UTILIZATION OF COWPEA AS A GREEN MANURE

TO REDUCE FERTILIZER NITROGEN

INPUTS WITH FALL BROCCOLI

By

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UTILIZATION OF COWPEA AS A GREEN MANURE TO REDUCE FERTILIZER NITROGEN INPUTS WITH FALL BROCCOLI

INTRODUCTION

Productive soil characteristics, combined with favorable soil management, are necessary for efficient, profitable production of fall broccoli [*Brassica oleracea* L. (Italica Group)]. Available soil nitrogen is a principal governing attribute for desirable yield and quality of this high value vegetable crop. Principal options for attaining favorable soil nitrogen sustenance include utilization of chemical fertilizers and increased natural organic nitrogen with symbiotic nitrogen fixation by desirable nodulated legumes. Favorable soil management of crop residues is requisite for attaining improvement and maintenance of productive soil physical, chemical, and biological properties that govern desirable vegetable crop production. Increased interest in improved crop residue management, including "green-manure" with and without chemical fertilization, has resulted from cost-return economical appraisals and the enhanced concern for environmental pollution of ground waters from underutilized nitrate nitrogen leachates.

Objectives of this study include practical evaluation of sustainable soil management practices developed for intensive, succession cropping systems utilizing summer grown cowpeas [*Vigna unguiculata* (L.) Walp.], followed by high value fall planted broccoli.

Comparisons include utilization of conventionally fertilized cowpeas as a green manure crop and using cowpeas inoculated with *Rhizobium* for nodulated symbiotic N fixation without chemical nitrogen fertiiization. Results were determined for seed yield and efficacious green manure attributes for improved broccoii production.

CHAPTER II

REVIEW OF LITERATURE

The term "green manure" is descriptive for the soil management practice of plowing under, and incorporating within the soil, still growing, succulent crop materials for improved soil productivity. Effectively nodulated and mycorrhizal colonized legume crops symbiotically fix inert atmospheric N. When utilized as green manure crops, these legumes increase available soil nitrogen from organic matter transformations for plant nutrition of subsequent crops (Piper and Pieters, 1922).

The rapidly decomposed plant materials within the soil contribute greatly to improved soil physical properties with desirable soil structure, moisture, and aeration characteristics resulting from accelerated soil microbial activity (Pieters and McKee, 1938). Although total soil humus is usually not increased, the increased soil microbiological transformations result in maintenance of intrinsic soil organic matter components that are diminished or dissipated with conventional cultivated, non residue management, cropping systems (Bin, 1983).

The favorable effectiveness of green manuring for improved crop production was recognized within ancient records of agricultural production. In 300 BC the Greeks recorded improved soil productivity with broadbean [*Vicia faba* (L.)] green manure culture. In the early years of the Roman Empire the utilization of lupines [*Lupinus sp*] and beans [*Phaseolus sp.*] for soil improvement was a common practice. The early American colonists used field grains as green manure crops (Pieters and McKee, 1938).

Prior to WWII years, horses and mules were still the principal farm work animals. Legumes as forage crops in pasture, hay, and as green manure crops were the conventional means utilized for increased soil productivity and improved livestock production. During the post WWII years, inexpensive and abundant synthetic nitrogen fertilizers, along with increased farm mechanization, diminished the utilization of N fixing legume crops within cropping systems (Hoyt and Hargrove, 1986). Most of the agricultural research with green manuring in soil-crop management systems was published 50 to 100 years ago (Pieters, 1917a, 1917b, 1917c; Pieters and McKee, 1929). However, the energy crisis from fossil fuel (petroleum) developments resulted in greatly increased chemical fertilizer costs and reduced availability. Concerns for nitrate pollution of ground water also have become prevalent. These events have resulted in a resurgence of interest in the utilization of green manure cropping systems with sustainable soil management systems for cultivated row crops.

GOVERNING SOIL-CLIMATE FACTORS

Recent reviews have summarized the extensive publications of past decades concerned with crop residue and green manure soil management practices. Bruce et al. (1991) presented diverse conditions that influence the role of principal cover cropping systems for improved soil productivity. The emphasis in this review was concerned with present day soil and water conservation practices directed toward reduced ground water pollution. In closely related reviews, Doran and Smith (1991) summarized the contribution of legume and non legume cover crop management for effective soil nitrogen cycling necessary for improved clean water having reduced nitrate content. The soil microbial interactions governing denitrification and organic nitrogen mineralization with effective cover crop management were summarized by Drury et al. (1991).

The paramount role of legumes recorded during past centuries with effective soil conservation tillage was presented by Hoyt (1987) and Elliott et al. (1987). Kurtz et al. (1984) summarized information related to practical crop rotation systems with green manure and crop residue management systems contributing to efficient soil nitrogen utilization.

Competition between biologically enhanced nitrogen fixing *Rhizobium* and indigenous *Rhizobium* species for desirable efficiencies with legume-*Rhizobium* symbioses were reviewed by Emerich and Evans (1984). Limitations to maximizing symbiotic nitrogen within sustainable crop sequence rotations were summarized by Rogers and Giddens (1957), Phillips and DeJong (1984), Janzen and Radder (1989), and Campbell et al. (1991). Microbial transformation of organic nitrogenous components with deaminization and nitrification of green manure and crop residues was summarized by Chater and Gasser (1970) and Heichel (1987). Soil management for systems utilizing catch, off season cropping for reduced soluble nitrogen forms leached with eventual entry into soil ground water was reviewed by Parr and Papendick (1978), Muller et al. (1989), and Follett and Walker (1989).

Publications reporting favorable green manure utilization for improved grain crop production include those of Bowen et al. (1988), Giddens et al. (1965), and Onim et al. (1990). Tillage and subsequent crop residue utilization has been of importance for improved soil productivity since the earliest historical recordings of agriculture (Phillips and DeJong, 1984; Sarrantonio and Scott, 1988). Many soil types within favorable climatic areas are particularly vulnerable to erosion and soil fertility losses with cultivated grain cropping systems (Coats and Baumhackl, 1989). Limitations with corn production have been of major concern for attaining sustained soil productivity and were summarized recently by Bhandari et al. (1989), Evanylo (1991), and Giddens et al. (1965). Green manure systems for wheat production were reported by Ladd et al. (1981), Jung et al. (1990), and Badaruddin and Meyer (1990). Similarly, centuries of rice production within the oriental countries have evolved effective green manure systems for improved soil productivity (Morris et al., 1986; Becker et al., 1990).

Maintenance of favorable soil fertility with intensive, high value vegetable and fruit production is achieved with advantageous soil organic matter management (Kelly, 1990; Shennan, 1992). Effects of legumes, green manure crops and manures for intensive vegetable cropping with favorable nitrogen nutrition were summarized by Ware and Johnson (1945), Singogo et al. (1991), and Sanders et al. (1993).

COWPEA: GREEN MANURE ATTRIBUTES

The cowpea, an old world food legume, was prominent in the ancient cultures of Africa and Asia. For centuries this crop has been widely cultivated throughout the temperate and tropical countries of the world. Most cultivars evolved in past centuries are productive for high yields of edible seed, pasturage, hay, ensilage and soil improving green manure utilization (Duke et al., 1981; Wien and Summerfield, 1984).

Profuse nodulation and ensuing symbiotic nitrogen fixation, when grown in low fertility soils within droughty climatic regions, contribute greatly to cowpea value for soil improvement (Dart and Wildon, 1970; Minchin et al., 1980; Miller et al., 1986).

