EFFECT OF INTERCROPPING AND TILLAGE/RESIDUE MANAGEMENT ON PLANT COMPETITION FOR WATER AND NUTRIENTS

by

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RESUME TRADUIT DE LA THESE

EFFETS DE L'ASSOCIATION DES CULTURES ET DU TRAVAIL DU SOL/GESTION DES RESIDUS SUR LA COMPETITION DES PLANTES POUR L'EAU ET LES ELEMENTS NUTRITIFS.

Problématique-Matériels et Méthodes

Dans l'agriculture traditionnelle en Afrique de l'Ouest, les paysans ont toujours pratiqué l'association des cultures sous divers systèmes de gestion des résidus de récolte, engendrant une grande variabilité dans les rendements. Malgré les difficultés énormes inhérentes à ces systèmes complexes de production, on y constate un déficit d'attention de la part des chercheurs. Nos travaux avaient pour but d'étudier, d'une part, les effets de l'association des cultures sur la compétition entre les plantes pour l'eau et les éléments minéraux, et d'autre part, les effets des différentes pratiques de travail du sol/gestion des résidus de récolte sur les cultures et la fertilité chimique et physique du sol, et enfin, d'étudier les interactions existant entre pratiques que de travail du sol/gestion des résidus et systèmes d'association des cultures.

Pour cela nous avons utilisé un dispositif "split-plot" pour, d'une part, comparer la pratique paysanne courante qui consiste à exporter les résidus de récolte en fin de campagne, puis à semer directement au début de la campagne suivante avec les pratiques de l'incorporation des résidus de récolte par labour conventionnel (pratique courante dans les exploitations modernes industrielles) et de semi direct sur sol paillé (pratique conservatoire anti-érosive recommandée par certains auteurs), et d'autre part, comparer les associations de deux légumineuses, l'arachide, *Arachis hypogeae* L. et le mucuna, *Stizolobium deeringianum* (une légumineuse en regain d'intérêt comme engrais vert et fourrage dans les Amériques du nord et du sud.) avec le sorgho, *sorghum bicolor* Moher.

Ces études ont été menées en Georgie aux U.S.A. dans des conditions pédologiques et agroclimatiques se rapprochant de celles du Burkina Faso dans le but de favoriser la transferabilité des résultats. Les résultats se présentent succinctement comme suit:

Comparaison des Pratiques du Travail du Sol/Gestion des Résidus

1) L'exportation des résidus de récolte appauvrit plus rapidement le sol en éléments minéraux disponibles et surtout en azote total, contrairement à leur incorporation ou à leur maintien à la surface du sol (paillage), ces deux dernières pratiques favorisant un recyclage des éléments minéraux dans le sol.

2) Les sols nus emblavés directement présentent un avantage d'humidité par rapport aux sols ayant fait l'objet d'incorporation des résidus de récolte par labour conventionnel.

3) Les mesures de l'infiltration de l'eau par simulation de pluie ont montré une meilleure infiltration de l'eau dans les parcelles nues à semis directs par rapport à celle dans les sols labourés, expliquant les différences observées en humidité du sol. Nous avons expliqué cette différence par la présence possible d'une macro-porosité créé après la décomposition des vieilles racines dans les parcelle à semis direct d'une part, et d'autre part, par l'encroûtement superficiel favorisé par le labour fin qui réduit la pénétration de l'eau dans les parcelles labourées. Le paillage est connu pour réduire les risques d'encroûtement superficiel du sol, le ruissellement et l'évaporation de l'eau, ainsi que pour favoriser la création de la macro-porosité du sol par l'action des invertébrés telluriques. Cela explique certainement l'infiltration significativement élevée dans les sols paillés à semi direct comparativement aux deux traitements précédents, justifiant du même coup leur supériorité en humidité.

Ces observations suggères que si labour grossier une stratégie de collecte et de conservation des eaux dans les régions à pluviométrie incertaines telle qu'au Burkina Faso, le labour fin doit y être par contre déconseillé.

4) Eu égard aux différences observées pour l'humidité et la fertilité des sols des différents traitements, le développement racinaire des cultures était plus élevé dans les parcelles paillées que dans les parcelles nues à semi direct ainsi que dans celles conventionnellement labourées.

