Br/Tb/Br (S3)	3327	4735	6916	4992
	673	673	673	601
	3698	4408	6889	
$\bar{X}$	635	635	635	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.1112	0.0001	0.0001	0.9621

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-34. Mean yield and value of broccoli at Knoxville, TN in 1989 by tillage and sequence.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Yield (10.43 kg boxes ha^{-1})			
Br/Tb[y] (S2)	296.1	190.2	678.5	388.3
	39.2[z]	39.2	39.2	22.7
Br/Tb/Br (S3)	206.5	288.2	623.7	372.8
	39.2	39.2	39.2	22.7
	251.3	239.2	651.1	
$\bar{X}$	27.7	27.7	27.7	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.7643	0.0001	0.0001	0.6406
	Value ($ ha^{-1})			
Br/Tb (S2)	2715	1744	6222	3561
	360	360	360	208
Br/Tb/Br (S3)	1894	2643	5720	3419
	360	360	360	208
	2305	2193	5971	
$\bar{X}$	254	254	254	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.7642	0.0001	0.0001	0.6406

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-35. Mean yield and value of broccoli at Knoxville, TN in 1990 by tillage and sequence.

Sequence (S)	Tillage (T)			
	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Yield (10.43-kg boxes ha^{-1})			
Br/Tb[y] (S2)	591.4 54.9[z]	700.1 54.9	818.2 54.9	703.2 37.5
Br/Tb/Br (S3)	519.0 54.9	744.4 54.9	884.6 54.9	716.0 37.5
$\bar{X}$	555.2 42.6	722.2 42.6	851.4 42.6	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0078	0.0002	0.0272	0.7570
	Value ($ ha^{-1})			
Br/Tb (S2)	5424 503	6420 503	7501 503	6449 344
Br/Tb/Br (S3)	4760 503	6825 503	8111 503	6565 344
$\bar{X}$	5091 390	6622 390	7808 390	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0078	0.0002	0.0272	0.7571

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-37. Mean marketability and average marketable head size of broccoli in 1989 by tillage and sequence combined over two locations.

Sequence (S)	Tillage (T) No-Till (T1)	 Conventional (cover) (T2)	 Conventional (no cover) (T3)	$\bar{X}$
	Marketability (%)			
Br/Tb[y] (S2)	58.5	95.5	99.3	84.4
	9.7[z]	9.7	9.7	7.9
Br/Tb/Br (S3)	50.0	87.1	86.7	74.6
	10.9	10.9	10.9	8.5
$\bar{X}$	54.3	91.3	93.0	
	9.2	9.7	9.7	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0007	0.0005	0.8423	0.1037
	Average Marketable Head (g)			
Br/Tb (S2)	113.4	174.6	230.2	172.7
	13.8	13.8	13.8	10.4
Br/Tb/Br (S3)	100.3	122.6	163.5	128.8
	16.6	16.6	16.6	12.7
$\bar{X}$	106.8	148.6	196.8	
	12.1	12.1	12.1	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0118	0.0001	0.0049	0.0114

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-38. Mean marketability and average marketable head size of broccoli in 1990 by tillage and sequence combined over two locations.

Sequence (S)	Tillage (T) No-Till (T1)	 Conventional (cover) (T2)	 Conventional (no cover) (T3)	 $\bar{X}$
	Marketability (%)			
Br/Tb[y] (S2)	94.7 4.9[z]	99.3 4.9	90.3 4.9	94.8 3.3
Br/Tb/Br (S3)	94.2 5.0	99.6 5.0	86.8 5.0	93.5 3.3
$\bar{X}$	94.5 4.9	99.4 4.9	88.6 4.9	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.4439	0.3666	0.1073	0.1854
	Average Marketable Head Size (g)			
Br/Tb (S2)	164.8 20.9	240.8 20.9	262.7 20.9	222.8 18.5
Br/Tb/Br (S3)	200.6 25.0	281.6 25.0	316.4 25.0	266.2 22.5
$\bar{X}$	182.7 18.0	261.2 18.0	289.6 18.0	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0003	0.0001	0.1088	0.1402

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-39. Mean marketability and average marketable head size of broccoli at Greeneville, TN by tillage and sequence combined over 1989 and 1990.

Sequence (S)	Tillage (T) No-Till (T1)	 Conventional (cover) (T2)	 Conventional (no cover) (T3)	 $\bar{X}$
	Marketability (%)			
Br/Tb[y] (S2)	67.4	98.6	84.5	83.5
	13.5[z]	13.5	13.5	10.3
Br/Tb/Br (S3)	63.5	87.8	69.8	73.7
	13.5	13.5	13.5	10.3
	65.4	93.2	77.1	
$\bar{X}$	12.8	12.8	12.8	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0662	0.4155	0.2681	0.0779
	Average Marketable Head Size (g)			
Br/Tb (S2)	178.6	293.7	282.4	251.6
	35.2	35.2	35.2	31.9
Br/Tb/Br (S3)	161.0	236.5	239.3	212.2
	35.2	35.2	35.2	31.9
	169.8	265.1	260.8	
$\bar{X}$	27.1	27.1	27.1	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0013	0.0018	0.8603	0.3799

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-40. Mean marketability and average marketable head size of broccoli at Greeneville, TN in 1989 by tillage and sequence.

Sequence (S)	Tillage (T) No-Till (T1)	 Conventional (cover) (T2)	 Conventional (no cover) (T3)	$\bar{X}$
		Marketability (%)		
Br/Tb[y] (S2)	34.8 13.5[z]	99.5 13.5	98.0 13.5	77.4 7.8
Br/Tb/Br (S3)	27.5 13.5	77.0 13.5	75.3 13.5	59.9 7.8
$\bar{X}$	31.1 10.1	88.3 10.1	86.6 10.1	
Contrast Prob. > F	T1 v T2 0.0031	T1 v T3 0.0037	T2 v T3 0.9121	S2 v S3 0.1242
		Average Marketable Head Size (g)		
Br/Tb (S2)	129.3 18.7	240.4 18.7	217.7 18.7	195.8 13.3
Br/Tb/Br (S3)	83.9 18.7	121.3 18.7	108.9 18.7	104.7 13.3
$\bar{X}$	106.6 16.3	180.9 16.3	163.3 16.3	
Contrast Prob. > F	T1 v T2 0.0032	T1 v T3 0.0140	T2 v T3 0.3707	S2 v S3 0.0001

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-41. Mean marketability and average marketable head size of broccoli at Greeneville, TN in 1990 by tillage and sequence.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Marketability (%)			
Br/Tb[y] (S2)	100.0	97.8	71.0	89.6
	10.4[z]	10.4	10.4	6.0
Br/Tb/Br (S3)	99.5	98.5	64.3	87.4
	10.4	10.4	10.4	6.0
	99.8	98.1	67.6	
$\bar{X}$	10.4	10.4	10.4	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.9140	0.0558	0.0669	0.2117
	Average Marketable Head Size (g)			
Br/Tb (S2)	227.9	347.0	347.0	308.5
	29.5	29.5	29.5	17.1
Br/Tb/Br (S3)	238.1	351.5	369.7	319.8
	29.5	29.5	29.5	17.1
	233.1	349.3	358.3	
$\bar{X}$	27.2	27.2	27.2	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0144	0.0099	0.8187	0.3753

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-42. Mean marketability and average marketable head size of broccoli at Knoxville, TN by tillage and sequence combined over 1989 and 1990.

Sequence (S)	Tillage (T)			
	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Marketability (%)			
Br/Tb[z] (S2)	98.9 4.0[z]	93.5 4.0	100.0 4.0	97.5 3.3
Br/Tb/Br (S3)	89.1 4.0	98.8 4.0	99.9 4.0	95.9 3.3
$\bar{X}$	94.0 3.5	96.1 3.5	99.9 3.5	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.4457	0.0457	0.1810	0.4971
	Average Marketable Head Size (g)			
Br/Tb (S2)	156.5 15.1	169.0 15.1	222.9 15.1	182.8 14.0
Br/Tb/Br (S3)	154.8 15.1	176.9 15.1	229.7 15.1	187.1 14.0
$\bar{X}$	155.6 14.4	173.0 14.4	226.3 14.4	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0369	0.0001	0.0001	0.4327

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-43. Mean marketability and average marketable head size of broccoli at Knoxville, TN in 1989 by tillage and sequence.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Marketability (%)			
Br/Tb[y] (S2)	98.0 4.9[z]	87.0 4.9	100.0 4.9	95.0 2.8
Br/Tb/Br (S3)	79.3 4.9	97.5 4.9	99.8 4.9	92.2 2.8
$\bar{X}$	88.6 3.6	92.3 3.6	99.9 3.6	
Contrast Prob. > F	T1 v T2 0.4932	T1 v T3 0.0539	T2 v T3 0.1672	S2 v S3 0.4797
	Average Marketable Head Size (g)			
Br/Tb (S2)	122.5 9.2	121.3 9.2	203.0 9.2	148.9 6.3
Br/Tb/Br (S3)	129.3 9.2	130.4 9.2	198.5 9.2	152.7 6.3
$\bar{X}$	125.9 6.9	125.9 6.9	200.7 6.9	
Contrast Prob. > F	T1 v T2 0.9999	T1 v T3 0.0001	T2 v T3 0.0001	S2 v S3 0.5996

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-44. Mean marketability and average marketable head size of broccoli at Knoxville, TN in 1990 by tillage and sequence.

Sequence (S)	Tillage (T)				
	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$	
	Marketability (%)				
Br/Tb[y] (S2)	99.8	100.0	100.0	99.9	
	0.3[z]	0.3	0.3	0.2	
Br/Tb/Br (S3)	99.0	100.0	100.0	99.7	
	0.3	0.3	0.3	0.2	
	99.4	100.0	100.0		
$\bar{X}$	0.2	0.2	0.2		
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3	
Prob. > F	0.0716	0.0716	0.9999	0.3434	
	Average Marketable Head Size (g)				
Br/Tb (S2)	190.5	216.6	242.7	216.6	
	11.7	11.7	11.7	9.4	
Br/Tb/Br (S3)	180.3	222.4	260.8	221.5	
	11.7	11.7	11.7	9.4	
	185.0	220.0	251.7		
$\bar{X}$	10.0	10.0	10.0		
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3	
Prob. > F	0.0027	0.0001	0.0045	0.4939	

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-45. Mean marketability and average marketable head size of broccoli by tillage and sequence combined over years and locations.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Marketability (%)			
Br/Tb[y] (S2)	76.6 9.1[z]	97.4 9.1	94.8 9.1	89.6 8.2
Br/Tb/Br (S3)	72.1 9.4	93.8 9.4	86.1 9.4	84.0 8.4
$\bar{X}$	74.3 8.9	95.6 8.9	90.5 8.9	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0016	0.0130	0.4107	0.0588
	Average Marketable Head Size (g)			
Br/Tb (S2)	139.1 47.6	207.7 47.6	246.4 47.6	197.8 47.1
Br/Tb/Br (S3)	135.2 48.6	187.2 48.6	226.8 48.6	183.0 47.9
$\bar{X}$	137.1 47.4	197.5 47.4	236.6 47.4	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0001	0.0001	0.0021	0.3448

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-46. Mean head and stem circumference, total leaf N concentration, yield and value of broccoli at Crossville, TN by tillage and sequence combined over 1989 and 1990.

Sequence (S)	Tillage (T)			
	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
		Head Circumference (cm)		
Br/Tb[y] (S2)	20.77 1.77[z]	35.22 1.77	41.10 1.77	
Contrast	T1 v T2	T1 v T3	T2 v T3	
Prob. > F	0.0001	0.0001	0.0275	
		Stem Circumference (cm)		
Br/Tb (S2)	8.08 1.04	11.48 1.04	12.21 1.04	
Contrast	T1 v T2	T1 v T3	T2 v T3	
Prob. > F	0.0005	0.0001	0.3517	
		N (%)		
Br/Tb (S2)	0.82 0.45	1.06 0.45	1.65 0.45	
Contrast	T1 v T2	T1 v T3	T2 v T3	
Prob. > F	0.2527	0.0010	0.0106	
		Yield (10.43-kg boxes ha^{-1})		
Br/Tb (S2)	113.2 55.5	521.9 55.5	771.6 55.5	
Contrast	T1 v T2	T1 v T3	T2 v T3	
Prob. > F	0.0001	0.0001	0.0034	
		Value (\$ ha^{-1})		
Br/Tb (S2)	1038 509	4786 509	7075 509	
Contrast	T1 v T2	T1 v T3	T2 v T3	
Prob. > F	0.0001	0.0001	0.0034	

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-47. Mean head and stem circumference, total leaf N concentration, yield and value of broccoli at Crossville, TN in 1989 by tillage and sequence.

Sequence (S)	Tillage (T)			
	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
		Head Circumference (cm)		
Br/Tb[y] (S2)	16.50 2.17[z]	35.30 2.17	43.38 2.17	
Contrast	T1 v T2	T1 v T3	T2 v T3	
Prob. > F	0.0001	0.0001	0.0039	
		Stem Circumference (cm)		
Br/Tb (S2)	7.15 0.57	9.67 0.57	12.11 0.57	
Contrast	T1 v T2	T1 v T3	T2 v T3	
Prob. > F	0.0004	0.0001	0.0004	
		N (%)		
Br/Tb (S2)	1.02 0.15	1.30 0.15	2.53 0.15	
Contrast	T1 v T2	T1 v T3	T2 v T3	
Prob. > F	0.2100	0.0003	0.0008	
		Yield (10.43-kg boxes ha^{-1})		
Br/Tb (S2)	63.1 83.3	531.6 83.3	906.9 83.3	
Contrast	T1 v T2	T1 v T3	T2 v T3	
Prob. > F	0.0006	0.0001	0.0021	
		Value (\$ ha^{-1})		
Br/Tb (S2)	578 764	4875 764	8316 764	
Contrast	T1 v T2	T1 v T3	T2 v T3	
Prob. > F	0.0006	0.0001	0.0021	

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-48. Mean head and stem circumference, total leaf N concentration, yield and value of broccoli at Crossville, TN in 1990 by tillage and sequence.

Sequence (S)	Tillage (T) No-Till (T1)	 Conventional (cover) (T2)	 Conventional (no cover) (T3)	$\bar{X}$
		Head Circumference (cm)		
Br/Tb[y] (S2)	25.04	35.15	38.82	
	2.18[z]	2.18	2.18	
Contrast	T1 v T2	T1 v T3	T2 v T3	
Prob. > F	0.0138	0.0034	0.2591	
		Stem Circumference (cm)		
Br/Tb (S2)	9.01	13.29	12.31	
	0.93	0.93	0.93	
Contrast	T1 v T2	T1 v T3	T2 v T3	
Prob. > F	0.0140	0.0385	0.4606	
		N (%)		
Br/Tb (S2)	0.62	0.82	0.78	
	0.06	0.06	0.06	
Contrast	T1 v T2	T1 v T3	T2 v T3	
Prob. > F	0.0218	0.0511	0.5423	
		Yield (10.43-kg boxes ha^{-1})		
Br/Tb (S2)	163.3	512.2	636.3	
	52.8	52.8	52.8	
Contrast	T1 v T2	T1 v T3	T2 v T3	
Prob. > F	0.0034	0.0007	0.1473	
		Value (\$ ha^{-1})		
Br/Tb (S2)	1497	4696	5835	
	484	484	484	
Contrast	T1 v T2	T1 v T3	T2 v T3	
Prob. > F	0.0034	0.0007	0.1473	

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-49. Mean marketability and average marketable head size of broccoli at Crossville, TN by tillage and sequence combined over 1989 and 1990.

Sequence (S)	Tillage (T) No-Till (T1)	 Conventional (cover) (T2)	 Conventional (no cover) (T3)	$\bar{X}$
	Marketability (%)			
Br/Tb[y] (S2)	63.5 9.1[z]	100.0 9.1	100.0 9.1	
Contrast	T1 v T2	T1 v T3	T2 v T3	
Prob. > F	0.0034	0.0034	0.9999	
	Average Marketable Head (g)			
Br/Tb (S2)	82.2 16.8	160.5 16.8	234.2 16.8	
Contrast	T1 v T2	T1 v T3	T2 v T3	
Prob. > F	0.0001	0.0001	0.0002	

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-50. Mean marketability and average marketable head size of broccoli at Crossville, TN in 1989 by tillage and sequence.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Marketability (%)			
Br/Tb[y] (S2)	42.8 12.1[z]	100.0 12.1	100.0 12.1	
Contrast	T1 v T2	T1 v T3	T2 v T3	
Prob. > F	0.0157	0.0157	0.9999	
	Average Marketable Head (g)			
Br/Tb (S2)	88.5 24.2	162.2 24.2	269.9 24.2	
Contrast	T1 v T2	T1 v T3	T2 v T3	
Prob. > F	0.0079	0.0001	0.0013	

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-51. Mean marketability and average marketable head size of broccoli at Crossville, TN in 1990 by tillage and sequence.

Sequence (S)	Tillage (T)			
	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Marketability (%)			
Br/Tb[y] (S2)	84.3	100.0	100.0	
	5.2[z]	5.2	5.2	
Contrast	T1 v T2	T1 v T3	T2 v T3	
Prob. > F	0.0768	0.0768	0.9999	
	Average Marketable Head (g)			
Br/Tb (S2)	76.0	158.8	198.5	
	9.8	9.8	9.8	
Contrast	T1 v T2	T1 v T3	T2 v T3	
Prob. > F	0.0009	0.0001	0.0267	

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-52. Mean value of tobacco-broccoli cropping systems by tillage and sequence combined over years and locations and combined over locations by year.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Over Years and Locations ($ ha^{-1})			
Tb/Br[y] (S1)	6331 1062[z]	7664 1062	7822 1062	7272 963
Br/Tb (S2)	10421 1065	14474 1062	14062 1062	12985 963
Br/Tb/Br (S3)	9700 1062	13439 1062	12992 1062	12044 963
$\bar{X}$	8815 966	11858 966	11624 966	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0001	0.0001	0.6752	0.0001	0.0001	0.0860

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	1989 Combined Over Locations ($ ha^{-1})			
Tb/Br (S1)	6491 1275	8126 1275	8116 1275	7578 1141
Br/Tb (S2)	8139 1279	13331 1275	14027 1275	11834 1141
Br/Tb/Br (S3)	7689 1275	11372 1275	11564 1275	10209 1141
$\bar{X}$	7440 1119	10945 1119	11236 1119	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0001	0.0001	0.6109	0.0001	0.0006	0.0252

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	1990 Combined Over Locations ($ ha^{-1})			
Tb/Br (S1)	6168 1697	7203 1697	7529 1697	6965 1566
Br/Tb (S2)	12486 1697	15615 1697	14094 1697	14064 1566
Br/Tb/Br (S3)	11708 1697	15507 1697	14420 1697	13879 1566
$\bar{X}$	10120 1630	12775 1630	12014 1630	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0074	0.0488	0.4145	0.0001	0.0001	0.6950

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-53. Mean value of tobacco-broccoli cropping systems by tillage and sequence at Greeneville, TN combined over years and for individual years.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Greeneville Combined Over Years ($ ha^{-1})			
Tb/Br[y] (S1)	8074 2319[z]	7600 2319	8139 2319	7939 2208
Br/Tb (S2)	11382 2327	16220 2319	13084 2319	13563 2211
Br/Tb/Br (S3)	10342 2319	12975 2319	11303 2319	11540 2208
$\bar{X}$	9932 2097	12266 2097	10843 2097	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0115	0.3002	0.1090	0.0001	0.0001	0.0136

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Greeneville 1989 ($ ha^{-1})			
Tb/Br (S1)	6713 909	6387 909	7390 909	6830 558
Br/Tb (S2)	7123 926	15102 909	13308 909	11844 561
Br/Tb/Br (S3)	6029 909	8670 909	8687 909	7795 558
$\bar{X}$	6622 585	10053 583	9796 583	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0003	0.0006	0.7379	0.0001	0.1844	0.0001

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Greeneville 1990 ($ ha^{-1})			
Tb/Br (S1)	9438 1099	8813 1099	8890 1099	9048 635
Br/Tb (S2)	15410 1099	17337 1099	12861 1099	15203 635
Br/Tb/Br (S3)	14652 1099	17280 1099	13921 1099	15284 635
$\bar{X}$	13168 835	14477 835	11891 835	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.2822	0.2942	0.0420	0.0001	0.0001	0.9104

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

Table A-54. Mean value of tobacco-broccoli cropping systems by tillage and sequence at Knoxville, TN combined over years and for individual years.

Sequence (S)	Tillage (T)			
	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Knoxville Combined Over Years (\$ ha^{-1})			
Tb/Br^y (S1)	4584	7729	7506	6607
	664^z	664	664	568
Br/Tb (S2)	9445	12725	15037	12404
	664	664	664	568
Br/Tb/Br (S3)	9055	13906	14679	12548
	664	664	664	568
	7697	11453	12407	
$\bar{X}$	487	487	487	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0001	0.0001	0.0291	0.0001	0.0001	0.8269

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Knoxville 1989 (\$ ha^{-1})			
Tb/Br (S1)	6269	9868	8845	8326
	701	701	701	405
Br/Tb (S2)	9327	11560	14748	11878
	701	701	701	405
Br/Tb/Br (S3)	9351	14077	14440	12622
	701	701	701	405
	8316	11834	12679	
$\bar{X}$	526	526	526	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0002	0.0001	0.2725	0.0001	0.0001	0.1262

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Knoxville 1990 (\$ ha^{-1})			
Tb/Br (S1)	2900	5590	6168	4886
	563	563	563	324
Br/Tb (S2)	9564	13894	15326	12928
	563	563	563	324
Br/Tb/Br (S3)	8761	13736	14916	12471
	563	563	563	324
	7074	11073	12138	
$\bar{X}$	324	324	324	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0001	0.0001	0.0324	0.0001	0.0001	0.3341

[y] Tb=Tobacco, Br=Broccoli. [z] Standard error appears below each mean.

APPENDIX B
TOMATO/BROCCOLI FIELD DATA

Table B-1. Mean leaf N concentration and percentage of No. 1 quality and cull tomatoes in 1989 by tillage and sequence combined over two locations.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Nitrogen (%)			
Tm/Br[y] (S1)	5.09 0.51[z]	5.17 0.51	5.86 0.51	5.37 0.30
Br/Tm (S2)	4.89 0.51	5.50 0.51	5.26 0.51	5.22 0.30
Br/Tm/Br (S3)	5.86 0.51	5.84 0.51	4.97 0.51	5.55 0.30
$\bar{X}$	5.28 0.30	5.50 0.30	5.36 0.30	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.5904	0.8456	0.7306	0.7060	0.6643	0.4193

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	No. 1 Quality Fruit (%)			
Tm/Br (S1)	20.9 5.2	28.0 5.2	22.3 5.2	23.7 4.4
Br/Tm (S2)	29.9 5.2	18.4 5.2	18.1 5.2	22.1 4.4
Br/Tm/Br (S3)	20.6 5.2	20.9 5.2	19.8 5.2	20.4 4.4
$\bar{X}$	23.8 4.4	22.4 4.4	20.0 4.4	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.6164	0.1780	0.3890	0.5643	0.2354	0.5342

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Cull Fruit (%)			
Tm/Br (S1)	24.6 4.4	24.9 4.4	28.9 4.4	26.1 3.4
Br/Tm (S2)	22.0 4.4	28.0 4.4	32.0 4.4	27.3 3.4
Br/Tm/Br (S3)	26.9 4.4	27.0 4.4	29.9 4.4	27.9 3.4
$\bar{X}$	24.5 3.1	26.6 3.1	30.3 3.1	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.5719	0.1329	0.3375	0.7888	0.6915	0.8971

[y]Tm=Tomato, Br=Broccoli. [z]Standard error appears below each mean.

Table B-2. Mean leaf N concentration and percentage of No. 1 quality and cull tomatoes in 1990 by tillage and sequence combined over two locations.

Sequence (S)	Tillage (T)			
	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Nitrogen (%)			
Tm/Br[y] (S1)	3.68	3.50	3.75	3.64
	0.41[z]	0.41	0.41	0.39
Br/Tm (S2)	3.31	3.37	3.80	3.49
	0.41	0.41	0.41	0.39
Br/Tm/Br (S3)	3.40	3.42	3.57	3.46
	0.41	0.41	0.41	0.39
	3.46	3.43	3.71	
$\bar{X}$	0.39	0.39	0.39	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.7830	0.0916	0.0525	0.2806	0.2002	0.8340

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	No. 1 Quality Fruit (%)			
Tm/Br (S1)	23.9	22.8	22.0	22.9
	2.6	2.6	2.6	1.9
Br/Tm (S2)	19.0	18.5	17.3	18.3
	2.6	2.6	2.6	1.9
Br/Tm/Br (S3)	25.9	19.5	18.8	21.4
	2.6	2.6	2.6	1.9
	22.9	20.3	19.3	
$\bar{X}$	1.7	1.7	1.7	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.1539	0.0589	0.6184	0.0423	0.4959	0.1617

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Cull Fruit (%)			
Tm/Br (S1)	22.6	28.3	28.4	26.4
	8.0	8.0	8.0	7.8
Br/Tm (S2)	22.8	23.9	27.3	24.6
	8.0	8.0	8.0	7.8
Br/Tm/Br (S3)	18.5	23.5	25.5	22.5
	8.0	8.0	8.0	7.8
	21.3	25.2	27.0	
$\bar{X}$	7.8	7.8	7.8	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0394	0.0037	0.3205	0.3315	0.0394	0.2510

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-3. Mean leaf N concentration and percentage of No. 1 quality and cull tomatoes at Greeneville, TN by tillage and sequence combined over 1989 and 1990.

	Tillage (T)			
Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	X̄
	Nitrogen (%)			
Tm/Br[y] (S1)	3.73	3.65	4.68	4.02
	1.10[z]	1.10	1.10	1.05
Br/Tm (S2)	3.83	4.29	4.12	4.08
	1.10	1.10	1.10	1.05
Br/Tm/Br (S3)	4.46	4.47	4.39	4.44
	1.10	1.10	1.10	1.05
	4.00	4.14	4.40	
X̄	1.05	1.05	1.05	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.7146	0.2772	0.4662	0.8607	0.2448	0.3207

	No. 1 Quality Fruit (%)			
Tm/Br (S1)	22.9	31.3	29.3	27.8
	3.5	3.5	3.5	2.5
Br/Tm (S2)	28.8	17.6	20.0	22.1
	3.5	3.5	3.5	2.5
Br/Tm/Br (S3)	24.3	20.5	23.4	22.7
	3.5	3.5	3.5	2.5
	25.3	23.1	24.2	
X̄	2.5	2.5	2.5	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.4010	0.6731	0.6731	0.0339	0.0552	0.8201

	Cull Fruit (%)			
Tm/Br (S1)	24.5	21.1	23.1	22.9
	5.2	5.2	5.2	4.7
Br/Tm (S2)	15.5	17.8	18.5	17.3
	5.2	5.2	5.2	4.7
Br/Tm/Br (S3)	22.9	23.9	23.1	23.3
	5.2	5.2	5.2	4.7
	21.0	20.9	21.6	
X̄	4.6	4.6	4.6	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.9875	0.8146	0.8025	0.0808	0.9054	0.0636

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-4. Mean leaf N concentration and percentage of No. 1 quality and cull tomatoes at Greeneville, TN in 1989 by tillage and sequence.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Nitrogen (%)			
Tm/Br[y] (S1)	4.48	4.28	6.02	4.93
	0.88[z]	0.88	0.88	0.51
Br/Tm (S2)	4.43	5.52	5.00	4.98
	0.88	0.88	0.88	0.51
Br/Tm/Br (S3)	5.80	5.69	5.63	5.70
	0.88	0.88	0.88	0.51
	4.90	5.16	5.55	
$\bar{X}$	0.51	0.51	0.51	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.7236	0.3837	0.6001	0.9392	0.2954	0.3305

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	No. 1 Quality Fruit (%)			
Tm/Br (S1)	18.8	32.0	31.5	27.4
	5.3	5.3	5.3	3.1
Br/Tm (S2)	39.5	20.5	23.8	27.9
	5.3	5.3	5.3	3.1
Br/Tm/Br (S3)	22.3	23.5	24.0	23.3
	5.3	5.3	5.3	3.1
	26.8	25.3	26.4	
$\bar{X}$	3.1	3.1	3.1	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.7316	0.9240	0.8042	0.9089	0.3461	0.2928

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Cull Fruit (%)			
Tm/Br (S1)	32.3	27.8	25.8	28.6
	5.3	5.3	5.3	3.0
Br/Tm (S2)	15.0	14.5	18.3	15.9
	5.3	5.3	5.3	3.0
Br/Tm/Br (S3)	33.8	30.3	32.0	32.0
	5.3	5.3	5.3	3.0
	27.0	24.2	25.3	
$\bar{X}$	3.7	3.7	3.7	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.5915	0.7516	0.8245	0.0035	0.3762	0.0005

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-5. Mean leaf N concentration and percentage of No. 1 quality and cull tomatoes at Greeneville, TN in 1990 by tillage and sequence.

Sequence (S)	Tillage (T)			
	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Nitrogen (%)			
Tm/Br[y] (S1)	2.97 0.18[z]	3.02 0.18	3.34 0.18	3.11 0.11
Br/Tm (S2)	3.22 0.18	3.06 0.18	3.25 0.18	3.18 0.11
Br/Tm/Br (S3)	3.12 0.18	3.24 0.18	3.16 0.18	3.17 0.11
$\bar{X}$	3.10 0.11	3.11 0.11	3.25 0.11	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.9823	0.3475	0.3585	0.6432	0.6590	0.9823

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	No. 1 Quality Fruit (%)			
Tm/Br (S1)	27.0 2.5	30.5 2.5	27.0 2.5	28.2 1.5
Br/Tm (S2)	18.0 2.5	14.8 2.5	16.3 2.5	16.3 1.5
Br/Tm/Br (S3)	26.3 2.5	17.5 2.5	22.8 2.5	22.2 1.5
$\bar{X}$	23.8 1.9	20.9 1.9	22.0 1.9	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.3072	0.5245	0.6925	0.0001	0.0020	0.0025

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Cull Fruit (%)			
Tm/Br (S1)	16.8 2.2	14.5 2.2	20.5 2.2	17.3 1.3
Br/Tm (S2)	16.0 2.2	21.0 2.2	18.8 2.2	18.6 1.3
Br/Tm/Br (S3)	12.0 2.2	17.5 2.2	14.3 2.2	14.6 1.3
$\bar{X}$	14.9 1.3	17.7 1.3	17.8 1.3	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.1605	0.1379	0.9303	0.4664	0.1540	0.0385

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-6. Mean leaf N concentration and percentage of No. 1 quality and cull tomatoes at Knoxville, TN by tillage and sequence combined over 1989 and 1990.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Nitrogen (%)			
Tm/Br^y (S1)	5.04	5.02	4.93	5.00
	0.87^z	0.87	0.87	0.83
Br/Tm (S2)	4.37	4.58	4.93	4.63
	0.87	0.87	0.87	0.83
Br/Tm/Br (S3)	4.80	4.79	4.14	4.58
	0.87	0.87	0.87	0.83
	4.74	4.80	4.67	
$\bar{X}$	0.84	0.84	0.84	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.8315	0.7833	0.6262	0.1284	0.0867	0.8361

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	No. 1 Quality Fruit (%)			
Tm/Br (S1)	21.9	19.5	15.0	18.8
	2.5	2.5	2.5	1.5
Br/Tm (S2)	20.1	19.3	15.4	18.3
	2.5	2.5	2.5	1.5
Br/Tm/Br (S3)	22.3	19.9	15.1	19.1
	2.5	2.5	2.5	1.5
	21.4	19.5	15.2	
$\bar{X}$	1.5	1.5	1.5	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.3733	0.0054	0.0438	0.7957	0.8891	0.6906

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Cull Fruit (%)			
Tm/Br (S1)	22.8	32.0	34.1	29.6
	3.4	3.4	3.4	2.4
Br/Tm (S2)	29.3	34.1	40.8	34.7
	3.4	3.4	3.4	2.4
Br/Tm/Br (S3)	22.5	26.6	32.3	27.1
	3.4	3.4	3.4	2.4
	24.8	30.9	35.7	
$\bar{X}$	2.3	2.3	2.3	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0219	0.0002	0.0661	0.0917	0.3977	0.0145

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-7. Mean leaf N concentration and percentage of No. 1 quality and cull tomatoes at Knoxville, TN in 1989 by tillage and sequence.

Sequence (S)	Tillage (T) No-Till (T1)	 Conventional (cover) (T2)	 Conventional (no cover) (T3)	 $\bar{X}$
	Nitrogen (%)			
Tm/Br[y] (S1)	5.69 0.52[z]	6.07 0.52	5.70 0.52	5.82 0.30
Br/Tm (S2)	5.35 0.52	5.48 0.52	5.51 0.52	5.45 0.30
Br/Tm/Br (S3)	5.93 0.52	5.98 0.52	4.31 0.52	5.40 0.30
$\bar{X}$	5.65 0.30	5.85 0.30	5.17 0.30	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.6602	0.2740	0.1326	0.3965	0.3439	0.9187

Sequence (S)	T1	T2	T3	$\bar{X}$
	No. 1 Quality Fruit (%)			
Tm/Br (S1)	23.0 3.8	24.0 3.8	13.0 3.8	20.0 2.2
Br/Tm (S2)	20.3 3.8	16.3 3.8	12.5 3.8	16.3 2.2
Br/Tm/Br (S3)	19.0 3.8	18.3 3.8	15.5 3.8	17.6 2.2
$\bar{X}$	20.8 2.5	19.5 2.5	13.7 2.5	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.7252	0.0582	0.1130	0.2280	0.4215	0.6756

Sequence (S)	T1	T2	T3	$\bar{X}$
	Cull Fruit (%)			
Tm/Br (S1)	17.0 4.3	22.0 4.3	32.0 4.3	23.7 2.5
Br/Tm (S2)	29.0 4.3	41.5 4.3	45.8 4.3	38.8 2.5
Br/Tm/Br (S3)	20.0 4.3	23.8 4.3	27.8 4.3	23.8 2.5
$\bar{X}$	22.0 3.3	29.1 3.3	35.2 3.3	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.1462	0.0113	0.2085	0.0001	0.9511	0.0001

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-8. Mean leaf N concentration and percentage of No. 1 quality and cull tomatoes at Knoxville, TN in 1990 by tillage and sequence.

Sequence (S)	Tillage (T)			
	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	X̄
	Nitrogen (%)			
Tm/Br[y] (S1)	4.40	3.97	4.17	4.18
	0.28[z]	0.28	0.28	0.16
Br/Tm (S2)	3.40	3.67	4.35	3.81
	0.28	0.28	0.28	0.16
Br/Tm/Br (S3)	3.68	3.59	3.98	3.75
	0.28	0.28	0.28	0.16
	3.83	3.75	4.16	
X̄	0.16	0.16	0.16	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.7264	0.1502	0.0795	0.1145	0.0732	0.8097

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	X̄
	No. 1 Quality Fruit (%)			
Tm/Br (S1)	20.8	15.0	17.0	17.6
	3.3	3.3	3.3	1.9
Br/Tm (S2)	20.0	22.3	18.3	20.2
	3.3	3.3	3.3	1.9
Br/Tm/Br (S3)	25.5	21.5	14.8	20.6
	3.3	3.3	3.3	1.9
	22.1	19.6	16.7	
X̄	1.9	1.9	1.9	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.3711	0.0623	0.2986	0.3557	0.2854	0.8802

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	X̄
	Cull Fruit (%)			
Tm/Br (S1)	28.5	42.0	36.3	35.6
	3.4	3.4	3.4	2.0
Br/Tm (S2)	29.5	26.8	35.8	30.7
	3.4	3.4	3.4	2.0
Br/Tm/Br (S3)	25.0	29.5	36.8	30.4
	3.4	3.4	3.4	2.0
	27.7	32.8	36.3	
X̄	2.0	2.0	2.0	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0843	0.0064	0.2245	0.0941	0.0797	0.9294

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-9. Mean leaf N concentration and percentage of No. 1 quality and cull tomatoes by tillage and sequence combined over years and locations.