Cowpea species have been utilized for numerous fundamental studies with *Rhizobium* inoculation (Atkins et al., 1984; Neeves et al., 1981; Wadisirisuk and Weaver, 1985; Lawn and Bushby, 1982). Nodule development and interrelationships with symbiotic nitrogen fixation and subsequent soil organic nitrogen accretion has been studied by many researchers (Kahn and Stoffella, 1991; Awonaike et al., 1991; Minchin et al., 1981; Luyindula and Weaver, 1989).

Nitrogen nutrition of cowpea species and effects of applied fertilizer nitrogen with nodulated nitrogen fixation have been reported previously (Summerfield et al., 1977; Dart et al., 1977; Eaglesham et al., 1983; Halsey, 1960; Fernandez and Miller, 1986). Distinctive ureide nitrogen transformations; biological partitioning with inoculation; and nodulation as influenced by nitrate nitrogen have been studied (Ezedinma, 1964; Douglas and Weaver, 1986; Dart and Wildon, 1970; DeMallorca and Izaguine-Mayoral, 1993).

Cowpea used as a green manure ahead of cereal grains was investigated by John et al. (1989) and Bhandari et al. (1989). The effects of cowpea as a green manure ahead of vegetable cole crops were reported by Ware and Johnson (1945) and Pieters and McKee (1929).

Influences of favorable soil nitrogen on yield and desirable quality of broccoli were reported by Kahn et al. (1991); Kowalenko and Hall (1987); Letey et al. (1983); and Liu and Shelp (1993). Cover crop management and legume interseeding influencing desirable growth and plant nutrient availability were reported by Magnifico et al. (1979); Foulds et al. (1991); and Mangan et al. (1991).

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CHAPTER III

UTILIZATION OF COWPEA AS A GREEN MANURE TO REDUCE FERTILIZER NITROGEN INPUTS WITH FALL BROCCOLI

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Additional index words: green manure, nitrogen fixation, *Brassica oleracea* L. (Italica Group), broccoli, *Vigna unguiculata* (L.) Walp., cowpea

ABSTRACT

UTILIZATION OF COWPEA AS A GREEN MANURE TO REDUCE FERTILIZER NITROGEN INPUTS WITH FALL BROCCOLI

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Cowpea [*Vigna unguiculata* (L.) Walp.] was grown as a green manure preceding a fall crop of broccoli [*Brassica oleracea* L. (Italica Group)] in 1992, 1993, and 1994. Urea was used to supply 0, 84, or 168 $kg{\cdot}ha^{-1}$ of supplemental nitrogen (N) to broccoli which followed cowpeas. Control broccoli plots were grown on fallowed ground and supplied with 168 $kg{\cdot}ha^{-1}$ of N from urea. In 1994 a fourth experiment included factorial cowpea, urea fertilization and differential application of trifluralin herbicide treatments. Soil analyses included non NO_3^- N (Kjeldahl) and extractable soil nitrate N, at 0-15 cm and 15-30 cm depths, before cowpea plantings, before broccoli planting and after broccoli harvest. Marketable broccoli was determined including stand counts, days to first harvest, petiole N(%), and fresh and dry weights. Highly significant reduced nitrate N concentrations occurred with all cowpea green manure treatments at 15-30 cm soil depths at broccoli planting and after harvest. Marketable broccoli yields, 1992 and 1993, were highest for Pre:N+Side:N with both cowpea and no cowpea combinations. In 1993 there were highly significant decreased head counts and weights for cowpea nonfertilized and with only single fertilization treatments. Broccoli yields were not significantly different between treatments in 1994 with cowpea inoculation and higher levels of urea fertilization. However, petiole N(%) was significantly lower for all cowpea green manure treatments compared to the control. Numerically highest marketable broccoli head yields ($Mg{\cdot}ha^{-1}$) within the fourth experiment in 1994 resulted from the treatment utilizing cowpea green manure, pre-cowpea trifluralin (PPT), and pre-broccoli trifluralin (PBT). Numerically lowest marketable broccoli head yields in the fourth experiment resulted from two treatments: without cowpeas but with PPT and PBT, and with cowpeas and PPT but without PBT. A preceding cowpea green manure crop apparently will not provide adequate available N for the following broccoli crop. Immobilization with decomposition of the cowpea green manure residues significantly reduces available soil N for broccoli growth. Levels of 168 $kg{\text -}ha^{-1}$ of supplemental N as urea were requisite for high broccoli yield with or without cowpea. Nitrate levels at 15-30 cm soil depth were apparently consistent indicators of restrictive N immobilization by cowpea green manure residue decomposition.

INTRODUCTION

The soil management system of plowing under still growing crop materials for improved soil productivity is termed "green manure" cropping. Nodulated legumes fix inert atmospheric nitrogen. When properly utilized as green manure crops, effectively nodulated legumes increase soil nitrogen for plant nutrition of subsequent cropping systems (Piper and Pieters, 1922). Total soil humus is usually not increased, but increased soil microbial transformations maintain soil organic matter components that are lost in cultivated, non residue cropping systems (Bin, 1983). The decomposing green manure materials contribute to improved soil physical structure with desirable soil moisture and aeration characteristics (Pieters and McKee, 1938).

There is an increased interest concerning environmental factors affecting human health with present widespread use of agricultural chemicals. Pollution control for toxic residues, with reduced contamination of soil and ground water, has become a major concern worldwide. A renewed interest in utilization of sustainable "green-manure" legume cropping systems to substitute for nitrogen fertilization for intensive crop production has developed (Kurtz et al. 1984; Hoyt 1987; Elliott et al. 1987).

Improved soil productivity and subsequent increased food crop production was observed and recorded in ancient records of the Greek civilization and within Roman writing (Pieters and McKee, 1938). Legumes as green manure crops, and as principal forage crops for hay and pasture, were utilized extensively in American agriculture until about 50 years ago. The availability of abundant inexpensive chemical nitrogen fertilizers greatly reduced the utilization of legume crops for symbiotic nitrogen fixation (Hoyt and

Hargrove, 1986).

Agricultural research with green manuring in soil-crop management systems was published extensively in past years (Pieters, 1917a, 1917b, 1917c; Pieters and McKee, 1929). A recent summary of green manure soil management systems was given by Bruce et al. (1991). In another review, Doran and Smith (1991) summarized the role of legume cover crop management in reducing nitrate accumulations in ground water.

Many soil types within humid agricultural regions are vulnerable to erosion and soil fertility losses (Coats and Baumhackl, 1989). Crop residue management and improved tillage have been important for improved soil productivity and have long been recognized as necessary for sustained agriculture (Phillips and DeJong, 1984; Sarrantonio and Scott, 1988). Soil organic matter decomposition with microbial transformations of crop residues and green manure crops were summarized by Chater and Gasser (1970) and Heichel (1987).

Apparent limitations to symbiotic nitrogen fixation within sustainable crop rotations were reported by Campbell et al. (1991), Phillips and DeJong (1984), Rogers and Giddens (1957), and Janzen and Radder (1989). Soil management for legume cropping to attain reduced soluble nitrate leachates within soil ground water was reviewed by Muller et al. (1989), Parr and Papendick (1978), and Follett and Walker (1989).