5) Par conséquent, la production globale de biomasse était plus importante dans les parcelles à semi direct paillée que dans celles labourées conventionnellement et 1992 où la pluviométrie était déficiente. La teneur en azote et en potassium était plus élevée dans les parcelles à semi direct paillées que dans les deux autres traitements principaux à la fin de l'expérience en 1992.

<u>Comparaison des Traitements de Cultures</u>

6) Le rendement du mucuna en biomasse aérienne, en azote (N) et en calcium (Ca) était plus élevé que celui des deux autres cultures en 1991 comme en 1992. Son rendement en biomasse était en moyenne de 11 393 kg/ha en 1991 et 9 544 kg/ha en 1992 pendant que celui en N avoisinait 200 kg/ha quelque soit le système de labour/gestion des résidus de récolte, particulièrement en 1992. Cependant, les sols à mucuna sont restés comparables aux autres sols quant à la teneur en N et en Ca, probablement parce que la durée de l'expérience était insuffisante pour permettre un recyclage de la totalité des résidus produits. Seul la teneur en potassium (K) était plus élevée dans les sols à mucuna dans les premiers 7,5 cm de profondeur après les deux années de l'expérience.

7) En dépit de leur bonne couverture par la biomasse au cours de la campagne, les sols à mucuna présentaient une humidité < sols à sorgho < sols à arachide. Mais la densité racinaire chez le sorgho était > mucuna > arachide. Cela suggère que même si la densité racinaire est important pour un prélèvement maximum de l'eau du sol elle n'est pas le seul facteur d'épuisement.

8) La teneur en eau réduite dans les parcelles d'association sorgho arachide à la profondeur de 60 cm suggère que la compétition entre ces deux cultures est plus forte à ladite profondeur.

9) Bien qu'étant tous deux des légumineuses, l'arachide, et le mucuna, ont eu des effets opposés sur le sorgho, dans les parcelles à association. L'association sorgho/arachide a favorisé le sorgho et déprimé l'arachide. Ce qui était contraire dans l'association sorgho/mucuna où le mucuna a exhibé un rendement significativement plus élevé aussi bien en biomasse qu'en grains, comparé au mucuna en pur. Cela était particulièrement vrai pour 1992.

10) une forte interaction entre pratiques de travail du sol/gestion des résidus de récolte et associations des cultures a été observée, interpellant beaucoup à l'entreprise de recherches pluridisciplinaires pour répondre aux questions suivantes: quelles espèces associer, où, quand et comment?.

Eu égard au rendement élevé du mucuna en biomasse végétative, en azote et en calcium, cette culture mérite d'être recommandée comme une composante des stratégies d'agriculture durable. Son adaptation aux conditions sahéliennes permettra de l'utiliser dans les systèmes de production agro-sylvo-pastoraux pour la restauration rapide et le maintien de la fertilité de nombreux sols dégradés, des jachères comme des sols en culture, ainsi que pour la production de fourrage. Du fait de sa nature volubile, sa culture en association présenterait plus d'inconvénients que d'avantages pour la seconde culture. Par contre, son utilisation dans les cultures en bandes serait très recommandable car cela faciliterait les opérations culturales tout en permettant un système aisé de rotation et de lutter contre certains ravageurs. Je me suis engagé à continuer le travail dans ce sens une fois de retour au pays.

SALIBO SOMÉ
Effect of Intercropping and Tillage/residue Management on Plant Competition for Water and Nutrients.
(Under the direction of DR. WILLIAM L. HARGROVE)

Small-holding farmers in the tropics have traditionally intercropped their lands under different tillage and residue management systems. Yet, little quantitative information is available about water use by intercropped species grown under varying tillage and residue management systems. To examine the effect of intercropping and tillage/residue management practices on plant competition for water and nutrients, grain sorghum [Sorghum bicolor (L.) Moench,cv. "Pioneer 8230"] was intercropped with peanut [Arachis hypogaea L., cv. "Southern Runner"] or velvet bean [Stizolobium deeringianum Bort, vc. "Early Speckled Velvet Bean"] under conventional tillage (CT), no-tillage with residue cover (NTC) or no-tillage bare (NTB) in 1991 and 1992. The parameters of concern were plant root growth, soil water content, biomass production, and yield and soil properties.