Sequence (S)	Tillage (T)			
	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Nitrogen (%)			
Tm/Br[y] (S1)	4.38 0.99[z]	4.33 0.99	4.81 0.99	4.51 0.97
Br/Tm (S2)	4.10 0.99	4.43 0.99	4.53 0.99	4.35 0.97
Br/Tm/Br (S3)	4.63 0.99	4.63 0.99	4.27 0.99	4.51 0.97
$\bar{X}$	4.37 0.97	4.47 0.97	4.53 0.97	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.6666	0.4580	0.7545	0.4761	0.9992	0.4755

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	No. 1 Quality Fruit (%)			
Tm/Br (S1)	22.4 3.4	25.4 3.4	22.1 3.4	23.3 2.9
Br/Tm (S2)	24.4 3.4	18.4 3.4	17.7 3.4	20.2 2.9
Br/Tm/Br (S3)	23.3 3.4	20.2 3.4	19.3 3.4	20.9 2.9
$\bar{X}$	23.4 2.9	21.3 2.9	19.7 2.9	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.2346	0.0333	0.3320	0.0701	0.1597	0.6753

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Cull Fruit (%)			
Tm/Br (S1)	23.6 5.2	26.6 5.2	28.6 5.2	26.3 4.9
Br/Tm (S2)	22.4 5.2	25.9 5.2	29.6 5.2	26.0 4.9
Br/Tm/Br (S3)	22.7 5.2	25.3 5.2	27.7 5.2	25.2 4.9
$\bar{X}$	22.9 4.8	25.9 4.8	28.7 4.8	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.1304	0.0049	0.1710	0.9029	0.6568	0.7471

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-10. Mean yield of No. 1 and No. 2 quality and value of No. 1 quality tomatoes in 1989 by tillage and sequence combined over two locations.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	No. 1 Yield (11.34-kg boxes ha^{-1})			
Tm/Br^y (S1)	1307	1694	1467	1489
	314^z	314	314	288
Br/Tm (S2)	322	270	186	259
	314	314	314	288
Br/Tm/Br (S3)	993	1344	1117	1151
	314	314	314	288
$\bar{X}$	874	1102	923	
	280	280	280	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.1371	0.7420	0.2410	0.0001	0.0812	0.0001

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	No. 2 Yield (11.34-kg boxes ha^{-1})			
Tm/Br (S1)	3258	2535	2858	2884
	240	240	240	178
Br/Tm (S2)	742	652	501	632
	240	240	240	178
Br/Tm/Br (S3)	2390	3229	2768	2796
	240	240	240	178
$\bar{X}$	2130	2139	2043	
	164	164	164	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.9651	0.6697	0.6383	0.0001	0.7123	0.0001

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	No. 1 Value ($ ha^{-1})			
Tm/Br (S1)	11473	14869	12879	13074
	2761	2761	2761	2527
Br/Tm (S2)	2823	2371	1630	2275
	2761	2761	2761	2527
Br/Tm/Br (S3)	8714	11797	9811	10107
	2761	2761	2761	2527
$\bar{X}$	7672	9680	8107	
	2463	2463	2463	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.1371	0.7419	0.2410	0.0001	0.0812	0.0001

[y]Tm=Tomato, Br=Broccoli. [z]Standard error appears below each mean.

Table B-11. Mean yield of No. 1 and No. 2 quality and value of No. 1 quality tomatoes in 1990 by tillage and sequence combined over two locations.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	No. 1 Yield (11.34-kg boxes ha^{-1})			
Tm/Br[y] (S1)	1417	1126	1360	1301
	187[z]	187	187	153
Br/Tm (S2)	681	989	926	865
	187	187	187	153
Br/Tm/Br (S3)	683	720	835	746
	187	187	187	153
	927	945	1040	
$\bar{X}$	139	139	139	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.8777	0.3289	0.4090	0.0111	0.0017	0.4627

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	No. 2 Yield (11.34-kg boxes ha^{-1})			
Tm/Br (S1)	3152	2307	3017	2825
	428	428	428	401
Br/Tm (S2)	2258	3041	2982	2760
	428	428	428	401
Br/Tm/Br (S3)	1346	2114	2437	1966
	428	428	428	401
	2252	2487	2812	
$\bar{X}$	398	398	398	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.1919	0.0036	0.0759	0.7453	0.0002	0.0004

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	No. 1 Value (\$ ha^{-1})			
Tm/Br (S1)	12441	9887	11942	11424
	1643	1643	1643	1346
Br/Tm (S2)	5985	8685	8126	7598
	1643	1643	1643	1346
Br/Tm/Br (S3)	6000	6321	7333	6550
	1643	1643	1643	1346
	8141	8297	9134	
$\bar{X}$	1218	1218	1218	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.8777	0.3289	0.4090	0.0111	0.0017	0.4627

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-12. Mean yield of No. 1 and No. 2 quality and value of No. 1 quality tomatoes at Greeneville, TN by tillage and sequence combined over 1989 and 1990.

Sequence (S)	Tillage (T) No-Till (T1)	 Conventional (cover) (T2)	 Conventional (no cover) (T3)	 $\bar{X}$
	No. 1 Yield (11.34-kg boxes ha^{-1})			
Tm/Br[y] (S1)	1568 188[z]	2121 188	2052 188	1914 150
Br/Tm (S2)	462 188	489 188	558 188	503 150
Br/Tm/Br (S3)	869 188	1130 188	1219 188	1072 150
$\bar{X}$	966 121	1247 121	1276 121	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0484	0.0303	0.8285	0.0001	0.0003	0.0098

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	No. 2 Yield (11.34-kg boxes ha^{-1})			
Tm/Br (S1)	3533 511	3164 511	3365 511	3354 484
Br/Tm (S2)	1562 511	1903 511	1970 511	1811 484
Br/Tm/Br (S3)	1774 511	2757 511	2633 511	2388 484
$\bar{X}$	2290 397	2608 397	2656 397	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0789	0.0452	0.7866	0.0053	0.0688	0.2686

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	No. 1 Value ($ ha^{-1})			
Tm/Br (S1)	13770 1655	18626 1655	18019 1655	16803 1314
Br/Tm (S2)	4056 1655	4295 1655	4900 1655	4416 1314
Br/Tm/Br (S3)	7627 1655	9920 1655	10705 1655	9416 1314
$\bar{X}$	8484 1057	10947 1057	11206 1057	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0484	0.0303	0.8285	0.0001	0.0003	0.0098

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-13. Mean yield of No. 1 and No. 2 quality and value of No. 1 quality tomatoes at Greeneville, TN in 1989 by tillage and sequence.

Sequence (S)	Tillage (T)			
	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	X̄
	No. 1 Yield (11.34-kg boxes ha^{-1})			
Tm/Br^{y} (S1)	1335	2547	2376	2086
	176^{z}	176	176	106
Br/Tm (S2)	144	142	162	149
	176	176	176	106
Br/Tm/Br (S3)	1191	1694	1510	1465
	176	176	176	106
X̄	890	1461	1349	
	106	106	106	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0007	0.0043	0.4374	0.0001	0.0003	0.0001

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	X̄
	No. 2 Yield (11.34-kg boxes ha^{-1})			
Tm/Br (S1)	3286	3223	3400	3303
	305	305	305	176
Br/Tm (S2)	204	313	303	273
	305	305	305	176
Br/Tm/Br (S3)	2335	3347	2793	2825
	305	305	305	176
X̄	1942	2294	2165	
	212	212	212	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.2551	0.4661	0.6717	0.0001	0.0432	0.0001

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	X̄
	No. 1 Value ($ ha^{-1})			
Tm/Br (S1)	11718	22358	20862	18313
	1546	1546	1546	929
Br/Tm (S2)	1262	1245	1418	1309
	1546	1546	1546	929
Br/Tm/Br (S3)	10456	14877	13256	12864
	1546	1546	1546	929
X̄	7813	12827	11846	
	929	929	929	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0007	0.0043	0.4374	0.0001	0.0003	0.0001

^{y}Tm=Tomato, Br=Broccoli. ^{z}Standard error appears below each mean.

Table B-14. Mean yield of No. 1 and No. 2 quality and value of No. 1 quality tomatoes at Greeneville, TN in 1990 by tillage and sequence.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	X̄
	No. 1 Yield (11.34-kg boxes ha^{-1})			
Tm/Br[y] (S1)	1802	1696	1728	1742
	202[z]	202	202	139
Br/Tm (S2)	780	837	955	857
	202	202	202	139
Br/Tm/Br (S3)	546	565	929	680
	202	202	202	139
X̄	1043	1033	1204	
	176	176	176	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.9617	0.4560	0.4282	0.0001	0.0001	0.0902

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	X̄
	No. 2 Yield (11.34-kg boxes ha^{-1})			
Tm/Br (S1)	3780	3105	3329	3405
	353	353	353	304
Br/Tm (S2)	2920	3493	3637	3350
	353	353	353	304
Br/Tm/Br (S3)	1213	2167	2472	1951
	353	353	353	304
X̄	2637	2922	3146	
	304	304	304	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.1317	0.0112	0.2278	0.7635	0.0001	0.0001

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	X̄
	No. 1 Value ($ ha^{-1})			
Tm/Br (S1)	15823	14894	15176	15297
	1773	1773	1773	1223
Br/Tm (S2)	6849	7346	8381	7526
	1773	1773	1773	1223
Br/Tm/Br (S3)	4797	4962	8153	5970
	1773	1773	1773	1223
X̄	9156	9067	10569	
	1546	1546	1546	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.9618	0.4560	0.4282	0.0001	0.0001	0.0902

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-15. Mean yield of No. 1 and No. 2 quality and value of No. 1 quality tomatoes at Knoxville, TN by tillage and sequence combined over 1989 and 1990.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	X̄
	No. 1 Yield (11.34-kg boxes ha^{-1})			
Tm/Br^y (S1)	1155 145^z	698 145	775 145	876 97
Br/Tm (S2)	541 145	770 145	553 145	621 97
Br/Tm/Br (S3)	807 145	934 145	734 145	825 97
X̄	835 97	801 97	687 97	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.7549	0.1822	0.3015	0.0253	0.6367	0.0697

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	X̄
	No. 2 Yield (11.34-kg boxes ha^{-1})			
Tm/Br (S1)	2877 258	1679 258	2510 258	2355 206
Br/Tm (S2)	1438 258	1790 258	1514 258	1580 206
Br/Tm/Br (S3)	1962 258	2586 258	2573 258	2374 206
X̄	2092 185	2018 185	2199 185	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.7393	0.6309	0.4181	0.0076	0.9461	0.0064

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	X̄
	No. 1 Value ($ ha^{-1})			
Tm/Br (S1)	10147 1275	6131 1275	6805 1275	7694 852
Br/Tm (S2)	4752 1275	6760 1275	4856 1275	5456 852
Br/Tm/Br (S3)	7086 1275	8198 1275	6439 1275	7242 852
X̄	7328 852	7030 852	6034 852	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.7549	0.1823	0.3015	0.0253	0.6367	0.0697

^{y}Tm=Tomato, Br=Broccoli. ^{z}Standard error appears below each mean.

Table B-16. Mean yield of No. 1 and No. 2 quality and value of No. 1 quality tomatoes at Knoxville, TN in 1989 by tillage and sequence.

Sequence (S)	Tillage (T)			
	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	No. 1 Yield (11.34-kg boxes ha^{-1})			
Tm/Br[y] (S1)	1279	841	558	893
	169[z]	169	169	98
Br/Tm (S2)	499	398	210	369
	169	169	169	98
Br/Tm/Br (S3)	794	993	725	838
	169	169	169	98
$\bar{X}$	858	744	498	
	120	120	120	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.5108	0.0476	0.1628	0.0003	0.6489	0.0010

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	No. 2 Yield (11.34-kg boxes ha^{-1})			
Tm/Br (S1)	3230	1848	2316	2464
	282	282	282	210
Br/Tm (S2)	1279	991	700	990
	282	282	282	210
Br/Tm/Br (S3)	2445	3111	2744	2766
	282	282	282	210
$\bar{X}$	2318	1983	1920	
	225	225	225	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.1491	0.0899	0.7787	0.0001	0.0911	0.0001

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	No. 1 Value (\$ ha^{-1})			
Tm/Br (S1)	11231	7583	4898	7837
	1482	1482	1482	855
Br/Tm (S2)	4384	3498	1843	3243
	1482	1482	1482	855
Br/Tm/Br (S3)	6973	8717	6368	7353
	1482	1482	1482	855
$\bar{X}$	7529	6533	4369	
	1050	1050	1050	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.5108	0.0476	0.1628	0.0003	0.6489	0.0010

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-17. Mean yield of No. 1 and No. 2 quality and value of No. 1 quality tomatoes at Knoxville, TN in 1990 by tillage and sequence.

Sequence (S)	Tillage (T) No-Till (T1)	 Conventional (cover) (T2)	 Conventional (no cover) (T3)	 $\bar{X}$
	No. 1 Yield (11.34-kg boxes ha^{-1})			
Tm/Br[y] (S1)	1032	556	992	860
	172[z]	172	172	100
Br/Tm (S2)	583	1142	897	874
	172	172	172	100
Br/Tm/Br (S3)	820	875	742	812
	172	172	172	100
$\bar{X}$	812	857	877	
	100	100	100	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.7498	0.6495	0.8915	0.9234	0.7381	0.6673

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	No. 2 Yield (11.34-kg boxes ha^{-1})			
Tm/Br (S1)	2524	1510	2705	2246
	251	251	251	145
Br/Tm (S2)	1596	2589	2327	2171
	251	251	251	145
Br/Tm/Br (S3)	1480	2061	2401	1981
	251	251	251	145
$\bar{X}$	1866	2053	2478	
	215	215	215	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.5462	0.0594	0.1794	0.5660	0.0546	0.1585

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	No. 1 Value (\$ ha^{-1})			
Tm/Br (S1)	9062	4881	8712	7551
	1514	1514	1514	874
Br/Tm (S2)	5120	10023	7872	7672
	1514	1514	1514	874
Br/Tm/Br (S3)	7200	7679	6513	7131
	1514	1514	1514	874
$\bar{X}$	7128	7529	7699	
	874	874	874	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.7498	0.6495	0.8915	0.9234	0.7381	0.6673

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-18. Mean yield of No. 1 and No. 2 quality and value of No. 1 quality tomatoes by tillage and sequence combined over years and locations.

Sequence (S)	Tillage (T)			
	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	No. 1 Yield (11.34-kg boxes ha^{-1})			
Tm/Br[y] (S1)	1362	1410	1414	1395
	228[z]	228	228	212
Br/Tm (S2)	502	630	556	562
	228	228	228	212
Br/Tm/Br (S3)	838	1032	976	949
	228	228	228	212
$\bar{X}$	901	1024	982	
	202	202	202	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.1973	0.3928	0.6594	0.0001	0.0030	0.0096

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	No. 2 Yield (11.34-kg boxes ha^{-1})			
Tm/Br (S1)	3205	2421	2938	2855
	310	310	310	288
Br/Tm (S2)	1500	1847	1742	1696
	310	310	310	288
Br/Tm/Br (S3)	1868	2672	2603	2381
	310	310	310	288
$\bar{X}$	2191	2313	2427	
	247	247	247	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.3943	0.1022	0.4260	0.0002	0.1130	0.0235

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	No. 1 Value (\$ ha^{-1})			
Tm/Br (S1)	11957	12380	12412	12249
	2003	2003	2003	1857
Br/Tm (S2)	4404	5528	4878	4938
	2003	2003	2003	1857
Br/Tm/Br (S3)	7358	9057	8573	8329
	2003	2003	2003	1857
$\bar{X}$	7906	8988	8620	
	1773	1773	1773	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.1973	0.3928	0.6594	0.0001	0.0030	0.0096

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-19. Mean value of No. 2 fruit, total value and average size of No. 1 tomatoes in 1989 by tillage and sequence combined over two locations.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	X̄
	No. 2 Value ($ ha^{-1})			
Tm/Br^{y} (S1)	17169 1265^{z}	13360 1265	15062 1265	15198 939
Br/Tm (S2)	3910 1265	3438 1265	2643 1265	3330 939
Br/Tm/Br (S3)	12595 1265	17016 1265	14590 1265	14734 939
X̄	11224 862	11271 862	10764 862	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.9651	0.6697	0.6383	0.0001	0.7123	0.0001

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	X̄
	Total Value ($ ha^{-1})			
Tm/Br (S1)	28642 3411	28232 3411	27941 3411	28272 2944
Br/Tm (S2)	6733 3411	5809 3411	4273 3411	5604 2944
Br/Tm/Br (S3)	21311 3411	28813 3411	24401 3411	24841 2944
X̄	18896 2801	20951 2801	18871 2801	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.3553	0.9915	0.3499	0.0001	0.2136	0.0001

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	X̄
	Average No. 1 Fruit (g)			
Tm/Br (S1)	176.4 24.2	190.0 24.2	187.1 24.2	184.5 23.5
Br/Tm (S2)	166.7 24.2	175.2 24.2	167.3 24.2	169.7 23.5
Br/Tm/Br (S3)	167.8 24.2	181.4 24.2	174.6 24.2	174.6 23.5
X̄	170.3 23.4	182.2 23.4	176.4 23.4	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0923	0.3783	0.3981	0.0726	0.2203	0.5386

^{y}Tm=Tomato, Br=Broccoli. ^{z}Standard error appears below each mean.

Table B-20. Mean value of No. 2 fruit, total value and average size of No. 1 tomatoes in 1990 by tillage and sequence combined over two locations.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	No. 2 Value ($ ha^{-1})			
Tm/Br[y] (S1)	16611 2255[z]	12160 2255	15899 2255	14889 2114
Br/Tm (S2)	11898 2255	16025 2255	15174 2255	14546 2114
Br/Tm/Br (S3)	7094 2255	11142 2255	12842 2255	10359 2114
$\bar{X}$	11868 2097	13108 2097	14818 2097	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.1919	0.0036	0.0759	0.74531	0.0002	0.0004

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Total Value ($ ha^{-1})			
Tm/Br (S1)	29052 3665	22045 3665	27844 3665	26313 3347
Br/Tm (S2)	17883 3665	24710 3665	23840 3665	22144 3347
Br/Tm/Br (S3)	13093 3665	17460 3665	20175 3665	16910 3347
$\bar{X}$	20009 3231	21405 3231	23952 3231	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.3814	0.0180	0.1158	0.0662	0.0002	0.0233

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Average No. 1 Fruit (g)			
Tm/Br (S1)	167.8 10.3	160.5 10.3	167.3 10.3	165.2 9.8
Br/Tm (S2)	180.3 10.3	179.8 10.3	188.2 10.3	182.8 9.8
Br/Tm/Br (S3)	172.1 10.3	176.4 10.3	180.9 10.3	176.1 9.8
$\bar{X}$	173.1 9.8	172.2 9.8	178.8 9.8	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.8173	0.1728	0.1139	0.0001	0.0043	0.0711

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-21. Mean value of No. 2 fruit, total value and average size of No. 1 tomatoes at Greeneville, TN by tillage and sequence combined over 1989 and 1990.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	No. 2 Value ($ ha^{-1})			
Tm/Br^y (S1)	18619 2692^z	16675 2692	17732 2692	17675 2552
Br/Tm (S2)	8233 2692	10028 2692	10379 2692	9547 2552
Br/Tm/Br (S3)	9349 2692	14529 2692	13874 2692	12585 2552
$\bar{X}$	12066 2092	13743 2092	13995 2092	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0789	0.0452	0.7865	0.0053	0.0688	0.2686

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Total Value ($ ha^{-1})			
Tm/Br (S1)	32389 3498	35299 3498	35751 3498	34479 3100
Br/Tm (S2)	12288 3498	14324 3498	15279 3498	13963 3100
Br/Tm/Br (S3)	16976 3498	24448 3498	24579 3498	22000 3100
$\bar{X}$	20550 2102	24690 2102	25201 2102	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0306	0.0162	0.7801	0.0001	0.0077	0.0749

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Average No. 1 Fruit (g)			
Tm/Br (S1)	190.0 5.5	193.4 5.5	192.8 5.5	192.0 4.0
Br/Tm (S2)	212.1 5.5	204.2 5.8	205.8 5.5	207.3 4.1
Br/Tm/Br (S3)	190.5 5.5	201.3 5.5	203.0 5.5	198.3 4.0
$\bar{X}$	197.5 3.6	199.6 3.6	200.5 3.6	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.6373	0.4936	0.8350	0.0089	0.2582	0.1059

^{y}Tm=Tomato, Br=Broccoli. ^{z}Standard error appears below each mean.

Table B-22. Mean value of No. 2 fruit, total value and average size of No. 1 tomatoes at Greeneville, TN in 1989 by tillage and sequence.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	No. 2 Value (\$ ha^{-1})			
Tm/Br[y] (S1)	17317	16986	17920	17409
	1608[z]	1608	1608	929
Br/Tm (S2)	1077	1650	1596	1440
	1608	1608	1608	929
Br/Tm/Br (S3)	12308	17638	14719	14889
	1608	1608	1608	929
$\bar{X}$	10233	12091	11411	
	1116	1116	1116	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.2551	0.4660	0.6717	0.0001	0.0432	0.0001

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Total Value (\$ ha^{-1})			
Tm/Br (S1)	29035	39345	38779	35719
	2497	2497	2497	1442
Br/Tm (S2)	2339	2895	3013	2749
	2497	2497	2497	1442
Br/Tm/Br (S3)	22764	32515	27975	27750
	2497	2497	2497	1442
$\bar{X}$	18046	24917	23255	
	1746	1746	1746	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0123	0.0493	0.5093	0.0001	0.0003	0.0001

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Average No. 1 Fruit (g)			
Tm/Br (S1)	196.2	200.7	203.0	199.9
	8.3	8.3	8.3	4.8
Br/Tm (S2)	208.7	207.2	200.7	205.5
	8.3	9.5	8.3	5.0
Br/Tm/Br (S3)	182.6	199.6	196.2	192.8
	8.3	8.3	8.3	4.8
$\bar{X}$	195.8	202.5	202.7	
	4.8	5.0	4.8	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.3475	0.5447	0.7199	0.4336	0.3007	0.0831

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-23. Mean value of No. 2 fruit, total value and average size of No. 1 tomatoes at Greeneville, TN in 1990 by tillage and sequence.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	No. 2 Value (\$ ha^{-1})			
Tm/Br^{y} (S1)	19921	16361	17544	17942
	1860^{z}	1860	1860	1601
Br/Tm (S2)	15386	18409	19165	17653
	1860	1860	1860	1601
Br/Tm/Br (S3)	6392	11419	13029	10280
	1860	1860	1860	1601
$\bar{X}$	13901	15396	16581	
	1601	1601	1601	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.1317	0.0112	0.2278	0.7635	0.0001	0.0001

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Total Value (\$ ha^{-1})			
Tm/Br (S1)	35743	31255	32720	33239
	3349	3349	3349	2734
Br/Tm (S2)	22235	25755	27545	25179
	3349	3349	3349	2734
Br/Tm/Br (S3)	11189	16381	21183	16250
	3349	3349	3349	2734
$\bar{X}$	23057	24463	27150	
	2947	2947	2947	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.5788	0.1165	0.2934	0.0001	0.0001	0.0001

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Average No. 1 Fruit (g)			
Tm/Br (S1)	183.7	186.0	182.6	184.1
	6.8	6.8	6.8	5.5
Br/Tm (S2)	215.5	201.9	210.9	209.4
	6.8	6.8	6.8	5.5
Br/Tm/Br (S3)	198.5	203.0	209.8	203.8
	6.8	6.8	6.8	5.5
$\bar{X}$	199.2	197.0	201.1	
	6.4	6.4	6.4	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.7159	0.7615	0.5065	0.0001	0.0001	0.0368

^{y}Tm=Tomato, Br=Broccoli. ^{z}Standard error appears below each mean.

Table B-24. Mean value of No. 2 fruit, total value and average size of No. 1 tomatoes at Knoxville, TN by tillage and sequence combined over 1989 and 1990.

Sequence (S)	Tillage (T) No-Till (T1)	 Conventional (cover) (T2)	 Conventional (no cover) (T3)	 X̄
	No. 2 Value ($ ha^{-1})			
Tm/Br[y] (S1)	15161 1359[z]	8845 1359	13229 1359	12412 1084
Br/Tm (S2)	7575 1359	9433 1359	7976 1359	8329 1084
Br/Tm/Br (S3)	10339 1359	13629 1359	13558 1359	12508 1084
X̄	11026 976	10636 976	11587 976	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.7393	0.6309	0.4181	0.0076	0.9461	0.0064

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	X̄
	Total Value ($ ha^{-1})			
Tm/Br (S1)	25305 2243	14978 2243	20034 2243	20106 1601
Br/Tm (S2)	12328 2243	16196 2243	12834 2243	13785 1601
Br/Tm/Br (S3)	17428 2243	21827 2243	19997 2243	19750 1601
X̄	18355 1487	17665 1487	17621 1487	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.7174	0.6999	0.9812	0.0063	0.8695	0.0095

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	X̄
	Average No. 1 Fruit (g)			
Tm/Br (S1)	154.2 7.9	157.1 7.9	161.6 7.9	157.6 5.6
Br/Tm (S2)	134.9 7.9	150.8 7.9	149.7 7.9	145.2 5.6
Br/Tm/Br (S3)	148.6 7.9	156.5 7.9	152.5 7.9	152.5 5.6
X̄	145.9 5.3	154.8 5.3	154.6 5.3	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.2008	0.2103	0.9780	0.1024	0.4954	0.3269

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-25. Mean value of No. 2 fruit, total value and average size of No. 1 tomatoes at Knoxville, TN in 1989 by tillage and sequence.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	No. 2 Value ($ ha^{-1})			
Tm/Br[y] (S1)	17021 1484[z]	9737 1484	12204 1484	12987 1104
Br/Tm (S2)	6741 1484	5227 1484	3688 1484	5219 1104
Br/Tm/Br (S3)	12884 1484	16393 1484	14462 1484	14580 1104
$\bar{X}$	12214 1186	10453 1186	10117 1186	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.1491	0.0899	0.7787	0.0001	0.0911	0.0001

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Total Value ($ ha^{-1})			
Tm/Br (S1)	28249 2517	17120 2517	17102 2517	20825 1531
Br/Tm (S2)	11125 2517	8724 2517	5530 2517	8460 1531
Br/Tm/Br (S3)	19856 2517	25110 2517	20830 2517	21934 1531
$\bar{X}$	19745 1971	16984 1971	14487 1971	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.3127	0.0634	0.3597	0.0001	0.4879	0.0001

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Average No. 1 Fruit (g)			
Tm/Br (S1)	156.5 12.9	179.2 12.9	171.2 12.9	169.0 7.5
Br/Tm (S2)	124.7 12.9	144.0 12.9	133.8 12.9	134.2 7.5
Br/Tm/Br (S3)	153.1 12.9	163.3 12.9	153.1 12.9	156.5 7.5
$\bar{X}$	144.8 8.7	162.2 8.7	152.7 8.7	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.1746	0.5269	0.4523	0.0019	0.2093	0.0318

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-26. Mean value of No. 2 fruit, total value and average size of No. 1 tomatoes at Knoxville, TN in 1990 by tillage and sequence.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	No. 2 Value ($ ha^{-1})			
Tm/Br[y] (S1)	13298 1321[z]	7956 1321	14254 1321	11836 763
Br/Tm (S2)	8410 1321	13642 1321	12264 1321	11439 763
Br/Tm/Br (S3)	7798 1321	10863 1321	12651 1321	10438 763
$\bar{X}$	9836 1131	10821 1131	13056 1131	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.5462	0.0594	0.1794	0.5660	0.0546	0.1585

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Total Value ($ ha^{-1})			
Tm/Br (S1)	22361 2327	12837 2327	22966 2327	19387 1344
Br/Tm (S2)	13531 2327	23665 2327	20135 2327	19110 1344
Br/Tm/Br (S3)	15000 2327	18542 2327	19165 2327	17569 1344
$\bar{X}$	16964 1354	18347 1354	20755 1354	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.4788	0.0631	0.2247	0.8852	0.3494	0.4261

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Average No. 1 Fruit (g)			
Tm/Br (S1)	152.0 5.9	134.9 5.9	152.0 5.9	146.3 3.4
Br/Tm (S2)	145.2 5.9	157.6 5.9	165.6 5.9	156.1 3.4
Br/Tm/Br (S3)	144.0 5.9	149.7 5.9	152.0 5.9	148.6 3.4
$\bar{X}$	147.1 3.5	147.4 3.5	156.5 3.5	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.9406	0.0749	0.0863	0.0516	0.6363	0.1262

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-27. Mean value of No. 2 fruit, total value and average size of No. 1 tomatoes by tillage and sequence combined over years and locations.

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	No. 2 Value (\$ ha^{-1})			
Tm/Br[y] (S1)	16890	12760	15482	15042
	1635[z]	1635	1635	1519
Br/Tm (S2)	7904	9732	9179	8939
	1635	1635	1635	1519
Br/Tm/Br (S3)	9845	14079	13716	12548
	1635	1635	1635	1519
$\bar{X}$	11547	12189	12792	
	1302	1302	1302	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.3943	0.1022	0.4260	0.0002	0.1130	0.0235

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Total Value (\$ ha^{-1})			
Tm/Br (S1)	28847	25140	27891	27294
	3401	3401	3401	3189
Br/Tm (S2)	12308	15260	14057	13874
	3401	3401	3401	3189
Br/Tm/Br (S3)	17204	23136	22287	20876
	3401	3401	3401	3189
$\bar{X}$	19454	21178	21412	
	2912	2912	2912	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.2187	0.1633	0.8669	0.0001	0.0180	0.0102

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Average No. 1 Fruit (g)			
Tm/Br (S1)	172.1	175.2	177.2	174.8
	14.4	14.4	14.4	14.0
Br/Tm (S2)	173.5	177.6	177.8	176.3
	14.4	14.4	14.4	14.0
Br/Tm/Br (S3)	169.6	178.9	177.8	175.4
	14.4	14.4	14.4	14.0
$\bar{X}$	171.7	177.2	177.6	
	13.9	13.9	13.9	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.1801	0.1543	0.9365	0.7731	0.9111	0.8594

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-28. Mean head and stem circumference and total leaf N concentration of broccoli in 1989 by tillage and sequence combined over two locations.

Sequence (S)	Tillage (T)			
	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Head Circumference (cm)			
Br/Tm[y] (S2)	21.48	31.67	35.24	29.47
	2.34[z]	2.34	2.34	1.41
Br/Tm/Br (S3)	17.81	20.03	25.82	21.22
	2.86	2.86	2.86	1.72
$\bar{X}$	19.64	25.85	30.53	
	1.88	1.88	1.88	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0295	0.0008	0.0885	0.0016
	Stem Circumference (cm)			
Br/Tm (S2)	9.31	10.75	11.36	10.47
	0.45	0.45	0.45	0.26
Br/Tm/Br (S3)	9.16	9.59	10.97	9.90
	0.56	0.56	0.56	0.32
$\bar{X}$	9.23	10.17	11.16	
	0.36	0.36	0.36	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0875	0.0019	0.0697	0.1911
	N (%)			
Br/Tm (S2)	2.92	3.58	3.96	3.49
	0.38	0.38	0.38	0.36
Br/Tm/Br (S3)	3.73	3.80	3.92	3.82
	0.47	0.47	0.47	0.44
$\bar{X}$	3.33	3.69	3.94	
	0.32	0.32	0.32	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.1396	0.0194	0.3006	0.5587

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-29. Mean head and stem circumference and total leaf N concentration of broccoli in 1990 by tillage and sequence combined over two locations.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Head Circumference (cm)			
Br/Tm[y] (S2)	28.84	42.75	45.74	39.11
	4.92[z]	4.92	4.92	4.73
Br/Tm/Br (S3)	34.14	41.11	42.36	39.20
	5.05	5.05	5.05	4.79
$\bar{X}$	31.49	41.93	44.05	
	4.87	4.87	4.87	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0002	0.0001	0.3275	0.9446
	Stem Circumference (cm)			
Br/Tm (S2)	10.51	12.96	13.04	12.17
	0.35	0.35	0.35	0.21
Br/Tm/Br (S3)	11.55	12.16	13.26	12.32
	0.40	0.40	0.40	0.24
$\bar{X}$	11.03	12.56	13.15	
	0.32	0.32	0.32	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0042	0.0003	0.2086	0.5118
	N (%)			
Br/Tm (S2)	2.57	2.90	3.28	2.92
	0.42	0.42	0.42	0.41
Br/Tm/Br (S3)	2.76	2.70	2.98	2.81
	0.43	0.43	0.43	0.41
$\bar{X}$	2.67	2.80	3.13	
	0.42	0.42	0.42	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.4409	0.0123	0.0565	0.2874

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-30. Mean head and stem circumference and total leaf N concentration of broccoli at Greeneville, TN by tillage and sequence combined over 1989 and 1990.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
		Head Circumference (cm)		
Br/Tm[y] (S2)	31.37	42.73	43.84	39.31
	5.33[z]	5.33	5.33	5.05
Br/Tm/Br (S3)	27.00	34.88	36.43	32.77
	5.33	5.33	5.33	5.05
$\bar{X}$	29.18	38.81	40.13	
	5.01	5.01	5.01	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0006	0.0002	0.5499	0.0386
		Stem Circumference (cm)		
Br/Tm (S2)	11.25	11.72	12.00	11.66
	1.33	1.33	1.33	1.29
Br/Tm/Br (S3)	10.09	11.26	11.61	10.98
	1.33	1.33	1.33	1.29
$\bar{X}$	10.67	11.49	11.80	
	1.29	1.29	1.29	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0593	0.0132	0.4465	0.1130
		N (%)		
Br/Tm (S2)	4.41	4.43	4.56	4.47
	0.28	0.28	0.28	0.24
Br/Tm/Br (S3)	4.88	4.59	4.68	4.71
	0.28	0.28	0.28	0.24
$\bar{X}$	4.64	4.51	4.62	
	0.25	0.25	0.25	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.4216	0.8855	0.5067	0.0785

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-31. Mean head and stem circumference and total leaf N concentration of broccoli at Greeneville, TN in 1989 by tillage and sequence.

Sequence (S)	Tillage (T)			
	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Head Circumference (cm)			
Br/Tm[y] (S2)	22.85	33.50	34.75	30.37
	3.63[z]	3.63	3.63	2.10
Br/Tm/Br (S3)	12.18	18.52	20.30	17.00
	3.63	3.63	3.63	2.10
	17.51	26.01	27.52	
$\bar{X}$	2.58	2.58	2.58	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0449	0.0228	0.6884	0.0014
	Stem Circumference (cm)			
Br/Tm (S2)	10.56	10.84	11.09	10.83
	0.63	0.63	0.63	0.37
Br/Tm/Br (S3)	7.74	10.24	9.83	9.27
	0.63	0.63	0.63	0.37
	9.15	10.54	10.46	
$\bar{X}$	0.45	0.45	0.45	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0546	0.0676	0.8984	0.0139
	N (%)			
Br/Tm (S2)	4.63	4.56	4.60	4.60
	0.26	0.26	0.26	0.15
Br/Tm/Br (S3)	5.50	4.76	4.91	5.06
	0.26	0.26	0.26	0.15
	5.07	4.66	4.75	
$\bar{X}$	0.18	0.18	0.18	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.1522	0.2573	0.7311	0.0574

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-32. Mean head and stem circumference and total leaf N concentration of broccoli at Greeneville, TN in 1990 by tillage and sequence.