Succession cropping is commonly practiced in Oklahoma vegetable production. We wanted to study a system where a spring/summer green manure crop might be used to reduce fertilizer nitrogen inputs with fall broccoli [*Brassica oleracea* L. (Italica Group)]. We chose cowpea [*Vigna unguiculata* (L.) Walp.] as the green manure crop. Oklahoma has an established market for cowpeas, and use of a grain legume as a green manure provides an opportunity for additional grower income as opposed to alternative green manures like vetch (*Vicia* sp.). Legumes are known to be useful as green manures (Hoyt and Hargrove, 1986; Elliott et al., 1987; Power and Biederbeck, 1991). However, there are limited references to cowpea as a green manure crop (John et al., 1989; Bhandari et al., 1989; Lohnis, 1926; Pieters and McKee, 1929). Also, while much is known about nitrogen nutrition of broccoli (Kahn et al., 1991; Kowalenko and Hall 1987; Letey et al., 1983; Liu and Shelp, 1993; Magnifico et al., 1979; Foulds et al., 1991; Mangan et al., 1991), we found very few references on use of green manures for broccoli production or, for that matter, production of any major cole crop (Pieters and McKee, 1929; Ware and Johnson, 1945).

The objective of these experiments was to evaluate cowpeas, used as a green manure crop, for the reduction of chemical nitrogen fertilizer inputs in fall broccoli production.

MATERIALS AND METHODS

Four field experiments were conducted at the Vegetable Research Station, Bixby, Oklahoma on a Severn very fine sandy loam [coarse-silty, mixed (calcareous) thermic Typic Udifluvent]. Each experiment occupied a different field at the station. Irrigation with an overhead sprinkler system was utilized in all three years as needed on both broccoli and cowpeas. The crop cultivars used were 'Pinkeye Purplehull BVR' cowpea and 'Mariner' broccoli.

Experiments 1, 2, and 3

Standard pest control practices were utilized with preplant-soil incorporated trifluralin at 560 g ha^{-1} applied 10 June 1992, 27 May 1993, and 19 May 1994 (cowpea area only) and on 17 August 1992 and 19 August 1993 (entire experimental area). In 1992 the broccoli was sprayed for Lepidoptera larvae on 28 August and 2 Oct. with methomyl at the rate of 1 $kg{\cdot}ha^{-1}$. On 13 June 1993 the cowpeas were sprayed for thrips with methomyl at the rate of 1 $kg{\cdot}ha^{-1}$, and the broccoli was sprayed with permethrin on 27 August at the rate of 0.22 $kg{\cdot}ha^{-1}$. In 1994 the broccoli was sprayed for Lepidoptera larvae with methomyl on 6 September at the rate of 0.50 $kg{\cdot}ha^{-1}$ and also on 14 and 29 September with *Bacillus thuringienis* at the rate of 1.12 $kg{\cdot}ha^{-1}$.

The experimental design was a randomized block with four replications in 1992 and 1993. The control used the standard commercial practice of one preplant application and two sidedresses of nitrogen and no preceding cowpea crop. The four treatments were all preceded by cowpeas with (+ or -) preplant nitrogen and (+ or -) sidedress nitrogen (Table 1). Split-plots were arranged in randomized blocks with four replications in 1994.

An inoculation variable was included in 1994 to try to further reduce fertilizer nitrogen inputs in the system. The main plot treatments were (+ or -) cowpea inoculation and subplots were N treatments on broccoli (Table 1). The cowpea plots were 6 m length. The broccoli plots were centered on cowpea plots, excepting the control plots where cowpeas were not grown, and were 4 m long. The broccoli plots were separated by at least 4 m in all directions to prevent effects resulting from soluble soil N movement between plots.

Cowpea culture, 1992: Nitrogen from urea was broadcast and preplant-incorporated at the rate of 23 $kg \cdot ha^{-1}$ on 10 June. The cowpeas were seeded on 12 June at about 2.8 $kg \cdot ha^{-1}$ with 0.9 m between rows. Stand counts were taken on 26 June and any rows with > 60 plants in 6 m were thinned to 60 plants. A once-over hand harvest of marketable green-shell-stage pods from all rows was done on 6 Aug. Yield samples were saved from 12 m of row length per future broccoli plot. Also sampled were 32 entire plants (two per future broccoli plot) for biomass and N concentration. The plants were mowed with a rotary mower then rototilled into the soil on 10 Aug.

Cowpea culture, 1993: Nitrogen from urea was broadcast and preplant incorporated at the rate of 23 $kg \cdot ha^{-1}$ on 26 May. The cowpeas were seeded on 27 May at about 2.8 $kg \cdot ha^{-1}$ with 0.9 m between rows. Stand counts were taken on 11 June and any rows with > 60 plants in 6 m were thinned to 60 plants. A once-over hand harvest of marketable green-shell-stage pods from all rows was done on 6 Aug. Yield samples were saved from 12 m of row length per future broccoli plot. Also sampled were 32 entire plants (two per future broccoli plot) for biomass and N concentration. The plants were mowed and rototilled into the soil on 8 Aug.

Cowpea culture, 1994: The plots to be sown with non-inoculated seed received broadcast, preplant-incorporated nitrogen from urea at the rate of 23 kg·ha^{-1} on 18 May; plots to be sown with inoculated seed received no preplant N. The cowpeas were seeded on 20 May at about 4.2 kg·ha^{-1} with 0.9 m between rows. Stand counts were taken on 8 June and any rows with > 60 plants in 6 m were thinned to 60 plants. A once-over hand harvest of marketable green-shell-stage pods from all rows was taken on 18 July. Yield samples were saved from 12 m of row length per future broccoli plot. Also sampled were 48 entire plants (two per future broccoli plot) for biomass and N concentration. The plants were mowed and rototilled into soil on 20 July.

Broccoli culture: Broccoli was planted in double-row units with 30 cm between the two rows in each unit and 90 cm between centers of units. Each N plot contained three double-row units; the center unit was used for data. Transplants were set in the field on 20 Aug. 1992, 20 Aug. 1993, and 17 Aug. 1994 at 30 cm within rows. Each transplant received 200 ml of starter solution, which provided 1438N-628P-1194K (mg·liter^{-1}), respectively, plus diazinon at 300 mg/liter. Petiole samples were taken in early Oct. (shortly before heading) from three or four plants per data unit to measure N concentration (Kjeldahl). Five harvests were made as central heads matured (20 Oct. - 2 Nov. 1992; 15 - 28 Oct. 1993; 17 - 31 Oct. 1994). Stalks were trimmed at 20.5 cm from the top of the dome before weighing. Average broccoli plant dry weight was obtained in 1993 and 1994 by cutting two plants per plot at ground level just before first harvest. The plants were sliced to facilitate drying at 51°C. The plants were then weighed. No dry weight samples were taken in 1992.

Soil nitrogen content and relative nitrification transformation were determined with three random soil core samples each from 0-15 and 15-30 cm depths within each plot. The samples were composited in plastic bags and stored at 0°C until analysis. Non nitrate N was determined by Kjeldahl procedure (Horowitz 1980) with nitrate N extracted with KCl reduced to NO_2 cadmium reduction and quantified colorimetrically (Page and Keeney, 1982).

Soil sampling dates were:

10 June 1992}

21 May 1993} before fertilizing and planting cowpeas

10 May 1994}

18 Aug. 1992}

17 Aug. 1993} before fertilizing and planting broccoli

15 Aug. 1994}

10 Nov. 1992}

10 Nov. 1993} after broccoli harvest

3 Nov. 1994}

Experiment 4

A fourth study was conducted during 1994. Fertilizer treatments included preplant-incorporated 36N-16P-30K ($kg \cdot ha^{-1}$) before cowpea planting. All broccoli plots received 168 $kg \cdot ha^{-1}$ of external N from urea, which was lightly incorporated after application, as follows: 84 $kg \cdot ha^{-1}$ preplant on 23 Aug.; 42 $kg \cdot ha^{-1}$ sidedressed on 13 Sept.; and 42 $kg \cdot ha^{-1}$ sidedressed on 6 October. Weeds were controlled with preplant-incorporated trifluralin at 560 $g \cdot ha^{-1}$ applied to selected plots on 20 May (before cowpea planting) and on 23 Aug. (before broccoli planting). Hand weeding was done as necessary. Insects were controlled with the same insecticidal treatments previously described for Experiment 3.