Root length density (RLD) and root dry weight (RDW) were higher in NTC and NTB than in CT, and this was largely attributed to higher soil moisture content. All combinations produced significantly more roots within the top 10 cm depth than deeper depths. Sorghum produced more roots followed by velvet bean and peanut. Intercropping resulted in intermediary root production compared to the component sole crops. Root growth was greater in 1992 than in 1991, despite the reduced rainfall in 1992, and this was attributed to stimulative effect of the water shortage and changes in soil fertility. The ratio of root weight to root length density suggested that finer roots were produced in 1992 compared to 1991.

The measurement of soil water content by time domain reflectrometry clearly confirmed the moisture disadvantage of conventional tillage over no-tillage systems. Crop residue removal from no-tillage plots resulted in insignificantly less soil water content than otherwise. These differences corroborate the water infiltration measurements. Reduced soil water content in mixtures suggested a more thorough soil exploration and a greater water use by intercrops when compared to sorghum monocrop. Increased competition for water between sorghum and either legume in the mixtures appeared to occur at 45-60 cm soil depth.

In general, plant biomass production, nutrient uptake and grain yield drastically decreased in the second year of the experiment as a result of unfavorable rainfall distribution, late planting and reduced soil nutrient content. On the average, CT favored plant biomass production, nutrient uptake and yield in 1991 where rainfall distribution was satisfactory. NTC was advantageous under the drier conditions during the 1992 growing season. Although NTB differed little from NTC, soil nutrient content and pH in NTB suggested that residue removal may lead to long-term soil infertility. Velvet bean biomass production and nitrogen yield were interestingly high, encouraging the use of this crop for improving soil properties. In general, intercropping improved the residue quality and provided an overall yield advantage over monocultures.

In general, the interactions between intercropping and tillage/residue management systems were significant and complex, suggesting careful selection of intercrops and soil management systems for satisfactory crop production.

INDEX WORDS: Intercropping, Plant Competition, Tillage, Residue Management, Water Infiltration, Plant Root Growth, Soil Water Content, Sorghum, Velvet Bean, Peanut.

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by

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Date

A i pög, Mèda Agnès-Marie, a i bibïr, Somè Sankaar, Nirsaalo, a ni Ampô Kpipô yang nan ka i gnè a tuo a gnan.

A i saan, Somda Nanwyir, lè ti kpïr ka ku m'an a nuör gnan. A nan wa ti ta a gnan, i tièra ka i mi tu nan a nuör ti ta a lè a i fong na ta. Naanmwin·lè a ti fong, ni a ti kpà tièrè. K'ô wul m'an a sör ka kum'an a chaala ni a fong, ka i tüon kö a i saan nuör ô nana gman kö m'an, a i yèb, a i yèb-pouli, ni a Naanmwin ti saan pu vièlu yang.

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Root length density (RLD) and root dry weight (RDW) were higher in NTC and NTB than in CT in accordance with soil water measurements, and were also higher within the top 10 cm depth than deeper. Sorghum produced more roots followed by velvet bean and peanut. Intercropping resulted in intermediary root production compared to the component sole crops. Water shortage during the 1992 growing season seemed to simulate finer and more extensive root growth - compared to 1991.

The measurement of soil water content by time domain reflectometry clearly confirmed the moisture advantage of NTC over CT, and corroborated the water infiltration measurements. NTB exhibited mean values. Intercropping seemed to favor a more thorough use of soil water compared to sorghum monocrop. A greater inter-crop competition for water was observed at 45-60 cm soil depth.

On the average, CT was more productive in 1991 where rainfall distribution was satisfactory, but NTC was advantageous under the drier conditions of the 1992 growing season. Although NTB differed little from NTC, the decrease of soil pH and nutrient content in NTB suggested that residue removal may lead to a long-term soil infertility. Velvet bean showed promise for improving soil properties. Intercropping improved the residue quality and exhibited an overall yield advantage over monocultures.

In general, the interactions between intercropping and tillage/residue management systems were significant and complex, suggesting careful selection of intercrops and soil management systems for satisfactory crop production.