Sequence (S)	Tillage (T) No-Till (T1)	 Conventional (cover) (T2)	 Conventional (no cover) (T3)	 $\bar{X}$
	Head Circumference (cm)			
Br/Tm[y] (S2)	39.89 3.10[z]	51.96 3.10	52.93 3.10	48.26 2.74
Br/Tm/Br (S3)	41.81 3.10	51.25 3.10	52.57 3.10	48.54 2.74
$\bar{X}$	40.85 2.88	51.60 2.88	52.75 2.88	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0004	0.0002	0.5691	0.8335
	Stem Circumference (cm)			
Br/Tm (S2)	11.95 0.45	12.60 0.45	12.91 0.45	12.48 0.33
Br/Tm/Br (S3)	12.44 0.45	12.29 0.45	13.39 0.45	12.70 0.33
$\bar{X}$	12.19 0.37	12.44 0.37	13.15 0.37	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.5216	0.0310	0.0918	0.4938
	N (%)			
Br/Tm (S2)	4.19 0.18	4.30 0.18	4.52 0.18	4.34 0.14
Br/Tm/Br (S3)	4.25 0.18	4.42 0.18	4.45 0.18	4.37 0.14
$\bar{X}$	4.22 0.15	4.36 0.15	4.49 0.15	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.3596	0.1035	0.4196	0.7218

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-33. Mean head and stem circumference and total leaf N concentration of broccoli at Knoxville, TN by tillage and sequence combined over 1989 and 1990.

Sequence (S)	Tillage (T)			
	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
		Head Circumference (cm)		
Br/Tm^y (S2)	27.82 4.21^z	27.19 4.21	33.57 4.21	29.53 3.94
Br/Tm/Br (S3)	27.62 4.21	27.13 4.21	32.56 4.21	29.10 3.94
$\bar{X}$	27.72 4.04	27.16 4.04	33.06 4.04	
Contrast Prob. > F	T1 v T2 0.7814	T1 v T3 0.0171	T2 v T3 0.0098	S2 v S3 0.7580
		Stem Circumference (cm)		
Br/Tm (S2)	10.78 0.84	11.47 0.84	11.64 0.84	11.30 0.80
Br/Tm/Br (S3)	11.20 0.84	10.30 0.84	12.45 0.84	11.32 0.80
$\bar{X}$	10.99 0.82	10.89 0.82	12.05 0.82	
Contrast Prob. > F	T1 v T2 0.7557	T1 v T3 0.0065	T2 v T3 0.0035	S2 v S3 0.9218
		N (%)		
Br/Tm (S2)	3.10 0.19	3.67 0.19	4.01 0.19	3.60 0.14
Br/Tm/Br (S3)	2.69 0.19	2.81 0.19	2.97 0.19	2.82 0.14
$\bar{X}$	2.90 0.17	3.24 0.17	3.49 0.17	
Contrast Prob. > F	T1 v T2 0.1285	T1 v T3 0.0138	T2 v T3 0.2504	S2 v S3 0.0004

^{y}Tm=Tomato, Br=Broccoli. ^{z}Standard error appears below each mean.

Table B-34. Mean head and stem circumference and total leaf N concentration of broccoli at Knoxville, TN in 1989 by tillage and sequence.

Sequence (S)	Tillage (T)			
	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Head Circumference (cm)			
Br/Tm[y] (S2)	28.33	20.43	28.55	25.77
	1.29[z]	1.29	1.29	0.92
Br/Tm/Br (S3)	23.09	21.20	31.01	25.10
	1.29	1.29	1.29	0.92
$\bar{X}$	25.71	20.82	29.78	
	1.13	1.13	1.13	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0048	0.0129	0.0001	0.3818
	Stem Circumference (cm)			
Br/Tm (S2)	10.32	10.34	10.78	10.48
	0.33	0.33	0.33	0.22
Br/Tm/Br (S3)	10.58	8.94	12.11	10.54
	0.33	0.33	0.33	0.22
$\bar{X}$	10.45	9.64	11.44	
	0.27	0.27	0.27	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0427	0.0174	0.0005	0.7776
	N (%)			
Br/Tm (S2)	3.27	4.17	4.30	3.91
	0.15	0.15	0.15	0.09
Br/Tm/Br (S3)	2.29	2.94	2.71	2.65
	0.15	0.15	0.15	0.09
$\bar{X}$	2.78	3.55	3.50	
	0.13	0.13	0.13	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0020	0.0031	0.7931	0.0001

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-35. Mean head and stem circumference and total leaf N concentration of broccoli at Knoxville, TN in 1990 by tillage and sequence.

Sequence (S)	Tillage (T)			
	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Head Circumference (cm)			
Br/Tm[y] (S2)	27.32 3.02[z]	33.96 3.02	38.59 3.02	33.29 1.75
Br/Tm/Br (S3)	32.14 3.02	33.06 3.02	34.11 3.02	33.10 1.75
$\bar{X}$	29.73 2.28	33.51 2.28	36.35 2.28	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.2704	0.0699	0.4010	0.9382
	Stem Circumference (cm)			
Br/Tm (S2)	11.24 0.42	12.61 0.42	12.51 0.42	12.12 0.25
Br/Tm/Br (S3)	11.83 0.42	11.66 0.42	12.79 0.42	12.09 0.25
$\bar{X}$	11.53 0.32	12.13 0.32	12.65 0.32	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.2169	0.0349	0.2787	0.9423
	N (%)			
Br/Tm (S2)	2.94 0.26	3.17 0.26	3.73 0.26	3.28 0.15
Br/Tm/Br (S3)	3.10 0.26	2.68 0.26	3.22 0.26	3.00 0.15
$\bar{X}$	3.02 0.24	2.92 0.24	3.48 0.24	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.7852	0.2026	0.1323	0.0645

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-36. Mean head and stem circumference and total leaf N concentration of broccoli by tillage and sequence combined across years and locations.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
		Head Circumference (cm)		
Br/Tm^y (S2)	25.16	37.21	40.49	34.29
	6.20^z	6.20	6.20	6.09
Br/Tm/Br (S3)	26.18	31.44	34.82	30.82
	6.30	6.30	6.30	6.14
$\bar{X}$	25.67	34.33	37.66	
	6.15	6.15	6.15	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0001	0.0001	0.0603	0.0226
		Stem Circumference (cm)		
Br/Tm (S2)	9.91	11.85	12.20	11.32
	1.04	1.04	1.04	1.01
Br/Tm/Br (S3)	10.60	10.77	12.02	11.13
	1.06	1.06	1.06	1.02
$\bar{X}$	10.25	11.31	12.11	
	1.02	1.02	1.02	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0021	0.0001	0.0164	0.4473
		N (%)		
Br/Tm (S2)	2.76	3.24	3.62	3.20
	0.60	0.60	0.60	0.59
Br/Tm/Br (S3)	2.90	2.89	3.08	2.96
	0.61	0.61	0.61	0.60
$\bar{X}$	2.83	3.06	3.35	
	0.60	0.60	0.60	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0806	0.0004	0.0383	0.0907

^{y}Tm=Tomato, Br=Broccoli. ^{z}Standard error appears below each mean.

Table B-37. Mean yield and value of broccoli in 1989 by tillage and sequence combined over two locations.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Yield (10.43-kg boxes ha^{-1})			
Br/Tm[z] (S2)	203.0	493.1	655.5	450.5
	109.9[z]	109.9	109.9	91.9
Br/Tm/Br (S3)	276.9	338.4	614.8	410.0
	126.0	126.0	126.0	103.0
$\bar{X}$	240.0	415.7	635.3	
	102.2	102.3	102.3	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0733	0.0007	0.0299	0.6409
	Value ($ ha^{-1})			
Br/Tm (S2)	1862	4523	6012	4132
	1008	1008	1008	842
Br/Tm/Br (S3)	2539	3105	5637	3759
	1156	1156	1156	944
$\bar{X}$	2201	3814	5824	
	939	939	939	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0733	0.0007	0.0299	0.6409

[y]Tm=Tomato, Br=Broccoli. [z]Standard error appears below each mean.

Table B-38. Mean yield and value of broccoli in 1990 by tillage and sequence combined over two locations.

Sequence (S)	Tillage (T) No-Till (T1)	 Conventional (cover) (T2)	 Conventional (no cover) (T3)	 $\bar{X}$
	Yield (10.43-kg boxes ha^{-1})			
Br/Tm[y] (S2)	379.1	897.4	1082.6	786.4
	168.2[z]	168.2	168.2	159.8
Br/Tm/Br (S3)	520.7	766.9	948.2	745.2
	175.6	175.6	175.6	163.5
	449.8	832.1	1015.4	
$\bar{X}$	165.0	165.0	165.0	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0002	0.0001	0.0307	0.4941
	Value (\$ ha^{-1})			
Br/Tm (S2)	3478	8230	9927	7212
	1544	1544	1544	1467
Br/Tm/Br (S3)	4775	7032	8694	6834
	1610	1610	1610	1499
	4125	7632	9312	
$\bar{X}$	1512	1512	1512	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0002	0.0001	0.0307	0.4941

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-39. Mean yield and value of broccoli at Greeneville, TN by tillage and sequence combined over 1989 and 1990.

Sequence (S)	Tillage (T)			
	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Yield (10.43-kg boxes ha^{-1})			
Br/Tm^y (S2)	409.8	890.7	991.7	764.0
	408.8^z	408.8	408.8	404.1
Br/Tm/Br (S3)	370.8	636.0	765.7	590.8
	408.8	408.8	408.8	404.1
	390.3	763.5	878.6	
$\bar{X}$	405.6	405.6	405.6	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0005	0.0001	0.1842	0.0154
	Value ($ ha^{-1})			
Br/Tm (S2)	3757	8168	9092	7005
	3749	3749	3749	3705
Br/Tm/Br (S3)	3399	5832	7022	5417
	3749	3749	3749	3705
	3579	7000	8057	
$\bar{X}$	3720	3720	3720	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0005	0.0001	0.1842	0.0154

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-40. Mean yield and value of broccoli at Greeneville, TN in 1989 by tillage and sequence.

Sequence (S)	Tillage (T) No-Till (T1)	 Conventional (cover) (T2)	 Conventional (no cover) (T3)	$\bar{X}$
		Yield (10.43-kg boxes ha^{-1})		
Br/Tm[y] (S2)	153.9	540.2	566.1	420.2
	84.5[z]	84.5	84.5	48.9
Br/Tm/Br (S3)	21.5	140.5	225.8	129.2
	84.5	84.5	84.5	48.9
	87.7	340.4	395.9	
$\bar{X}$	66.7	66.7	66.7	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0251	0.0096	0.5689	0.0009
		Value ($ ha^{-1})		
Br/Tm (S2)	1410	4952	5192	3851
	776	776	776	447
Br/Tm/Br (S3)	198	1287	2070	1186
	776	776	776	447
	803	3120	3631	
$\bar{X}$	610	610	610	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0251	0.0096	0.5690	0.0009

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-41. Mean yield and value of broccoli at Greeneville, TN in 1990 by tillage and sequence.

Sequence (S)	Tillage (T)			
	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Yield (10.43-kg boxes ha^{-1})			
Br/Tm[y] (S2)	665.4	1241.4	1417.0	1108.0
	152.7[z]	152.7	152.7	119.6
Br/Tm/Br (S3)	719.8	1131.8	1305.6	1052.5
	152.7	152.7	152.7	119.6
$\bar{X}$	692.6	1186.6	1361.2	
	128.7	128.7	128.7	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0021	0.0003	0.1662	0.5717
	Value ($ ha^{-1})			
Br/Tm (S2)	6103	11384	12995	10159
	1400	1400	1400	1097
Br/Tm/Br (S3)	6602	10376	11972	9650
	1400	1400	1400	1097
$\bar{X}$	6353	10880	12483	
	1181	1181	1181	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0021	0.0003	0.1662	0.5717

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-42. Mean yield and value of broccoli at Knoxville, TN by tillage and sequence combined over 1989 and 1990.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Yield (10.43-kg boxes ha^{-1})			
Br/Tm^y (S2)	429.5 95.3^z	376.2 95.3	635.0 95.3	480.2 75.3
Br/Tm/Br (S3)	513.0 95.3	461.9 95.3	793.1 95.3	589.3 75.3
$\bar{X}$	471.3 80.3	418.9 80.3	714.1 80.3	
Contrast Prob. > F	T1 v T2 0.4913	T1 v T3 0.0054	T2 v T3 0.0013	S2 v S3 0.1133
	Value ($ ha^{-1})			
Br/Tm (S2)	3937 874	3448 874	5821 874	4404 692
Br/Tm/Br (S3)	4703 874	4236 874	7272 874	5404 692
$\bar{X}$	4320 736	3843 736	6548 736	
Contrast Prob. > F	T1 v T2 0.4913	T1 v T3 0.0054	T2 v T3 0.0013	S2 v S3 0.1133

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-43. Mean yield and value of broccoli at Knoxville, TN in 1989 by tillage and sequence.

Sequence (S)	Tillage (T)			
	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Yield (10.43-kg boxes ha^{-1})			
Br/Tm^{y} (S2)	447.8	126.5	448.1	340.9
	79.8^{z}	79.8	79.8	53.6
Br/Tm/Br (S3)	530.1	387.3	860.8	592.8
	79.8	79.8	79.8	53.6
$\bar{X}$	488.8	256.9	654.3	
	65.7	65.7	65.7	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0174	0.0679	0.0008	0.0009
	Value ($ ha^{-1})			
Br/Tm (S2)	4105	1161	4108	3125
	731	731	731	492
Br/Tm/Br (S3)	4861	3549	7894	5434
	731	731	731	492
$\bar{X}$	4483	2356	6000	
	603	603	603	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0174	0.0679	0.0008	0.0009

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-44. Mean yield and value of broccoli at Knoxville, TN in 1990 by tillage and sequence.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Yield (10.43-kg boxes ha^{-1})			
Br/Tm[y] (S2)	411.3 100.3[z]	625.7 100.3	822.0 100.3	619.5 57.8
Br/Tm/Br (S3)	495.7 100.3	536.5 100.3	725.4 100.3	585.9 57.8
$\bar{X}$	453.5 70.9	581.2 70.9	773.6 70.9	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.2349	0.0109	0.0870	0.6903
	Value ($ ha^{-1})			
Br/Tm (S2)	3772 919	5738 919	7536 919	5681 531
Br/Tm/Br (S3)	4547 919	4920 919	6652 919	5372 531
$\bar{X}$	4159 650	5328 650	7094 650	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.2349	0.0109	0.0870	0.6920

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-45. Mean yield and value of broccoli by tillage and sequence combined across years and locations.

Sequence (S)	Tillage (T) No-Till (T1)	 Conventional (cover) (T2)	 Conventional (no cover) (T3)	 $\bar{X}$
	Yield (10.43-kg boxes ha^{-1})			
Br/Tm[y] (S2)	291.2 172.4[z]	695.3 172.4	869.0 172.4	618.5 167.5
Br/Tm/Br (S3)	401.4 177.4	565.4 177.4	793.9 177.4	586.9 170.2
$\bar{X}$	346.3 170.4	630.3 170.4	831.4 170.4	
Contrast Prob. > F	T1 v T2 0.0001	T1 v T3 0.0001	T2 v T3 0.0029	S2 v S3 0.5589
	Value ($ ha^{-1})			
Br/Tm (S2)	2670 1581	6375 1581	7968 1581	5671 1536
Br/Tm/Br (S3)	3680 1625	5185 1625	7282 1625	5382 1560
$\bar{X}$	3174 1564	5780 1564	7625 1564	
Contrast Prob. > F	T1 v T2 0.0001	T1 v T3 0.0001	T2 v T3 0.0029	S2 v S3 0.5589

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-46. Mean marketability and average marketable head size of broccoli in 1989 by tillage and sequence combined over two locations.

Sequence (S)	Tillage (T)			
	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Marketability (%)			
Br/Tm[y] (S2)	53.7	88.7	99.2	80.5
	10.9[z]	10.9	10.9	8.9
Br/Tm/Br (S3)	47.7	85.0	87.2	73.3
	12.2	12.2	12.2	9.6
$\bar{X}$	50.7	86.9	93.2	
	10.3	10.3	10.3	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0019	0.0005	0.5154	0.2745
	Average Marketable Head Size (g)			
Br/Tm (S2)	140.1	186.3	214.3	180.3
	36.8	34.7	34.7	28.4
Br/Tm/Br (S3)	189.5	258.7	201.4	216.6
	43.6	41.4	41.4	33.3
$\bar{X}$	164.8	222.5	207.9	
	31.8	30.3	30.3	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0691	0.1631	0.6067	0.3014

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-47. Mean marketability and average marketable head size of broccoli in 1990 by tillage and sequence combined over two locations.

Sequence (S)	Tillage (T) No-Till (T1)	 Conventional (cover) (T2)	 Conventional (no cover) (T3)	$\bar{X}$
	Marketability (%)			
Br/Tm[y] (S2)	76.0	99.8	99.9	91.9
	5.4[z]	5.4	5.4	4.1
Br/Tm/Br (S3)	93.2	96.9	97.8	95.9
	6.2	6.2	6.2	4.5
$\bar{X}$	84.6	98.4	98.8	
	5.0	5.0	5.0	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0210	0.0175	0.9273	0.2693
	Average Marketable Head Size (g)			
Br/Tm (S2)	152.0	273.3	326.6	250.6
	29.9	29.9	29.9	26.9
Br/Tm/Br (S3)	173.2	265.3	319.9	252.8
	32.3	32.3	32.3	28.8
$\bar{X}$	162.6	269.3	323.3	
	29.1	29.1	29.1	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0002	0.0001	0.0239	0.9062

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-48. Mean marketability and average marketable head size of broccoli at Greeneville, TN by tillage and sequence combined over 1989 and 1990.

Sequence (S)	Tillage (T)			
	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Marketability (%)			
Br/Tm[y] (S2)	73.3	97.3	99.6	90.0
	15.8[z]	15.8	15.8	14.5
Br/Tm/Br (S3)	58.0	88.0	89.6	78.5
	15.8	15.8	15.8	14.5
$\bar{X}$	65.6	92.6	94.6	
	15.0	15.0	15.0	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0064	0.0040	0.8159	0.0652
	Average Marketable Head Size (g)			
Br/Tm (S2)	197.9	280.7	328.3	268.9
	47.0	47.0	47.0	43.7
Br/Tm/Br (S3)	173.4	263.1	291.4	242.6
	47.4	47.0	47.0	43.7
$\bar{X}$	185.6	271.9	309.9	
	45.0	45.0	45.0	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0093	0.0007	0.1995	0.3042

[y]Tm=Tomato, Br=Broccoli. [z]Standard error appears below each mean.

Table B-49. Mean marketability and average marketable head size of broccoli at Greeneville, TN in 1989 by tillage and sequence.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Marketability (%)			
Br/Tm[y] (S2)	51.8	94.8	99.5	82.0
	11.8[z]	11.8	11.8	6.8
Br/Tm/Br (S3)	16.5	78.3	80.0	58.3
	11.8	11.8	11.8	6.8
$\bar{X}$	34.1	86.5	89.8	
	8.3	8.3	8.3	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0016	0.0011	0.7886	0.0354
	Average Marketable Head Size (g)			
Br/Tm (S2)	158.8	186.0	209.8	184.8
	21.0	21.0	21.0	12.1
Br/Tm/Br (S3)	98.3	140.6	123.6	120.8
	24.1	21.0	21.0	11.4
$\bar{X}$	128.5	163.3	166.7	
	17.0	15.9	15.9	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.1733	0.1394	0.8835	0.0043

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-50. Mean marketability and average marketable head size of broccoli at Greeneville, TN in 1990 by tillage and sequence.

Sequence (S)	Tillage (T) No-Till (T1)	 Conventional (cover) (T2)	 Conventional (no cover) (T3)	 $\bar{X}$
	Marketability (%)			
Br/Tm[y] (S2)	94.8	99.8	99.8	98.1
	2.1[z]	2.1	2.1	1.4
Br/Tm/Br (S3)	99.5	99.8	99.3	98.8
	2.1	2.1	2.1	1.4
	97.1	98.8	99.5	
$\bar{X}$	1.6	1.6	1.6	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.4414	0.2694	0.7187	0.6597
	Average Marketable Head Size (g)			
Br/Tm (S2)	237.1	375.4	446.3	353.0
	41.8	41.8	41.8	35.3
Br/Tm/Br (S3)	246.1	385.6	459.3	363.7
	41.8	41.8	41.8	35.3
	241.5	380.5	453.1	
$\bar{X}$	37.0	37.0	37.0	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0007	0.0001	0.0264	0.6470

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-51. Mean marketability and average marketable head size of broccoli at Knoxville, TN by tillage and sequence combined over 1989 and 1990.

Sequence (S)	Tillage (T) No-Till (T1)	 Conventional (cover) (T2)	 Conventional (no cover) (T3)	 $\bar{X}$
	Marketability (%)			
Br/Tm[y] (S2)	91.1	85.6	99.0	91.9
	4.7[z]	4.7	4.7	2.7
Br/Tm/Br (S3)	98.0	96.9	99.9	98.3
	4.7	4.7	4.7	2.7
	94.6	91.3	99.4	
$\bar{X}$	3.5	3.5	3.5	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.5106	0.3373	0.1174	0.0994
	Average Marketable Head Size (g)			
Br/Tm (S2)	149.1	157.6	192.2	166.3
	33.3	33.3	33.3	21.7
Br/Tm/Br (S3)	209.3	262.5	236.5	236.1
	33.3	33.3	33.3	21.7
	179.2	210.1	214.3	
$\bar{X}$	23.6	23.6	23.6	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.3352	0.2753	0.8927	0.0397

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-52. Mean marketability and average marketable head size of broccoli at Knoxville, TN in 1989 by tillage and sequence.

Sequence (S)	Tillage (T)			
	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Marketability (%)			
Br/Tm^y (S2)	99.8	71.3	98.0	89.7
	4.4^z	4.4	4.4	2.9
Br/Tm/Br (S3)	97.8	94.0	99.8	97.2
	4.4	4.4	4.4	2.9
$\bar{X}$	98.8	82.6	98.9	
	3.5	3.5	3.5	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0052	0.9780	0.0050	0.0343
	Average Marketable Head Size (g)			
Br/Tm (S2)	147.4	127.0	145.2	139.8
	55.0	55.0	55.0	31.8
Br/Tm/Br (S3)	256.3	359.5	262.0	292.6
	55.0	55.0	55.0	31.8
$\bar{X}$	201.9	243.3	203.6	
	38.9	38.9	38.9	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.4713	0.9760	0.4892	0.0079

^{y}Tm=Tomato, Br=Broccoli. ^{z}Standard error appears below each mean.

Table B-53. Mean marketability and average marketable head size of broccoli at Knoxville, TN in 1990 by tillage and sequence.

Sequence (S)	Tillage (T)			
	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Marketability (%)			
Br/Tm[y] (S2)	82.5	100.0	100.0	94.2
	7.1[z]	7.1	7.1	4.1
Br/Tm/Br (S3)	98.3	99.8	100.0	99.3
	7.1	7.1	7.1	4.1
$\bar{X}$	90.4	99.9	100.0	
	5.0	5.0	5.0	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.2105	0.2015	0.9862	0.3925
	Average Marketable Head Size (g)			
Br/Tm (S2)	150.8	188.2	239.3	192.8
	21.2	21.2	21.2	12.2
Br/Tm/Br (S3)	162.2	165.6	210.9	179.5
	21.2	21.2	21.2	12.2
$\bar{X}$	156.5	176.9	225.1	
	16.9	16.9	16.9	
Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.4150	0.0184	0.0744	0.3923

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-54. Mean marketability and average marketable head size of broccoli by tillage and sequence combined across years and locations.

Sequence (S)	Tillage (T)			
	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	X̄
	Marketability (%)			
Br/Tm[y] (S2)	64.8 9.5[z]	94.3 9.5	99.5 9.5	86.2 8.7
Br/Tm/Br (S3)	70.4 10.0	90.5 10.0	92.1 10.0	84.3 9.0
X̄	67.6 9.2	92.4 9.2	95.8 9.2	

Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0001	0.0001	0.5389	0.6215

Sequence (S)	T1	T2	T3	X̄
	Average Marketable Head Size (g)			
Br/Tm (S2)	143.7 33.3	229.8 32.9	270.5 32.9	214.6 30.4
Br/Tm/Br (S3)	181.9 36.4	263.7 35.9	264.7 35.9	236.7 32.6
X̄	162.6 32.0	246.8 31.6	267.6 31.6	

Contrast	T1 v T2	T1 v T3	T2 v T3	S2 v S3
Prob. > F	0.0001	0.0001	0.2741	0.2946

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-55. Mean head and stem circumference, total leaf N concentration, yield and value of broccoli at Crossville, TN by tillage and sequence combined over 1989 and 1990.

Sequence (S)	Tillage (T) No-Till (T1)	 Conventional (cover) (T2)	 Conventional (no cover) (T3)	$\bar{X}$
		Head Circumference (cm)		
Br/Tm[y] (S2)	16.30	41.71	44.07	
	1.98[z]	1.98	1.98	
Contrast	T1 v T2	T1 v T3	T2 v T3	
Prob. > F	0.0001	0.0001	0.1497	
		Stem Circumference (cm)		
Br/Tm (S2)	7.71	12.37	12.96	
	0.96	0.96	0.96	
Contrast	T1 v T2	T1 v T3	T2 v T3	
Prob. > F	0.0001	0.0001	0.3065	
		N (%)		
Br/Tm (S2)	0.75	1.61	2.28	
	0.43	0.43	0.43	
Contrast	T1 v T2	T1 v T3	T2 v T3	
Prob. > F	0.0045	0.0001	0.0180	
		Yield (10.43-kg boxes ha^{-1})		
Br/Tm (S2)	34.3	818.8	980.6	
	57.6	57.6	57.6	
Contrast	T1 v T2	T1 v T3	T2 v T3	
Prob. > F	0.0001	0.0001	0.0294	
		Value (\$ ha^{-1})		
Br/Tm (S2)	314	7509	8993	
	526	526	526	
Contrast	T1 v T2	T1 v T3	T2 v T3	
Prob. > F	0.0001	0.0001	0.0294	

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-56. Mean head and stem circumference, total leaf N concentration, yield and value of broccoli at Crossville, TN in 1989 by tillage and sequence.

Sequence (S)	Tillage (T) No-Till (T1)	 Conventional (cover) (T2)	 Conventional (no cover) (T3)	$\bar{X}$
		Head Circumference (cm)		
Br/Tm[y] (S2)	13.28 2.01[z]	41.08 2.01	42.43 2.01	
Contrast Prob. > F	T1 v T2 0.0001	T1 v T3 0.0001	T2 v T3 0.5441	
		Stem Circumference (cm)		
Br/Tm (S2)	7.06 0.92	11.06 0.92	12.21 0.92	
Contrast Prob. > F	T1 v T2 0.0073	T1 v T3 0.0022	T2 v T3 0.2962	
		N (%)		
Br/Tm (S2)	0.87 0.30	2.00 0.30	2.99 0.30	
Contrast Prob. > F	T1 v T2 0.0236	T1 v T3 0.0013	T2 v T3 0.0382	
		Yield (10.43-kg boxes ha^{-1})		
Br/Tm (S2)	7.6 104.5	812.6 104.5	952.5 104.5	
Contrast Prob. > F	T1 v T2 0.0005	T1 v T3 0.0002	T2 v T3 0.2842	
		Value ($ ha^{-1})		
Br/Tm (S2)	70 959	7451 959	8734 959	
Contrast Prob. > F	T1 v T2 0.0005	T1 v T3 0.0002	T2 v T3 0.2842	

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-57. Mean head and stem circumference, total leaf N concentration, yield and value of broccoli at Crossville, TN in 1990 by tillage and sequence.

Sequence (S)	Tillage (T) No-Till (T1)	 Conventional (cover) (T2)	 Conventional (no cover) (T3)	$\bar{X}$
	Head Circumference (cm)			
Br/Tm[y] (S2)	19.33 1.69[z]	42.35 1.69	45.71 1.69	
Contrast	T1 v T2	T1 v T3	T2 v T3	
Prob. > F	0.0001	0.0001	0.1759	
	Stem Circumference (cm)			
Br/Tm (S2)	8.36 0.37	13.69 0.37	13.72 0.37	
Contrast	T1 v T2	T1 v T3	T2 v T3	
Prob. > F	0.0001	0.0001	0.9616	
	N (%)			
Br/Tm (S2)	0.64 0.15	1.22 0.15	1.58 0.15	
Contrast	T1 v T2	T1 v T3	T2 v T3	
Prob. > F	0.0301	0.0037	0.1277	
	Yield (10.43-kg boxes ha^{-1})			
Br/Tm (S2)	60.8 64.5	825.2 64.5	1008.7 64.5	
Contrast	T1 v T2	T1 v T3	T2 v T3	
Prob. > F	0.0001	0.0001	0.0616	
	Value ($ ha^{-1})			
Br/Tm (S2)	558 590	7568 590	9250 590	
Contrast	T1 v T2	T1 v T3	T2 v T3	
Prob. > F	0.0001	0.0001	0.0616	

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-58. Mean marketability and average marketable head size of broccoli at Crossville, TN by tillage and sequence combined across 1989 and 1990.

Sequence (S)	Tillage (T) No-Till (T1)	 Conventional (cover) (T2)	 Conventional (no cover) (T3)	$\bar{X}$
		Marketability (%)		
Br/Tm[y] (S2)	30.1	99.9	100.0	
	8.8[z]	8.8	8.8	
Contrast	T1 v T2	T1 v T3	T2 v T3	
Prob. > F	0.0001	0.0001	0.9898	
		Average Marketable Head (g)		
Br/Tm (S2)	58.5	251.2	290.9	
	19.3	17.7	17.7	
Contrast	T1 v T2	T1 v T3	T2 v T3	
Prob. > F	0.0001	0.0001	0.0295	

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-59. Mean marketability and average marketable head size of broccoli at Crossville, TN in 1989 by tillage and sequence.

Sequence (S)	Tillage (T)			
	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Marketability (%)			
Br/Tm[y] (S2)	9.5	100.0	100.0	
	4.7[z]	4.7	4.7	
Contrast	T1 v T2	T1 v T3	T2 v T3	
Prob. > F	0.0001	0.0001	0.9999	
	Average Marketable Head (g)			
Br/Tm (S2)	40.0	246.1	288.0	
	40.9	34.5	34.5	
Contrast	T1 v T2	T1 v T3	T2 v T3	
Prob. > F	0.0038	0.0019	0.1829	

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-60. Mean marketability and average marketable head size of broccoli at Crossville, TN in 1990 by tillage and sequence.

Sequence (S)	Tillage (T)			
	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Marketability (%)			
Br/Tm[y] (S2)	50.8	99.8	100.0	
	10.9[z]	10.9	10.9	
Contrast	T1 v T2	T1 v T3	T2 v T3	
Prob. > F	0.0185	0.0181	0.9875	
	Average Marketable Head (g)			
Br/Tm (S2)	68.0	256.3	293.7	
	18.5	18.5	18.5	
Contrast	T1 v T2	T1 v T3	T2 v T3	
Prob. > F	0.0002	0.0001	0.1494	

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-61. Mean value of tomato-broccoli cropping systems by tillage and sequence combined over years and locations and combined over locations by year.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$		
	Over Years and Locations ($ ha^{-1})					
Tm/Br^y (S1)	28847	25140	27891	27294		
	4404^z	4404	4404	4214		
Br/Tm (S2)	16154	21069	21514	19580		
	4404	4404	4404	4214		
Br/Tm/Br (S3)	21254	28170	29435	26286		
	4404	4404	4404	4214		
$\bar{X}$	22084	24794	26281			
	4004	4004	4004			
Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0898	0.0097	0.3471	0.0078	0.7171	0.0183
	1989 Combined Over Locations ($ ha^{-1})					
Tm/Br (S1)	28642	28232	27941	28272		
	3016	3016	3016	2445		
Br/Tm (S2)	9490	8867	8922	9092		
	3016	3016	3016	2445		
Br/Tm/Br (S3)	23838	31233	29383	28151		
	3016	3016	3016	2445		
$\bar{X}$	20657	22776	22082			
	2374	2374	2374			
Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.3918	0.5633	0.7778	0.0001	0.9641	0.0001
	1990 Combined Over Locations ($ ha^{-1})					
Tm/Br (S1)	29052	22045	27844	26313		
	4960	4960	4960	4683		
Br/Tm (S2)	22820	33271	34106	30065		
	4960	4960	4960	4683		
Br/Tm/Br (S3)	18668	25110	29487	24421		
	4960	4960	4960	4683		
$\bar{X}$	23514	26809	30480			
	4668	4668	4668			
Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0666	0.0004	0.0425	0.0521	0.3149	0.0049

^{y}Tm=Tomato, Br=Broccoli. ^{z}Standard error appears below each mean.

Table B-62. Mean value of tomato-broccoli cropping systems by tillage and sequence at Greeneville, TN combined over years and for individual years.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Greeneville Combined Over Years ($ ha^{-1})			
Tm/Br[y] (S1)	32389	35299	35751	34479
	5002[z]	5002	5002	4710
Br/Tm (S2)	16045	22492	24374	20970
	5002	5002	5002	4710
Br/Tm/Br (S3)	20375	30280	31601	27419
	5002	5002	5002	4710
$\bar{X}$	22936	29358	30574	
	4029	4029	4029	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0025	0.0005	0.5341	0.0070	0.1398	0.1761

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Greeneville 1989 ($ ha^{-1})			
Tm/Br (S1)	29035	39345	38779	35719
	2477	2477	2477	1430
Br/Tm (S2)	3749	7847	8205	6602
	2477	2477	2477	1430
Br/Tm/Br (S3)	22961	33802	30045	28936
	2477	2477	2477	1430
$\bar{X}$	18582	26997	25676	
	1875	1875	1875	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0052	0.0154	0.6241	0.0001	0.0005	0.0001

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Greeneville 1990 ($ ha^{-1})			
Tm/Br (S1)	35743	31255	32720	33239
	3821	3821	3821	3194
Br/Tm (S2)	28338	37136	40540	35338
	3821	3821	3821	3194
Br/Tm/Br (S3)	17791	26758	33155	25900
	3821	3821	3821	3194
$\bar{X}$	27291	31717	35472	
	3339	3339	3339	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.0956	0.0044	0.1528	0.2732	0.0009	0.0001

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

Table B-63. Mean value of tomato-broccoli cropping systems by tillage and sequence at Knoxville, TN combined over years and for individual years.

Sequence (S)	Tillage (T) No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Knoxville Combined Over Years (\$ ha^{-1})			
Tm/Br[y] (S1)	25305	14978	20034	20106
	2566[z]	2566	2566	1857
Br/Tm (S2)	16265	19644	18656	18189
	2566	2566	2566	1857
Br/Tm/Br (S3)	22131	26063	27269	25154
	2566	2566	2566	1857
$\bar{X}$	21235	20227	21988	
	1697	1697	1697	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.6247	0.7143	0.3947	0.4345	0.0460	0.0075

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Knoxville 1989 (\$ ha^{-1})			
Tm/Br (S1)	28249	17120	17102	20825
	2450	2450	2450	1415
Br/Tm (S2)	15230	9885	9640	11584
	2450	2450	2450	1415
Br/Tm/Br (S3)	24717	28662	28724	27368
	2450	2450	2450	1415
$\bar{X}$	22734	18555	18488	
	1875	1875	1875	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.1323	0.1266	0.9801	0.0001	0.0006	0.0001

Sequence (S)	No-Till (T1)	Conventional (cover) (T2)	Conventional (no cover) (T3)	$\bar{X}$
	Knoxville 1990 (\$ ha^{-1})			
Tm/Br (S1)	22361	12837	22966	19387
	2653	2653	2653	1531
Br/Tm (S2)	17300	29403	27671	24791
	2653	2653	2653	1531
Br/Tm/Br (S3)	19545	23463	25816	22941
	2653	2653	2653	1531
$\bar{X}$	19735	21901	25485	
	1531	1531	1531	

Contrast	T1 v T2	T1 v T3	T2 v T3	S1 v S2	S1 v S3	S2 v S3
Prob. > F	0.3307	0.0161	0.1153	0.0225	0.1182	0.4042

[y] Tm=Tomato, Br=Broccoli. [z] Standard error appears below each mean.

APPENDIX C
GREENHOUSE DATA

Table C-1. Mean shoot fresh weight of greenhouse broccoli by experiment and treatment and combined across acids and concentrations.