The field plot experimental design was a 2x2x2 factorial treatment series arranged in randomized blocks with three replications. Factors were (+ or -) cowpeas [COW], (+ or -) trifluralin before cowpea planting [PPT], and (+ or -) trifluralin before broccoli planting [PBT]. Plots were 4 m x 4 m and were separated from each other by 3 m in all directions to guard against herbicide or N movement between plots.

Cowpea culture: The cowpeas were seeded on 8 June at about 8 $kg \cdot ha^{-1}$ with 1 m between rows and 4 rows/plot. Stand counts were taken on 21 June and all rows were thinned to 40 plants. A once-over hand harvest of marketable green-shell-stage pods from all rows was done on 5 August. Yield samples were saved from 8 m of row length per future broccoli plot. Also sampled were 24 cowpea plants (two per future broccoli plot) for above-ground biomass. The plants were mowed and rototilled into soil on 5 August.

Broccoli culture: The broccoli was planted in single-row plots with 1 m between rows and 3 rows/plot. The center rows were used for data. Transplants were set in the field on 23 Aug. at 20 cm within rows. Each transplant received 200 ml. of starter solution which provided 959N-422P-796K ($mg \cdot liter^{-1}$), respectively, plus diazinon at 200 mg/liter. Dead plants were counted and replaced on 30 August. Two plants per plot were sampled for above-ground biomass on 17 October. Six harvests were made as central heads matured (17 Oct. - 3 Nov.). The stalks were trimmed at 20.5 cm from the top of the dome before weighing.

Soil sampling was not performed in Experiment 4.

RESULTS AND DISCUSSION

Experiments 1, 2, and 3

Soil Nitrogen Analyses:

Results with soil sampling depths of 0-15 cm and 15-30 cm at preplant, at broccoli planting, and after broccoli harvest, 1992, are summarized in Table II. Effects of cowpea green manure and urea fertilization treatment combinations on total Kjeldahl soil N and extractable NO_3 content are presented with N analyses as $\mu g\ g^{-1}$ soil.

There were no significant treatment effects on soil Kjeldahl N at any of the sampling times.

Extractable NO_3 levels of 0-15 cm soil samples at preplant ranged from 1.1 to 1.6 $\mu g\ g^{-1}$ without significant differences. At broccoli planting, soil NO_3 levels had increased about five fold ranging from 6.5 to 7.2 $\mu g\ g^{-1}$ without significant differences between treatments. Soil NO_3 levels were low after broccoli harvest. Soil in plots without preplant N was lower in nitrates than soil in plots with preplant N. Plots without preplant N also had lower nitrate levels than control plots.

Preplant NO_3 levels of 15-30 cm soil samples ranged from 3.6 to 4.3 $\mu g\ g^{-1}$ and were not significantly different among treatments although about 3 fold higher than analogous 0-15 cm soil samples from the same treatment plots. NO_3 levels of 15-30 cm soil samples at broccoli planting ranged from 2.0 to 7.4 $\mu g\ g^{-1}$. Nitrates were significantly depressed in soils from all plots where a cowpea green manure had been incorporated relative to soils in fallowed control plots. Distinctive immobilization of available soil NO_3 results with microbial decomposition of highly carbonaceous root tissues of the green manure crop residues at this soil depth. NO_3 levels at 15-30 cm depth after broccoli harvest showed the same significant effects as were noted for the 0-15 cm depth.

Results with soil N analyses at the two soil sampling depths at preplant, at broccoli planting, and after broccoli harvest, 1993, are presented in Table III.

Total Kjeldahl N from soil samples at preplant showed no differences within future + C treatment plots. However, Kjeldahl N levels at the 0-15 cm depth were higher in future + C - Pre:N plots than in control plots. Since no treatments had been applied at this time, the effect was due to random variability in the field. There were no differences in preplant soil NO_3 levels.

Total soil Kjeldahl N at broccoli planting at the 0-15 cm depth was not significantly different. However, NO_3 levels for all cowpea plots were highly significantly lower than NO_3 levels in control plots at 0-15 cm depths. Soil Kjeldahl N at 15-30 cm depth was not significantly different. However, differences in NO_3 levels, although about half of corresponding treatment plot NO_3 levels at the 0-15 cm depth, were likewise highly significant. Nitrate levels in the cowpea plots were all about half of the 7.8 $\mu g\ g^{-1}$ NO_3 level of the control plots. These results were similar to the previous year's soil analysis indicating immobilization of soil N during decomposition of plant rhizosphere components.

Total soil Kjeldahl N after broccoli harvest at 0-15 cm depth was significantly higher for all cowpea green manure plots compared to control plots. Soil NO_3 levels were variable between treatments with a significant increase apparent as a main effect of Pre:N within cowpea green manure treatments. At 15-30 cm depth, total soil Kjeldahl N levels showed no significant differences. Nitrate levels were more variable than at the 0-15 cm depth, but a significant main effect of Pre:N again was evident within the cowpea green manure treatments.

Soil analyses for 1994 are summarized in Table IV. Treatments differed from the two previous years in that a combination of Pre:N and 1Side:N (total of 126 kg ha^{-1} N) was included and cowpea inoculation was added. Kjeldahl N and NO_3 levels of preplant samples at both the 0-15 cm depth and the 15-30 cm depth were not significantly different among treatments.

Differences in levels of soil N at broccoli planting were not significant at 0-15 cm depths for Kjeldahl N and NO_3. Differences were also not significant for Kjeldahl N levels of 15-30 cm samples at broccoli planting. However, NO_3 was significantly lower for all cowpea green manure treatments compared to control plots, as was found at planting at the 15-30 cm depth during the previous two years of the experiment.

Soil Kjeldahl N and NO_3 levels from + C plots did not differ from those of control plots at either the 0-15 cm or 15-30 cm depths after broccoli harvest. However, at the 0-15 cm depth, residual nitrates were higher in green manured plots receiving 126 kg·ha^{-1} of N than in green manured plots receiving 84 kg·ha-^{1} of N.

Results with total Kjeldahl N at soil depths of 0-15 cm and 15-30 cm, at various sampling times during the three year field experiment, generally confirmed previous research. Experiment Station publications of extensive field research, and concomitant soil analyses during the past century, were recently summarized in reports by Bin (1983), Bowen et al. (1988), Elliott et al. (1987), Emerich and Evans (1984), and Rogers and Giddens (1957). Constancy of total soil Kjeldahl N composition is characteristic of nonerosive soils with productive crop management. An equilibrium in total soil N level is governed by intrinsic soil-environmental parameters (Giddens et al., 1965; Heichel, 1987; Hoyt, 1987; Campbell et al., 1991). Observations of increased desirable soil microbial transformations for available forms of nitrogen favorable to plant nutrition with cover-green manure utilization were frequently published during the past century (Piper, 1922; Coats and Baumhackl, 1989; Bruce et al., 1991; Kurtz et al., 1984).