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CHAPTER 1

INTRODUCTION

Conventional agriculture as practiced in developed countries entails monocropping with intensive tillage and large inputs of synthetic fertilizers and pesticides (Barrett, 1981; Follett and Walker, 1989; Batie and Taylor, 1990). As such, it is capital intensive, and depends on energy derived mainly from non-renewable resources (Sanchez and Benites, 1987; Follet and Walker, 1989; National Research Council, 1989). Although this high-input agriculture has spurred agricultural production worldwide, its adverse effects on the environment and human health raise concerns about the sustainability of conventional agriculture (Barrett, 1981; Batie and Taylor, 1989; National Research Council, 1989).

A prominent component of conventional agriculture, monocropping creates homogeneous agroecosystems that are highly vulnerable to pests and diseases (Baker and Cook, 1974; Barrett, 1981). The disastrous potato blight (Phytophtera infestans) epidemic in Ireland in the 1840's, and the southern corn leaf blight (Helminthosporium maydis) epidemic in the U.S. in the 1970's (Bezdicek and Granatstein, 1990) are historical illustrations of the disease disadvantage of monocropping systems. In uniform pure stand communities, plants explore the soil at the same depth and have the same peak demand for resources. Monoculture therefore, encourages intra-specific competition that can resulting in yield loss.

Use of commercial fertilizers to maximize yield has increased drastically since the Second World War (Follett and Walker, 1984; Keeney, 1986). In particular, the use of nitrogen fertilizers accounts for 30-40% of total crop productivity (Wolfe and Minchin, 1984), with the United States as the leading consumer (FAO, 1984, 1986). In the United States about 50 kg N was applied per hectare of arable land in 1985 (FAO, 1986). Nitrogen fertilizer inputs in excess of crop N requirement or poorly timed application permit nitrate to concentrate in cropped soils and to leach to ground water, raising environmental and health concerns (Hallberg, 1989; Keeney, 1986; Follett and Walker, 1989).

Another prominent component of conventional agriculture, intensive tillage, promotes water runoff and soil erosion, resulting in loss of soil productivity, reduction in surface water quality, and the siltation of streams, lakes and reservoirs. On many soils conventional tillage is unsustainable. With the removal of topsoil, organic matter and nutrients are lost, exposing subsoil which is frequently more acidic and usually less productive. In these situations, loss of productive topsoil increases reliance on liming and fertilization for continued agricultural production.

In many African countries, crops are produced on small holdings by subsistence farmers using hand tools. Such labor-intensive production methods permit mixtures of different species or varieties to be grown concurrently on the same parcel of land, a practice termed intercropping. Crop diversification through intercropping can maximize resource utilization and ensure yield security in the event of epidemics or water shortage

(Okigbo, 1990; Sanders, 1989; Ikeorgu and Odurukwe, 1989). Interplanting legume with non-legume crops can forestall soil nutrient depletion (Russelle and Hargrove, 1989). While non-legume crops deplete soil-N, legumes and their rhizobial symbionts fix atmospheric N that can supply crop N needs, and often build up soil N reserves. In addition, intercropping benefits small farmers by providing them a way to grow a wide array of crops required for household use, freeing them from the burden of purchasing food and feed for livestock.

In many developing countries, growing populations, a shrinking resource base, and inappropriate production methods combine to threaten the sustainability of agriculture. Under current production practices in subhumid regions of Africa, crop residues are often exported as feed, fuel, or building materials, grazed or burned, exposing the soil to high thermal fluctuation, and wind and rain erosion (Okiggo, 1980). Such removal of crop residue accelerates soil and nutrient depletion. Shifting cultivation systems that once included alternate fallow periods for nutrient replenishment (Nye and Greenland, 1960; Sanders, 1989; Okigbo, 1990) are now disappearing rapidly, the result of increasing population pressure on land (Said, 1984; Vierch and Stoop, 1990). In many areas, agriculture has moved onto marginal lands and fragile soils, further compounding soil degradation (Malton, 1984; Sanders, 1989). Unlike in developed countries, small holders in developing countries often cannot afford inorganic fertilizers. The overall result of inadequate cropping systems and residue exportation in the absence of fertilizer application are drastic increases in soil erosion, decreases in soil nutrient and organic matter contents, and an exacerbation of soil acidity (Okigbo, 1980; Lal, 1987). As is the case in developed countries, many current agricultural production practices in developing countries are also not sustainable.