		Experiment		
Acid	Conc.	1990	1991	Combined
		Shoot Fresh Weight (g)		
Ferulic	1000μM	17.50^{C*}	23.73^{A-B}	20.61^{C-D}
	100μM	19.50^{A-C}	25.98^{A-B}	22.74^{B-D}
	10μM	21.25^{A-C}	33.13^{A}	27.19^{A-B}
	1μM	19.00^{A-C}	30.70^{A}	24.85^{A-D}
Coumaric	1000μM	21.50^{A-C}	26.83^{A-B}	24.16^{A-D}
	100μM	22.75^{A-C}	28.45^{A-B}	25.60^{A-D}
	10μM	18.00^{C}	29.78^{A-B}	23.89^{A-D}
	1μM	21.75^{A-C}	30.43^{A}	26.09^{A-D}
Syringic	1000μM	23.25^{A-C}	26.23^{A-B}	24.74^{A-D}
	100μM	19.50^{A-C}	28.00^{A-B}	23.75^{A-D}
	10μM	20.75^{A-C}	30.83^{A}	25.79^{A-D}
	1μM	20.75^{A-C}	31.70^{A}	26.23^{A-D}
Vanillic	1000μM	23.25^{A-C}	28.33^{A-B}	25.79^{A-D}
	100μM	19.25^{A-C}	28.98^{A-B}	24.11^{A-D}
	10μM	22.00^{A-C}	31.58^{A}	26.79^{A-C}
	1μM	18.25^{C}	28.43^{A-B}	23.34^{B-C}
Benzoic	1000μM	20.75^{A-C}	19.38^{B}	20.06^{D}
	100μM	18.50^{B-C}	31.20^{A}	24.85^{A-D}
	10μM	23.50^{A-C}	32.25^{A}	27.88^{A-B}
	1μM	25.25^{A}	31.68^{A}	28.46^{A-B}
Check	0μM	22.58^{A-C}	31.54^{A}	27.06^{A-B}
Combined Across Conc.				
Ferulic		19.31^{A**}	28.39^{A}	23.85^{A}
Coumaric		21.00^{A-B}	28.88^{A}	24.94^{A}
Syringic		21.06^{A-B}	29.19^{A}	25.13^{A}
Vanillic		20.69^{A-B}	29.33^{A}	25.01^{A}
Benzoic		22.00^{B}	28.63^{A}	25.31^{A}
Combined Across Acids				
	1000μM	21.25^{A**}	24.90^{A}	23.08^{A}
	100μM	19.90^{A}	28.52^{B}	24.21^{A-B}
	10μM	21.10^{A}	31.51^{B}	26.31^{B}
	1μM	21.00^{A}	30.59^{B}	25.79^{B}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

Table C-2. Mean root fresh weight of greenhouse broccoli by experiment and treatment and combined across acids and concentrations.

Acid	Conc.	Experiment 1990	Experiment 1991	Experiment Combined
		Root Fresh Weight (g)		
Ferulic	1000μM	7.00^{A-B*}	11.58^{A-B}	9.29^{A-C}
	100μM	7.00^{A-B}	9.75^{B}	8.38^{B-C}
	10μM	7.25^{A-B}	13.75^{A-B}	10.50^{A-C}
	1μM	8.25^{A-B}	11.28^{A-B}	9.76^{A-C}
Coumaric	1000μM	8.00^{A-B}	13.55^{A-B}	10.78^{A-C}
	100μM	6.75^{A-B}	11.18^{A-B}	8.96^{B-C}
	10μM	6.75^{A-B}	9.53^{B}	8.14^{C}
	1μM	6.25^{B}	11.88^{A-B}	9.06^{B-C}
Syringic	1000μM	8.00^{A-B}	16.15^{A-B}	12.08^{A-C}
	100μM	9.00^{A-B}	17.23^{A}	13.11^{A}
	10μM	8.00^{A-B}	12.23^{A-B}	10.11^{A-C}
	1μM	8.00^{A-B}	12.93^{A-B}	10.46^{A-C}
Vanillic	1000μM	8.00^{A-B}	13.83^{A-B}	10.91^{A-C}
	100μM	7.50^{A-B}	13.23^{A-B}	10.36^{A-C}
	10μM	9.25^{A-B}	10.70^{A-B}	9.98^{A-C}
	1μM	6.50^{B}	11.60^{A-B}	9.05^{B-C}
Benzoic	1000μM	9.25^{A-B}	11.30^{A-B}	10.28^{A-C}
	100μM	8.50^{A-B}	11.98^{A-B}	10.24^{A-C}
	10μM	8.25^{A-B}	16.35^{A-B}	12.30^{A-B}
	1μM	10.00^{A}	12.73^{A-B}	11.36^{A-C}
Check	0μM	8.33^{A-B}	11.93^{A-B}	10.13^{A-C}
Combined Across Conc.				
Ferulic		7.38^{A**}	11.59^{A}	9.48^{B-C}
Coumaric		6.94^{A}	11.54^{A}	9.24^{C}
Syringic		8.25^{A-B}	14.64^{B}	11.44^{A}
Vanillic		7.81^{A-B}	12.34^{A-B}	10.08^{A-C}
Benzoic		9.00^{B}	13.09^{A-B}	11.05^{A-B}
Combined Across Acids				
	1000μM	8.05^{A**}	13.28^{A}	10.67^{A}
	100μM	7.75^{A}	12.67^{A}	10.21^{A}
	10μM	7.90^{A}	12.51^{A}	10.21^{A}
	1μM	7.80^{A}	12.08^{A}	9.94^{A}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

Table C-3. Mean shoot dry weight of greenhouse broccoli by experiment and treatment and combined across acids and concentrations.

		Experiment		
Acid	Conc.	1990	1991	Combined
		Shoot Dry Weight (g)		
Ferulic	1000μM	5.10^{A-C*}	7.14^{E-D}	6.12^{E-F}
	100μM	5.40^{A-C}	9.05^{A-E}	7.22^{A-F}
	10μM	6.53^{A-C}	11.19^{A-B}	8.86^{A-B}
	1μM	6.10^{A-C}	10.31^{A-D}	8.20^{A-E}
Coumaric	1000μM	4.00^{C}	7.79^{C-E}	5.90^{F}
	100μM	5.94^{A-C}	9.04^{A-E}	7.49^{A-F}
	10μM	5.05^{A-C}	9.75^{A-D}	7.40^{A-F}
	1μM	6.08^{A-C}	11.33^{A-B}	8.70^{A-C}
Syringic	1000μM	4.56^{B-C}	8.61^{A-E}	6.58^{C-F}
	100μM	5.99^{A-C}	9.12^{A-E}	7.56^{A-F}
	10μM	4.75^{A-C}	10.95^{A-C}	7.85^{A-F}
	1μM	6.57^{A-C}	11.11^{A-C}	8.84^{A-B}
Vanillic	1000μM	6.06^{A-C}	8.02^{B-E}	7.04^{B-F}
	100μM	5.40^{A-C}	9.68^{A-E}	7.54^{A-F}
	10μM	4.87^{A-C}	10.08^{A-D}	7.48^{A-F}
	1μM	4.92^{A-C}	10.32^{A-D}	7.62^{A-F}
Benzoic	1000μM	6.36^{A-C}	6.43^{E}	6.40^{D-F}
	100μM	5.16^{A-C}	9.76^{A-D}	7.46^{A-F}
	10μM	6.28^{A-C}	10.25^{A-D}	8.27^{A-E}
	1μM	7.36^{A}	9.39^{A-E}	8.37^{A-D}
Check	0μM	6.52^{A-C}	10.14^{A-D}	8.33^{A-D}
Combined Across Conc.				
Ferulic		5.78^{A-B**}	9.42^{A}	7.60^{A}
Coumaric		5.27^{B}	9.48^{A}	7.37^{A}
Syringic		5.47^{A-B}	9.95^{A}	7.71^{A}
Vanillic		5.31^{B}	9.53^{A}	7.42^{A}
Benzoic		6.29^{A}	8.96^{A}	7.63^{A}
Combined Across Acids				
	1000μM	5.22^{A**}	7.60^{A}	6.41^{A}
	100μM	5.58^{A}	9.33^{B}	7.45^{A-B}
	10μM	5.50^{A}	10.44^{B}	7.97^{B}
	1μM	6.21^{A}	10.49^{B}	8.35^{B}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

Table C-4. Mean root dry weight of greenhouse broccoli by experiment and treatment and combined across acids and concentrations.

		Experiment		
Acid	Conc.	1990	1991	Combined
		Root Dry Weight (g)		
Ferulic	1000μM	3.93^{A*}	5.87^{A-B}	4.90^{A-B}
	100μM	4.14^{A}	5.02^{B}	4.58^{B}
	10μM	3.97^{A}	6.73^{A-B}	5.35^{A-B}
	1μM	4.06^{A}	5.47^{A-B}	4.76^{B}
Coumaric	1000μM	3.22^{A}	6.67^{A-B}	4.94^{A-B}
	100μM	3.72^{A}	5.57^{A-B}	4.65^{B}
	10μM	3.82^{A}	4.73^{B}	4.27^{B}
	1μM	3.78^{A}	5.23^{B}	4.51^{B}
Syringic	1000μM	3.12^{A}	6.74^{A-B}	4.93^{A-B}
	100μM	5.01^{A}	9.21^{A}	7.11^{A}
	10μM	3.69^{A}	6.68^{A-B}	5.19^{A-B}
	1μM	4.09^{A}	6.70^{A-B}	5.39^{A-B}
Vanillic	1000μM	4.71^{A}	5.63^{A-B}	5.17^{A-B}
	100μM	4.16^{A}	6.66^{A-B}	5.41^{A-B}
	10μM	4.34^{A}	5.72^{A-B}	5.03^{A-B}
	1μM	3.55^{A}	5.93^{A-B}	4.74^{B}
Benzoic	1000μM	4.89^{A}	4.97^{B}	4.93^{A-B}
	100μM	5.26^{A}	6.07^{A-B}	5.67^{A-B}
	10μM	4.78^{A}	7.28^{A-B}	6.03^{A-B}
	1μM	5.75^{A}	6.11^{A-B}	5.93^{A-B}
Check	0μM	4.68^{A}	6.36^{A-B}	5.52^{A-B}
Combined Across Conc.				
Ferulic		4.03^{A-B**}	5.77^{A}	4.90^{A-B}
Coumaric		3.64^{B}	5.55^{A}	4.59^{B}
Syringic		3.98^{B}	7.33^{B}	5.66^{A}
Vanillic		4.19^{A-B}	5.99^{A-B}	5.09^{A-B}
Benzoic		5.17^{A}	6.11^{A-B}	5.64^{A}
Combined Across Acids				
	1000μM	3.97^{A**}	5.98^{A}	4.97^{A}
	100μM	4.46^{A}	6.51^{A}	5.48^{A}
	10μM	4.12^{A}	6.23^{A}	5.17^{A}
	1μM	4.25^{A}	5.89^{A}	5.07^{A}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

Table C-5. Mean fresh shoot to root ratio of greenhouse broccoli by experiment and treatment and combined across acids and concentrations.

		Experiment		
Acid	Conc.	1990	1991	Combined
		Fresh Shoot to Root Ratio		
Ferulic	1000μM	2.50^{C*}	3.38^{A-C}	2.94^{A}
	100μM	2.83^{A-C}	2.86^{A-C}	2.85^{A}
	10μM	2.96^{A-C}	2.98^{A-C}	2.97^{A}
	1μM	2.45^{C}	2.98^{A-C}	2.72^{A}
Coumaric	1000μM	2.72^{B-C}	3.49^{A}	3.10^{A}
	100μM	3.40^{A-B}	3.15^{A-C}	3.27^{A}
	10μM	2.71^{B-C}	3.05^{A-C}	2.88^{A}
	1μM	3.62^{A}	2.69^{C}	3.16^{A}
Syringic	1000μM	2.98^{A-C}	3.07^{A-C}	3.02^{A}
	100μM	2.39^{C}	3.06^{A-C}	2.73^{A}
	10μM	2.66^{B-C}	2.83^{A-C}	2.74^{A}
	1μM	2.58^{B-C}	2.89^{A-C}	2.73^{A}
Vanillic	1000μM	3.01^{A-C}	3.48^{A-B}	3.24^{A}
	100μM	2.63^{B-C}	2.99^{A-C}	2.81^{A}
	10μM	2.45^{C}	3.11^{A-C}	2.78^{A}
	1μM	2.85^{A-C}	2.74^{B-C}	2.79^{A}
Benzoic	1000μM	2.42^{C}	3.24^{A-C}	2.83^{A}
	100μM	2.25^{C}	3.21^{A-C}	2.73^{A}
	10μM	2.99^{A-C}	3.17^{A-C}	3.08^{A}
	1μM	2.68^{B-C}	3.29^{A-C}	2.98^{A}
Check	0μM	2.80^{B-C}	3.14^{A-C}	2.97^{A}
Combined Across Conc.				
Ferulic		2.69^{A**}	3.05^{A}	2.87^{A}
Coumaric		3.11^{B}	3.10^{A}	3.10^{B}
Syringic		2.65^{A}	2.96^{A}	2.81^{A}
Vanillic		2.74^{A}	3.08^{A}	2.91^{A-B}
Benzoic		2.59^{A}	3.23^{A}	2.91^{A-B}
Combined Across Acids				
	1000μM	2.73^{A**}	3.33^{A}	3.03^{A}
	100μM	2.70^{A}	3.05^{B}	2.88^{A}
	10μM	2.75^{A}	3.03^{B}	2.89^{A}
	1μM	2.84^{A}	2.92^{B}	2.88^{A}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

Table C-6. Mean dry shoot to root ratio of greenhouse broccoli by experiment and treatment and combined across acids and concentrations.

		Experiment		
Acid	Conc.	1990	1991	Combined
		Dry Shoot to Root Ratio		
Ferulic	1000μM	1.35^{A-B*}	1.33^{B-C}	1.34^{B-C}
	100μM	1.35^{A-B}	1.82^{A-C}	1.59^{A-C}
	10μM	1.67^{A}	1.71^{A-C}	1.69^{A-B}
	1μM	1.57^{A-B}	1.91^{A-B}	1.74^{A-B}
Coumaric	1000μM	1.26^{A-B}	1.17^{C}	1.21^{C}
	100μM	1.61^{A-B}	1.77^{A-C}	1.69^{A-B}
	10μM	1.35^{A-B}	2.06^{A}	1.71^{A-B}
	1μM	1.62^{A}	2.20^{A}	1.91^{A}
Syringic	1000μM	1.45^{A-B}	1.32^{B-C}	1.38^{B-C}
	100μM	1.31^{A-B}	1.53^{A-C}	1.42^{B-C}
	10μM	1.31^{A-B}	1.71^{A-C}	1.54^{A-C}
	1μM	1.64^{A}	1.64^{A-C}	1.64^{A-C}
Vanillic	1000μM	1.31^{A-B}	1.51^{A-C}	1.41^{B-C}
	100μM	1.34^{A-B}	1.52^{A-C}	1.43^{B-C}
	10μM	1.88^{A-B}	1.77^{A-C}	1.52^{A-C}
	1μM	1.34^{A-B}	1.79^{A-C}	1.57^{A-C}
Benzoic	1000μM	1.53^{A-B}	1.31^{B-C}	1.42^{B-C}
	100μM	1.03^{A}	1.81^{A-C}	1.42^{B-C}
	10μM	1.37^{A-B}	1.60^{A-C}	1.48^{A-C}
	1μM	1.49^{A-B}	1.59^{A-C}	1.54^{A-C}
Check	0μM	1.43^{A-B}	1.64^{A-C}	1.54^{A-C}
Combined Across Conc.				
Ferulic		1.49^{A**}	1.69^{A}	1.59^{A}
Coumaric		1.46^{A}	1.80^{A}	1.63^{A}
Syringic		1.43^{A}	1.55^{A}	1.50^{A}
Vanillic		1.47^{A}	1.65^{A}	1.48^{A}
Benzoic		1.36^{A}	1.58^{A}	1.47^{A}
Combined Across Acids				
	1000μM	1.38^{A-B**}	1.33^{A}	1.35^{A}
	100μM	1.33^{B}	1.69^{B}	1.51^{A-B}
	10μM	1.52^{A-B}	1.77^{B}	1.59^{B-C}
	1μM	1.53^{A}	1.83^{B}	1.68^{C}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

Table C-7. Mean leaf nitrogen content of greenhouse broccoli by experiment and treatment and combined across acids and concentrations.

		Experiment		
Acid	Conc.	1990	1991	Combined
		Nitrogen (%)		
Ferulic	1000μM	0.90^{A-B}*	0.78^{A}	0.84^{A-B}
	100μM	0.95^{A-B}	0.82^{A}	0.88^{A-B}
	10μM	0.99^{A-B}	0.78^{A}	0.88^{A-B}
	1μM	0.99^{A-B}	0.74^{A}	0.85^{A-B}
Coumaric	1000μM	0.96^{A-B}	0.72^{A}	0.82^{A-B}
	100μM	0.90^{A-B}	0.76^{A}	0.83^{A-B}
	10μM	1.03^{A-B}	0.94^{A}	0.98^{A-B}
	1μM	0.90^{A-B}	0.69^{A}	0.79^{B}
Syringic	1000μM	0.97^{A-B}	0.95^{A}	0.96^{A-B}
	100μM	0.83^{B}	0.77^{A}	0.79^{B}
	10μM	0.98^{A-B}	0.91^{A}	0.94^{A-B}
	1μM	0.88^{A-B}	0.71^{A}	0.79^{B}
Vanillic	1000μM	0.78^{B}	0.83^{A}	0.80^{B}
	100μM	1.02^{A-B}	0.76^{A}	0.89^{A-B}
	10μM	0.80^{A}	0.91^{A}	0.86^{A-B}
	1μM	1.19^{A}	0.85^{A}	1.02^{A}
Benzoic	1000μM	0.82^{A}	0.74^{A}	0.78^{B}
	100μM	0.95^{A-B}	0.80^{A}	0.87^{A-B}
	10μM	0.94^{A-B}	0.83^{A}	0.88^{A-B}
	1μM	1.01^{A-B}	0.88^{A}	0.94^{A-B}
Check	0μM	0.91^{A-B}	0.74^{A}	0.82^{A-B}
Combined Across Conc.				
Ferulic		0.96^{A}**	0.78^{A}	0.86^{A}
Coumaric		0.95^{A}	0.78^{A}	0.86^{A}
Syringic		0.92^{A}	0.84^{A}	0.87^{A}
Vanillic		0.95^{A}	0.84^{A}	0.89^{A}
Benzoic		0.93^{A}	0.81^{A}	0.87^{A}
Combined Across Acids				
	1000μM	0.89^{A}**	0.80^{A}	0.84^{A}
	100μM	0.93^{A}	0.78^{A}	0.85^{A}
	10μM	0.95^{A}	0.87^{A}	0.91^{A}
	1μM	0.99^{A}	0.77^{A}	0.88^{A}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

Table C-8. Mean plant height at harvest of greenhouse broccoli by experiment and treatment and combined across acids and concentrations.

		Experiment		
Acid	Conc.	1990	1991	Combined
		Plant Height (cm)		
Ferulic	1000μM	22.5^{A-C*}	19.3^{A-B}	20.9^{A-B}
	100μM	23.0^{A-C}	21.0^{A-B}	22.0^{A}
	10μM	23.0^{A-C}	21.8^{A}	22.4^{A}
	1μM	21.6^{A-C}	22.0^{A}	21.8^{A-B}
Coumaric	1000μM	24.1^{A}	19.8^{A-B}	21.9^{A}
	100μM	21.5^{A-C}	20.0^{A-B}	20.8^{A-B}
	10μM	22.9^{A-C}	22.3^{A}	22.6^{A}
	1μM	21.9^{A-C}	22.5^{A}	22.2^{A}
Syringic	1000μM	22.3^{A-C}	19.8^{A-B}	21.0^{A-B}
	100μM	21.5^{A-C}	20.0^{A-B}	20.8^{A-B}
	10μM	21.6^{A-C}	22.8^{A}	22.2^{A}
	1μM	21.3^{B-C}	22.0^{A}	21.6^{A-B}
Vanillic	1000μM	21.8^{A-C}	20.0^{A-B}	20.9^{A-B}
	100μM	22.8^{A-C}	20.5^{A-B}	21.6^{A-B}
	10μM	21.9^{A-C}	20.8^{A-B}	21.3^{A-B}
	1μM	20.9^{C}	21.5^{A-B}	21.2^{A-B}
Benzoic	1000μM	21.3^{B-C}	18.0^{B}	19.6^{B}
	100μM	22.3^{A-C}	22.5^{A}	22.4^{A}
	10μM	22.9^{A-C}	22.3^{A}	22.6^{A}
	1μM	22.9^{A-C}	20.3^{A-B}	21.6^{A-B}
Check	0μM	23.3^{A-C}	21.7^{A}	22.5^{A}
Combined Across Conc.				
Ferulic		22.5^{A**}	21.0^{A}	21.8^{A}
Coumaric		22.6^{A}	21.2^{A}	21.9^{A}
Syringic		21.7^{A}	21.2^{A}	21.4^{A}
Vanillic		21.9^{A}	20.7^{A}	21.3^{A}
Benzoic		22.4^{A}	20.8^{A}	21.6^{A}
Combined Across Acids				
	1000μM	22.4^{A**}	19.4^{A}	20.9^{A}
	100μM	22.2^{A}	20.8^{B}	21.5^{A-B}
	10μM	22.5^{A}	22.0^{B}	22.2^{B}
	1μM	21.7^{A}	21.7^{B}	21.7^{B}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

Table C-9. Mean leaf number at harvest of greenhouse broccoli by experiment and treatment and combined across acids and concentrations.

Acid	Conc.	Experiment		
		1990	1991	Combined
		Leaf Number		
Ferulic	1000μM	10.5^{A*}	11.5^{E-F}	11.0^{D-E}
	100μM	11.0^{A}	13.3^{A-E}	12.1^{A-D}
	10μM	11.3^{A}	13.8^{A-C}	12.5^{A-B}
	1μM	10.8^{A}	13.0^{A-E}	11.9^{A-D}
Coumaric	1000μM	11.3^{A}	12.0^{C-E}	11.6^{B-E}
	100μM	11.0^{A}	13.3^{A-E}	12.1^{A-D}
	10μM	11.0^{A}	14.0^{A-B}	12.5^{A-B}
	1μM	11.3^{A}	12.8^{A-E}	12.0^{A-D}
Syringic	1000μM	10.8^{A}	11.5^{E-F}	11.1^{C-E}
	100μM	10.8^{A}	13.0^{A-E}	11.9^{A-D}
	10μM	11.3^{A}	13.0^{A-E}	12.1^{A-D}
	1μM	11.8^{A}	13.3^{A-E}	12.5^{A-B}
Vanillic	1000μM	10.8^{A}	12.3^{B-E}	11.5^{B-E}
	100μM	11.3^{A}	13.0^{A-E}	12.1^{A-D}
	10μM	11.5^{A}	13.3^{A-E}	12.4^{A-C}
	1μM	11.3^{A}	12.8^{A-E}	12.0^{A-D}
Benzoic	1000μM	10.8^{A}	10.3^{F}	10.5^{E}
	100μM	10.5^{A}	11.8^{D-F}	11.1^{C-E}
	10μM	11.5^{A}	13.5^{A-D}	12.5^{A-B}
	1μM	11.5^{A}	13.3^{A-E}	12.4^{A-C}
Check	0μM	11.6^{A}	13.5^{A-D}	12.5^{A-B}
Combined Across Conc.				
Ferulic		10.9^{A**}	12.9^{A-B}	11.9^{A}
Coumaric		11.2^{A}	13.0^{B}	12.1^{A}
Syringic		11.2^{A}	12.7^{A-B}	11.9^{A}
Vanillic		11.2^{A}	12.9^{A-B}	12.0^{A}
Benzoic		11.1^{A}	12.2^{A}	11.6^{A}
Combined Across Acids				
	1000μM	10.8^{A**}	11.5^{A}	11.1^{A}
	100μM	10.9^{A}	12.9^{B}	11.9^{B}
	10μM	11.3^{A}	13.5^{C}	12.4^{C}
	1μM	11.3^{A}	13.0^{B-C}	12.2^{B-C}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

Table C-10. Mean stem diameter at harvest of greenhouse broccoli by experiment and treatment and combined across acids and concentrations.

		Experiment		
Acid	Conc.	1990	1991	Combined
		Stem Diameter (mm)		
Ferulic	1000μM	5.40^{B-D*}	5.88^{B}	5.64^{B}
	100μM	5.53^{A-D}	6.13^{B}	5.83^{B}
	10μM	6.08^{A-D}	6.65^{B}	6.36^{B}
	1μM	6.24^{A-C}	6.48^{B}	6.36^{B}
Coumaric	1000μM	5.38^{B-D}	5.95^{B}	5.66^{B}
	100μM	6.45^{A-B}	6.18^{B}	6.31^{B}
	10μM	5.86^{A-D}	6.45^{B}	6.16^{B}
	1μM	6.49^{A}	6.68^{B}	6.58^{A-B}
Syringic	1000μM	6.21^{A-D}	6.00^{B}	6.11^{B}
	100μM	5.69^{A-D}	6.35^{B}	6.02^{B}
	10μM	6.13^{A-D}	6.50^{B}	6.31^{B}
	1μM	6.49^{A}	6.73^{B}	6.61^{A-B}
Vanillic	1000μM	5.93^{A-D}	6.05^{B}	5.99^{B}
	100μM	6.09^{A-D}	6.45^{B}	6.27^{B}
	10μM	6.15^{A-D}	6.50^{B}	6.33^{B}
	1μM	5.35^{C-D}	6.45^{B}	5.90^{B}
Benzoic	1000μM	6.11^{A-D}	4.93^{B}	5.52^{B}
	100μM	5.15^{D}	6.60^{B}	5.88^{B}
	10μM	6.45^{A-B}	6.48^{B}	6.46^{B}
	1μM	6.49^{A}	8.80^{A}	7.64^{A-B}
Check	0μM	6.08^{A-D}	6.43^{B}	6.26^{B}
Combined Across Conc.				
Ferulic		5.81^{A**}	6.29^{A}	6.05^{A}
Coumaric		6.05^{A}	6.32^{A}	6.18^{A}
Syringic		6.13^{A}	6.40^{A}	6.26^{A}
Vanillic		5.88^{A}	6.36^{A}	6.12^{A}
Benzoic		6.05^{A}	6.70^{A}	6.38^{A}
Combined Across Acids				
	1000μM	5.81^{A-B**}	5.76^{A}	5.78^{A}
	100μM	5.78^{B}	6.34^{A-B}	6.06^{A-B}
	10μM	6.13^{A-B}	6.52^{A-B}	6.32^{B-C}
	1μM	6.21^{A}	7.03^{B}	6.62^{C}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

Table C-11. Mean growth in plant height over time of greenhouse broccoli by experiment and treatment and combined across acids and concentrations.

		Experiment		
Acid	Conc.	1990	1991	Combined
		Plant Height Growth Per Day		
Ferulic	1000μM	0.103^{B-C*}	0.155^{B}	0.129^{C}
	100μM	0.156^{A-C}	0.294^{A}	0.225^{A}
	10μM	0.129^{A-C}	0.182^{B}	0.156^{B-C}
	1μM	0.153^{A-C}	0.179^{B}	0.166^{A-C}
Coumaric	1000μM	0.148^{A-C}	0.166^{B}	0.157^{B-C}
	100μM	0.107^{B-C}	0.163^{B}	0.135^{C}
	10μM	0.140^{A-C}	0.206^{A-B}	0.173^{A-C}
	1μM	0.139^{A-C}	0.202^{A-B}	0.170^{A-C}
Syringic	1000μM	0.149^{A-C}	0.160^{B}	0.155^{B-C}
	100μM	0.124^{A-C}	0.143^{B}	0.134^{C}
	10μM	0.154^{A-C}	0.207^{A-B}	0.181^{A-C}
	1μM	0.085^{C}	0.206^{A-B}	0.145^{B-C}
Vanillic	1000μM	0.123^{A-C}	0.162^{B}	0.143^{B-C}
	100μM	0.083^{C}	0.160^{B}	0.122^{C}
	10μM	0.145^{A-C}	0.166^{B}	0.156^{B-C}
	1μM	0.126^{A-C}	0.177^{B}	0.152^{B-C}
Benzoic	1000μM	0.114^{B-C}	0.146^{B}	0.130^{C}
	100μM	0.206^{A}	0.202^{A-B}	0.204^{A-B}
	10μM	0.120^{B-C}	0.180^{B}	0.150^{B-C}
	1μM	0.128^{A-C}	0.174^{B}	0.151^{B-C}
Check	0μM	0.156^{A-C}	0.189^{B}	0.173^{A-C}
Combined Across Conc.				
Ferulic		0.14^{A**}	0.20^{A}	0.17^{A}
Coumaric		0.13^{A}	0.18^{A}	0.16^{A}
Syringic		0.13^{A}	0.18^{A}	0.15^{A}
Vanillic		0.12^{A}	0.17^{A}	0.14^{A}
Benzoic		0.14^{A}	0.18^{A}	0.16^{A}
Combined Across Acids				
	1000μM	0.13^{A**}	0.16^{A}	0.14^{A}
	100μM	0.14^{A}	0.19^{A}	0.16^{A}
	10μM	0.14^{A}	0.19^{A}	0.16^{A}
	1μM	0.13^{A}	0.19^{A}	0.16^{A}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

Table C-12. Mean growth in leaf number over time of greenhouse broccoli by experiment and treatment and combined across acids and concentrations.

		Experiment		
Acid	Conc.	1990	1991	Combined
		Leaf Number Growth Per Day		
Ferulic	1000μM	0.11^{A*}	0.10^{A-B}	0.10^{A-B}
	100μM	0.10^{A}	0.11^{A}	0.10^{A-B}
	10μM	0.12^{A}	0.11^{A}	0.12^{A-B}
	1μM	0.12^{A}	0.10^{A-B}	0.11^{A-B}
Coumaric	1000μM	0.12^{A}	0.11^{A}	0.12^{A-B}
	100μM	0.11^{A}	0.10^{A-B}	0.11^{A-B}
	10μM	0.12^{A}	0.11^{A}	0.12^{A-B}
	1μM	0.13^{A}	0.10^{A-B}	0.11^{A-B}
Syringic	1000μM	0.11^{A}	0.09^{A-B}	0.09^{B}
	100μM	0.11^{A}	0.09^{A-B}	0.10^{A-B}
	10μM	0.12^{A}	0.10^{A-B}	0.11^{A-B}
	1μM	0.13^{A}	0.11^{A}	0.12^{A-B}
Vanillic	1000μM	0.10^{A}	0.10^{A-B}	0.10^{A-B}
	100μM	0.14^{A}	0.10^{A-B}	0.12^{A-B}
	10μM	0.12^{A}	0.10^{A-B}	0.11^{A-B}
	1μM	0.12^{A}	0.10^{A-B}	0.11^{A-B}
Benzoic	1000μM	0.12^{A}	0.08^{B}	0.09^{B}
	100μM	0.10^{A}	0.09^{A-B}	0.09^{B}
	10μM	0.14^{A}	0.10^{A-B}	0.12^{A-B}
	1μM	0.14^{A}	0.11^{A}	0.12^{A-B}
Check	0μM	0.13^{A}	0.11^{A}	0.12^{A-B}
Combined Across Conc.				
Ferulic		0.11^{A**}	0.11^{A-B}	0.11^{A}
Coumaric		0.12^{A}	0.12^{A}	0.12^{A}
Syringic		0.12^{A}	0.11^{A-B}	0.11^{A}
Vanillic		0.12^{A}	0.11^{A-B}	0.11^{A}
Benzoic		0.13^{A}	0.10^{B}	0.11^{A}
Combined Across Acids				
	1000μM	0.11^{A**}	0.11^{A}	0.10^{A}
	100μM	0.11^{A}	0.10^{A-B}	0.10^{A}
	10μM	0.12^{A}	0.09^{B}	0.12^{A}
	1μM	0.13^{A}	0.10^{A-B}	0.11^{A}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

Table C-13. Mean growth in stem diameter over time of greenhouse broccoli by experiment and treatment and combined across acids and concentrations.

		Experiment		
Acid	Conc.	1990	1991	Combined
		Stem Diameter Growth Per Day		
Ferulic	1000μM	-0.050^{A-B*}	0.067^{B}	0.008^{B-C}
	100μM	-0.058^{B}	0.071^{B}	0.007^{B-C}
	10μM	-0.059^{B}	0.079^{B}	0.010^{B-C}
	1μM	-0.023^{A-B}	0.070^{B}	0.023^{A-C}
Coumaric	1000μM	-0.050^{A-B}	0.069^{B}	0.010^{B-C}
	100μM	-0.054^{A-B}	0.069^{B}	0.008^{B-C}
	10μM	-0.034^{A-B}	0.077^{B}	0.022^{A-C}
	1μM	-0.016^{A}	0.079^{B}	0.032^{A-B}
Syringic	1000μM	-0.031^{A-B}	0.066^{B}	0.018^{A-C}
	100μM	-0.025^{A-B}	0.072^{B}	0.023^{A-C}
	10μM	-0.041^{A-B}	0.073^{B}	0.016^{A-C}
	1μM	-0.042^{A-B}	0.078^{B}	0.018^{A-C}
Vanillic	1000μM	-0.051^{A-B}	0.068^{B}	0.009^{B-C}
	100μM	-0.026^{A-B}	0.074^{B}	0.024^{A-C}
	10μM	-0.049^{A-B}	0.075^{B}	0.013^{A-C}
	1μM	-0.047^{A-B}	0.070^{B}	0.012^{B-C}
Benzoic	1000μM	-0.048^{A-B}	0.047^{B}	-0.007^{C}
	100μM	-0.055^{A-B}	0.080^{B}	0.012^{A-C}
	10μM	-0.035^{A-B}	0.075^{B}	0.020^{A-C}
	1μM	-0.035^{A-B}	0.110^{A}	0.037^{A}
Check	0μM	-0.037^{A-B}	0.073^{B}	0.018^{A-C}
Combined Across Conc.				
Ferulic		-0.05^{A**}	0.07^{A}	0.01^{A}
Coumaric		-0.04^{A}	0.07^{A}	0.02^{A}
Syringic		-0.03^{A}	0.07^{A}	0.02^{A}
Vanillic		-0.04^{A}	0.07^{A}	0.01^{A}
Benzoic		-0.04^{A}	0.08^{A}	0.02^{A}
Combined Across Acids				
	1000μM	-0.05^{A**}	0.06^{A}	0.01^{A}
	100μM	-0.04^{A}	0.07^{A-B}	0.01^{A}
	10μM	-0.04^{A}	0.08^{B}	0.02^{A-B}
	1μM	-0.03^{A}	0.08^{B}	0.02^{B}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

Table C-14. Mean shoot fresh weight of greenhouse tomatoes by experiment and treatment and combined across acids and concentrations.