Soil analyses for available N, as plant nutrient components, are difficult to interpret as a result of the continuous soil microbiological transformations governing N immobilization and ammonification. These edaphic and climatic influences were recently summarized by Chater and Gasser (1970), Parr and Papendick (1978), and Janzen and Radder (1989). For over a century, soil NO_3 has been recognized as a principal available plant nutrient source. Early, precise chemical analysis procedures for NO_3 quantitation at $\mu g\ g^{-1}$ content have resulted in many reports on soil nitrate interactions for plant nutrition; these were summarized by Ladd et al. (1981) and Kurtz et al. (1984). Recent ecological interest in ground water pollution by accumulative soil nitrate concentrations has resulted in environmental protection studies such as those of Follet and Walker (1989) and Muller et al. (1989). Results from soil nitrate determinations in our study were generally reflective of results with previous nitrification studies. Highest NO_3 levels were detected in the 0-15 cm soil depths for all treatments at broccoli planting for each of the three years. Significant immobilization of soil N, not extractable as NO_3, resulted in all three years at 15-30 cm soil depths as a result of cowpea-green manure treatment combinations as compared to the no cowpea, urea-fertilized plots (-C+Pre:N+Side:N). Lowest NO_3 levels were from soil samples attained after broccoli harvest at both soil depths for all three years of our study. Many previous authors have reported on improved soil productivity with green-manure crop management, that includes amelioration of soil aeration and moisture with improved soil physical structure (Campbell et al., 1991; Giddens and Rogers, 1965; Onim et al., 1990). This soil series, Severn very fine sandy loam, is characterized by fertility and structure properties conducive to favorable ammonification-nitrification microbiological transformations.

Broccoli Yields:

Effects of cowpea green manure and urea fertilization treatment combinations on marketable broccoli parameters during 1992 are summarized in Table V. There were no significant differences in the number and weight of marketable broccoli heads per hectare. An interaction of Pre:N and Side:N was evident within + C treatments for average head weight, with the lowest average weight obtained from the treatment lacking fertilizer nitrogen. This treatment also resulted in heads with lower average weights than heads from control plots. When broccoli followed cowpeas, heads grown with Pre:N matured an average of two days earlier than those grown without Pre:N. Also, within + C treatments, broccoli petiole N concentrations were higher in plants receiving either Pre:N or Side:N than in plants not receiving these treatments. However, plants without Pre:N had lower petiole N concentrations than control plants. Results of the first year's study were nonconclusive but were somewhat indicative that the cowpea-green manure treatments were less favorable for quality broccoli production compared to urea fertilization without the cowpea green manure cropping system.

Effects of cowpea green manure and urea fertilization treatment combinations on marketable broccoli parameters during 1993 are summarized in Table VI. A highly significant reduction in number and weight of marketable heads per hectare compared to the control resulted with all cowpea green manure treatments except the treatment with the full compliment of fertilizer N. The high urea fertilization with cowpea treatment resulted in almost double the weight of marketable heads per hectare compared to cowpea treatments receiving only one urea fertilization. Average broccoli head weight variation between treatments was not significant.

The contrasts within the +C treatments for the main effect of Side:N showed significantly lower numbers for broccoli head count and weight when sidedressing was absent than when sidedressing was used. Weight of marketable heads per hectare also was lower when preplant nitrogen was absent than when preplant N was used.

Differences in days to first harvest were highly significant with the (+) cowpea treatments taking an average of seven days longer to mature than the control with the full compliment of N and no preceding cowpeas. This delay in harvesting for the + cowpea treatments directly contributed to the lower weight and count of marketable heads in the three +C treatments. The earlier harvested control escaped an early freeze that hit the later maturing +C treatments. The quality of the still immature heads was damaged by the freeze, resulting in termination of the experiment.

Petiole N concentration in 1993 was significantly reduced compared to the control in the treatments that had no or only partial supplemental N. Differences of average dry weight per plant were highly significant with reductions in the broccoli plant weight in the two treatments which lacked sidedress N.

Within the +C treatments, petiole N concentrations and average dry weights per plant were higher when preplant N or sidedress N were used than when they were not used. Differences in petiole N concentration corresponded closely to differences in average plant dry weight.

Immobilization of available nitrogen forms resulting from accelerated soil microbiological decomposition of residue plant material is well corroborated with the 1993 broccoli yields. Ample plant nutrient nitrogen availability has been reported as requisite for yields of high quality broccoli (Kahn et al. 1991; Letey et al. 1983; Liu and Shelp 1993). Increased levels of urea fertilization appeared necessary for improved broccoli yields with the cowpea green manure treatment series. Therefore, the experimental plan for the following year, 1994, included increased urea fertilization as a sidedressed application.

Results of the effects of cowpea green manure and urea fertilization treatment combinations on marketable broccoli parameters during 1994 are summarized in Table VII.

There were no significant differences from the control with marketable head count. Within the +C treatments, the treatments with the lower rate of 84 $kg \cdot ha^{-1}$ N had higher head counts than the treatments with the higher rate of 126 $kg \cdot ha^{-1}$ N. There were also no significant differences apparent within weight of marketable broccoli heads. The +C, non-inoculated treatment with no sidedress N resulted in lower average head weights than the control. Within the +C treatments, the heavier heads were obtained with two sidedressings as opposed to preplant N.

There were no significant differences in days to first harvest ranging only from 63 to 65 days. Petiole N concentration in all the (+)C treatments was significantly lowered from the control and as expected in the 126 $kg \cdot ha^{-1}$ N treatment the N concentration in the plant was higher than in the 84 $kg \cdot ha^{-1}$ treatment. Unlike 1993, however, there were no significant differences in average plant dry weight in Experiment 3. Petiole N concentrations were higher in 1994 than in 1993. Although petiole N concentrations were significantly reduced by the +C treatments compared to the control, the plants apparently still contained enough N to prevent significant reductions in dry weight.

Experiment 4

Broccoli Yields

The main effects of cowpeas (COW); pre-cowpea trifluralin (PPT); and pre-broccoli trifluralin (PBT), as well as their interactions, were tested. The following variables showed no significant ($P \leq 0.05$) effects of these factors: average above-ground dry weight per plant, plant stands at harvest, average weight per marketable head, diameter at base of trimmed stalk on marketable heads, and number of cull heads per hectare.

Main Effects on Broccoli

For the main effect of COW, there were more dead transplants per data row which had to be replaced when broccoli followed cowpeas (4.6) than when broccoli was planted in fallowed soil (2.4). No other main effects of COW were significant.

For the main effect of PPT, cull head weight in $Mg \cdot ha^{-1}$ was greater when PPT was present (1.1) than when it was absent (0.4). More days to first harvest were required when PPT was present (61) than when it was absent (58). Marketable head number in thou./ha was greater when PPT was absent (42) than when it was present (38), but a significant interaction also was evident. No other main effects of PPT were significant.

The main effect of PBT was not significant for any measured variable in the entire experiment.

Two-Factor Interactions on Broccoli

For the COW*PPT interaction, when PPT was present, the percent of marketable heads harvested after two picks was greater in the absence of COW than in the presence of COW. When PPT was absent, the presence or absence of COW made no difference, as shown below. Otherwise, the COW*PPT interaction was not significant.

-COW -PPT: 58 ab	+COW -PPT: 64 ab
-COW +PPT: 77 a	+COW +PPT: 48 b

For the COW*PBT interaction, there was some evidence of an interaction for marketable head weight in $Mg \cdot ha^{-1}$. However, differences could not be detected with an interaction LSD, and the three-factor interaction was significant. Otherwise, the COW*PBT interaction was not significant.

The PPT*PBT interaction was not significant for any measured variable in the entire experiment.

Three-Factor Interactions on Broccoli

The three-factor interaction (COW*PPT*PBT) was significant only for marketable broccoli yields, as presented in Table VIII. For marketable head count per hectare, with COW present, the presence or absence of herbicide treatments had no effect. With COW absent and PBT present, more marketable heads were harvested when PPT was absent than when it was present. The interaction was somewhat different for marketable head weight per hectare. When COW was absent, the presence or absence of herbicide treatments had no effect. With COW present and PPT present, the marketable head weight was greater when PBT was present than when it was absent.