Numerous alternatives have been proposed to sustain soil productivity with little harm to the environment. Among these, carefully designed intercrop systems and improved crop residue management practices are being widely advocated (National Research Council, 1989; Russelle and Hargrove, 1989; Batie and Taylor, 1990). A review by Okigbo (1969) showed that crop residues efficiently protect the soil against wind and water erosion, and high thermal fluctuations, allowing better plant growth (Lal, 1975; Harrison and Lal, 1979).

Another factor with potential for increasing sustainability, intercropping can lessen intraspecific competition which consequently may improve the efficiency of water and nutrient use by crops (Russelle and Hargrove, 1989). In particular, the intercropping of legumes and cereals appear to be an efficient strategy for sustaining soil fertility (Follett and Walker, 1989; Russelle and Hargrove, 1989; Cook and Baker, 1983). A recent review by Russelle and Hargrove (1989) indicates that deep rooting species, including some legumes, can be used to reduce nitrate leaching and retain N in the system. Intercropped deep-rooted species can also transfer subsoil water and nutrients to shallow rooted companion crops (Nobel, 1991).

Although the benefits of intercropping appear obvious, careful analysis of crop performance in mixed stands is limited. Numerous factors affect crop performance in mixtures (Lai and Lawton, 1962; Reedy and Willey, 1980; Pleasant, 1982). Complex interaction among these factors add to the scarcity of data to make it difficult to predict the performance of untested intercrop mixtures. Reports of legume/cereal intercropping are especially contradictory in this regard (Lai and Lawton, 1962; Pleasant, 1982; Wolfe and Lazenby, 1973; Wolfe et al., 1982). Additional field work is required to identify suitable combinations for intercropping and their management requirements for optimal intercrop production. Among the factors affecting crop performance in mixtures, the effect of tillage and crop residue management practices has not been well investigated.

The present work was designed to study the effect of intercropping grain sorghum with peanut or velvet bean under conventional tillage, no-tillage with residue cover, or no-tillage with residue removed, on root growth, soil moisture depletion, crop biomass production, yield, and soil properties.

CHAPTER 2

LITERATURE REVIEW

I. INTERCROPPING

Unlike monocropping, intercropping entails the growing of two or more crops on the same land, at the same time, in proximate but different stands (Nyambo et al., 1980; Davis et al., 1986). Intercropping systems are diverse and include mixed cropping, row cropping, patch cropping, relay cropping and alley cropping (Francis, 1986). Because of the physiological and morphological heterogeneity that characterize mixed communities, mechanization of some cropping operations, like pesticide and fertilizer application, and harvesting is difficult in intercropped systems. Consequently, crop associations, except for relay cropping, are not common in industrialized countries. In contrast, small-holding subsistence farmers in the tropics have traditionally intercropped their lands to minimize risks associated with monocultures, and to assure stable income and nutrition (Francis et al., 1975). Advantages associated with intercropping include, 1) yield security in the event of insect plagues, disease outbreaks, water shortage, or flooding, 2) reduced plant competition for resources, 3) high resource use efficiency, 4) yield advantage over monocropping, and 5) reduced rate of soil nutrient depletion (Willey, 1979; Okigbo, 1980; Ikeorgu and Odurukwe, 1989; Russelle and Hargrove, 1989). Despite the fragile soil fertility in the tropics, agriculture has sustained life in these regions for millennia, probably due in part, to the practice of intercropping.

INTERCROP COMPETITION FOR RESOURCES.

In crop monocultures, as in homogeneous plant communities generally, individual plants compete strongly when resources are limited, since requirements of each member are roughly the same (Hamblin and Donald, 1974). In mixed communities, resource requirements are variable in space and time, which minimizes both inter- and intra-crop competition (Huxley and Maingu, 1978; Izaurralde et al, 1990). In general, plant competition for resources (light, soil water, nutrients, and carbon dioxide) occurs during all or part of the growing season (Kurtz et al., 1952; Gomez and Gomez, 1983; Russelle and Hargrove, 1989) and the productivity of each companion crop is dependant on its ability to compete. The interaction among these factors can result in significant yield loss in mixed cropping (Fisher, 1977; Izaurralde et al., 1990).