Acid	Conc.	Experiment		
		1990	1991	Combined
		Shoot Fresh Weight (g)		
Ferulic	1000μM	46.30^{A-D*}	30.60^{B-F}	38.45^{B-D}
	100μM	52.75^{A-B}	31.58^{B-F}	42.16^{A-C}
	10μM	43.95^{A-D}	35.20^{A-F}	39.58^{B-C}
	1μM	46.55^{A-D}	27.70^{E-F}	37.13^{B-D}
Coumaric	1000μM	47.75^{A-D}	37.28^{A-D}	42.51^{A-C}
	100μM	47.25^{A-D}	34.48^{A-F}	40.86^{B-C}
	10μM	36.90^{C-D}	30.50^{B-F}	33.70^{C-D}
	1μM	43.80^{A-D}	32.13^{B-F}	37.96^{B-D}
Syringic	1000μM	41.83^{A-D}	31.25^{B-F}	36.54^{B-D}
	100μM	41.55^{A-D}	38.30^{A-D}	39.93^{B-C}
	10μM	44.30^{A-D}	31.70^{B-F}	38.00^{B-D}
	1μM	38.20^{B-D}	30.60^{B-F}	34.40^{C-D}
Vanillic	1000μM	52.85^{A-B}	36.75^{A-E}	44.80^{A-B}
	100μM	41.03^{B-D}	39.18^{A-C}	40.10^{B-C}
	10μM	34.18^{D}	26.95^{F}	30.56^{D}
	1μM	45.18^{A-D}	39.60^{A-B}	42.39^{A-C}
Benzoic	1000μM	56.50^{A}	42.68^{A}	49.59^{A}
	100μM	40.68^{B-D}	31.78^{B-F}	36.23^{B-D}
	10μM	50.33^{A-C}	29.95^{C-F}	40.14^{B-C}
	1μM	42.25^{A-D}	29.13^{D-F}	35.69^{C-D}
Check	0μM	44.70^{A-D}	34.94^{A-F}	39.82^{B-C}
Combined Across Conc.				
Ferulic		47.39^{A**}	31.27^{A}	39.33^{A}
Coumaric		43.93^{A-B}	33.60^{A-B}	38.76^{A}
Syringic		41.47^{B}	32.96^{A-B}	37.22^{A}
Vanillic		43.31^{A-B}	35.62^{B}	39.46^{A}
Benzoic		47.44^{A}	33.39^{A-B}	40.41^{A}
Combined Across Acids				
	1000μM	49.05^{A**}	35.71^{A}	42.38^{A}
	100μM	44.65^{A-B}	35.06^{A-B}	39.86^{A-B}
	10μM	41.93^{B}	30.86^{C}	36.40^{C}
	1μM	43.20^{B}	31.83^{B-C}	37.51^{B-C}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

Table C-15. Mean root fresh weight of greenhouse tomatoes by experiment and treatment and combined across acids and concentrations.

		Experiment		
Acid	Conc.	1990	1991	Combined
		Root Fresh Weight (g)		
Ferulic	1000μM	6.45^{A*}	9.68^{B-C}	8.06^{B-C}
	100μM	6.08^{A}	12.73^{B-C}	9.40^{A-C}
	10μM	5.60^{A}	15.85^{A-C}	10.73^{A-C}
	1μM	5.60^{A}	12.63^{B-C}	9.11^{A-C}
Coumaric	1000μM	4.80^{A}	11.43^{B-C}	8.11^{B-C}
	100μM	6.10^{A}	17.80^{A-C}	11.95^{A-C}
	10μM	7.05^{A}	10.80^{B-C}	8.93^{A-C}
	1μM	7.70^{A}	12.48^{B-C}	10.09^{A-C}
Syringic	1000μM	5.45^{A}	8.88^{C}	7.16^{C}
	100μM	6.08^{A}	16.60^{A-C}	11.34^{A-C}
	10μM	4.83^{A}	16.38^{A-C}	10.60^{A-C}
	1μM	7.58^{A}	15.93^{A-C}	11.75^{A-C}
Vanillic	1000μM	5.93^{A}	11.60^{B-C}	8.76^{A-C}
	100μM	5.13^{A}	15.80^{A-C}	10.46^{A-C}
	10μM	7.00^{A}	10.48^{B-C}	8.74^{A-C}
	1μM	4.53^{A}	22.25^{A}	13.39^{A}
Benzoic	1000μM	5.63^{A}	14.15^{A-C}	9.89^{A-C}
	100μM	5.75^{A}	14.55^{A-C}	10.15^{A-C}
	10μM	5.38^{A}	12.65^{B-C}	9.01^{A-C}
	1μM	5.75^{A}	11.48^{B-C}	8.61^{A-C}
Check	0μM	5.57^{A}	16.49^{A-C}	11.03^{A-C}
Combined Across Conc.				
Ferulic		5.93^{A**}	12.72^{A}	9.33^{A}
Coumaric		6.41^{A}	13.13^{A}	9.77^{A}
Syringic		5.99^{A}	14.45^{A}	10.21^{A}
Vanillic		5.65^{A}	15.03^{A}	10.34^{A}
Benzoic		5.63^{A}	13.21^{A}	9.42^{A}
Combined Across Acids				
	1000μM	5.65^{A**}	11.15^{A}	8.40^{A}
	100μM	5.83^{A}	15.50^{B}	10.66^{B}
	10μM	5.97^{A}	13.23^{A-B}	9.60^{A-B}
	1μM	6.23^{A}	14.95^{B}	10.59^{B}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

Table C-16. Mean shoot dry weight of greenhouse tomatoes by experiment and treatment and combined across acids and concentrations.

		Experiment		
Acid	Conc.	1990	1991	Combined
		Shoot Dry Weight (g)		
Ferulic	1000μM	9.46^{A-B*}	7.39^{C-D}	8.42^{C-E}
	100μM	10.65^{A-B}	10.36^{B-D}	10.21^{A-E}
	10μM	9.35^{A-C}	12.28^{A-D}	10.82^{A-D}
	1μM	10.43^{A-B}	9.88^{B-C}	10.15^{A-E}
Coumaric	1000μM	9.65^{A-B}	9.93^{B-C}	9.79^{B-E}
	100μM	9.65^{A-B}	12.17^{A-D}	10.91^{A-C}
	10μM	8.07^{A-C}	9.55^{B-D}	8.81^{C-E}
	1μM	9.60^{A-B}	10.40^{B-D}	10.00^{A-E}
Syringic	1000μM	6.66^{B-C}	7.05^{D}	6.86^{E}
	100μM	10.14^{A-B}	11.15^{B-D}	10.64^{A-D}
	10μM	7.13^{A-C}	12.32^{A-D}	9.72^{B-E}
	1μM	8.43^{A-C}	10.57^{B-D}	9.50^{B-E}
Vanillic	1000μM	9.81^{A-B}	9.41^{B-D}	9.61^{B-E}
	100μM	9.24^{A-C}	12.75^{A-D}	10.99^{A-C}
	10μM	5.45^{C}	9.32^{B-D}	7.38^{D-E}
	1μM	9.60^{A-B}	17.02^{A}	13.31^{A}
Benzoic	1000μM	7.93^{A-C}	11.56^{B-D}	9.74^{B-E}
	100μM	8.29^{A-C}	11.31^{B-D}	9.80^{B-E}
	10μM	9.65^{A-B}	9.49^{B-D}	9.57^{B-E}
	1μM	7.40^{A-C}	9.47^{B-D}	8.44^{C-E}
Check	0μM	9.55^{A-B}	12.39^{A-D}	10.97^{A-C}
Combined Across Conc.				
Ferulic		9.97^{A**}	9.98^{A}	9.90^{A}
Coumaric		9.24^{A-B}	10.51^{A}	9.88^{A}
Syringic		8.09^{B}	10.27^{A}	9.18^{A}
Vanillic		8.53^{A-B}	12.13^{A}	10.32^{A}
Benzoic		8.32^{A-B}	10.46^{A}	9.39^{A}
Combined Across Acids				
	1000μM	8.70^{A-B**}	9.07^{A}	8.88^{A}
	100μM	9.59^{A}	11.55^{B}	10.51^{B}
	10μM	7.93^{B}	10.59^{A-B}	9.26^{A-B}
	1μM	9.09^{A-B}	11.47^{B}	10.28^{B}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

Table C-17. Mean root dry weight of greenhouse tomatoes by experiment and treatment and combined across acids and concentrations.

		Experiment		
Acid	Conc.	1990	1991	Combined
		Root Dry Weight (g)		
Ferulic	1000μM	1.55^{A-B}*	2.22^{C}	1.89^{C-D}
	100μM	1.76^{A-B}	2.84^{B-C}	2.30^{B-D}
	10μM	1.59^{A-B}	4.08^{A-C}	2.84^{A-D}
	1μM	1.57^{A-B}	3.60^{A-C}	2.58^{A-D}
Coumaric	1000μM	1.18^{A-B}	2.43^{C}	1.80^{D}
	100μM	1.81^{A-B}	5.79^{A}	3.80^{A-B}
	10μM	2.71^{A-B}	2.97^{B-C}	2.84^{A-D}
	1μM	1.91^{A-B}	3.46^{A-C}	2.68^{A-D}
Syringic	1000μM	1.26^{A-B}	2.07^{C}	1.66^{D}
	100μM	1.91^{A-B}	5.70^{A}	3.80^{A-B}
	10μM	1.04^{B}	3.67^{A-C}	2.35^{B-D}
	1μM	2.75^{A}	5.24^{A-B}	3.99^{A}
Vanillic	1000μM	1.27^{A-B}	2.79^{B-C}	2.03^{C-D}
	100μM	1.61^{A-B}	4.21^{A-C}	2.91^{A-D}
	10μM	2.25^{A-B}	2.56^{B-C}	2.40^{A-D}
	1μM	1.23^{A-B}	5.75^{A}	3.49^{A-C}
Benzoic	1000μM	2.38^{A-B}	3.88^{A-C}	3.13^{A-D}
	100μM	1.92^{A-B}	4.54^{A-C}	3.23^{A-D}
	10μM	1.58^{A-B}	3.27^{A-C}	2.42^{A-D}
	1μM	1.66^{A-B}	3.43^{A-C}	2.55^{A-D}
Check	0μM	1.51^{A-B}	3.89^{A-C}	2.70^{A-D}
Combined Across Conc.				
Ferulic		1.62^{A}**	3.19^{A}	2.40^{A}
Coumaric		1.90^{A}	3.66^{A}	2.78^{A}
Syringic		1.74^{A}	4.17^{A}	2.95^{A}
Vanillic		1.59^{A}	3.83^{A}	2.71^{A}
Benzoic		1.89^{A}	3.78^{A}	2.83^{A}
Combined Across Acids				
	1000μM	1.53^{A}**	2.68^{A}	2.10^{A}
	100μM	1.80^{A}	4.62^{B}	3.21^{C}
	10μM	1.83^{A}	3.31^{A}	2.57^{A-B}
	1μM	1.82^{A}	4.30^{B}	3.06^{B-C}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

Table C-18. Mean fresh shoot to root ratio of greenhouse tomatoes by experiment and treatment and combined across acids and concentrations.

		Experiment		
Acid	Conc.	1990	1991	Combined
		Fresh Shoot to Root Ratio		
Ferulic	1000µM	7.52^{A-B}*	4.38^{A-B}	5.95^{A-C}
	100µM	8.90^{A-B}	3.07^{C-D}	5.98^{A-C}
	10µM	8.45^{A-B}	2.98^{C-D}	5.72^{A-C}
	1µM	8.84^{A-B}	2.90^{C-D}	5.87^{A-C}
Coumaric	1000µM	9.99^{A}	3.75^{A-D}	6.87^{A}
	100µM	7.74^{A-B}	2.86^{D}	5.30^{A-C}
	10µM	5.66^{A}	3.41^{A-D}	4.53^{B-C}
	1µM	7.87^{A-B}	3.11^{C-D}	5.49^{A-C}
Syringic	1000µM	7.68^{A-B}	4.49^{A}	6.08^{A-C}
	100µM	7.31^{A-B}	3.56^{A-D}	5.43^{A-C}
	10µM	9.17^{A-B}	2.80^{D}	5.99^{A-C}
	1µM	5.55^{B}	3.23^{B-D}	4.39^{C}
Vanillic	1000µM	9.28^{A-B}	4.13^{A-C}	6.71^{A-B}
	100µM	9.30^{A-B}	3.11^{C-D}	6.21^{A-C}
	10µM	5.77^{B}	2.92^{C-D}	4.34^{C}
	1µM	10.08^{A}	2.71^{D}	6.39^{A-C}
Benzoic	1000µM	10.19^{A}	3.64^{A-D}	6.92^{A}
	100µM	7.69^{A-B}	2.81^{D}	5.25^{A-C}
	10µM	10.04^{A}	3.19^{B-D}	6.61^{A-C}
	1µM	7.67^{A-B}	2.99^{C-D}	5.33^{A-C}
Check	0µM	9.22^{A-B}	2.93^{C-D}	6.07^{A-C}
Combined Across Conc.				
Ferulic		8.43^{A}**	3.33^{A}	5.88^{A}
Coumaric		7.82^{A}	3.28^{A}	5.55^{A}
Syringic		7.43^{A}	3.52^{A}	5.47^{A}
Vanillic		8.61^{A}	3.22^{A}	5.91^{A}
Benzoic		8.90^{A}	3.16^{A}	6.03^{A}
Combined Across Acids				
	1000µM	8.93^{A}**	4.08^{A}	6.51^{A}
	100µM	8.19^{A}	3.08^{B}	5.63^{B}
	10µM	7.82^{A}	3.06^{B}	5.44^{B}
	1µM	8.00^{A}	2.99^{B}	5.49^{B}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

Table C-19. Mean dry shoot to root ratio of greenhouse tomatoes by experiment and treatment and combined across acids and concentrations.

		Experiment		
Acid	Conc.	1990	1991	Combined
		Dry Shoot to Root Ratio		
Ferulic	1000μM	9.62^{A*}	4.97^{A}	7.29^{A}
	100μM	6.25^{A-B}	3.73^{A-B}	4.99^{A-D}
	10μM	5.97^{A-B}	3.29^{A-B}	4.63^{A-D}
	1μM	7.42^{A-B}	3.03^{A-B}	5.22^{A-D}
Coumaric	1000μM	8.27^{A-B}	4.37^{A-B}	6.32^{A-C}
	100μM	5.53^{A-B}	2.67^{A-B}	4.10^{B-D}
	10μM	3.93^{B}	3.36^{A-B}	3.65^{C-D}
	1μM	7.08^{A-B}	3.16^{A-B}	5.12^{A-D}
Syringic	1000μM	5.28^{A-B}	3.66^{A-B}	4.35^{B-D}
	100μM	5.91^{A-B}	2.03^{B}	3.97^{C-D}
	10μM	6.87^{A-B}	3.34^{A-B}	4.85^{A-D}
	1μM	3.71^{B}	2.57^{A-B}	3.14^{D}
Vanillic	1000μM	8.84^{A-B}	3.49^{A-B}	6.17^{A-C}
	100μM	7.03^{A-B}	3.72^{A-B}	5.38^{A-D}
	10μM	3.41^{B}	4.02^{A-B}	3.76^{C-D}
	1μM	8.30^{A-B}	3.15^{A-B}	5.72^{A-D}
Benzoic	1000μM	4.10^{B}	3.35^{A-B}	3.72^{C-D}
	100μM	4.51^{A-B}	2.83^{A-B}	3.67^{C-D}
	10μM	7.86^{A-B}	3.76^{A-B}	5.81^{A-D}
	1μM	4.87^{A-B}	2.91^{A-B}	3.75^{C-D}
Check	0μM	7.34^{A-B}	4.26^{A-B}	5.80^{A-D}
Combined Across Conc.				
Ferulic		7.32^{A**}	3.76^{A}	5.53^{A}
Coumaric		6.20^{A}	3.39^{A}	4.80^{A-C}
Syringic		5.44^{A}	2.90^{A}	4.08^{C}
Vanillic		6.90^{A}	3.60^{A}	5.26^{A-B}
Benzoic		5.34^{A}	3.21^{A}	4.24^{B-C}
Combined Across Acids				
	1000μM	7.22^{A**}	3.97^{A}	5.57^{A}
	100μM	5.85^{A}	3.00^{B}	4.42^{B}
	10μM	5.61^{A}	3.55^{A-B}	4.54^{A-B}
	1μM	6.28^{A}	2.96^{B}	4.59^{A-B}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

Table C-20. Mean leaf nitrogen concentration of greenhouse tomatoes by experiment and treatment and combined across acids and concentrations.

		Experiment		
Acid	Conc.	1990	1991	Combined
		Nitrogen (%)		
Ferulic	1000μM	1.38^{A*}	0.88^{A}	1.13^{A}
	100μM	1.08^{A}	0.74^{A}	0.91^{A}
	10μM	1.03^{A}	0.72^{A}	0.87^{A}
	1μM	1.15^{A}	0.67^{A}	0.91^{A}
Coumaric	1000μM	0.90^{A}	0.77^{A}	0.83^{A}
	100μM	1.02^{A}	0.70^{A}	0.86^{A}
	10μM	1.21^{A}	0.73^{A}	0.97^{A}
	1μM	0.93^{A}	0.78^{A}	0.85^{A}
Syringic	1000μM	1.34^{A}	0.75^{A}	1.05^{A}
	100μM	0.97^{A}	0.69^{A}	0.83^{A}
	10μM	1.36^{A}	0.82^{A}	1.09^{A}
	1μM	1.37^{A}	0.72^{A}	1.04^{A}
Vanillic	1000μM	0.72^{A}	0.80^{A}	0.76^{A}
	100μM	0.85^{A}	0.73^{A}	0.79^{A}
	10μM	0.98^{A}	0.68^{A}	0.81^{A}
	1μM	1.16^{A}	0.68^{A}	0.92^{A}
Benzoic	1000μM	0.81^{A}	0.75^{A}	0.78^{A}
	100μM	1.06^{A}	0.67^{A}	0.87^{A}
	10μM	1.05^{A}	0.98^{A}	1.01^{A}
	1μM	0.96^{A}	0.89^{A}	0.92^{A}
Check	0μM	1.09^{A}	0.72^{A}	0.91^{A}
Combined Across Conc.				
Ferulic		$1.16^{A\text{-}B**}$	0.75^{A}	$0.96^{A\text{-}B}$
Coumaric		$1.02^{A\text{-}B}$	0.75^{A}	$0.88^{A\text{-}B}$
Syringic		1.26^{A}	0.75^{A}	1.00^{A}
Vanillic		0.93^{B}	0.72^{A}	0.82^{B}
Benzoic		0.97^{B}	0.82^{A}	$0.90^{A\text{-}B}$
Combined Across Acids				
	1000μM	1.03^{A**}	0.79^{A}	0.91^{A}
	100μM	1.00^{A}	0.71^{A}	0.85^{A}
	10μM	1.13^{A}	0.79^{A}	0.95^{A}
	1μM	1.11^{A}	0.75^{A}	0.93^{A}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

Table C-21. Mean plant height at harvest of greenhouse tomatoes by experiment and treatment and combined across acids and concentrations.

		Experiment		
Acid	Conc.	1990	1991	Combined
		Plant Height (cm)		
Ferulic	1000μM	72.8^{A-B*}	56.3^{A}	64.5^{A-C}
	100μM	80.1^{A-B}	56.0^{A}	68.1^{A-C}
	10μM	70.8^{A-B}	59.0^{A}	64.9^{A-C}
	1μM	71.3^{A-B}	53.0^{A}	62.1^{A-C}
Coumaric	1000μM	73.3^{A-B}	65.3^{A}	69.3^{A-C}
	100μM	77.5^{A-B}	60.8^{A}	69.1^{A-C}
	10μM	66.1^{A-B}	56.5^{A}	61.3^{A-C}
	1μM	75.3^{A-B}	58.0^{A}	66.6^{A-C}
Syringic	1000μM	71.5^{A-B}	63.3^{A}	67.4^{A-C}
	100μM	68.9^{A-B}	61.5^{A}	65.2^{A-C}
	10μM	68.6^{A-B}	55.5^{A}	62.1^{A-C}
	1μM	56.4^{B}	56.8^{A}	56.6^{C}
Vanillic	1000μM	84.0^{A}	60.0^{A}	72.0^{A-B}
	100μM	65.0^{A-B}	57.3^{A}	61.1^{A-C}
	10μM	62.1^{A-B}	54.5^{A}	58.3^{B-C}
	1μM	75.3^{A-B}	63.5^{A}	69.4^{A-C}
Benzoic	1000μM	87.6^{A}	61.5^{A}	74.6^{A}
	100μM	63.5^{A-B}	60.3^{A}	61.9^{A-C}
	10μM	84.0^{A}	58.8^{A}	71.4^{A-B}
	1μM	63.5^{A-B}	60.0^{A}	61.8^{A-C}
Check	0μM	73.0^{A-B}	60.8^{A}	66.9^{A-C}
Combined Across Conc.				
Ferulic		73.8^{A**}	56.1^{A}	64.9^{A}
Coumaric		73.1^{A}	60.2^{A}	66.6^{A}
Syringic		66.4^{A}	59.3^{A}	62.8^{A}
Vanillic		71.6^{A}	58.8^{A}	65.2^{A}
Benzoic		74.7^{A}	60.2^{A}	67.4^{A}
Combined Across Acids				
	1000μM	77.8^{A**}	61.3^{A}	69.6^{A}
	100μM	71.0^{A-B}	59.2^{A-B}	65.1^{A-B}
	10μM	70.3^{A-B}	56.9^{B}	63.6^{B}
	1μM	68.4^{B}	58.3^{A-B}	63.3^{B}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

Table C-22. Mean leaf number at harvest of greenhouse tomatoes by experiment and treatment and combined across acids and concentrations.

		Experiment		
Acid	Conc.	1990	1991	Combined
		Leaf Number		
Ferulic	1000μM	8.5^{A-B*}	10.8^{B}	9.6^{A-B}
	100μM	10.5^{A}	11.5^{A-B}	11.0^{A}
	10μM	9.0^{A-B}	12.5^{A-B}	10.8^{A-B}
	1μM	8.3^{A-B}	11.8^{A-B}	10.0^{A-B}
Coumaric	1000μM	9.3^{A-B}	11.0^{B}	10.1^{A-B}
	100μM	9.5^{A-B}	11.3^{B}	10.4^{A-B}
	10μM	8.8^{A-B}	11.5^{A-B}	10.1^{A-B}
	1μM	8.0^{A-B}	12.3^{A-B}	10.1^{A-B}
Syringic	1000μM	9.3^{A-B}	11.5^{A-B}	10.4^{A-B}
	100μM	8.3^{A-B}	12.5^{A-B}	10.4^{A-B}
	10μM	9.8^{A-B}	12.3^{A-B}	11.0^{A}
	1μM	8.5^{A-B}	11.8^{A-B}	10.1^{A-B}
Vanillic	1000μM	9.5^{A-B}	12.3^{A-B}	10.9^{A-B}
	100μM	8.3^{A-B}	13.3^{A}	10.8^{A-B}
	10μM	8.0^{A-B}	10.8^{B}	9.4^{B}
	1μM	9.0^{A-B}	11.5^{A-B}	10.3^{A-B}
Benzoic	1000μM	10.3^{A-B}	11.5^{A-B}	10.9^{A-B}
	100μM	7.8^{B}	11.5^{A-B}	9.6^{A-B}
	10μM	8.8^{A-B}	11.3^{B}	10.0^{A-B}
	1μM	7.8^{B}	12.3^{A-B}	10.0^{A-B}
Check	0μM	23.3^{A-B}	12.3^{A-B}	10.8^{A-B}
Combined Across Conc.				
Ferulic		9.1^{A**}	11.7^{A}	10.4^{A}
Coumaric		8.9^{A}	11.5^{A}	10.2^{A}
Syringic		9.0^{A}	12.0^{A}	10.5^{A}
Vanillic		8.7^{A}	12.0^{A}	10.4^{A}
Benzoic		8.7^{A}	11.7^{A}	10.1^{A}
Combined Across Acids				
	1000μM	9.4^{A**}	11.4^{A}	10.4^{A}
	100μM	8.9^{A-B}	12.0^{A}	10.4^{A}
	10μM	8.9^{A-B}	11.7^{A}	10.3^{A}
	1μM	8.3^{B}	11.9^{A}	10.1^{A}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

Table C-23. Mean stem diameter at harvest of greenhouse tomatoes by experiment and treatment and combined across acids and concentrations.

		Experiment		
Acid	Conc.	1990	1991	Combined
		Stem Diameter (mm)		
Ferulic	1000μM	5.94^{A-B*}	5.90^{A-B}	5.92^{A-B}
	100μM	5.93^{A-B}	5.73^{B}	5.83^{B}
	10μM	6.50^{A-B}	6.40^{A-B}	6.45^{A-B}
	1μM	6.83^{A}	5.98^{A-B}	6.40^{A-B}
Coumaric	1000μM	6.19^{A-B}	6.63^{A-B}	6.41^{A-B}
	100μM	6.04^{A-B}	6.53^{A-B}	6.28^{A-B}
	10μM	6.25^{A-B}	6.50^{A-B}	6.38^{A-B}
	1μM	6.21^{A-B}	5.93^{A-B}	6.07^{A-B}
Syringic	1000μM	6.01^{A-B}	6.00^{A-B}	6.01^{A-B}
	100μM	6.46^{A-B}	6.53^{A-B}	6.49^{A-B}
	10μM	6.14^{A-B}	6.48^{A-B}	6.31^{A-B}
	1μM	6.66^{A-B}	6.13^{A-B}	6.39^{A-B}
Vanillic	1000μM	5.88^{A-B}	6.10^{A-B}	5.99^{A-B}
	100μM	6.23^{A-B}	6.65^{A-B}	6.44^{A-B}
	10μM	5.61^{B}	6.00^{A-B}	5.81^{B}
	1μM	5.91^{A-B}	6.05^{A-B}	5.98^{A-B}
Benzoic	1000μM	6.14^{A-B}	6.83^{A}	6.48^{A-B}
	100μM	5.99^{A-B}	6.45^{A-B}	6.22^{A-B}
	10μM	6.55^{A-B}	6.05^{A-B}	6.30^{A-B}
	1μM	6.20^{A-B}	6.45^{A-B}	6.33^{A-B}
Check	0μM	6.29^{A-B}	6.23^{A-B}	6.26^{A-B}
Combined Across Conc.				
Ferulic		6.30^{A**}	6.00^{A}	6.15^{A}
Coumaric		6.17^{A}	6.40^{B}	6.29^{A}
Syringic		6.32^{A}	6.29^{A-B}	6.30^{A}
Vanillic		5.91^{A}	6.20^{A-B}	6.06^{A}
Benzoic		6.22^{A}	6.45^{B}	6.33^{A}
Combined Across Acids				
	1000μM	6.03^{A**}	6.29^{A}	6.16^{A}
	100μM	6.13^{A}	6.38^{A}	6.25^{A}
	10μM	6.21^{A}	6.29^{A}	6.25^{A}
	1μM	6.36^{A}	6.11^{A}	6.23^{A}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

Table C-24. Mean fruit number of greenhouse tomatoes by experiment and treatment and combined across acids and concentrations.

		Experiment		
Acid	Conc.	1990	1991	Combined
		Fruit Number		
Ferulic	1000µM	1.25^{A-C*}	2.25^{A-C}	1.75^{A-B}
	100µM	0.25^{B-C}	2.00^{A-C}	1.13^{B}
	10µM	1.25^{A-C}	2.00^{A-C}	1.63^{A-B}
	1µM	1.50^{A-B}	1.00^{C}	1.25^{B}
Coumaric	1000µM	1.00^{A-C}	3.25^{A-B}	2.13^{A-B}
	100µM	1.00^{A-C}	2.25^{A-C}	1.63^{A-B}
	10µM	0.75^{A-C}	1.50^{B-C}	1.13^{B}
	1µM	1.00^{A-C}	2.00^{A-C}	1.50^{B}
Syringic	1000µM	1.25^{A-C}	2.50^{A-C}	1.88^{A-B}
	100µM	1.75^{A}	2.25^{A-C}	2.00^{A-B}
	10µM	1.25^{A-C}	1.75^{A-C}	1.50^{A}
	1µM	1.25^{A-C}	1.75^{A-C}	1.50^{B}
Vanillic	1000µM	0.50^{A-C}	1.75^{A-C}	1.13^{B}
	100µM	1.50^{A-B}	1.75^{A-C}	1.63^{A-B}
	10µM	0.75^{A-C}	1.50^{B-C}	1.13^{B}
	1µM	1.00^{A-C}	1.75^{A-C}	1.38^{B}
Benzoic	1000µM	0.00^{C}	2.75^{A-C}	1.38^{B}
	100µM	1.00^{A-C}	2.00^{A-C}	1.50^{B}
	10µM	1.00^{A-C}	2.75^{A-C}	1.88^{A-B}
	1µM	1.00^{A-C}	2.25^{A-C}	1.63^{A-B}
Check	0µM	1.00^{A-C}	2.33^{A-C}	1.67^{A-B}
Combined Across Conc.				
Ferulic		1.06^{A-B**}	1.81^{A}	1.44^{A}
Coumaric		0.94^{A-B}	2.25^{A}	1.60^{A}
Syringic		1.38^{A}	2.06^{A}	1.72^{A}
Vanillic		0.94^{A-B}	1.69^{A}	1.32^{A}
Benzoic		0.75^{B}	2.44^{A}	1.60^{A}
Combined Across Acids				
	1000µM	0.80^{A**}	2.50^{A}	1.65^{A}
	100µM	1.10^{A}	2.05^{A-B}	1.58^{A}
	10µM	1.00^{A}	1.90^{A-B}	1.45^{A}
	1µM	1.15^{A}	1.75^{B}	1.45^{A}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

Table C-25. Mean fruit weight of greenhouse tomatoes by experiment and treatment and combined across acids and concentrations.

		Experiment		
Acid	Conc.	1990	1991	Combined
		Fruit Weight (g)		
Ferulic	1000μM	26.30^{A-B*}	38.63^{A}	32.46^{A-B}
	100μM	4.90^{A-B}	46.17^{A}	25.54^{A-B}
	10μM	18.30^{A-B}	29.60^{A}	23.95^{A-B}
	1μM	25.82^{A-B}	37.90^{A}	31.86^{A-B}
Coumaric	1000μM	26.83^{A-B}	44.55^{A}	35.69^{A-B}
	100μM	14.25^{A-B}	50.85^{A}	32.55^{A-B}
	10μM	23.55^{A-B}	35.43^{A}	29.49^{A-B}
	1μM	31.17^{A}	35.17^{A}	33.18^{A-B}
Syringic	1000μM	14.75^{A-B}	43.48^{A}	29.11^{A-B}
	100μM	28.23^{A-B}	39.28^{A}	33.75^{A-B}
	10μM	25.58^{A-B}	40.63^{A}	33.10^{A-B}
	1μM	18.75^{A-B}	45.43^{A}	32.09^{A-B}
Vanillic	1000μM	12.53^{A-B}	56.35^{A}	34.44^{A-B}
	100μM	27.65^{A-B}	24.08^{A}	25.86^{A-B}
	10μM	33.95^{A}	53.98^{A}	43.96^{A}
	1μM	23.95^{A-B}	34.13^{A}	29.04^{A-B}
Benzoic	1000μM	0.00^{B}	42.83^{A}	21.41^{B}
	100μM	6.55^{A-B}	30.42^{A}	18.49^{B}
	10μM	18.23^{A-B}	53.60^{A}	35.91^{A-B}
	1μM	22.58^{A-B}	38.00^{A}	30.29^{A-B}
Check	0μM	15.46^{A-B}	40.06^{A}	27.76^{A-B}
Combined Across Conc.				
Ferulic		18.83^{A-B**}	38.08^{A}	28.45^{A}
Coumaric		23.95^{A-B}	41.50^{A}	32.73^{A}
Syringic		21.83^{A-B}	42.21^{A}	32.01^{A}
Vanillic		24.52^{A}	42.14^{A}	33.33^{A}
Benzoic		11.84^{B}	41.21^{A}	26.53^{A}
Combined Across Acids				
	1000μM	16.08^{A**}	45.17^{A}	30.62^{A}
	100μM	16.32^{A}	38.16^{A}	27.24^{A}
	10μM	23.92^{A}	42.65^{A}	33.28^{A}
	1μM	24.45^{A}	38.13^{A}	31.29^{A}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

Table C-26. Mean growth in plant height over time of greenhouse tomatoes by experiment and treatment and combined across acids and concentrations.

		Experiment		
Acid	Conc.	1990	1991	Combined
		Plant Height Growth Per Day		
Ferulic	1000μM	0.81^{A-B*}	0.83^{A}	0.82^{A-B}
	100μM	0.97^{A-B}	0.80^{A}	0.88^{A-B}
	10μM	0.83^{A-B}	0.87^{A}	0.85^{A-B}
	1μM	0.73^{A-B}	0.78^{A}	0.75^{A-B}
Coumaric	1000μM	0.78^{A-B}	0.99^{A}	0.88^{A-B}
	100μM	0.87^{A-B}	0.90^{A}	0.88^{A-B}
	10μM	0.67^{A-B}	0.80^{A}	0.73^{A-B}
	1μM	0.71^{A-B}	0.83^{A}	0.77^{A-B}
Syringic	1000μM	1.06^{A-B}	0.94^{A}	1.00^{A}
	100μM	0.58^{A-B}	0.87^{A}	0.73^{A-B}
	10μM	0.81^{A-B}	0.79^{A}	0.80^{A-B}
	1μM	0.11^{B}	0.81^{A}	0.46^{B}
Vanillic	1000μM	1.25^{A}	0.88^{A}	1.07^{A}
	100μM	0.76^{A-B}	0.83^{A}	0.79^{A-B}
	10μM	0.57^{A-B}	0.77^{A}	0.67^{A-B}
	1μM	0.86^{A-B}	0.93^{A}	0.89^{A-B}
Benzoic	1000μM	1.39^{A}	0.90^{A}	1.14^{A}
	100μM	0.45^{A-B}	0.88^{A}	0.67^{A-B}
	10μM	1.21^{A}	0.84^{A}	0.98^{A}
	1μM	0.62^{A-B}	0.86^{A}	0.74^{A-B}
Check	0μM	0.89^{A-B}	0.87^{A}	0.88^{A-B}
Combined Across Conc.				
Ferulic		0.84^{A**}	0.82^{A}	0.83^{A}
Coumaric		0.76^{A}	0.88^{A}	0.82^{A-B}
Syringic		0.64^{A}	0.85^{A}	0.75^{A-B}
Vanillic		0.86^{A}	0.85^{A}	0.86^{A-B}
Benzoic		0.92^{A}	0.87^{A}	0.88^{B}
Combined Across Acids				
	1000μM	1.06^{A**}	0.91^{A}	0.98^{A}
	100μM	0.73^{A-B}	0.86^{A-B}	0.79^{B}
	10μM	0.82^{A-B}	0.81^{B}	0.81^{B}
	1μM	0.61^{B}	0.84^{A-B}	0.72^{B}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

Table C-27. Mean growth in leaf number over time of greenhouse tomatoes by experiment and treatment and combined across acids and concentrations.

		Experiment		
Acid	Conc.	1990	1991	Combined
		Leaf Number Growth Per Day		
Ferulic	1000µM	-0.15^{A-B*}	0.09^{B}	-0.03^{A}
	100µM	-0.05^{A}	0.09^{B}	0.02^{A}
	10µM	-0.11^{A-B}	0.11^{A-B}	0.00^{A}
	1µM	-0.13^{A-B}	0.10^{A-B}	-0.01^{A}
Coumaric	1000µM	-0.17^{A-B}	0.10^{A-B}	-0.04^{A}
	100µM	-0.15^{A-B}	0.10^{A-B}	-0.03^{A}
	10µM	-0.08^{A-B}	0.10^{A-B}	0.01^{A}
	1µM	-0.19^{A-B}	0.11^{A-B}	-0.04^{A}
Syringic	1000µM	-0.12^{A-B}	0.10^{A-B}	-0.01^{A}
	100µM	-0.20^{B}	0.11^{A-B}	-0.05^{A}
	10µM	-0.12^{A-B}	0.11^{A-B}	-0.01^{A}
	1µM	-0.16^{A-B}	0.10^{A-B}	-0.03^{A}
Vanillic	1000µM	-0.11^{A-B}	0.10^{A-B}	0.00^{A}
	100µM	-0.19^{A-B}	0.13^{A}	-0.03^{A}
	10µM	-0.18^{A-B}	0.09^{B}	-0.05^{A}
	1µM	-0.15^{A-B}	0.10^{A-B}	-0.02^{A}
Benzoic	1000µM	-0.07^{A-B}	0.10^{A-B}	0.02^{A}
	100µM	-0.15^{A-B}	0.10^{A-B}	-0.02^{A}
	10µM	-0.16^{A-B}	0.10^{A-B}	-0.03^{A}
	1µM	-0.19^{A-B}	0.11^{A-B}	-0.04^{A}
Check	0µM	-0.16^{A-B}	0.11^{A-B}	-0.03^{A}
Combined Across Conc.				
Ferulic		-0.11^{A**}	0.10^{A}	-0.01^{A}
Coumaric		-0.15^{A}	0.10^{A}	-0.03^{A}
Syringic		-0.15^{A}	0.11^{A}	-0.03^{A}
Vanillic		-0.16^{A}	0.11^{A}	-0.03^{A}
Benzoic		-0.14^{A}	0.10^{A}	-0.02^{A}
Combined Across Acids				
	1000µM	-0.12^{A**}	0.10^{A}	-0.01^{A}
	100µM	-0.15^{A}	0.11^{A}	-0.02^{A}
	10µM	-0.13^{A}	0.10^{A}	-0.02^{A}
	1µM	-0.16^{A}	0.10^{A}	-0.03^{A}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

Table C-28. Mean growth in stem diameter over time of greenhouse tomatoes by experiment and treatment and combined across acids and concentrations.