As with the preceding three experiments, we can conclude that broccoli following cowpeas results in stand establishment problems. Both COW and PPT produced some negative main effects and two-factor interactions in Experiment 4. The pre-broccoli trifluralin seemed to be the least negative factor. However, the combination of all three factors (+COW +PPT +PBT in Table VIII) did not result in the lowest marketable broccoli yields. Evidently the relationships among the three factors are not simple. Results may have been different if the dead broccoli transplants had not been replaced.

SUMMARY AND CONCLUSIONS

This three year study was undertaken to determine effects of cowpea as green manure, with and without urea fertilization, for improved broccoli yields. The field experiments were conducted on Severn very fine sandy loam [coarse-silty, mixed (calcareous) thermic Typic Udifluvent] at the Vegetable Research Station, Bixby, Oklahoma, in 1992, 1993, and 1994.

Soil analyses included non nitrate N with Kjeldahl determinations and extractable soil nitrate N. Soil core samples were taken at random from 0-15 and 15-30 cm depths at preplant, at broccoli planting and after broccoli harvest.

Significant differences were apparent for non nitrate N by the Kjeldahl procedure only during the second year, 1993, of this study. The cowpea-green manure treatments were significantly higher than the noncowpea treatment at 0-15 cm depth at preplant and after broccoli harvest.

Principal differences in extractable soil nitrate N were apparent for each of the three years. Highly significant reduced nitrate levels relative to the control occurred with all cowpea green manure treatments at broccoli planting at the 15-30 cm depth. Reduced nitrate levels were apparent after harvest at both sampled soil depths only in 1992.

Marketable broccoli yields were numerically highest for the +Pre:N+Side:N treatments for both cowpea and no cowpea combinations in 1992. Yields and petiole N concentration (%) were analogous with lowest values for treatments receiving no urea fertilization or only sidedress N applications in 1992.

Results were similar in 1993 but with highly significant decreased head counts for cowpea nonfertilized or receiving 84 $kg \cdot ha^{-1}$ of N from urea fertilization. Marketable head weights and petiole N concentration were also highly significant with higher values for the 168 kg·ha^{-1} fertilization applications with and without cowpea green manure treatments. Increased days to harvest were highly significant for all cowpea green manure treatments relative to the control.

Broccoli yields were not significantly different between treatments in 1994 with cowpea inoculation and higher levels of urea fertilization that were included within treatments. However, petiole N concentration (%) was significantly reduced for all cowpea green manure treatments relative to the control.

Results of a three-factor study in 1994 showed a clear negative main effect of cowpea green manure on broccoli stand establishment. The presence of pre-cowpea trifluralin also had some negative effects on broccoli yield. However, the treatment combining cowpea green manure, pre-cowpea trifluralin, and pre-broccoli trifluralin did not result in the lowest marketable broccoli yields. Results may have differed if dead broccoli transplants had not been replaced.

A preceding cowpea green manure crop apparently will not provide adequate available nitrogen for the following broccoli crop.

Immobilization with decomposition of the cowpea green manure crop significantly reduces available soil N for broccoli growth.

Levels of 168 kg-ha^{-1} of supplemental N as urea were requisite for high broccoli yields with or without cowpea green manure treatments.

Soil nitrate levels at 15-30 cm soil depths were apparently consistent indicators of restrictive N immobilization by green manure residue decomposition.

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TABLE I

DATES AND LEVELS OF UREA NITROGEN FERTILIZATION WITH TREATMENT COMBINATIONS FOR BROCCOLI PRODUCTION DURING 1992, 1993 AND 1994 (EXPERIMENTS 1, 2, AND 3)

1992	External N inputs ($kg \cdot ha^{-1}$)		
	Preplant	Sidedress	
Treatment	(84)	(42) +	(42)
	Date applied		
-C +Pre:N +Side:N	20 Aug.	11 Sept.	28 Sept.
+C -Pre:N -Side:N	--	--	--
+C +Pre:N -Side:N	20 Aug.	--	--
+C -Pre:N +Side:N	--	11 Sept.	28 Sept.
+C +Pre:N +Side:N	20 Aug.	11 Sept.	28 Sept.

1993	External N inputs ($kg \cdot ha^{-1}$)		
	Preplant	Sidedress	
Treatment	(84)	(42) +	(42)
	Date applied		
-C +Pre:N +Side:N	20 Aug.	10 Sept.	29 Sept.
+C -Pre:N -Side:N	--	--	--
+C +Pre:N -Side:N	20 Aug.	--	--
+C -Pre:N +Side:N	--	10 Sept.	29 Sept.
+C +Pre:N +Side:N	20 Aug.	10 Sept.	29 Sept.

1994	External N inputs ($kg \cdot ha^{-1}$)		
	Preplant	Sidedress	
Treatment	(84)	(42) +	(42)
	Date applied		
-C +Pre:N +2Side:N	17 Aug.	8 Sept.	27 Sept.
+CI +Pre:N -Side:N	17 Aug.	--	--
+CI +Pre:N +1Side:N	17 Aug.	8 Sept.	--
+CI -Pre:N +2Side:N	--	8 Sept.	27 Sept.
+C +Pre:N -Side:N	17 Aug.	--	--
+C +Pre:N +1Side:N	17 Aug.	8 Sept.	--
+C -Pre:N +2Side:N	--	8 Sept.	27 Sept.

All external N supplied by urea, which was lightly incorporated after application.

C = non-inoculated cowpeas Pre:N = preplant N applied to broccoli
CI = inoculated cowpeas Side:N = sidedress N applied to broccoli
NS, *, ** = Nonsignificant or significant at $\underline{P} \leq 0.05$ or 0.01, respectively

TABLE II

EFFECTS OF COWPEA GREEN MANURE AND UREA FERTILIZATION TREATMENT COMBINATIONS ON TOTAL KJELDAHL SOIL N AND EXTRACTABLE NO_3 WITHIN TWO SOIL DEPTHS AT PREPLANT, AT BROCCOLI PLANTING AND AFTER HARVEST DURING 1992

1992	Preplant Soil N ($\mu g \cdot g^{-1}$ soil)			
	0-15 cm		15-30 cm	
Treatment	Kj/N	NO_3	Kj/N	NO_3
-C +Pre:N +Side:N	393	1.3	378	3.6
+C -Pre:N -Side:N	403	1.1	405	3.7
+C +Pre:N -Side:N	415	1.2	398	3.6
+C -Pre:N +Side:N	410	1.6	391	4.3
+C +Pre:N +Side:N	405	1.3	422	3.6
	Contrasts within +C treatments			
Main effect Pre:N	NS	NS	NS	NS
Main effect Side:N	NS	NS	NS	NS
Interaction	NS	NS	NS	NS

No treatment differs from control at $P \leq 0.05$ by least squares.

1992	Soil N at Broccoli Planting ($\mu g \cdot g^{-1}$ soil)			
	0-15 cm		15-30 cm	
Treatment	Kj/N	NO_3	Kj/N	NO_3
-C +Pre:N +Side:N	414	6.9	396	7.4
+C -Pre:N -Side:N	409	6.5	395	## 2.0
+C +Pre:N -Side:N	443	7.2	392	## 2.0
+C -Pre:N +Side:N	411	6.6	385	## 2.1
+C +Pre:N +Side:N	432	7.1	414	## 2.8
	Contrasts within +C treatments			
Main effect Pre:N	NS	NS	NS	NS
Main effect Side:N	NS	NS	NS	NS
Interaction	NS	NS	NS	NS

Treatment differs from control at $P \leq 0.01$ by least squares.