Competition for water and nutrients.

Kurtz et al. (1952) were among the first to report on intercrop competition for water and nutrients. Recent reports by Schultz et al. (1987) indicate that legumes can compete strongly with corn for nitrogen.

However, in most cases, grass crops such as cereals exhibit a much stronger competitiveness than legume crops when the two are grown together (Davis et al., 1986). During pasture development, Wolfe and Lazenby (1973) noted that grasses were more competitive than white clover for P uptake. Seedling forage legume growth was significantly reduced due to competition from corn (Lefrançois and Scott (1988). Chang and Shibles (1985) reported that corn strongly competed with cowpea for N and P. De Queiro and Galwey (1986) intercropped five sorghum genotypes with two cowpea genotypes, and reported that all sorghum genotypes affected the cowpea performance. The effect of cowpea on sorghum was less noticeable. This domination often has been attributed to the extensive root system of grasses which enables them to extract nutrients more efficiently than legumes (Lai and Lawton, 1962; Wolfe and Lazenby, 1973; Caradus, 1980). In general, cereal/legume competition is most severe for legumes during the early part of the season due to the slow root development of the latter (Manson et al, 1986). As a result, legume intercrops often experience slow early growth and reduced vigor (Pleasant, 1982; Wolfe et al, 1982).

Davis et al. (1986) distinguished two categories of intercrop legumes with cereals. One includes those which take advantage of temporal differences between crops and the other, those which rely on spatial differences. According to Davis et al. (1986), plant characters associated with these two categories are time to maturity (temporal differences), and plant architecture above and below ground (spatial differences). The severity of competition depends on a number of factors such as 1) soil water and nutrient availability, 2) intercrop planting density and geometry, 3) timing of planting, and 4) intercrop species or varieties (Willey et al., 1981).

Competition for water and nutrients is reduced in nutrient rich moist soils (Willey et al., 1981), but increases with resource depletion (Gliessman, 1986; Izaurralde et al, 1990). However, many factors can reduce plant competition for water and nutrients in intercropping systems. Among them, plant population of each intercrop species is generally lower than it is in monoculture. Therefore, the risk of moisture stress may be reduced in intercropping systems compared to monocultures. This is supported by reports that sorghum was less susceptible to moisture stress in sorghum/cowpea association than in pure stands (Andrews, 1973). Report by Murry and Swensen (1985) clearly demonstrated the importance of intercrop plant population on yield. Winter pea (P. sativum ssp. arvense L.) mixed with 25% winter cereals (barley or wheat) yielded up to 27% more seed than monocropped winter pea. In a reverse mixture, a 60% yield decrease was recorded for winter cereals. In a barley/pea intercropping, Izaurralde et al. (1990) reported that barley yield decreased linearly with increasing pea density. Andrews (1973) indicated that successful growth of peanut in mixtures requires either a low population of the other crop, or crops with a longer growth cycle planted after peanuts are established. This observation agrees with the critical nature of time of planting of component crops in associations stressed by Francis et al. (1985).

Another factor that can reduce plant competition for water and nutrients, complementary root systems of intercrops permit more efficient use of water and nutrients and, therefore, greater ability to withstand short falls in precipitation. In the experiment by Andrews (1973) sorghum withstood moisture stress in mixture with cowpea partially because it was deeper rooted, which created a spatial difference in resource utilization that reduced competition from cowpea.

In relay cropping systems in particular, where the growth periods of crops overlap only slightly, inter-crop competition may be minimal (Francis et al., 1985; Francis, 1986; Russelle and Hargrove, 1989). In any case, when time of planting is adjusted so that legumes overcome the competition from cereals, intercropping with legumes can benefit cereals by providing them with a nitrogen source (Agboola and Fayemi, 1972; Francis, 1986;).

Where spreading species such as Florunner peanut, cowpea or velvet bean are intercropped, ground coverage by the canopy may reduce water loss by evaporation enough to permit crop survival during drought periods or conserve more water for succeeding relay crop.