		Experiment		
Acid	Conc.	1990	1991	Combined
		Stem Diameter Growth Per Day		
Ferulic	1000μM	-0.07^{A-C*}	0.052^{A-C}	-0.010^{A-B}
	100μM	-0.09^{A-C}	0.045^{C}	-0.022^{A-B}
	10μM	-0.07^{A-C}	0.061^{A-B}	-0.004^{A-B}
	1μM	-0.05^{A-B}	0.056^{A-C}	0.001^{A-B}
Coumaric	1000μM	-0.13^{B-C}	0.063^{A-B}	-0.034^{A-B}
	100μM	-0.08^{A-C}	0.060^{A-C}	-0.012^{A-B}
	10μM	-0.15^{C}	0.059^{A-C}	-0.044^{B}
	1μM	-0.07^{A-C}	0.051^{A-C}	-0.008^{A-B}
Syringic	1000μM	-0.06^{A-C}	0.053^{A-C}	-0.005^{A-B}
	100μM	-0.04^{A-B}	0.061^{A-B}	0.009^{A}
	10μM	-0.05^{A-B}	0.060^{A-B}	0.005^{A}
	1μM	-0.05^{A-B}	0.051^{A-C}	0.002^{A}
Vanillic	1000μM	-0.08^{A-C}	0.048^{B-C}	-0.015^{A-B}
	100μM	-0.09^{A-C}	0.062^{A-B}	-0.015^{A-B}
	10μM	-0.08^{A-C}	0.053^{A-C}	-0.013^{A-B}
	1μM	-0.08^{A-C}	0.053^{A-C}	-0.015^{A-B}
Benzoic	1000μM	-0.05^{A-B}	0.064^{A}	0.004^{A}
	100μM	-0.06^{A-C}	0.063^{A}	0.001^{A}
	10μM	-0.07^{A-C}	0.058^{A-C}	-0.007^{A-B}
	1μM	-0.07^{A-C}	0.060^{A-C}	-0.006^{A-B}
Check	0μM	-0.04^{A-B}	0.055^{A-C}	0.006^{A}
Combined Across Conc.				
Ferulic		-0.07^{A-B**}	0.05^{A}	-0.01^{A-B}
Coumaric		-0.11^{B}	0.06^{A-B}	-0.02^{B}
Syringic		-0.05^{A}	0.06^{A-B}	0.00^{A}
Vanillic		-0.08^{A-B}	0.05^{A}	-0.01^{A-B}
Benzoic		-0.06^{A}	0.06^{B}	-0.00^{A}
Combined Across Acids				
	1000μM	-0.08^{A**}	0.06^{A}	-0.01^{A}
	100μM	-0.07^{A}	0.06^{A}	-0.01^{A}
	10μM	-0.08^{A}	0.06^{A}	-0.01^{A}
	1μM	-0.06^{A}	0.05^{A}	-0.01^{A}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

Table C-29. Mean shoot fresh weight of greenhouse tobacco by experiment and treatment and combined across acids and concentrations.

		Experiment		
Acid	Conc.	1990	1991	Combined
		Shoot Fresh Weight (g)		
Ferulic	1000μM	34.28^{A-C}*	48.83^{A-D}	41.55^{A-B}
	100μM	37.68^{A-B}	66.82^{A-B}	52.25^{A}
	10μM	36.30^{A-C}	36.70^{B-D}	36.50^{A-B}
	1μM	39.65^{A-B}	41.48^{A-D}	40.56^{A-B}
Coumaric	1000μM	31.08^{C}	43.60^{A-D}	37.34^{A-B}
	100μM	33.70^{A-C}	59.90^{A-C}	46.80^{A-B}
	10μM	37.70^{A-B}	36.57^{B-C}	37.14^{A-B}
	1μM	35.58^{A-C}	28.45^{C-D}	32.01^{B}
Syringic	1000μM	35.00^{A-C}	54.98^{A-D}	44.99^{A-B}
	100μM	42.13^{A}	47.00^{A-D}	44.56^{A-B}
	10μM	35.63^{A-C}	43.53^{A-D}	39.58^{A-B}
	1μM	36.50^{A-B}	33.90^{C-D}	35.20^{A-B}
Vanillic	1000μM	33.78^{A-C}	39.58^{A-D}	36.68^{A-B}
	100μM	37.30^{A-B}	44.13^{A-D}	40.71^{A-B}
	10μM	37.03^{A-B}	52.03^{A-D}	44.53^{A-B}
	1μM	37.28^{A-B}	54.30^{A-D}	45.79^{A-B}
Benzoic	1000μM	39.98^{A-C}	56.13^{A-D}	44.61^{A-B}
	100μM	31.25^{B-C}	45.30^{A-D}	38.28^{A-B}
	10μM	40.08^{A-B}	48.95^{A-D}	44.51^{A-B}
	1μM	41.08^{A}	45.05^{A-D}	43.06^{A-B}
Check	0μM	36.35^{A-B}	40.45^{A-D}	38.40^{A-B}
Combined Across Conc.				
Ferulic		36.98^{A}**	48.46^{A}	42.72^{A}
Coumaric		34.52^{A}	42.13^{A}	38.32^{A}
Syringic		37.32^{A}	44.85^{A}	41.08^{A}
Vanillic		36.35^{A}	47.51^{A}	41.93^{A}
Benzoic		38.10^{A}	48.86^{A}	42.62^{A}
Combined Across Acids				
	1000μM	34.82^{A}**	48.62^{A-B}	41.03^{A}
	100μM	36.41^{A-B}	52.63^{B}	44.52^{A}
	10μM	37.35^{B}	43.56^{A-B}	40.45^{A}
	1μM	38.02^{B}	40.64^{A}	39.32^{A}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

Table C-30. Mean root fresh weight of greenhouse tobacco by experiment and treatment and combined across acids and concentrations.

Acid	Conc.	Experiment 1990	 1991	 Combined
		Root Fresh Weight (g)		
Ferulic	1000μM	5.08^{A*}	75.62^{A}	40.35^{A}
	100μM	4.25^{A}	49.40^{A-C}	26.83^{A-B}
	10μM	6.18^{A}	63.35^{A-C}	34.76^{A-B}
	1μM	5.88^{A}	60.63^{A-C}	33.25^{A-B}
Coumaric	1000μM	5.38^{A}	72.47^{A}	38.93^{A-B}
	100μM	5.08^{A}	56.08^{A-C}	30.58^{A-B}
	10μM	6.45^{A}	38.82^{B-C}	22.64^{B}
	1μM	7.13^{A}	66.17^{A-C}	36.65^{A-B}
Syringic	1000μM	7.28^{A}	64.37^{A-C}	35.83^{A-B}
	100μM	6.55^{A}	48.30^{A-C}	27.43^{A-B}
	10μM	5.58^{A}	57.45^{A-C}	31.51^{A-B}
	1μM	6.40^{A}	54.80^{A-C}	30.60^{A-B}
Vanillic	1000μM	5.10^{A}	50.70^{A-C}	27.90^{A-B}
	100μM	8.08^{A}	36.00^{C}	22.04^{B}
	10μM	7.10^{A}	66.43^{A-C}	36.76^{A-B}
	1μM	5.13^{A}	71.78^{A-B}	38.45^{A-B}
Benzoic	1000μM	6.18^{A}	67.07^{A-C}	32.27^{A-B}
	100μM	5.60^{A}	55.32^{A-C}	30.46^{A-B}
	10μM	5.38^{A}	45.85^{A-C}	25.61^{A-B}
	1μM	7.78^{A}	61.33^{A-C}	34.55^{A-B}
Check	0μM	6.58^{A}	62.75^{A-C}	34.66^{A-B}
Combined Across Conc.				
Ferulic		5.35^{A**}	62.25^{A}	33.80^{A}
Coumaric		6.01^{A}	58.39^{A}	32.20^{A}
Syringic		6.45^{A}	56.23^{A}	31.34^{A}
Vanillic		6.35^{A}	56.23^{A}	31.29^{A}
Benzoic		6.24^{A}	57.39^{A}	30.72^{A}
Combined Across Acids				
	1000μM	5.80^{A**}	66.05^{A}	35.06^{A}
	100μM	5.91^{A}	49.02^{B}	27.47^{B}
	10μM	6.14^{A}	54.38^{A-B}	30.26^{A-B}
	1μM	6.46^{A}	62.94^{A}	34.70^{A}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

Table C-31. Mean shoot dry weight of greenhouse tobacco by experiment and treatment and combined across acids and concentrations.

Acid	Conc.	Experiment		
		1990	1991	Combined
		Shoot Dry Weight (g)		
Ferulic	1000µM	4.71^{A-B}*	19.40^{A-B}	12.06^{A-C}
	100µM	5.27^{A-B}	25.53^{A-B}	15.40^{A-C}
	10µM	4.76^{A-B}	12.20^{B}	8.48^{A-C}
	1µM	4.39^{A-B}	16.23^{A-B}	10.31^{A-C}
Coumaric	1000µM	4.03^{A-B}	18.18^{A-B}	11.10^{A-C}
	100µM	5.13^{A-B}	27.55^{A-B}	16.34^{A-B}
	10µM	4.89^{A-B}	13.18^{B}	9.03^{A-C}
	1µM	5.27^{A-B}	10.18^{B}	7.72^{B-C}
Syringic	1000µM	4.62^{A-B}	24.30^{A-B}	14.46^{A-C}
	100µM	5.22^{A-B}	22.30^{A-B}	13.76^{A-C}
	10µM	5.09^{A-B}	17.43^{A-B}	11.26^{A-C}
	1µM	5.18^{A-B}	16.68^{A-B}	10.93^{A-C}
Vanillic	1000µM	4.29^{A-B}	14.65^{A-B}	9.47^{A-C}
	100µM	5.21^{A-B}	13.60^{A-B}	9.41^{A-C}
	10µM	5.65^{A}	23.05^{A-B}	14.35^{A-C}
	1µM	4.82^{A-B}	22.13^{A-B}	13.47^{A-C}
Benzoic	1000µM	3.41^{A}	23.67^{A-B}	12.09^{A-C}
	100µM	4.21^{A-B}	17.48^{A-B}	10.84^{A-C}
	10µM	4.81^{A-B}	22.20^{A-B}	13.51^{A-C}
	1µM	5.39^{A}	15.78^{A-B}	10.58^{A-C}
Check	0µM	4.46^{A-B}	17.07^{A-B}	10.76^{A-C}
Combined Across Conc.				
Ferulic		4.78^{A}**	18.34^{A}	11.56^{A}
Coumaric		4.83^{A}	17.27^{A}	11.05^{A}
Syringic		5.03^{A}	20.18^{A}	12.60^{A}
Vanillic		4.99^{A}	18.36^{A}	11.68^{A}
Benzoic		4.46^{A}	19.78^{A}	11.76^{A}
Combined Across Acids				
	1000µM	4.21^{A}**	20.04^{A}	11.84^{A}
	100µM	5.01^{B}	21.29^{A}	13.15^{A}
	10µM	5.04^{B}	17.61^{A}	11.33^{A}
	1µM	5.01^{B}	16.20^{A}	10.60^{A}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

Table C-32. Mean root dry weight of greenhouse tobacco by experiment and treatment and combined across acids and concentrations.

		Experiment		
Acid	Conc.	1990	1991	Combined
		Root Dry Weight (g)		
Ferulic	1000μM	1.21^{B*}	6.80^{A}	$4.00^{A\text{-}B}$
	100μM	$1.37^{A\text{-}B}$	6.68^{A}	$4.02^{A\text{-}B}$
	10μM	$1.65^{A\text{-}B}$	5.48^{A}	$3.56^{A\text{-}B}$
	1μM	$1.90^{A\text{-}B}$	4.93^{A}	$3.41^{A\text{-}B}$
Coumaric	1000μM	$1.35^{A\text{-}B}$	6.28^{A}	$3.81^{A\text{-}B}$
	100μM	$1.66^{A\text{-}B}$	5.50^{A}	$3.58^{A\text{-}B}$
	10μM	$1.47^{A\text{-}B}$	3.60^{A}	2.54^{B}
	1μM	$2.35^{A\text{-}B}$	6.58^{A}	$4.46^{A\text{-}B}$
Syringic	1000μM	3.05^{A}	5.75^{A}	$4.40^{A\text{-}B}$
	100μM	$2.09^{A\text{-}B}$	4.30^{A}	$3.20^{A\text{-}B}$
	10μM	$1.65^{A\text{-}B}$	5.55^{A}	$3.60^{A\text{-}B}$
	1μM	$2.09^{A\text{-}B}$	5.80^{A}	$3.95^{A\text{-}B}$
Vanillic	1000μM	$1.56^{A\text{-}B}$	4.05^{A}	$2.81^{A\text{-}B}$
	100μM	3.02^{A}	4.98^{A}	$4.00^{A\text{-}B}$
	10μM	$2.52^{A\text{-}B}$	6.30^{A}	$4.41^{A\text{-}B}$
	1μM	$1.64^{A\text{-}B}$	7.10^{A}	$4.37^{A\text{-}B}$
Benzoic	1000μM	0.95^{B}	5.80^{A}	$3.03^{A\text{-}B}$
	100μM	1.08^{B}	4.78^{A}	$2.93^{A\text{-}B}$
	10μM	$1.40^{A\text{-}B}$	4.08^{A}	$2.74^{A\text{-}B}$
	1μM	$2.60^{A\text{-}B}$	6.25^{A}	$4.42^{A\text{-}B}$
Check	0μM	$2.11^{A\text{-}B}$	5.88^{A}	$3.99^{A\text{-}B}$
Combined Across Conc.				
Ferulic		$1.53^{A\text{-}B**}$	5.97^{A}	3.75^{A}
Coumaric		$1.71^{A\text{-}C}$	5.49^{A}	3.60^{A}
Syringic		2.22^{C}	5.35^{A}	3.79^{A}
Vanillic		$2.19^{B\text{-}C}$	5.61^{A}	3.90^{A}
Benzoic		1.51^{A}	5.23^{A}	3.28^{A}
Combined Across Acids				
	1000μM	1.62^{A**}	5.74^{A}	$3.61^{A\text{-}B}$
	100μM	1.84^{A}	5.25^{A}	$3.55^{A\text{-}B}$
	10μM	1.74^{A}	5.00^{A}	3.37^{A}
	1μM	2.12^{A}	6.13^{A}	4.12^{B}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

Table C-33. Mean fresh shoot to root ratio of greenhouse tobacco by experiment and treatment and combined across acids and concentrations.

		Experiment		
Acid	Conc.	1990	1991	Combined
		Fresh Shoot to Root Ratio		
Ferulic	1000μM	7.24^{A-B}*	3.03^{A}	5.13^{A}
	100μM	8.93^{A}	2.78^{A}	5.86^{A}
	10μM	6.02^{A-B}	3.10^{A}	4.56^{A}
	1μM	7.15^{A-B}	3.70^{A}	5.42^{A}
Coumaric	1000μM	5.98^{A-B}	2.78^{A}	4.39^{A}
	100μM	6.79^{A-B}	2.60^{A}	4.70^{A}
	10μM	7.36^{A-B}	2.97^{A}	5.17^{A}
	1μM	5.60^{A-B}	2.92^{A}	4.26^{A}
Syringic	1000μM	5.43^{A-B}	2.31^{A}	3.87^{A}
	100μM	6.75^{A-B}	2.76^{A}	4.75^{A}
	10μM	6.39^{A-B}	2.81^{A}	4.60^{A}
	1μM	6.39^{A-B}	2.08^{A}	4.23^{A}
Vanillic	1000μM	7.53^{A-B}	2.87^{A}	5.20^{A}
	100μM	4.90^{B}	3.27^{A}	4.08^{A}
	10μM	5.90^{A-B}	3.18^{A}	4.54^{A}
	1μM	8.28^{A-B}	2.78^{A}	5.53^{A}
Benzoic	1000μM	7.42^{A-B}	2.75^{A}	5.42^{A}
	100μM	5.90^{A-B}	3.35^{A}	4.63^{A}
	10μM	7.68^{A-B}	2.70^{A}	5.19^{A}
	1μM	6.00^{A-B}	2.88^{A}	4.44^{A}
Check	0μM	6.02^{A-B}	2.88^{A}	4.45^{A}
Combined Across Conc.				
Ferulic		7.34^{A}**	3.15^{A}	5.24^{A}
Coumaric		6.43^{A}	2.82^{A}	4.63^{A-B}
Syringic		6.24^{A}	2.49^{A}	4.36^{B}
Vanillic		6.65^{A}	3.03^{A}	4.84^{A-B}
Benzoic		6.75^{A}	2.92^{A}	4.92^{A-B}
Combined Across Acids				
	1000μM	6.72^{A}**	2.75^{A}	4.80^{A}
	100μM	6.65^{A}	2.95^{A}	4.80^{A}
	10μM	6.67^{A}	2.95^{A}	4.81^{A}
	1μM	6.68^{A}	2.87^{A}	4.78^{A}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

Table C-34. Mean dry shoot to root ratio of greenhouse tobacco by experiment and treatment and combined across acids and concentrations.

			Experiment	
Acid	Conc.	1990	1991	Combined
			Dry Shoot to Root Ratio	
Ferulic	1000μM	3.93^{B}*	2.70^{A-B}	3.32^{B}
	100μM	3.99^{B}	4.39^{A-B}	4.19^{B}
	10μM	2.95^{B}	2.57^{A-B}	2.76^{B}
	1μM	3.55^{B}	3.86^{A-B}	3.70^{B}
Coumaric	1000μM	3.51^{B}	3.31^{A-B}	3.41^{B}
	100μM	3.10^{B}	4.94^{A-B}	4.02^{B}
	10μM	3.79^{B}	3.72^{A-B}	3.76^{B}
	1μM	2.66^{B}	1.57^{B}	2.12^{B}
Syringic	1000μM	2.15^{B}	5.29^{A-B}	3.72^{B}
	100μM	2.60^{B}	4.46^{A-B}	3.53^{B}
	10μM	3.08^{B}	3.58^{A-B}	3.33^{B}
	1μM	3.04^{B}	3.17^{A-B}	3.11^{B}
Vanillic	1000μM	3.37^{B}	3.84^{A-B}	3.61^{B}
	100μM	1.97^{B}	3.03^{A-B}	2.50^{B}
	10μM	2.76^{B}	3.52^{A-B}	3.14^{B}
	1μM	3.53^{B}	3.39^{A-B}	3.46^{B}
Benzoic	1000μM	3.62^{B}	4.31^{A-B}	3.97^{B}
	100μM	11.79^{A}	3.93^{A-B}	7.86^{A}
	10μM	3.46^{B}	6.10^{A}	4.78^{B}
	1μM	2.50^{B}	2.84^{A-B}	2.67^{B}
Check	0μM	2.66^{B}	3.06^{A-B}	2.86^{B}
Combined Across Conc.				
Ferulic		3.61^{A}**	3.38^{A}	3.49^{A-B}
Coumaric		3.27^{A}	3.39^{A}	3.33^{A-B}
Syringic		2.72^{A}	4.13^{A}	3.42^{A-B}
Vanillic		2.91^{A}	3.45^{A}	3.18^{A}
Benzoic		5.34^{A}	4.30^{A}	4.82^{B}
Combined Across Acids				
	1000μM	3.32^{A}**	3.89^{A}	3.61^{A-B}
	100μM	4.69^{A}	4.15^{A}	4.42^{A}
	10μM	3.21^{A}	3.90^{A}	3.55^{A-B}
	1μM	3.06^{A}	2.97^{A}	3.01^{B}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

Table C-35. Mean leaf nitrogen content of greenhouse tobacco in 1990 by treatment and combined across acids and concentrations.

Acid	Conc.	Nitrogen (%)
Ferulic	1000µM	1.99^{A-B*}
	100µM	1.79^{A-B}
	10µM	1.44^{B}
	1µM	1.78^{A-B}
Coumaric	1000µM	1.75^{A-B}
	100µM	2.15^{A-B}
	10µM	1.57^{A-B}
	1µM	1.88^{A-B}
Syringic	1000µM	1.30^{B}
	100µM	1.43^{B}
	10µM	1.82^{A-B}
	1µM	1.71^{A-B}
Vanillic	1000µM	1.88^{A-B}
	100µM	1.71^{A-B}
	10µM	1.78^{A-B}
	1µM	2.31^{A}
Benzoic	1000µM	1.75^{A-B}
	100µM	1.76^{A-B}
	10µM	1.49^{A-B}
	1µM	1.48^{A-B}
Check	0µM	1.54^{A-B}
Combined Across Conc.		
Ferulic		1.75^{A-B**}
Coumaric		1.84^{A-B}
Syringic		1.57^{A}
Vanillic		1.92^{B}
Benzoic		1.62^{A-B}
Combined Across Acids		
	1000µM	1.73^{A**}
	100µM	1.77^{A}
	10µM	1.62^{A}
	1µM	1.83^{A}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

Table C-36. Mean plant height at harvest of greenhouse tobacco by experiment and treatment and combined across acids and concentrations.

Acid	Conc.	Experiment		
		1990	1991	Combined
		Plant Height (cm)		
Ferulic	1000μM	28.0^{A-C*}	62.5^{A}	45.3^{A}
	100μM	30.5^{A-C}	40.3^{B-C}	35.4^{B-C}
	10μM	29.1^{A-C}	48.0^{A-C}	38.6^{A-C}
	1μM	28.4^{A-C}	39.8^{B-C}	34.1^{B-C}
Coumaric	1000μM	28.4^{A-C}	46.0^{A-C}	37.2^{A-C}
	100μM	27.8^{A-C}	52.8^{A-B}	40.3^{A-B}
	10μM	28.4^{A-C}	31.5^{C}	29.9^{C}
	1μM	30.5^{A-C}	39.8^{B-C}	35.1^{B-C}
Syringic	1000μM	29.9^{A-C}	50.5^{A-B}	40.2^{A-B}
	100μM	32.6^{A-B}	42.3^{B-C}	37.4^{A-C}
	10μM	28.6^{A-C}	38.5^{B-C}	33.6^{B-C}
	1μM	27.3^{B-C}	39.0^{B-C}	33.1^{B-C}
Vanillic	1000μM	25.5^{C}	37.3^{B-C}	31.4^{B-C}
	100μM	28.4^{A-C}	37.5^{B-C}	32.9^{B-C}
	10μM	34.3^{A}	44.8^{B-C}	39.5^{A-C}
	1μM	28.6^{A-C}	51.8^{A-B}	40.2^{A-B}
Benzoic	1000μM	27.3^{B-C}	43.0^{B-C}	34.0^{B-C}
	100μM	28.6^{A-C}	44.8^{B-C}	36.7^{A-C}
	10μM	30.8^{A-C}	40.3^{B-C}	35.5^{B-C}
	1μM	31.3^{A-C}	51.3^{A-B}	41.3^{A-B}
Check	0μM	29.4^{A-C}	48.7^{A-B}	39.0^{A-C}
Combined Across Conc.				
Ferulic		29.0^{A**}	47.7^{A}	38.4^{A}
Coumaric		28.8^{A}	42.5^{A}	35.6^{A}
Syringic		29.6^{A}	42.6^{A}	36.1^{A}
Vanillic		29.2^{A}	42.9^{A}	36.0^{A}
Benzoic		29.5^{A}	44.9^{A}	36.9^{A}
Combined Across Acids				
	1000μM	27.8^{A**}	47.7^{A}	37.6^{A}
	100μM	29.6^{A}	43.5^{A-B}	36.5^{A}
	10μM	30.2^{A}	40.6^{B}	35.4^{A}
	1μM	29.2^{A}	44.3^{A-B}	36.8^{A}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

Table C-37. Mean leaf number at harvest of greenhouse tobacco by experiment and treatment and combined across acids and concentrations.

		Experiment		
Acid	Conc.	1990	1991	Combined
		Leaf Number		
Ferulic	1000μM	8.3^{A*}	12.8^{A}	10.5^{A}
	100μM	9.8^{A}	12.0^{A}	10.9^{A}
	10μM	8.8^{A}	11.8^{A}	10.3^{A}
	1μM	9.3^{A}	12.0^{A}	10.6^{A}
Coumaric	1000μM	8.8^{A}	11.5^{A}	10.1^{A}
	100μM	8.8^{A}	12.3^{A}	10.5^{A}
	10μM	9.3^{A}	10.5^{A}	9.9^{A}
	1μM	9.8^{A}	12.3^{A}	11.0^{A}
Syringic	1000μM	8.3^{A}	12.5^{A}	10.4^{A}
	100μM	9.5^{A}	11.5^{A}	10.5^{A}
	10μM	9.8^{A}	12.3^{A}	11.0^{A}
	1μM	8.8^{A}	11.8^{A}	10.3^{A}
Vanillic	1000μM	9.3^{A}	11.5^{A}	10.4^{A}
	100μM	9.8^{A}	11.3^{A}	10.5^{A}
	10μM	9.3^{A}	12.8^{A}	11.0^{A}
	1μM	9.3^{A}	12.8^{A}	11.0^{A}
Benzoic	1000μM	8.3^{A}	11.7^{A}	9.7^{A}
	100μM	9.8^{A}	11.3^{A}	10.5^{A}
	10μM	9.0^{A}	11.5^{A}	10.3^{A}
	1μM	9.5^{A}	13.0^{A}	11.3^{A}
Check	0μM	8.9^{A}	12.1^{A}	10.5^{A}
Combined Across Conc.				
Ferulic		9.1^{A**}	12.2^{A}	10.6^{A}
Coumaric		9.2^{A}	11.7^{A}	10.4^{A}
Syringic		9.1^{A}	12.0^{A}	10.6^{A}
Vanillic		9.4^{A}	12.1^{A}	10.7^{A}
Benzoic		9.2^{A}	11.9^{A}	10.5^{A}
Combined Across Acids				
	1000μM	8.6^{A**}	12.0^{A}	10.2^{A}
	100μM	9.5^{B}	11.7^{A}	10.6^{A}
	10μM	9.2^{A-B}	11.8^{A}	10.5^{A}
	1μM	9.3^{B}	12.4^{A}	10.8^{A}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

Table C-38. Mean stem diameter at harvest of greenhouse tobacco by experiment and treatment and combined across acids and concentrations.

		Experiment		
Acid	Conc.	1990	1991	Combined
		Stem Diameter (mm)		
Ferulic	1000μM	7.25^{A-B}*	8.95^{A-B}	8.10^{A-B}
	100μM	8.16^{A}	9.73^{A-B}	8.94^{A}
	10μM	7.23^{A-B}	9.18^{A-B}	8.20^{A-B}
	1μM	7.65^{A-B}	8.93^{A-B}	8.29^{A-B}
Coumaric	1000μM	6.75^{A-C}	9.35^{A-B}	8.05^{A-B}
	100μM	8.14^{A}	7.98^{A-B}	8.06^{A-B}
	10μM	8.13^{A}	8.08^{A-B}	8.10^{A-B}
	1μM	7.66^{A-B}	8.45^{A-B}	8.06^{A-B}
Syringic	1000μM	5.66^{B-C}	8.65^{A-B}	7.16^{B-C}
	100μM	7.69^{A-B}	7.75^{B}	7.72^{A-C}
	10μM	8.04^{A-B}	8.85^{A-B}	8.44^{A-B}
	1μM	7.75^{A-B}	8.13^{A-B}	7.94^{A-B}
Vanillic	1000μM	8.39^{A}	8.60^{A-B}	8.49^{A-B}
	100μM	6.59^{A-C}	8.33^{A-B}	7.46^{A-C}
	10μM	8.10^{A}	9.38^{A-B}	8.74^{A-B}
	1μM	7.60^{A-B}	8.45^{A-B}	8.03^{A-B}
Benzoic	1000μM	7.73^{A-B}	9.97^{A}	8.69^{A-B}
	100μM	7.91^{A-B}	8.43^{A-B}	8.17^{A-B}
	10μM	4.76^{C}	7.98^{A-B}	6.37^{C}
	1μM	7.75^{A-B}	8.48^{A-B}	8.11^{A-B}
Check	0μM	7.34^{A-B}	8.78^{A-B}	8.06^{A-B}
Combined Across Conc.				
Ferulic		7.57^{A}**	9.20^{A}	8.38^{A}
Coumaric		7.67^{A}	8.47^{A}	8.07^{A}
Syringic		7.29^{A}	8.35^{A}	7.82^{A}
Vanillic		7.67^{A}	8.69^{A}	8.18^{A}
Benzoic		7.04^{A}	8.72^{A}	7.84^{A}
Combined Across Acids				
	1000μM	7.16^{A}**	9.10^{A}	8.10^{A}
	100μM	7.70^{A}	8.44^{A}	8.07^{A}
	10μM	7.25^{A}	8.69^{A}	7.97^{A}
	1μM	7.68^{A}	8.49^{A}	8.09^{A}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

Table C-39. Mean growth in plant height over time of greenhouse tobacco by experiment and treatment and combined across acids and concentrations.

		Experiment		
Acid	Conc.	1990	1991	Combined
		Plant Height Growth Per Day		
Ferulic	1000μM	0.76^{A*}	1.10^{A}	0.93^{A}
	100μM	0.76^{A}	0.60^{B-C}	0.68^{B-D}
	10μM	0.68^{A-B}	0.78^{A-C}	0.73^{A-D}
	1μM	0.69^{A-B}	0.61^{B-C}	0.65^{B-D}
Coumaric	1000μM	0.67^{A-B}	0.77^{A-C}	0.72^{A-D}
	100μM	0.65^{A-B}	0.86^{A-B}	0.76^{A-C}
	10μM	0.64^{A-B}	0.40^{C}	0.52^{D}
	1μM	0.73^{A-B}	0.59^{B-C}	0.66^{B-D}
Syringic	1000μM	0.75^{A-B}	0.83^{A-B}	0.79^{A-B}
	100μM	0.77^{A}	0.66^{B-C}	0.71^{A-D}
	10μM	0.68^{A-B}	0.59^{B-C}	0.63^{B-D}
	1μM	0.62^{A-B}	0.54^{B-C}	0.58^{C-D}
Vanillic	1000μM	0.55^{A}	0.54^{B-C}	0.55^{C-D}
	100μM	0.64^{A-B}	0.55^{B-C}	0.59^{B-D}
	10μM	0.76^{A}	0.72^{A-C}	0.74^{A-D}
	1μM	0.68^{A-B}	0.84^{A-B}	0.75^{A-D}
Benzoic	1000μM	0.81^{A}	0.51^{C}	0.66^{B-D}
	100μM	0.64^{A-B}	0.71^{A-C}	0.68^{B-D}
	10μM	0.69^{A-B}	0.57^{B-C}	0.63^{B-D}
	1μM	0.78^{A}	0.84^{A-B}	0.81^{A-B}
Check	0μM	0.69^{A-B}	0.80^{A-C}	0.75^{A-D}
Combined Across Conc.				
Ferulic		0.72^{A**}	0.77^{A}	0.75^{A}
Coumaric		0.67^{A}	0.66^{A}	0.67^{A}
Syringic		0.71^{A}	0.66^{A}	0.68^{A}
Vanillic		0.66^{A}	0.66^{A}	0.66^{A}
Benzoic		0.73^{A}	0.66^{A}	0.70^{A}
Combined Across Acids				
	1000μM	0.71^{A**}	0.75^{A}	0.73^{A}
	100μM	0.69^{A}	0.68^{A}	0.68^{A}
	10μM	0.69^{A}	0.61^{A}	0.65^{A}
	1μM	0.70^{A}	0.68^{A}	0.69^{A}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

Table C-40. Mean growth in leaf number over time of greenhouse tobacco by experiment and treatment and combined across acids and concentrations.

		Experiment		
Acid	Conc.	1990	1991	Combined
		Leaf Number Growth Per Day		
Ferulic	1000μM	0.15^{A-C*}	0.22^{A-B}	0.18^{A-C}
	100μM	0.14^{A-C}	0.18^{A-B}	0.16^{B-D}
	10μM	0.10^{C}	0.18^{A-B}	0.14^{C-D}
	1μM	0.15^{A-C}	0.21^{A-B}	0.18^{A-C}
Coumaric	1000μM	0.13^{A-C}	0.18^{A-B}	0.16^{B-D}
	100μM	0.13^{A-C}	0.19^{A-B}	0.16^{B-D}
	10μM	0.11^{C}	0.14^{B}	0.13^{D}
	1μM	0.17^{A-C}	0.20^{A-B}	0.19^{A-C}
Syringic	1000μM	0.16^{A-C}	0.22^{A-B}	0.19^{A-C}
	100μM	0.15^{A-C}	0.17^{A-B}	0.16^{B-D}
	10μM	0.15^{A-C}	0.20^{A-B}	0.17^{A-C}
	1μM	0.12^{B-C}	0.17^{A-B}	0.15^{C-D}
Vanillic	1000μM	0.12^{B-C}	0.18^{A-B}	0.15^{C-D}
	100μM	0.16^{A-C}	0.18^{A-B}	0.17^{A-D}
	10μM	0.15^{A-C}	0.22^{A}	0.19^{A-C}
	1μM	0.18^{A-B}	0.23^{A}	0.20^{A-B}
Benzoic	1000μM	0.13^{A-C}	0.18^{A-B}	0.15^{C-D}
	100μM	0.14^{A-C}	0.16^{A-B}	0.15^{C-D}
	10μM	0.13^{A-C}	0.17^{A-B}	0.15^{C-D}
	1μM	0.19^{A}	0.23^{A}	0.21^{A}
Check	0μM	0.15^{A-C}	0.20^{A-B}	0.17^{A-D}
Combined Across Conc.				
Ferulic		0.14^{A**}	0.20^{A}	0.17^{A-B}
Coumaric		0.14^{A}	0.18^{A}	0.16^{A}
Syringic		0.15^{A}	0.19^{A}	0.17^{A-B}
Vanillic		0.15^{A}	0.20^{A}	0.18^{B}
Benzoic		0.15^{A}	0.19^{A}	0.17^{A-B}
Combined Across Acids				
	1000μM	0.14^{A**}	0.20^{A-B}	0.17^{A}
	100μM	0.14^{A-B}	0.18^{A}	0.16^{A}
	10μM	0.13^{A}	0.18^{A}	0.16^{A}
	1μM	0.16^{B}	0.21^{B}	0.19^{B}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

Table C-41. Mean growth in stem diameter over time of greenhouse tobacco by experiment and treatment and combined across acids and concentrations.