1992	Soil N After Broccoli Harvest ($\mu g \cdot g^{-1}$ soil)			
	0-15 cm		15-30 cm	
Treatment	Kj/N	NO_3	Kj/N	NO_3
-C +Pre:N +Side:N	416	1.4	407	2.6
+C -Pre:N -Side:N	422	## 0.4	424	# 1.2
+C +Pre:N -Side:N	437	0.9	426	2.1
+C -Pre:N +Side:N	431	## 0.5	419	# 1.0
+C +Pre:N +Side:N	434	1.5	455	3.0
	Contrasts within +C treatments			
Main effect Pre:N	NS	**	NS	**
Main effect Side:N	NS	NS	NS	NS
Interaction	NS	NS	NS	NS

#, ## Treatment differs from control at $P \leq 0.05$ or 0.01, respectively, by least squares.

TABLE III

EFFECTS OF COWPEA GREEN MANURE AND UREA FERTILIZER TREATMENT COMBINATIONS ON TOTAL KJELDAHL SOIL N AND EXTRACTABLE NO_3 WITHIN TWO SOIL DEPTHS AT PREPLANT, BROCCOLI PLANTING AND AFTER HARVEST DURING 1993

1993	Preplant Soil N ($\mu g \cdot g^{-1}$ soil)			
	0-15 cm		15-30 cm	
Treatment	Kj/N	NO_3	Kj/N	NO_3
-C +Pre:N +Side:N	427	4.1	437	4.2
+C -Pre:N -Side:N	# 461	5.2	431	4.3
+C +Pre:N -Side:N	456	4.5	445	4.7
+C -Pre:N +Side:N	# 466	4.6	439	4.4
+C +Pre:N +Side:N	455	4.2	438	4.8
	Contrasts within +C treatments			
Main effect Pre:N	NS	NS	NS	NS
Main effect Side:N	NS	NS	NS	NS
Interaction	NS	NS	NS	NS

Treatment differs from control at $P \leq 0.05$ by least squares.

1993	Soil N at Broccoli Planting ($\mu g \cdot g^{-1}$ soil)			
	0-15 cm		15-30 cm	
Treatment	Kj/N	NO_3	Kj/N	NO_3
-C +Pre:N +Side:N	468	15.6	422	7.8
+C -Pre:N -Side:N	465	## 9.5	428	## 4.3
+C +Pre:N -Side:N	484	## 9.6	425	## 4.7
+C -Pre:N +Side:N	465	## 8.2	447	## 3.8
+C +Pre:N +Side:N	472	## 8.0	429	## 4.3
	Contrasts within +C treatments			
Main effect Pre:N	NS	NS	NS	NS
Main effect Side:N	NS	NS	NS	NS
Interaction	NS	NS	NS	NS

Treatment differs from control at $P \leq 0.01$ by least squares.

1993	Soil N After Broccoli Harvest ($\mu g \cdot g^{-1}$ soil)			
	0-15 cm		15-30 cm	
Treatment	Kj/N	NO_3	Kj/N	NO_3
-C +Pre:N +Side:N	428	3.0	441	7.8
+C -Pre:N -Side:N	## 477	1.9	453	2.4
+C +Pre:N -Side:N	## 483	2.1	462	5.4
+C -Pre:N +Side:N	# 466	1.9	448	2.7
+C +Pre:N +Side:N	## 481	3.3	464	11.8
	Contrasts within +C treatments			
Main effect Pre:N	NS	*	NS	**
Main effect Side:N	NS	NS	NS	NS
Interaction	NS	NS	NS	NS

#, ## Treatment differs from control at $P \leq 0.05$ or 0.01, respectively, by least squares.

TABLE IV

EFFECTS OF COWPEA GREEN MANURE AND UREA FERTILIZATION TREATMENT COMBINATIONS ON TOTAL KJELDAHL N AND EXTRACTABLE NO_3 WITHIN TWO SOIL DEPTHS AT PREPLANT, BROCCOLI PLANTING AND AFTER HARVEST DURING 1994

1994	Preplant Soil N ($\mu g \cdot g^{-1}$ soil)			
	0-15 cm		15-30 cm	
Treatment	Kj/N	NO_3	Kj/N	NO_3
-C +Pre:N +2Side:N	504	3.7	514	4.3
+CI +Pre:N -Side:N	497	5.2	519	4.8
+CI +Pre:N +1Side:N	487	4.7	533	5.1
+CI -Pre:N +2Side:N	512	3.2	474	3.9
+C +Pre:N -Side:N	527	4.0	522	4.2
+C +Pre:N +1Side:N	502	2.9	487	3.3
+C -Pre:N +2Side:N	486	3.3	525	3.0
	Contrasts within +C treatments			
84 vs. 126 $kg \cdot ha^{-1}$ N	NS	NS	NS	NS
Pre:N vs. 2Side:N	NS	NS	NS	NS

No treatment differs from control at $P \leq 0.05$ by least squares.

1994	Soil N at Broccoli Planting ($\mu g \cdot g^{-1}$ soil)			
	0-15 cm		15-30 cm	
Treatment	Kj/N	NO_3	Kj/N	NO_3
-C +Pre:N +2Side:N	501	8.9	487	14.1
+CI +Pre:N -Side:N	514	12.6	501	## 7.8
+CI +Pre:N +1Side:N	537	9.2	494	# 9.0
+CI -Pre:N +2Side:N	518	9.7	480	## 6.4
+C +Pre:N -Side:N	529	12.0	524	## 8.9
+C +Pre:N +1Side:N	507	10.5	484	## 8.0
+C -Pre:N +2Side:N	498	11.1	519	# 9.1
	Contrasts within +C treatments			
84 vs. 126 $kg \cdot ha^{-1}$ N	NS	NS	NS	NS
Pre:N vs. 2Side:N	NS	NS	NS	NS

#, ## Treatment differs from control at $P \leq 0.05$ or $P \leq 0.01$, respectively, by least squares.

1994	Soil N After Broccoli Harvest ($\mu g \cdot g^{-1}$ soil)			
	0-15 cm		15-30 cm	
Treatment	Kj/N	NO_3	Kj/N	NO_3
-C +Pre:N +2Side:N	505	2.3	492	2.1
+CI +Pre:N -Side:N	523	1.6	517	2.1
+CI +Pre:N +1Side:N	527	2.8	510	3.0
+CI -Pre:N +2Side:N	527	1.6	510	1.8
+C +Pre:N -Side:N	536	1.6	507	1.7
+C +Pre:N +1Side:N	508	2.6	488	2.0
+C -Pre:N +2Side:N	518	1.8	502	1.9
	Contrasts within +C treatments			
84 vs. 126 $kg \cdot ha^{-1}$ N	NS	**	NS	NS
Pre:N vs. 2Side:N	NS	NS	NS	NS

No treatment differs from control at $P \leq 0.05$ by least squares.

TABLE V

EFFECTS OF COWPEA GREEN MANURE AND UREA FERTILIZATION TREATMENT COMBINATIONS ON MARKETABLE BROCCOLI PARAMETERS DURING 1992

Broccoli, 1992	Marketable heads		
Treatment	Count (thou./ha)	Weight ($Mg \cdot ha^{-1}$)	Avg. wt. (g/head)
-C +Pre:N +Side:N	51	12.0	235
+C -Pre:N -Side:N	46	7.8	## 174 b
+C +Pre:N -Side:N	40	9.8	248 a
+C -Pre:N +Side:N	44	9.6	216 a
+C +Pre:N +Side:N	46	10.8	235 a
	Contrasts within +C treatments		
Main effect Pre:N	NS	NS	--
Main effect Side:N	NS	NS	--
Interaction[z]	NS	NS	*

Treatment differs from control at $P \leq 0.01$ by least squares.