		Experiment		
Acid	Conc.	1990	1991	Combined
		Stem Diameter Growth Per Day		
Ferulic	1000μM	0.12^{A-B*}	0.10^{A}	0.11^{A}
	100μM	0.09^{A-B}	0.11^{A}	0.10^{A}
	10μM	0.09^{A-C}	0.12^{A}	0.10^{A}
	1μM	0.11^{A-B}	0.10^{A}	0.10^{A}
Coumaric	1000μM	0.10^{A-B}	0.11^{A}	0.11^{A}
	100μM	0.08^{A-C}	0.06^{A}	0.07^{A-B}
	10μM	0.06^{A-C}	0.07^{A}	0.07^{A-B}
	1μM	0.11^{A-B}	0.10^{A}	0.11^{A}
Syringic	1000μM	0.07^{A-C}	0.09^{A}	0.08^{A-B}
	100μM	0.11^{A-B}	0.08^{A}	0.09^{A}
	10μM	0.10^{A-B}	0.09^{A}	0.09^{A}
	1μM	0.10^{A-B}	0.08^{A}	0.09^{A}
Vanillic	1000μM	0.10^{A-B}	0.09^{A}	0.09^{A}
	100μM	0.08^{A-C}	0.08^{A}	0.08^{A-B}
	10μM	0.06^{B-C}	0.09^{A}	0.07^{A-B}
	1μM	0.09^{A-B}	0.09^{A}	0.09^{A}
Benzoic	1000μM	0.13^{A}	0.09^{A}	0.11^{A}
	100μM	0.07^{A-C}	0.08^{A}	0.08^{A-B}
	10μM	0.02^{C}	0.06^{A}	0.04^{B}
	1μM	0.10^{A-B}	0.09^{A}	0.10^{A}
Check	0μM	0.09^{A-B}	0.11^{A}	0.10^{A}
Combined Across Conc.				
Ferulic		0.10^{A**}	0.11^{A}	0.10^{A}
Coumaric		0.09^{A}	0.09^{A}	0.09^{A-B}
Syringic		0.10^{A}	0.09^{A}	0.09^{A-B}
Vanillic		0.08^{A}	0.09^{A}	0.08^{A-B}
Benzoic		0.08^{A}	0.08^{A}	0.08^{B}
Combined Across Acids				
	1000μM	0.10^{A**}	0.10^{A}	0.10^{A}
	100μM	0.09^{A-B}	0.08^{A}	0.08^{A-B}
	10μM	0.07^{B}	0.09^{A}	0.07^{A}
	1μM	0.10^{A}	0.09^{A}	0.10^{A}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

Table C-42. Mean plant height, leaf number and stem diameter of greenhouse cocklebursby treatment and combined across acids and concentrations.

Acid	Conc.	Experiment		
		1990	1991	Combined
		Plant Ht.	Leaf No.	Stem Dia.
Ferulic	1000μM	11.0^{B}*	6.50^{B}	$1.37^{A\text{-}C}$
	100μM	12.1^{B}	$7.45^{A\text{-}B}$	$1.43^{A\text{-}C}$
	10μM	12.2^{B}	6.73^{B}	$1.40^{A\text{-}C}$
	1μM	10.3^{B}	$7.57^{A\text{-}B}$	$1.27^{A\text{-}C}$
Coumaric	1000μM	12.5^{B}	$7.23^{A\text{-}B}$	$1.77^{A\text{-}B}$
	100μM	11.8^{B}	$7.63^{A\text{-}B}$	$1.75^{A\text{-}B}$
	10μM	11.8^{B}	6.80^{B}	$1.13^{B\text{-}C}$
	1μM	16.9^{A}	9.10^{A}	1.90^{A}
Syringic	1000μM	10.3^{B}	7.00^{B}	$1.48^{A\text{-}C}$
	100μM	10.9^{B}	$7.17^{A\text{-}B}$	$1.27^{A\text{-}C}$
	10μM	9.1^{B}	$7.17^{A\text{-}B}$	$1.37^{A\text{-}C}$
	1μM	12.7^{B}	7.13^{B}	$1.48^{A\text{-}C}$
Vanillic	1000μM	9.7^{B}	$7.20^{A\text{-}B}$	$1.28^{A\text{-}C}$
	100μM	11.1^{B}	6.93^{B}	$1.28^{A\text{-}C}$
	10μM	11.7^{B}	7.08^{B}	1.08^{C}
	1μM	12.1^{B}	$7.23^{A\text{-}B}$	$1.27^{A\text{-}C}$
Benzoic	1000μM	12.6^{B}	$7.63^{A\text{-}B}$	$1.58^{A\text{-}C}$
	100μM	12.3^{B}	$7.50^{A\text{-}B}$	$1.68^{A\text{-}C}$
	10μM	11.8^{B}	$7.55^{A\text{-}B}$	$1.68^{A\text{-}C}$
	1μM	12.6^{B}	6.88^{B}	$1.28^{A\text{-}C}$
Check	0μM	12.1^{B}	7.08^{B}	$1.52^{A\text{-}C}$
Combined Across Conc.				
Ferulic		$11.40^{A\text{-}B}$**	7.06^{A}	$1.37^{A\text{-}B}$
Coumaric		13.25^{A}	7.69^{A}	1.64^{C}
Syringic		10.75^{B}	7.12^{A}	$1.40^{A\text{-}C}$
Vanillic		11.15^{B}	7.11^{A}	1.23^{A}
Benzoic		$12.33^{A\text{-}B}$	7.39^{A}	$1.56^{B\text{-}C}$
Combined Across Acids				
	1000μM	11.22^{A}**	7.11^{A}	1.50^{A}
	100μM	$11.64^{A\text{-}B}$	7.34^{A}	1.48^{A}
	10μM	11.32^{A}	7.07^{A}	1.33^{A}
	1μM	12.92^{B}	7.58^{A}	1.44^{A}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

Table C-43. Mean shoot fresh weight, root fresh weight, and wet shoot to root ratio of greenhouse cocklebures by treatment and combined across acids and concentrations.

		Experiment		
Acid	Conc.	1990	1991	Combined
		Shoot FW[z]	Root FW	Wet S/R Ratio
Ferulic	1000μM	2.90^{B*}	0.43^{A}	7.27^{A-B}
	100μM	2.13^{B}	0.35^{A}	6.42^{A-B}
	10μM	2.46^{B}	0.51^{A}	5.02^{A-B}
	1μM	2.01^{B}	0.46^{A}	4.21^{A-B}
Coumaric	1000μM	2.35^{B}	0.52^{A}	4.54^{A-B}
	100μM	2.49^{B}	0.30^{A}	7.72^{A-B}
	10μM	1.60^{B}	0.43^{A}	3.95^{A-B}
	1μM	4.63^{A}	0.52^{A}	8.93^{A}
Syringic	1000μM	1.93^{B}	0.29^{A}	6.50^{A-B}
	100μM	1.53^{B}	0.37^{A}	5.44^{A-B}
	10μM	1.35^{B}	0.26^{A}	5.62^{A-B}
	1μM	2.21^{B}	0.40^{A}	5.66^{A-B}
Vanillic	1000μM	1.37^{B}	0.55^{A}	2.54^{B}
	100μM	2.17^{B}	0.45^{A}	5.79^{A-B}
	10μM	1.95^{B}	0.38^{A}	5.42^{A-B}
	1μM	1.87^{B}	0.47^{A}	4.18^{A-B}
Benzoic	1000μM	2.71^{B}	0.55^{A}	8.09^{A}
	100μM	2.60^{B}	0.56^{A}	4.79^{A-B}
	10μM	2.08^{B}	0.47^{A}	4.89^{A-B}
	1μM	1.85^{B}	0.49^{A}	4.06^{A-B}
Check	0μM	2.28^{B}	0.50^{A}	5.85^{A-B}
Combined Across Conc.				
Ferulic		2.38^{A-B**}	0.44^{A-B}	5.73^{A}
Coumaric		2.77^{A}	0.44^{A-B}	6.29^{A}
Syringic		1.76^{B}	0.33^{A}	5.81^{A}
Vanillic		1.84^{B}	0.46^{A-B}	4.48^{A}
Benzoic		2.31^{A-B}	0.52^{B}	5.46^{A}
Combined Across Acids				
	1000μM	2.25^{A**}	0.47^{A}	5.79^{A}
	100μM	2.18^{A}	0.41^{A}	6.03^{A}
	10μM	1.89^{A}	0.41^{A}	4.98^{A}
	1μM	2.51^{A}	0.47^{A}	5.41^{A}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

[z] FW=Fresh weight;

Table C-44. Mean shoot dry weight, root dry weight, and dry shoot to root ratio of greenhouse cockleburs by treatment and combined across acids and concentrations.

		Experiment		
Acid	Conc.	1990	1991	Combined
		Shoot DW^{z}	Root DW	Dry S/R Ratio
Ferulic	1000μM	0.79^{A-C*}	0.078^{A-C}	11.0^{B}
	100μM	0.73^{A-C}	0.069^{A-C}	12.5^{B}
	10μM	0.74^{A-C}	0.053^{B-C}	14.6^{B}
	1μM	0.71^{A-C}	0.053^{B-C}	13.5^{B}
Coumaric	1000μM	0.66^{B-C}	0.084^{A-C}	8.6^{B}
	100μM	0.91^{A-C}	0.050^{B-C}	20.1^{A-B}
	10μM	0.77^{A-C}	0.079^{A-C}	10.5^{B}
	1μM	1.17^{A}	0.108^{A-B}	12.2^{B}
Syringic	1000μM	0.58^{B-C}	0.080^{A-C}	7.3^{B}
	100μM	0.77^{A-C}	0.040^{B-C}	19.3^{A-B}
	10μM	0.50^{C}	0.023^{C}	18.1^{A-B}
	1μM	0.76^{A-C}	0.060^{B-C}	15.1^{B}
Vanillic	1000μM	0.50^{C}	0.046^{B-C}	11.9^{B}
	100μM	0.77^{A-C}	0.084^{A-C}	12.8^{B}
	10μM	0.65^{B-C}	0.075^{A-C}	8.9^{B}
	1μM	0.80^{A-C}	0.062^{B-C}	13.1^{B}
Benzoic	1000μM	1.02^{A-B}	0.052^{B-C}	27.2^{A}
	100μM	0.89^{A-C}	0.106^{A-B}	8.6^{B}
	10μM	0.83^{A-C}	0.066^{B-C}	13.8^{B}
	1μM	0.77^{A-C}	0.104^{A-B}	8.0^{B}
Check	0μM	0.80^{A-C}	0.078^{A-C}	13.4^{B}
Combined Across Conc.				
Ferulic		0.74^{A-C**}	0.06^{A-B}	12.90^{A}
Coumaric		0.88^{B-C}	0.08^{A}	12.85^{A}
Syringic		0.65^{A}	0.05^{B}	14.95^{A}
Vanillic		0.68^{A-B}	0.07^{A-B}	11.68^{A}
Benzoic		0.88^{C}	0.08^{A}	14.40^{A}
Combined Across Acids				
	1000μM	0.71^{A**}	0.07^{A}	13.20^{A}
	100μM	0.81^{A}	0.07^{A}	14.66^{A}
	10μM	0.70^{A}	0.06^{A}	13.18^{A}
	1μM	0.84^{A}	0.08^{A}	12.38^{A}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

^{z}DW=Dry weight;

Table C-45. Mean number of seeds emerged, days to emergence and % leaf N of greenhouse cockleburs by treatment and combined across acids and concentrations.

		Experiment		
Acid	Conc.	1990	1991	Combined
		No. Emerged	Days to Emer.	% Leaf N
Ferulic	1000μM	0.67^{B-C*}	34.5^{A}	1.08^{C}
	100μM	2.25^{A-B}	26.8^{A-C}	2.00^{A-C}
	10μM	1.50^{A-C}	27.2^{A-C}	2.74^{A-B}
	1μM	1.33^{A-C}	20.0^{A-C}	2.68^{A-B}
Coumaric	1000μM	1.00^{A-C}	23.7^{A-C}	1.82^{A-C}
	100μM	0.75^{B-C}	21.0^{A-C}	3.17^{A}
	10μM	2.00^{A-C}	17.4^{C}	2.68^{A-B}
	1μM	1.33^{A-C}	28.7^{A-C}	2.15^{A-C}
Syringic	1000μM	1.75^{A-C}	19.5^{B-C}	2.82^{A-B}
	100μM	1.67^{A-C}	17.8^{C}	2.68^{A-B}
	10μM	2.00^{A-C}	20.6^{A-C}	2.01^{A-C}
	1μM	1.75^{A-C}	21.9^{A-C}	2.20^{A-C}
Vanillic	1000μM	1.75^{A-C}	22.0^{A-C}	2.35^{A-C}
	100μM	0.75^{B-C}	19.7^{A-C}	2.29^{A-C}
	10μM	2.50^{A}	23.9^{A-C}	2.72^{A-B}
	1μM	1.33^{A-C}	16.0^{C}	2.86^{A-B}
Benzoic	1000μM	1.25^{A-C}	18.5^{B-C}	2.28^{A-C}
	100μM	2.00^{A-C}	28.5^{A-C}	1.97^{A-C}
	10μM	1.50^{A-C}	22.0^{A-C}	2.49^{A-B}
	1μM	1.75^{A-C}	18.6^{B-C}	1.71^{B-C}
Check	0μM	1.08^{A-C}	24.4^{A-C}	1.96^{A-C}
Combined Across Conc.				
Ferulic		1.44^{A**}	27.13^{A}	2.13^{A}
Coumaric		1.27^{A}	22.70^{A-B}	2.46^{A}
Syringic		1.79^{A}	19.95^{B}	2.43^{A}
Vanillic		1.58^{A}	20.40^{B}	2.56^{A}
Benzoic		1.63^{A}	21.90^{A-B}	2.11^{A}
Combined Across Acids				
	1000μM	1.28^{A**}	23.64^{A}	2.07^{A}
	100μM	1.48^{A-B}	22.76^{A}	2.42^{A}
	10μM	1.90^{B}	22.22^{A}	2.53^{A}
	1μM	1.50^{A-B}	21.04^{A}	2.32^{A}

* Means with the same letter are not significantly different at alpha=0.05 (DMRT).

** Means with the same letter are not significantly different at p=0.05 (Contrasts).

APPENDIX D
LAB DATA

Table D-1. Mean concentration of p-hydroxybenzoic and vanillic acids by tillage and sequence at first sampling for Knoxville and Greenville in 1990 and combined over locations.

		Tillage (T)							
		No-Till		Conv. (cover)		Conv. (no cover)			
Sequence (S)		(T1)		(T2)		(T3)		$\bar{X}$	
		Acid							
		BEN	VAN	BEN	VAN	BEN	VAN	BEN	VAN
		TES Concentration ($\mu g\ g^{-1}$)							
Tb/Br[y]	(S1)	2.47	3.49	1.35	2.95	1.79	2.87	1.86	3.10
		1.24[z]	0.52	1.47	0.62	1.27	0.54	0.73	0.31
Br/Tb/Br	(S3)	2.15	0.96	2.76	1.43	5.34	2.34	3.41	1.58
		1.28	0.54	1.31	0.55	1.26	0.53	0.73	0.31
	$\bar{X}$	2.30	2.23	2.06	2.19	3.56	2.61		
		0.91	0.38	1.03	0.44	0.92	0.39		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob.>F	BEN	0.8674		0.3293		0.3328		0.1668	
	VAN	0.9566		0.4755		0.5195		0.0049	
		PSF Concentration ($\mu g\ g^{-1}$)							
Tb/Br	(S1)	1.31	2.81	1.03	3.29	1.00	3.13	1.11	3.08
		0.14	0.52	0.14	0.50	0.14	0.50	0.09	0.29
Br/Tb/Br	(S3)	0.71	2.49	0.97	2.72	0.88	2.72	0.85	2.64
		0.16	0.58	0.14	0.50	0.14	0.51	0.09	0.29
	$\bar{X}$	1.01	2.64	1.00	3.00	0.94	2.93		
		0.12	0.39	0.11	0.36	0.11	0.36		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob.>F	BEN	0.9410		0.6288		0.6366		0.0245	
	VAN	0.5430		0.6319		0.8791		0.3140	
		Overall Concentration ($\mu g\ g^{-1}$)							
Tb/Br	(S1)	1.80	3.19	1.33	3.09	1.34	3.00	1.49	3.10
		1.43	0.35	1.43	0.36	1.43	0.35	1.34	0.20
Br/Tb/Br	(S3)	1.29	1.71	2.01	2.06	3.10	2.54	2.13	2.11
		1.44	0.36	1.43	0.35	1.43	0.35	1.34	0.20
	$\bar{X}$	1.55	2.46	1.67	2.58	2.22	2.77		
		1.37	0.25	1.37	0.26	1.36	0.25		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob.>F	BEN	0.8556		0.3058		0.4019		0.2147	
	VAN	0.7417		0.3781		0.5953		0.0014	

[y] Tb=Tobacco, Br=Broccoli, TES=Tobacco Experiment Station (Greeneville), PSF=Plant Science Farm (Knoxville), BEN=p-hydroxybenzoic acid, VAN=vanillic acid. [z] Standard error appears below each mean.

Table D-2. Mean concentration of p-hydroxybenzoic and vanillic acids by tillage and sequence at second sampling for Knoxville and Greenville in 1990 and combined over locations.

Sequence (S)		Tillage (T)							
		No-Till (T1)		Conv. (cover) (T2)		Conv. (no cover) (T3)		$\bar{X}$	
		Acid							
		BEN	VAN	BEN	VAN	BEN	VAN	BEN	VAN
		TES Concentration ($\mu g\ g^{-1}$)							
Tb/Br^{y}	(S1)	2.32	5.24	2.02	5.84	0.41	2.24	1.58	4.44
		0.51^{z}	0.76	0.49	0.73	0.45	0.67	0.31	0.41
Br/Tb/Br	(S3)	1.43	4.34	1.35	4.08	0.51	1.25	1.09	3.22
		0.48	0.71	0.44	0.66	0.49	0.74	0.31	0.41
	$\bar{X}$	1.87	4.79	1.68	4.96	0.46	1.75		
		0.35	0.51	0.33	0.46	0.38	0.54		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob.>F	BEN	0.6598		0.0189		0.0231		0.2620	
	VAN	0.8013		0.0030		0.0010		0.0811	
		PSF Concentration ($\mu g\ g^{-1}$)							
Tb/Br	(S1)	0.95	0.83	0.85	0.93	0.90	0.47	0.90	0.74
		0.14	0.07	0.12	0.06	0.12	0.06	0.09	0.04
Br/Tb/Br	(S3)	0.88	0.51	0.89	0.44	0.97	0.38	0.92	0.44
		0.12	0.06	0.13	0.63	0.12	0.06	0.09	0.04
	$\bar{X}$	0.91	0.67	0.87	0.68	0.94	0.42		
		0.09	0.05	0.09	0.05	0.09	0.05		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob.>F	BEN	0.7119		0.8346		0.5531		0.8951	
	VAN	0.8780		0.0008		0.0006		0.0002	
		Overall Concentration ($\mu g\ g^{-1}$)							
Tb/Br	(S1)	1.56	2.77	1.38	3.22	0.77	1.52	1.24	2.50
		0.29	1.55	0.28	1.54	0.27	1.54	0.20	1.51
Br/Tb/Br	(S3)	1.09	2.36	1.08	2.28	0.87	1.11	1.01	1.92
		0.27	1.54	0.27	1.54	0.28	1.54	0.20	1.51
	$\bar{X}$	1.32	2.57	1.23	2.75	0.82	1.32		
		0.22	1.51	0.22	1.51	0.22	1.51		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob.>F	BEN	0.6879		0.0387		0.0782		0.2857	
	VAN	0.6379		0.0039		0.0008		0.1053	

[y] Tb=Tobacco, Br=Broccoli, TES=Tobacco Experiment Station (Greeneville), PSF=Plant Science Farm (Knoxville), BEN=p-hydroxybenzoic acid, VAN=vanillic acid. [z] Standard error appears below each mean.

Table D-3. Mean concentration of p-hydroxybenzoic and vanillic acids by tillage and sequence at third sampling for Knoxville and Greenville in 1990 and combined over locations.

Sequence (S)		Tillage (T)							
		No-Till (T1)		Conv. (cover) (T2)		Conv. (no cover) (T3)		$\bar{X}$	
		Acid							
		BEN	VAN	BEN	VAN	BEN	VAN	BEN	VAN
		TES Concentration ($\mu g\ g^{-1}$)							
Tb/Br[y]	(S1)	1.20	4.40	1.29	3.56	0.64	2.83	1.04	3.60
		0.17[z]	0.40	0.19	0.45	0.17	0.41	0.10	0.23
Br/Tb/Br	(S3)	1.45	4.68	1.16	3.66	1.07	2.64	1.23	3.66
		0.17	0.40	0.17	0.41	0.17	0.41	0.10	0.23
	$\bar{X}$	1.33	4.54	1.22	3.61	0.86	2.74		
		0.12	0.29	0.13	0.31	0.12	0.29		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob.>F	BEN	0.5936		0.0161		0.0765		0.2112	
	VAN	0.0525		0.0006		0.0752		0.8457	
		PSF Concentration ($\mu g\ g^{-1}$)							
Tb/Br	(S1)	0.90	0.90	0.94	0.67	0.93	0.37	0.92	0.65
		0.13	0.09	0.12	0.09	0.12	0.08	0.07	0.05
Br/Tb/Br	(S3)	0.96	0.56	0.85	0.41	0.87	0.45	0.89	0.47
		0.12	0.08	0.12	0.08	0.13	0.09	0.07	0.05
	$\bar{X}$	0.93	0.73	0.89	0.54	0.90	0.41		
		0.08	0.06	0.09	0.06	0.09	0.06		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob.>F	BEN	0.7886		0.8283		0.9606		0.7832	
	VAN	0.0462		0.0026		0.1594		0.0361	
		Overall Concentration ($\mu g\ g^{-1}$)							
Tb/Br	(S1)	1.16	2.71	1.03	2.15	0.84	1.61	1.01	2.16
		0.14	0.60	0.14	0.60	0.13	0.60	0.08	0.56
Br/Tb/Br	(S3)	1.15	2.63	0.98	2.06	0.97	1.41	1.03	2.03
		0.13	0.60	0.14	0.60	0.13	0.60	0.08	0.56
	$\bar{X}$	1.16	2.67	1.00	2.10	0.90	1.51		
		0.10	0.57	0.10	0.57	0.10	0.57		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob.>F	BEN	0.2740		0.0599		0.4576		0.8356	
	VAN	0.0392		0.0001		0.0272		0.5557	

[y] Tb=Tobacco, Br=Broccoli, TES=Tobacco Experiment Station (Greeneville), PSF=Plant Science Farm (Knoxville), BEN=p-hydroxybenzoic acid, VAN=vanillic acid. [z] Standard error appears below each mean.

Table D-4. Mean concentration of p-hydroxybenzoic and vanillic acids by tillage and sequence at fourth sampling for Knoxville and Greenville in 1990 and combined over locations.

	Tillage (T)							
	No-Till (T1)		Conv. (cover) (T2)		Conv. (no cover) (T3)		$\bar{X}$	
	Acid							
Sequence (S)	BEN	VAN	BEN	VAN	BEN	VAN	BEN	VAN
	TES Concentration ($\mu g\ g^{-1}$)							
Tb/Br[y] (S1)	4.03	3.87	1.61	2.71	1.90	3.37	2.51	3.32
	1.53[z]	0.66	1.51	0.65	1.57	0.67	0.89	0.42
Br/Tb/Br (S3)	2.82	1.77	1.56	0.52	4.26	2.38	2.88	1.55
	1.64	0.70	1.66	0.71	1.62	0.70	0.89	0.42
$\bar{X}$	3.43	2.82	1.59	1.61	3.08	2.87		
	1.11	0.50	1.12	0.50	1.09	0.49		
Contrast	T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob. > F BEN	0.2776		0.8267		0.3637		0.7800	
VAN	0.0942		0.9369		0.0767		0.0058	
	PSF Concentration ($\mu g\ g^{-1}$)							
Tb/Br (S1)	1.20	3.18	1.44	4.47	1.17	3.71	1.27	3.78
	0.18	0.55	0.21	0.65	0.18	0.56	0.10	0.32
Br/Tb/Br (S3)	0.85	3.09	1.05	2.47	0.81	2.03	0.90	2.53
	0.19	0.58	0.18	0.56	0.18	0.54	0.10	0.32
$\bar{X}$	1.03	3.14	1.24	3.47	0.99	2.87		
	0.14	0.42	0.15	0.46	0.13	0.39		
Contrast	T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob. > F BEN	0.3551		0.8215		0.2419		0.0335	
VAN	0.6391		0.6355		0.3682		0.0203	
	Overall Concentration ($\mu g\ g^{-1}$)							
Tb/Br (S1)	2.72	3.47	1.45	3.58	1.34	3.47	1.84	3.51
	1.21	0.44	1.21	0.44	1.21	0.44	1.05	0.26
Br/Tb/Br (S3)	1.69	2.41	1.47	1.55	2.69	2.28	1.95	2.08
	1.21	0.44	1.22	0.45	1.21	0.44	1.05	0.26
$\bar{X}$	2.20	2.94	1.46	2.57	2.01	2.88		
	1.09	0.32	1.09	0.32	1.09	0.32		
Contrast	T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob. > F BEN	0.3344		0.7994		0.4768		0.8528	
VAN	0.3970		0.8754		0.4916		0.0003	

[y] Tb=Tobacco, Br=Broccoli, TES=Tobacco Experiment Station (Greeneville), PSF=Plant Science Farm (Knoxville), BEN=p-hydroxybenzoic acid, VAN=vanillic acid. [z] Standard error appears below each mean.

Table D-5. **Mean concentration change per day of p-hydroxybenzoic and vanillic acids by tillage and sequence for Knoxville and Greenville in 1990 and combined over locations.**

		Tillage (T)							
		No-Till		Conv. (cover)		Conv. (no cover)			
Sequence (S)		(T1)		(T2)		(T3)		$\bar{X}$	
		Acid							
		BEN	VAN	BEN	VAN	BEN	VAN	BEN	VAN
		TES Concentration Change Per Day ($\mu g\ g^{-1}$)							
Tb/Br[y]	(S1)	-0.17	0.05	-0.01	0.16	-0.10	-0.04	-0.10	0.06
			0.07	0.13	0.07	0.13	0.07	0.08	0.05
Br/Tb/Br	(S3)	-0.09	0.34	-0.12	0.32	-0.41	0.00	-0.21	0.22
		0.13	0.07	0.13	0.07	0.13	0.07	0.08	0.05
		-0.13	0.19	-0.06	0.24	-0.26	-0.02		
	$\bar{X}$	0.09	0.05	0.09	0.05	0.09	0.05		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob.>F	BEN	0.5948		0.3518		0.1533		0.3116	
	VAN	0.4698		0.0033		0.0007		0.0070	
		PSF Concentration Change Per Day ($\mu g\ g^{-1}$)							
Tb/Br	(S1)	-0.02	-0.16	-0.02	-0.21	-0.01	-0.17	-0.02	-0.18
		0.01	0.04	0.01	0.04	0.01	0.04	0.01	0.02
Br/Tb/Br	(S3)	0.01	-0.12	-0.01	-0.15	0.00	-0.15	0.00	-0.14
		0.01	0.04	0.01	0.04	0.01	0.04	0.01	0.02
		-0.01	-0.14	-0.01	-0.18	0.00	-0.16		
	$\bar{X}$	0.01	0.03	0.01	0.03	0.01	0.03		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob.>F	BEN	0.5995		0.2156		0.4610		0.0765	
	VAN	0.2464		0.5423		0.5688		0.1669	
		Overall Concentration Change Per Day ($\mu g\ g^{-1}$)							
Tb/Br	(S1)	-0.10	-0.05	-0.01	-0.02	-0.05	-0.11	-0.06	-0.06
		0.09	0.15	0.09	0.15	0.09	0.15	0.08	0.15
Br/Tb/Br	(S3)	-0.04	0.11	-0.06	0.08	-0.20	-0.08	-0.10	0.04
		0.09	0.15	0.09	0.15	0.09	0.15	0.08	0.15
		-0.07	0.03	-0.04	0.03	-0.13	-0.09		
	$\bar{X}$	0.08	0.15	0.08	0.15	0.08	0.15		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob.>F	BEN	0.6242		0.3804		0.1755		0.3804	
	VAN	0.9791		0.0104		0.0098		0.0084	

[y] Tb=Tobacco, Br=Broccoli, TES=Tobacco Experiment Station (Greeneville), PSF=Plant Science Farm (Knoxville), BEN=p-hydroxybenzoic acid, VAN=vanillic acid. [z] Standard error appears below each mean.

Table D-6. Mean concentration of p-coumaric and ferulic acids by tillage and sequence at first sampling for Knoxville and Greenville in 1990 and combined over locations.

		Tillage (T)							
Sequence (S)		No-Till (T1)		Conv. (cover) (T2)		Conv. (no cover) (T3)		$\bar{X}$	
		Acid							
		COU	FER	COU	FER	COU	FER	COU	FER
		TES Concentration ($\mu g\ g^{-1}$)							
Tb/Br[y]	(S1)	11.79	5.55	9.87	4.12	6.98	2.90	9.55	4.19
		0.99[z]	0.81	1.18	0.96	1.02	0.82	0.58	0.47
Br/Tb/Br	(S3)	10.67	3.52	11.36	3.52	6.97	2.48	9.67	3.17
		1.02	0.83	1.05	0.85	1.01	0.82	0.58	0.47
		11.23	4.53	10.61	3.82	6.97	2.69		
	$\bar{X}$	0.73	0.59	0.82	0.67	0.73	0.60		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob.>F	COU	0.6106		0.0010		0.0102		0.8942	
	FER	0.4685		0.0398		0.2666		0.1624	
		PSF Concentration ($\mu g\ g^{-1}$)							
Tb/Br	(S1)	6.87	5.88	5.96	5.29	6.22	3.74	6.35	4.97
		1.61	0.87	1.55	0.83	1.55	0.83	0.97	0.48
Br/Tb/Br	(S3)	7.54	5.67	7.89	4.39	7.35	3.82	7.60	4.62
		1.78	0.96	1.57	0.84	1.58	0.85	0.97	0.48
		7.20	5.77	6.93	4.84	6.79	3.78		
	$\bar{X}$	1.26	0.66	1.16	0.60	1.16	0.60		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob.>F	COU	0.8707		0.8058		0.9238		0.3272	
	FER	0.3404		0.0558		0.2212		0.6244	
		Overall Concentration ($\mu g\ g^{-1}$)							
Tb/Br	(S1)	9.55	5.65	7.72	4.81	6.50	3.40	7.92	4.62
		1.06	0.54	1.07	0.55	1.05	0.54	0.77	0.31
Br/Tb/Br	(S3)	9.18	4.58	9.61	3.85	7.18	3.14	8.66	3.86
		1.06	0.56	1.06	0.54	1.06	0.54	0.77	0.31
		9.36	5.12	8.66	4.33	6.84	3.27		
	$\bar{X}$	0.86	0.39	0.87	0.40	0.86	0.39		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob.>F	COU	0.4636		0.0092		0.0571		0.3150	
	FER	0.1806		0.0021		0.0688		0.0913	

[y] Tb=Tobacco, Br=Broccoli, TES=Tobacco Experiment Station (Greeneville), PSF=Plant Science Farm (Knoxville), COU=p-coumaric acid, FER=ferulic acid. [z] Standard error appears below each mean.

Table D-7. Mean concentration of p-coumaric and ferulic acids by tillage and sequence at second sampling for Knoxville and Greenville in 1990 and combined over locations.

Sequence (S)		Tillage (T)							
		No-Till (T1)		Conv. (cover) (T2)		Conv. (no cover) (T3)		$\bar{X}$	
		Acid							
		COU	FER	COU	FER	COU	FER	COU	FER
		TES Concentration ($\mu g\ g^{-1}$)							
Tb/Br[y]	(S1)	12.04	12.79	10.67	9.38	4.54	2.15	9.08	8.11
		2.57[z]	2.87	2.47	2.76	2.28	2.54	1.40	1.56
Br/Tb/Br	(S3)	9.49	9.50	11.40	5.65	11.06	7.70	10.65	7.62
		2.41	2.69	2.23	2.48	2.51	2.81	1.40	1.56
	$\bar{X}$	10.76	11.14	11.04	7.51	7.80	4.93		
		1.71	1.90	1.56	1.74	1.82	2.03		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob.>F	COU	0.9061		0.3066		0.2213		0.4835	
	FER	0.1741		0.0677		0.3729		0.8437	
		PSF Concentration ($\mu g\ g^{-1}$)							
Tb/Br	(S1)	5.17	2.44	4.61	1.05	1.58	0.27	3.78	1.26
		0.44	0.45	0.39	0.40	0.39	0.40	0.24	0.25
Br/Tb/Br	(S3)	3.52	0.73	2.33	0.72	1.94	0.09	2.60	0.51
		0.38	0.39	0.40	0.42	0.38	0.40	0.24	0.25
	$\bar{X}$	4.34	1.58	3.47	0.88	1.76	0.18		
		0.27	0.28	0.27	0.28	0.27	0.27		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob.>F	COU	0.0472		0.0001		0.0008		0.0085	
	FER	0.1103		0.0041		0.0981		0.0781	
		Overall Concentration ($\mu g\ g^{-1}$)							
Tb/Br	(S1)	8.59	7.62	7.59	4.99	2.76	0.79	6.31	4.64
		3.88	3.80	3.87	3.78	3.85	3.75	3.76	3.60
Br/Tb/Br	(S3)	6.74	5.72	7.11	3.59	6.39	3.53	6.74	4.28
		3.86	3.75	3.86	3.76	3.87	3.77	3.76	3.60
	$\bar{X}$	7.66	6.67	7.35	4.29	4.57	2.16		
		3.78	3.64	3.78	3.63	3.78	3.64		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob.>F	COU	0.7766		0.0106		0.0166		0.6684	
	FER	0.0884		0.0030		0.1256		0.8826	

[y] Tb=Tobacco, Br=Broccoli, TES=Tobacco Experiment Station (Greeneville), PSF=Plant Science Farm (Knoxville), COU=p-coumaric acid, FER=ferulic acid. [z] Standard error appears below each mean.

Table D-8. Mean concentration of p-coumaric and ferulic acids by tillage and sequence at third sampling for Knoxville and Greenville in 1990 and combined over locations.

Sequence (S)		Tillage (T)							
		No-Till (T1)		Conv. (cover) (T2)		Conv. (no cover) (T3)		X̄	
		Acid							
		COU	FER	COU	FER	COU	FER	COU	FER
		TES Concentration ($\mu g\ g^{-1}$)							
Tb/Br[y]	(S1)	11.11	8.68	10.77	8.52	4.93	2.70	8.94	6.63
		2.10[z]	2.50	2.34	2.79	2.10	2.50	1.25	1.43
Br/Tb/Br	(S3)	10.75	10.33	10.42	6.82	4.53	2.42	8.57	6.52
		2.07	2.46	2.11	2.51	2.12	2.53	1.25	1.43
	X̄	10.93	9.51	10.60	7.67	4.73	2.56		
		1.51	1.76	1.63	1.92	1.55	1.82		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob.>F	COU	0.8825		0.0095		0.0246		0.8277	
	FER	0.5066		0.0149		0.0906		0.9583	
		PSF Concentration ($\mu g\ g^{-1}$)							
Tb/Br	(S1)	4.86	3.50	2.89	1.40	1.40	0.29	3.05	1.73
		0.54	0.33	0.52	0.32	0.50	0.30	0.31	0.18
Br/Tb/Br	(S3)	2.02	-0.08	1.30	-0.26	1.54	0.28	1.62	-0.02
		0.49	0.30	0.50	0.31	0.54	0.33	0.31	0.18
	X̄	3.44	1.71	2.10	0.57	1.47	0.29		
		0.36	0.22	0.37	0.22	0.37	0.22		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob.>F	COU	0.0217		0.0022		0.2596		0.0063	
	FER	0.0037		0.0008		0.4098		0.0001	
		Overall Concentration ($\mu g\ g^{-1}$)							
Tb/Br	(S1)	7.58	4.78	7.09	6.39	2.93	0.67	5.87	3.94
		3.98	4.13	3.99	4.13	3.98	4.11	3.87	3.93
Br/Tb/Br	(S3)	6.66	5.90	6.03	3.93	2.97	0.64	5.22	3.49
		3.97	4.11	3.98	4.12	3.97	4.11	3.87	3.93
	X̄	7.12	5.34	6.56	5.16	2.95	0.65		
		3.90	3.98	3.90	3.98	3.90	3.97		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob.>F	COU	0.6331		0.0006		0.0032		0.4867	
	FER	0.9105		0.0037		0.0067		0.7207	

[y] Tb=Tobacco, Br=Broccoli, TES=Tobacco Experiment Station (Greeneville), PSF=Plant Science Farm (Knoxville), COU=p-coumaric acid, FER=ferulic acid. [z] Standard error appears below each mean.

Table D-9. Mean concentration of p-coumaric and ferulic acids by tillage and sequence at fourth sampling for Knoxville and Greenville in 1990 and combined over locations.

		Tillage (T)							
Sequence (S)		No-Till (T1)		Conv. (cover) (T2)		Conv. (no cover) (T3)		$\bar{X}$	
		Acid							
		COU	FER	COU	FER	COU	FER	COU	FER
		TES Concentration ($\mu g\ g^{-1}$)							
Tb/Br[y]	(S1)	13.06	6.20	9.27	3.69	9.24	4.48	10.52	4.79
		1.46[z]	0.80	1.43	0.79	1.48	0.81	0.99	0.53
Br/Tb/Br	(S3)	10.25	3.66	9.95	1.20	5.44	1.61	8.55	2.16
		1.54	0.85	1.56	0.86	1.53	0.84	0.99	0.53
		11.66	4.93	9.61	2.45	7.34	3.04		
	$\bar{X}$	1.14	0.62	1.14	0.62	1.13	0.61		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob.>F	COU	0.1664		0.0075		0.1202		0.0980	
	FER	0.0079		0.0282		0.4503		0.0011	
		PSF Concentration ($\mu g\ g^{-1}$)							
Tb/Br	(S1)	8.12	5.27	10.14	7.36	7.06	4.63	8.44	5.76
		2.12	1.04	2.42	1.22	2.17	1.07	1.65	0.72
Br/Tb/Br	(S3)	6.52	4.82	8.52	3.94	8.84	4.75	7.96	4.50
		2.21	1.10	2.17	1.07	2.10	1.03	1.65	0.72
		7.32	5.05	9.33	5.65	7.95	4.69		
	$\bar{X}$	1.84	0.85	1.96	0.93	1.79	0.82		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob.>F	COU	0.3670		0.7066		0.5080		0.7396	
	FER	0.6217		0.7112		0.4099		0.1419	
		Overall Concentration ($\mu g\ g^{-1}$)							
Tb/Br	(S1)	10.73	5.70	9.22	5.28	8.10	4.40	9.35	5.12
		1.23	1.44	1.22	1.44	1.24	1.44	0.85	1.34
Br/Tb/Br	(S3)	8.42	4.15	9.16	2.71	7.56	3.58	8.38	3.48
		1.24	1.44	1.26	1.45	1.22	1.44	0.85	1.34
		9.58	4.92	9.19	3.99	7.83	3.99		
	$\bar{X}$	0.96	1.37	0.98	1.37	0.97	1.37		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob.>F	COU	0.7295		0.1195		0.2339		0.2789	
	FER	0.1648		0.1580		0.9962		0.0036	

[y] Tb=Tobacco, Br=Broccoli, TES=Tobacco Experiment Station (Greeneville), PSF=Plant Science Farm (Knoxville), COU=p-coumaric acid, FER=ferulic acid. [z] Standard error appears below each mean.

Table D-10. Mean concentration change per day of p-coumaric and ferulic acids by tillage and sequence for Knoxville and Greenville in 1990 and combined over locations.

		Tillage (T)							
Sequence (S)		No-Till (T1)		Conv. (cover) (T2)		Conv. (no cover) (T3)		$\bar{X}$	
		Acid							
		COU	FER	COU	FER	COU	FER	COU	FER
		TES Concentration Change Per Day ($\mu g\ g^{-1}$)							
Tb/Br[y]	(S1)	-0.07	0.45	0.19	0.65	-0.31	-0.15	-0.06	0.32
		0.20[z]	0.27	0.20	0.27	0.20	0.27	0.13	0.16
Br/Tb/Br	(S3)	0.05	0.78	-0.07	0.34	-0.06	0.06	-0.03	0.39
		0.20	0.27	0.20	0.27	0.20	0.27	0.13	0.16
	$\bar{X}$	-0.01	0.62	0.06	0.49	-0.19	-0.05		
		0.15	0.19	0.15	0.19	0.15	0.19		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob.>F	COU	0.7154		0.3625		0.2096		0.8296	
	FER	0.6471		0.0223		0.0551		0.7361	
		PSF Concentration Change Per Day ($\mu g\ g^{-1}$)							
Tb/Br	(S1)	-0.11	-0.22	-0.26	-0.34	-0.38	-0.28	-0.25	-0.28
		0.12	0.06	0.12	0.06	0.12	0.06	0.09	0.03
Br/Tb/Br	(S3)	-0.30	-0.31	-0.48	-0.28	-0.47	-0.29	-0.42	-0.30
		0.12	0.06	0.12	0.06	0.12	0.06	0.09	0.03
	$\bar{X}$	-0.20	-0.27	-0.37	-0.31	-0.43	-0.28		
		0.10	0.04	0.10	0.04	0.10	0.04		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob.>F	COU	0.1215		0.0469		0.6086		0.0667	
	FER	0.4545		0.7766		0.6389		0.7197	
		Overall Concentration Change Per Day ($\mu g\ g^{-1}$)							
Tb/Br	(S1)	-0.09	0.11	-0.04	0.16	-0.35	-0.21	-0.16	0.02
		0.17	0.35	0.17	0.35	0.17	0.35	0.15	0.33
Br/Tb/Br	(S3)	-0.13	0.24	-0.28	0.03	-0.27	-0.12	-0.22	0.05
		0.17	0.35	0.17	0.35	0.17	0.35	0.15	0.33
	$\bar{X}$	-0.11	0.18	-0.16	0.09	-0.31	-0.16		
		0.16	0.33	0.16	0.33	0.16	0.33		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob.>F	COU	0.6443		0.0664		0.1618		0.4489	
	FER	0.5610		0.0222		0.0795		0.8127	

[y] Tb=Tobacco, Br=Broccoli, TES=Tobacco Experiment Station (Greeneville), PSF=Plant Science Farm (Knoxville), COU=p-coumaric acid, FER=ferulic acid. [z] Standard error appears below each mean.

Table D-11. Mean concentration of syringic acid and total acids by tillage and sequence at first sampling for Knoxville and Greenville in 1990 and combined over locations.

		Tillage (T)							
Sequence (S)		No-Till (T1)		Conv. (cover) (T2)		Conv. (no cover) (T3)		$\bar{X}$	
		Acid							
		SYR	TOT	SYR	TOT	SYR	TOT	SYR	TOT
		TES Concentration ($\mu g\ g^{-1}$)							
Tb/Br[y]	(S1)	1.09	24.39	0.80	19.09	0.55	15.09	0.81	19.52
		0.71[z]	3.36	0.84	3.99	0.72	3.44	0.41	1.96
Br/Tb/Br	(S3)	2.45	19.75	2.79	21.85	3.75	20.88	3.00	20.83
		0.73	3.47	0.75	3.54	0.72	3.42	0.41	1.96
	$\bar{X}$	1.77	22.07	1.79	20.47	2.15	17.99		
		0.52	2.46	0.59	2.79	0.52	2.49		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob.>F	SYR	0.9786		0.6030		0.6858		0.0033	
	TOT	0.6968		0.2454		0.5501		0.6545	
		PSF Concentration ($\mu g\ g^{-1}$)							
Tb/Br	(S1)	0.86	17.76	0.81	16.37	0.51	14.59	0.73	16.24
		0.15	2.78	0.14	2.67	0.14	2.66	0.08	1.61
Br/Tb/Br	(S3)	0.56	16.96	0.60	16.56	0.46	15.23	0.54	16.25
		0.17	3.07	0.15	2.70	0.15	2.73	0.08	1.61
	$\bar{X}$	0.71	17.36	0.70	16.47	0.48	14.91		
		0.11	2.15	0.10	1.97	0.10	1.97		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob.>F	SYR	0.9690		0.1837		0.1412		0.1350	
	TOT	0.7682		0.4231		0.5555		0.9957	
		Overall Concentration ($\mu g\ g^{-1}$)							
Tb/Br	(S1)	0.94	21.23	0.84	17.79	0.48	14.68	0.75	17.90
		0.97	3.07	0.97	3.09	0.96	3.06	0.90	2.62
Br/Tb/Br	(S3)	1.41	18.21	1.82	19.32	2.13	18.05	1.78	18.52
		0.97	3.12	0.97	3.08	0.97	3.07	0.90	2.62
	$\bar{X}$	1.17	19.72	1.33	18.55	1.30	16.36		
		0.92	2.77	0.92	2.77	0.92	2.75		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob.>F	SYR	0.7323		0.7652		0.9557		0.0051	
	TOT	0.5807		0.1051		0.2868		0.6941	

[y] Tb=Tobacco, Br=Broccoli, TES=Tobacco Experiment Station (Greeneville), PSF=Plant Science Farm (Knoxville), SYR=syringic acid, TOT=total acids. [z] Standard error appears below each mean.

Table D-12. Mean concentration of syringic acid and total acids by tillage and sequence at second sampling for Knoxville and Greenville in 1990 and combined over locations.

Sequence (S)		Tillage (T)							
		No-Till (T1)		Conv. (cover) (T2)		Conv. (no cover) (T3)		$\bar{X}$	
		Acid							
		SYR	TOT	SYR	TOT	SYR	TOT	SYR	TOT
		TES Concentration ($\mu g\ g^{-1}$)							
Tb/Br[y]	(S1)	1.36	33.75	1.76	29.69	0.13	9.46	1.08	24.30
		0.40[z]	4.81	0.39	4.63	0.36	4.26	0.22	2.61
Br/Tb/Br	(S3)	0.62	25.37	0.61	23.07	0.01	20.52	0.41	22.99
		0.38	4.51	0.35	4.16	0.40	4.70	0.22	2.61
	$\bar{X}$	0.99	29.56	1.18	26.38	0.07	14.99		
		0.27	3.19	0.25	2.92	0.29	3.41		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob. > F	SYR	0.5930		0.0573		0.0154		0.0741	
	TOT	0.4656		0.0158		0.0317		0.7513	
		PSF Concentration ($\mu g\ g^{-1}$)							
Tb/Br	(S1)	1.58	10.96	1.30	8.76	1.27	4.50	1.39	8.07
		0.32	0.79	0.28	0.70	0.28	0.70	0.17	0.43
Br/Tb/Br	(S3)	1.23	6.88	0.94	5.31	1.15	4.53	1.11	5.57
		0.27	0.68	0.29	0.72	0.28	0.69	0.17	0.43
	$\bar{X}$	1.41	8.91	1.12	7.04	1.21	4.51		
		0.20	0.49	0.19	0.48	0.19	0.48		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob. > F	SYR	0.3314		0.4955		0.7428		0.3227	
	TOT	0.0207		0.0001		0.0030		0.0029	
		Overall Concentration ($\mu g\ g^{-1}$)							
Tb/Br	(S1)	1.33	21.86	1.44	18.64	0.77	6.59	1.18	15.70
		0.31	9.01	0.30	8.99	0.29	8.95	0.24	8.79
Br/Tb/Br	(S3)	0.91	16.81	0.80	14.86	0.73	12.64	0.81	14.77
		0.30	8.96	0.30	8.97	0.30	8.98	0.24	8.79
	$\bar{X}$	1.12	19.33	1.12	16.75	0.75	9.62		
		0.25	8.83	0.25	8.82	0.25	8.83		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob. > F	SYR	0.9856		0.1195		0.1120		0.0822	
	TOT	0.2575		0.0002		0.0033		0.6523	

[y] Tb=Tobacco, Br=Broccoli, TES=Tobacco Experiment Station (Greeneville), PSF=Plant Science Farm (Knoxville), SYR=syringic acid, TOT=total acids. [z] Standard error appears below each mean.

Table D-13. Mean concentration of syringic acid and total acids by tillage and sequence at third sampling for Knoxville and Greenville in 1990 and combined over locations.

		Tillage (T)							
		No-Till (T1)		Conv. (cover) (T2)		Conv. (no cover) (T3)		$\bar{X}$	
		Acid							
Sequence (S)		SYR	TOT	SYR	TOT	SYR	TOT	SYR	TOT
		TES Concentration ($\mu g\ g^{-1}$)							
Tb/Br[y]	(S1)	0.65	26.01	0.69	24.91	0.35	11.42	0.56	20.78
		0.23[z]	4.23	0.25	4.70	0.23	4.24	0.14	2.55
Br/Tb/Br	(S3)	0.84	28.02	0.67	22.79	0.50	11.14	0.67	20.65
		0.22	4.17	0.23	4.26	0.23	4.28	0.14	2.55
	$\bar{X}$	0.74	27.01	0.68	23.85	0.43	11.28		
		0.17	3.07	0.18	3.31	0.17	3.15		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob. > F	SYR	0.8003		0.1633		0.3109		0.5443	
	TOT	0.4890		0.0020		0.0174		0.9696	
		PSF Concentration ($\mu g\ g^{-1}$)							
Tb/Br	(S1)	1.63	11.66	0.94	6.89	1.10	4.03	1.23	7.53
		0.23	0.91	0.22	0.88	0.21	0.84	0.14	0.50
Br/Tb/Br	(S3)	1.30	4.81	0.67	3.03	1.24	4.40	1.07	4.08
		0.21	0.84	0.21	0.85	0.22	0.92	0.14	0.50
	$\bar{X}$	1.46	8.23	0.81	4.96	1.17	4.22		
		0.16	0.60	0.17	0.62	0.16	0.62		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob. > F	SYR	0.0064		0.1598		0.1049		0.3780	
	TOT	0.0029		0.0006		0.4290		0.0006	
		Overall Concentration ($\mu g\ g^{-1}$)							
Tb/Br	(S1)	1.15	17.39	0.85	17.48	0.73	6.79	0.91	13.89
		0.24	9.31	0.24	9.32	0.24	9.30	0.20	9.08
Br/Tb/Br	(S3)	1.12	17.47	0.72	13.70	0.73	6.72	0.86	12.63
		0.23	9.29	0.24	9.31	0.23	9.29	0.20	9.08
	$\bar{X}$	1.13	17.43	0.79	15.59	0.73	6.76		
		0.21	9.14	0.21	9.15	0.21	9.13		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob. > F	SYR	0.0484		0.0164		0.7338		0.7034	
	TOT	0.4784		0.0001		0.0013		0.5416	

[y] Tb=Tobacco, Br=Broccoli, TES=Tobacco Experiment Station (Greeneville), PSF=Plant Science Farm (Knoxville), SYR=syringic acid, TOT=total acids. [z] Standard error appears below each mean.

Table D-14. **Mean concentration of syringic acid and total acids by tillage and sequence at fourth sampling for Knoxville and Greenville in 1990 and combined over locations.**

Sequence (S)		No-Till (T1)		Conv. (cover) (T2)		Conv. (no cover) (T3)		$\bar{X}$	
		SYR	TOT	SYR	TOT	SYR	TOT	SYR	TOT
		TES Concentration ($\mu g\ g^{-1}$)							
Tb/Br[y]	(S1)	2.11	29.13	0.83	18.09	0.50	19.52	1.15	22.25
		0.97[z]	4.28	0.96	4.20	0.99	4.37	0.56	2.54
Br/Tb/Br	(S3)	2.77	21.35	2.58	15.64	2.94	16.84	2.76	17.94
		1.04	4.56	1.06	4.63	1.03	4.52	0.56	2.54
	$\bar{X}$	2.44	25.24	1.71	16.87	1.72	18.18		
		0.70	3.13	0.71	3.15	0.69	3.08		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob.>F	SYR	0.4893		0.4833		0.9883		0.0708	
	TOT	0.0848		0.1271		0.7682		0.2466	
		PSF Concentration ($\mu g\ g^{-1}$)							
Tb/Br	(S1)	0.78	18.57	1.29	24.66	0.71	17.22	0.93	20.15
		0.21	3.38	0.25	3.94	0.21	3.46	0.14	2.43
Br/Tb/Br	(S3)	0.44	15.77	0.52	16.52	0.43	16.87	0.46	16.39
		0.22	3.55	0.21	3.46	0.21	3.35	0.14	2.43
	$\bar{X}$	0.61	17.17	0.91	20.59	0.57	17.05		
		0.17	2.82	0.19	3.05	0.16	2.72		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob.>F	SYR	0.2374		0.8349		0.1590		0.0133	
	TOT	0.3781		0.9669		0.3331		0.1528	
		Overall Concentration ($\mu g\ g^{-1}$)							
Tb/Br	(S1)	1.52	24.19	1.00	20.51	0.51	17.82	1.01	20.84
		1.00	2.59	1.00	2.58	1.01	2.62	0.91	1.61
Br/Tb/Br	(S3)	1.61	18.25	1.58	16.46	1.74	17.86	1.64	17.52
		1.01	2.63	1.01	2.66	1.00	2.58	0.91	1.61
	$\bar{X}$	1.56	21.22	1.29	18.48	1.12	17.84		
		0.94	1.91	0.94	1.94	0.94	1.93		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob.>F	SYR	0.5923		0.3921		0.7570		0.1356	
	TOT	0.2893		0.1873		0.8044		0.1112	

[y] Tb=Tobacco, Br=Broccoli, TES=Tobacco Experiment Station (Greeneville), PSF=Plant Science Farm (Knoxville), SYR=syringic acid, TOT=total acids. [z] Standard error appears below each mean.

Table D-15. Mean concentration change per day of syringic acid and total acids by tillage and sequence for Knoxville and Greenville in 1990 and combined over locations.

Sequence (S)		Tillage (T)							
		No-Till (T1)		Conv. (cover) (T2)		Conv. (no cover) (T3)		X̄	
		Acid							
		SYR	TOT	SYR	TOT	SYR	TOT	SYR	TOT
		TES Concentration Change Per Day ($\mu g\ g^{-1}$)							
Tb/Br[y]	(S1)	-0.08	0.18	0.02	1.02	-0.01	-0.61	-0.02	0.19
			0.46	0.08	0.46	0.08	0.46	0.04	0.32
Br/Tb/Br	(S3)	-0.17	0.90	-0.23	0.24	-0.32	-0.74	-0.24	0.13
		0.08	0.46	0.08	0.46	0.08	0.46	0.04	0.32
		-0.13	0.54	-0.10	0.63	-0.16	-0.68		
	X̄	0.05	0.36	0.05	0.36	0.05	0.36		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob.>F	SYR	0.7211		0.6603		0.4294		0.0035	
	TOT	0.8233		0.0085		0.0054		0.8549	
		PSF Concentration Change Per Day ($\mu g\ g^{-1}$)							
Tb/Br	(S1)	0.07	-0.46	0.01	-0.82	0.04	-0.82	0.04	-0.70
		0.04	0.20	0.04	0.20	0.04	0.20	0.02	0.14
Br/Tb/Br	(S3)	0.13	-0.70	0.01	-0.82	0.06	-0.87	0.07	-0.80
		0.04	0.20	0.04	0.20	0.04	0.20	0.02	0.14
		0.10	-0.58	0.01	-0.82	0.05	-0.84		
	X̄	0.03	0.16	0.03	0.16	0.03	0.16		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob.>F	SYR	0.0155		0.1843		0.2010		0.3432	
	TOT	0.1878		0.1490		0.8895		0.5087	
		Overall Concentration Change Per Day ($\mu g\ g^{-1}$)							
Tb/Br	(S1)	-0.01	-0.14	0.02	0.10	0.02	-0.71	0.01	-0.25
		0.10	0.51	0.10	0.51	0.10	0.51	0.09	0.47
Br/Tb/Br	(S3)	-0.02	0.10	-0.11	-0.29	-0.13	-0.80	-0.09	-0.33
		0.10	0.51	0.10	0.51	0.10	0.51	0.09	0.47
		-0.01	-0.02	-0.05	-0.09	-0.06	-0.76		
	X̄	0.10	0.48	0.10	0.48	0.10	0.48		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob.>F	SYR	0.4988		0.3961		0.8616		0.0201	
	TOT	0.7664		0.0045		0.0097		0.6969	

[y] Tb=Tobacco, Br=Broccoli, TES=Tobacco Experiment Station (Greeneville), PSF=Plant Science Farm (Knoxville), SYR=syringic acid, TOT=total acids. [z] Standard error appears below each mean.

Table D-16. Mean % of total acid as p-coumaric and ferulic acid by tillage and sequence at first sampling for Knoxville and Greenville in 1990 and combined over locations.

Sequence (S)		Tillage (T)							
		No-Till (T1)		Conv. (cover) (T2)		Conv. (no cover) (T3)		$\bar{X}$	
		Acid							
		PCO	PFER	PCO	PFER	PCO	PFER	PCO	PFER
		TES (%)							
Tb/Br[y]	(S1)	48.3	22.5	52.4	20.3	46.5	19.5	49.1	20.8
		4.2[z]	3.1	5.0	3.7	4.3	3.2	2.5	1.8
Br/Tb/Br	(S3)	53.6	18.0	53.4	16.2	40.0	11.4	49.0	15.2
		4.4	3.2	4.5	3.3	4.3	3.2	2.5	1.8
	$\bar{X}$	51.0	20.2	52.9	18.2	43.3	15.4		
		3.1	2.3	3.5	2.5	3.1	2.3		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob. > F	PCOU	0.7074		0.1461		0.4668		0.0542	
	PFER	0.5995		0.0918		0.0825		0.9821	
		PSF (%)							
Tb/Br	(S1)	38.5	33.0	35.1	33.3	44.6	24.3	39.4	30.2
		4.4	3.3	4.2	3.2	4.2	3.2	2.7	1.8
Br/Tb/Br	(S3)	45.0	31.9	45.6	27.7	46.5	26.0	45.7	28.6
		4.8	3.7	4.2	3.2	4.3	3.2	2.7	1.8
	$\bar{X}$	41.7	32.5	40.3	30.5	45.5	25.1		
		3.4	2.5	3.2	2.3	3.2	2.3		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob. > F	PCOU	0.7602		0.4104		0.2044		0.0753	
	PFER	0.5962		0.0642		0.1121		0.5434	
		Overall (%)							
Tb/Br	(S1)	43.8	27.5	42.7	27.5	45.6	22.2	44.0	25.7
		3.0	5.5	3.1	5.5	3.0	5.5	1.7	5.2
Br/Tb/Br	(S3)	49.4	25.4	49.5	21.1	43.7	18.2	47.6	21.6
		3.1	5.6	3.0	5.5	3.0	5.5	1.7	5.2
	$\bar{X}$	46.6	26.4	46.1	24.3	44.7	20.2		
		2.2	5.3	2.2	5.3	2.2	5.3		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob. > F	PCOU	0.8723		0.5279		0.6487		0.1557	
	PFER	0.3843		0.0126		0.0935		0.0328	

[y] Tb=Tobacco, Br=Broccoli, TES=Tobacco Experiment Station (Greeneville), PSF=Plant Science Farm (Knoxville), PCOU=% p-coumaric acid, PFER=% ferulic acid. [z] Standard error appears below each mean.

Table D-17. Mean % of total acid as p-coumaric and ferulic acid by tillage and sequence at second sampling for Knoxville and Greenville in 1990 and combined over locations.

		Tillage (T)							
Sequence (S)		No-Till (T1)		Conv. (cover) (T2)		Conv. (no cover) (T3)		$\bar{X}$	
		Acid							
		PCO	PFER	PCO	PFER	PCO	PFER	PCO	PFER
		TES (%)							
Tb/Br[y]	(S1)	31.6	36.9	35.1	31.7	46.2	16.3	37.6	28.3
		4.4[z]	5.6	4.2	5.4	3.9	5.0	2.5	3.0
Br/Tb/Br	(S3)	37.0	35.0	48.3	25.0	55.4	33.7	46.9	31.2
		4.1	5.3	3.8	4.9	4.2	5.5	2.5	3.0
		34.3	35.9	41.7	28.3	50.8	25.0		
	$\bar{X}$	3.0	3.7	2.8	3.4	3.2	4.0		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob. > F	PCOU	0.0669		0.0036		0.0472		0.0239	
	PFER	0.1479		0.0965		0.5553		0.5495	
		PSF (%)							
Tb/Br	(S1)	46.6	22.4	52.1	11.8	38.1	3.1	45.6	12.4
		2.8	5.2	2.5	4.6	2.5	4.6	1.7	3.0
Br/Tb/Br	(S3)	49.9	10.8	40.5	17.3	41.0	4.1	43.8	10.7
		2.4	4.5	2.6	4.8	2.5	4.5	1.7	3.0
		48.3	16.6	46.3	14.6	39.5	3.6		
	$\bar{X}$	1.9	3.4	1.9	3.3	1.8	3.3		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob. > F	PCOU	0.4262		0.0025		0.0112		0.4377	
	PFER	0.6617		0.0113		0.0250		0.6970	
		Overall (%)							
Tb/Br	(S1)	40.4	29.9	45.0	21.7	41.7	8.8	42.4	20.1
		3.2	9.0	3.2	8.9	3.0	8.8	1.8	8.4
Br/Tb/Br	(S3)	42.7	24.4	43.7	21.9	47.3	17.4	44.6	21.2
		3.1	8.9	3.1	8.9	3.1	8.9	1.8	8.4
		41.5	27.1	44.3	21.8	44.5	13.1		
	$\bar{X}$	2.2	8.5	2.1	8.5	2.2	8.5		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob. > F	PCOU	0.3707		0.3524		0.9501		0.4198	
	PFER	0.1334		0.0004		0.0161		0.7319	

[y] Tb=Tobacco, Br=Broccoli, TES=Tobacco Experiment Station (Greeneville), PSF=Plant Science Farm (Knoxville), PCOU=% p-coumaric acid, PFER=% ferulic acid. [z] Standard error appears below each mean.

Table D-18. Mean % of total acid as p-coumaric and ferulic acid by tillage and sequence at third sampling for Knoxville and Greenville in 1990 and combined over locations.

Sequence (S)		Tillage (T) No-Till (T1)		Conv. (cover) (T2)		Conv. (no cover) (T3)		$\bar{X}$	
		Acid PCO	PFER	PCO	PFER	PCO	PFER	PCO	PFER
		TES (%)							
Tb/Br[y]	(S1)	42.7	29.4	44.5	30.7	44.9	19.9	44.0	26.7
		2.9[z]	5.0	3.2	5.6	2.9	5.0	1.7	3.0
Br/Tb/Br	(S3)	37.9	32.5	45.3	25.8	42.7	14.0	42.0	24.1
		2.8	5.0	2.9	5.1	2.9	5.1	1.7	3.0
		40.3	30.9	44.9	28.3	43.8	16.9		
	$\bar{X}$	2.1	3.6	2.2	3.9	2.1	3.7		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob.>F	PCOU	0.1450		0.2270		0.7162		0.3765	
	PFER	0.6229		0.0136		0.0622		0.5306	
		PSF (%)							
Tb/Br	(S1)	41.8	28.8	40.3	21.6	34.6	4.8	38.9	18.4
		4.5	3.9	4.3	3.8	4.2	3.6	3.1	2.2
Br/Tb/Br	(S3)	38.0	0.6	35.9	0.0	35.6	5.3	36.5	1.9
		4.2	3.6	4.2	3.7	4.4	4.0	3.1	2.2
		39.9	14.7	38.1	10.7	35.1	5.0		
	$\bar{X}$	3.4	2.6	3.5	2.7	3.5	2.7		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob.>F	PCOU	0.6335		0.2060		0.4427		0.4550	
	PFER	0.3145		0.0261		0.1772		0.0003	
		Overall (%)							
Tb/Br	(S1)	43.0	25.5	41.2	29.1	40.3	10.4	41.5	21.7
		3.5	9.7	3.5	9.7	3.5	9.7	2.9	9.2
Br/Tb/Br	(S3)	37.2	18.8	40.0	15.0	40.4	7.7	39.2	13.8
		3.5	9.6	3.5	9.7	3.5	9.6	2.9	9.2
		40.1	22.1	40.6	22.0	40.3	9.1		
	$\bar{X}$	3.1	9.3	3.1	9.3	3.1	9.3		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob.>F	PCOU	0.8474		0.9333		0.9070		0.2466	
	PFER	0.9791		0.0013		0.0020		0.0176	

[y] Tb=Tobacco, Br=Broccoli, TES=Tobacco Experiment Station (Greeneville), PSF=Plant Science Farm (Knoxville), PCOU=% p-coumaric acid, PFER=% ferulic acid. [z] Standard error appears below each mean.

Table D-19. Mean % of total acid as p-coumaric and ferulic acid by tillage and sequence at fourth sampling for Knoxville and Greenville in 1990 and combined over locations.

Sequence (S)		Tillage (T)							
		No-Till (T1)		Conv. (cover) (T2)		Conv. (no cover) (T3)		$\bar{X}$	
		Acid							
		PCO	PFER	PCO	PFER	PCO	PFER	PCO	PFER
		TES (%)							
Tb/Br[y]	(S1)	45.9	22.3	50.6	20.9	45.6	24.1	47.4	22.4
		4.7[z]	3.0	4.7	2.9	4.8	3.0	2.7	2.0
Br/Tb/Br	(S3)	48.5	16.6	61.5	8.3	42.7	8.8	50.9	11.2
		5.1	3.1	5.1	3.2	5.0	3.1	2.7	2.0
		47.2	19.4	56.1	14.6	44.1	16.4		
	$\bar{X}$	3.4	2.3	3.4	2.3	3.4	2.3		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob. >F	PCOU	0.1017		0.5431		0.0314		0.3928	
	PFER	0.1160		0.2981		0.5260		0.0003	
		PSF (%)							
Tb/Br	(S1)	42.5	28.1	39.3	30.1	42.6	27.1	41.5	28.4
		5.1	4.1	6.0	4.8	5.3	4.2	3.8	3.0
Br/Tb/Br	(S3)	42.6	30.5	48.0	25.1	48.2	30.0	46.2	28.5
		5.4	4.3	5.3	4.2	5.1	4.1	3.8	3.0
		42.6	29.3	43.6	27.6	45.4	28.5		
	$\bar{X}$	4.3	3.4	4.7	3.7	4.2	3.3		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob. >F	PCOU	0.8485		0.5177		0.7414		0.2220	
	PFER	0.7114		0.8215		0.8342		0.9806	
		Overall (%)							
Tb/Br	(S1)	44.4	24.7	45.6	25.1	45.4	24.9	45.1	24.9
		3.4	8.2	3.4	8.2	3.5	8.2	2.1	7.9
Br/Tb/Br	(S3)	46.2	22.9	53.3	17.7	44.1	20.6	47.9	20.4
		3.5	8.2	3.5	8.2	3.4	8.2	2.1	7.9
		45.3	23.8	49.4	21.4	44.8	22.8		
	$\bar{X}$	2.5	7.9	2.5	8.0	2.5	8.0		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob. >F	PCOU	0.2353		0.8768		0.1869		0.3192	
	PFER	0.3722		0.6931		0.6157		0.0409	

[y] Tb=Tobacco, Br=Broccoli, TES=Tobacco Experiment Station (Greeneville), PSF=Plant Science Farm (Knoxville), PCOU= % p-coumaric acid, PFER= % ferulic acid. [z] Standard error appears below each mean.

Table D-20. Mean change per day in % of total acid as p-coumaric and ferulic acid by tillage and sequence for Knoxville and Greenville in 1990 and combined over locations.

Sequence (S)		Tillage (T): No-Till (T1)		Conv. (cover) (T2)		Conv. (no cover) (T3)		$\bar{X}$	
		Acid: PCO	PFER	PCO	PFER	PCO	PFER	PCO	PFER
		TES (% Change Per Day)							
Tb/Br[y]	(S1)	-0.64	1.08	-1.09	1.27	-0.15	-0.35	-0.62	0.67
		0.47[z]	0.60	0.47	0.60	0.47	0.60	0.27	0.35
Br/Tb/Br	(S3)	-1.55	1.86	-1.16	1.16	0.63	0.80	-0.69	1.27
		0.47	0.60	0.47	0.60	0.47	0.60	0.27	0.35
	$\bar{X}$	-1.09	1.47	-1.12	1.22	0.24	0.22		
		0.33	0.43	0.33	0.43	0.33	0.43		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob. >F	PCOU	0.9449		0.0130		0.0113		0.8635	
	PFER	0.6766		0.0557		0.1200		0.2358	
		PSF (% Change Per Day)							
Tb/Br	(S1)	0.50	-0.66	0.69	-2.80	-0.68	-1.54	0.17	-1.66
		0.41	1.24	0.41	1.24	0.41	1.24	0.30	0.71
Br/Tb/Br	(S3)	0.06	-3.97	-0.78	-1.34	-0.90	-1.63	-0.54	-2.31
		0.41	1.24	0.41	1.24	0.41	1.24	0.30	0.71
	$\bar{X}$	0.28	-2.32	-0.04	-2.07	-0.79	-1.58		
		0.33	0.87	0.33	0.87	0.33	0.87		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob. >F	PCOU	0.3634		0.0071		0.0458		0.0225	
	PFER	0.8434		0.5616		0.7001		0.5298	
		Overall (% Change Per Day)							
Tb/Br	(S1)	-0.07	0.21	-0.20	-0.76	-0.41	-0.94	-0.23	-0.50
		0.41	1.61	0.41	1.61	0.41	1.61	0.28	1.51
Br/Tb/Br	(S3)	-0,74	-1.05	-0.97	-0.09	-0.13	-0.42	-0.62	-0.52
		0.41	1.61	0.41	1.61	0.41	1.61	0.28	1.51
	$\bar{X}$	-0.41	-0.42	-0.58	-0.43	-0.27	-0.68		
		0.32	1.53	0.32	1.53	0.32	1.53		
Contrast		T1 v T2		T1 v T3		T2 v T3		S1 v S3	
Prob. >F	PCOU	0.6355		0.7241		0.4100		0.2065	
	PFER	0.9559		0.7196		0.7235		0.9708	

[y] Tb=Tobacco, Br=Broccoli, TES=Tobacco Experiment Station (Greeneville), PSF=Plant Science Farm (Knoxville), PCOU=% p-coumaric acid, PFER=% ferulic acid. [z] Standard error appears below each mean.

Vita

William Terry Kelley was born June 8, 1961 in Waynesville, N.C. (Haywood County). He grew up in the mountains of western North Carolina, where he worked summers at the Mountain Research Station for seven years beginning in his late teens. Two of those summers were spent as an R.J. Reynolds extension apprentice under the direction of Mr. R.L. Davis, N.C. State University Burley Extension Specialist. He graduated from Tuscola Senior High School in May, 1979. He is a lifelong member of Waynesville First Baptist Church. He enrolled in August, 1979 at North Carolina State University. During his undergraduate career, he served as Sports Editor (1981-83) of the *Technician*, N.C. State's student newspaper, and was a member of the student senate and an active member of the agronomy club, participating in the national student speech contest for the club and in the national soil judging contest in 1985. He also worked as a freelance writer during this time, with work appearing mostly in *The Raleigh Times* and *The Wolfpacker*. He received his B.S. degree in Agronomy from N.C. State in December, 1984. In August, 1985 he enrolled in graduate school at N.C. State in the Department of Crop Science. While there he worked on the effects of topping stage and genotype on maturity in burley tobacco under the direction of Dr. Daryl Bowman. He also helped coordinate the Official Variety Testing and Regional Variety Testing programs in burley and flue-cured tobacco while in that program. He graduated with a Master of Science from N.C. State in August, 1988. That same month he enrolled in graduate school at the University of Tennessee in the Department of Plant & Soil Science. He was a finalist for the American Society for Horticultural Science Congressional Fellowship in March, 1992. In May, 1993 he graduated from UT with a Doctor of Philosophy. In February of the same year he began work as an assistant professor in the Department of Horticulture at the University of Georgia, stationed at the Rural Development Center in Tifton, Georgia with responsibilities as Extension Vegetable Specialist. He is a member of Gamma Sigma Delta, Sigma Xi, the Crop Science Society of America, the Soil Science Society of America, the American Society of Agronomy and the American Society for Horticultural Science.