[z] If significant, mean separation in columns by least squares, $P \leq 0.05$.

Broccoli, 1992 Treatment	Days to first harvest	Petiole N concn (%)
-C +Pre:N +Side:N	64	3.0
+C -Pre:N -Side:N	64	## 1.5
+C +Pre:N -Side:N	63	2.8
+C -Pre:N +Side:N	66	## 2.0
+C +Pre:N +Side:N	63	3.1
	Contrasts within +C treatments	
Main effect Pre:N	*	**
Main effect Side:N	NS	*
Interaction	NS	NS

Treatment differs from control at $P \leq 0.01$ by least squares.

Information about the Cowpea Crop, 1992

Mean stand = 9.4 plants/m^2 or about 94,000 plants/ha
Mean green shell seed yield = 217 $kg \cdot ha^{-1}$
Mean dry biomass incorporated = 3870 $kg \cdot ha^{-1}$
Mean dry weight of N incorporated = 106 $kg \cdot ha^{-1}$

Raw data for all of the above variables were collected by location in the field, according to what would be future N treatment plots. Analyses showed no significant ($P \leq 0.05$) differences for any variable due to location of future N treatment.

TABLE VI

EFFECTS OF COWPEA GREEN MANURE AND UREA FERTILIZATION TREATMENT COMBINATIONS ON MARKETABLE BROCCOLI PARAMETERS DURING 1993

Broccoli, 1993	Marketable heads		
	Count	Weight	Avg. wt.
Treatment	(thou./ha)	($Mg{\cdot}ha^{-1}$)	(g/head)
-C +Pre:N +Side:N	49	10.1	205
+C -Pre:N -Side:N	## 10	## 1.5	158
+C +Pre:N -Side:N	## 16	## 3.1	203
+C -Pre:N +Side:N	## 18	## 3.2	175
+C +Pre:N +Side:N	37	7.6	206
	Contrasts within +C treatments		
Main effect Pre:N	NS	*	NS
Main effect Side:N	*	*	NS
Interaction	NS	NS	NS

Treatment differs from control at $P \leq 0.01$ by least squares.

Broccoli, 1993			
	Days to first harvest	Petiole N concn.	Avg. dry wt.
Treatment	(no.)	(%)	(g/plant)
-C +Pre:N +Side:N	57	3.2	65
+C -Pre:N -Side:N	## 66	## 1.2	## 23
+C +Pre:N -Side:N	## 64	## 2.2	# 45
+C -Pre:N +Side:N	## 65	## 2.0	50
+C +Pre:N +Side:N	# 62	3.0	57
	Contrasts within +C treatments		
Main effect Pre:N	NS	**	*
Main effect Side:N	NS	**	**
Interaction	NS	NS	NS

#, ## Treatment differs from control at $P \leq 0.05$ or 0.01, respectively, by least squares.

Information about the Cowpea Crop, 1993

Mean stand = 10.3 plants/m^2 or about 103,000 plants/ha
Mean green shell seed yield = 488 $kg{\cdot}ha^{-1}$
Mean dry biomass incorporated = 5678 $kg{\cdot}ha^{-1}$
Mean dry weight of N incorporated = 131 $kg{\cdot}ha^{-1}$

Raw data for all of the above variables were collected by location in the field, according to what would be future N treatment plots. Analyses showed no significant ($P \leq 0.05$) differences for any variable due to location of future N treatment.

TABLE VII

EFFECTS OF COWPEA GREEN MANURE AND UREA FERTILIZATION TREATMENT COMBINATIONS ON MARKETABLE BROCCOLI PARAMETERS DURING 1994

Broccoli, 1994	Marketable heads		
	Count	Weight	Avg. wt.
Treatment	(thou./ha)	($Mg\cdot ha^{-1}$)	(g/head)
-C +Pre:N +2Side:N	47	8.4	178
+CI +Pre:N -Side:N	56	9.2	166
+CI +Pre:N +1Side:N	42	7.1	171
+CI -Pre:N +2Side:N	58	10.0	173
+C +Pre:N -Side:N	49	8.0	# 162
+C +Pre:N +1Side:N	48	8.6	181
+C -Pre:N 2+Side:N	52	9.1	177
	Contrasts within +C treatments		
84 vs. 126 $kg\cdot ka^{-1}$ N	*	NS	NS
Pre:N vs. 2Side:N	NS	NS	**

Treatment differs from control at $P \leq 0.05$ by least squares.

Broccoli, 1994			
	Days to first harvest	Petiole N concn.	Avg. dry wt.
Treatment	(no.)	(%)	(g/plant)
-C +Pre:N +2Side:N	63	3.6	66
+CI +Pre:N -Side:N	64	## 2.7	54
+CI +Pre:N +1Side:N	63	# 3.1	64
+CI -Pre:N +2Side:N	65	## 2.7	58
+C +Pre:N -Side:N	64	## 2.6	66
+C +Pre:N +1Side:N	64	## 3.0	66
+C -Pre:N +2Side:N	65	## 2.8	61
	Contrasts within +C treatments		
84 vs. 126 $kg\cdot ka^{-1}$ N	NS	**	NS
Pre:N vs. 2Side:N	NS	NS	NS

#, ## Treatment differs from control at $P \leq 0.05 > 05$ or 0.01, respectively, by least squares.

Information about the Cowpea Crop, 1994

Mean stand = 8.8 plants/m^2 or about 88,000 plants/ha
Mean green shell seed yield = 796 $kg\cdot ha^{-1}$
Mean dry biomass incorporated = 3014 $kg\cdot ha^{-1}$
 Pre:N (3340) vs. 2Side:N (2670) *
Mean dry weight of N incorporated = 73 $kg\cdot ha^{-1}$
 Pre:N (83) vs. 2Side:N (63) **

Raw data for all of the above variables were collected by location in the field, according to what would be future N treatment plots. Analyses showed no significant ($P \leq 0.05$) differences for stand or seed yield due to location of future N treatment. Inoculation had only one significant effect in the entire study (a minor effect on soil N after broccoli harvest).

TABLE VIII

THREE-FACTOR INTERACTIONS OF COWPEAS, PRE-COWPEA TRIFLURALIN AND PRE-BROCCOLI TRIFLURALIN TREATMENTS ON MARKETABLE BROCCOLI YIELDS DURING 1994

	Marketable heads	
Factors	Count (thou./ha)	Weight ($Mg \cdot ha^{-1}$)
-COW -PPT - PBT	43 ab	9.4 ab
-COW -PPT +PBT	45 a	9.7 ab
-COW +PPT -PBT	43 ab	9.9 ab
-COW +PPT +PBT	32 b	7.5 b
+COW -PPT -PBT	43 ab	9.8 ab
+COW -PPT +PBT	38 ab	9.2 ab
+COW +PPT -PBT	32 b	7.6 b
+COW +PPT +PBT	43 ab	10.2 a
LSD, $P \leq 0.01$	12	2.5

Information about the Cowpea Crop

Mean stand = 10 plants/m^2 or about 100,000 plants/ha
Mean in-the-pod green shell seed yield = 4229 $kg \cdot ha^{-1}$
Mean dry above-ground biomass incorporated = 3500 $kg \cdot ha^{-1}$

All plots contained 40 cowpea plants per row.
Analyses of variance for all of the above variables showed no significant ($P \leq 0.05$) differences for main effects of pre-cowpea trifluralin, future location of pre-broccoli trifluralin plots, or their interaction.

COW = cowpeas
PPT = pre-cowpea trifluralin
PBT = pre-broccoli trifluralin

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