Crops are very variable in their rooting patterns and include deep and shallow rooting species (Gregory, 1988). Use of deep rooting intercrop components can result in tapping deeper horizons and bringing up water and nutrients for shallow rooting companion crops (Harwood, 1984). The mechanisms by which water and nutrients are transferred from one companion crop to another has not been well documented. Hillel (1980), Gregory (1988) and Nobel (1991) indicated that such phenomenon can occur whenever the soil water potential is reduced enough to cause a reverse flow of water from the root to the soil matrix. Blevins (1987) and Corak et al. (1987) reported that such transfer of subsoil water from alfalfa was enough for corn to survive a 100 day drought. According to Agboola and Fayemi (1972) legumes also have the potential for excreting fixed nitrogen for companion crop uptake. Senesced legume roots during the growing season may also decompose rapidly enough to supply nitrogen to companion cereals. Thus, these phenomena reduce intercrop competition and can improve water and nutrient use efficiency (Reddy and Willey, 1980; Natarajan and Willey, 1980).

Competition for water and nutrients is reflected by the dynamics of the soil moisture and nutrients in the root zone or soil profile. Where these resources are limiting, lower plant density is generally recommended to minimize yield loss. For the majority of crops, little information is available concerning their reaction in intercropping systems.

Competition for light.

Light interception by the plant canopy depends on the leaf area index (LAI). In intercropping systems, above ground spatial differences among associated crops favors the development of an increased leaf area index (IRRI, 1975). As a result, light use efficiency is expected to be higher in mixed than in pure stands. Willey and Osiru (1972) attributed yield advantage of their mixtures to more efficient utilization of light that arose from the complementarity of crop heights. However, this advantage is not always observed, especially when planting geometry is inadequate, as in large/small crop associations where shading effects from larger crops are more likely. In peanut/cereal mixtures for instance, shading from cereal intercrops contribute to depress peanut yield (Koli, 1975; Stirling et al, 1990). Light interception by sorghum or millet in mixtures with green-gram contributed to yield loss by the latter (Keswani and Mreta, 1980). Shading effect is more deleterious during critical growth stages of the short intercrop (Stirling et al, 1990).

Despite the shading effects, the combination of short and tall species is believed to improve the overall light use efficiency. Although it may not be important under moisture stress condition, improved light use efficiency can reduce yield loss under nitrogen stress (Reddy and Willey, 1980). Light use efficiency in intercropping can be improved by the complementarity of leaf area indices in space and time. In sorghum/millet mixture for example, Kassan and Stockinger (1973) found that rapidly expanding leaves of millet intercepted most of the light early in the season. Slower growing sorghum leaves took over later as the millet ripened. Accessibility of the short component intercrop to light depends on the plant density, height, leafiness (Liebman and Robichaux, 1990), and leaf orientation (Nobel, 1991) of the tall component. Intercropping species with good complementary effect is recommended to minimize competition and yield loss (Dalal, 1974; De and Singh, 1979; Willey and Reddy, 1981; Gomez and Gomez, 1983; Russelle and Hargrove, 1989).

II. INCIDENCE OF DISEASES AND INSECTS IN INTERCROPPING SYSTEMS.

Numerous examples of disease limitation in crop mixtures, compared with pure stands have been reported (Wolfe and Minchin, 1982; Ikeorgu et al., 1984). Historically, crop association has contributed to the control of barley and wheat mildews in the United States (Wolfe and Minchin, 1982; Wagstaff, 1987). Peanut grown in combination with beans showed less severity of leaf spot disease and rosette than in pure stands (Mukiibi, 1980). Damage by flies, midges and aphids to sorghum was reduced when sorghum was grown in association with simsim (Kato et al., 1980). In maize/cowpea mixture, cowpea yield was improved as a result of reduced insect pest invasion (Karel et al., 1980). Similar results were reported for beans in mixture with maize (Rheenen et al., 1980. Clifford et al., (1989) reported lower numbers of cassava whiteflies in cassava/cowpea systems than in cassava monoculture.

Mechanisms by which diseases and insects are reduced by mixtures are not well documented. Because the population is genetically homogeneous, monocultures are highly prone to epidemics that can lead to economic disasters (Bezdicek and Granatstein, 1990). In mixed communities, genetic diversity is higher and damage by polyphagous pests is reduced on individual intercrop component (Chin, 1979). In addition, non-matching hosts behave as barriers to monophagous invaders and limit their spread within the community. Mixed stands can also result in a greater complexity of the soil microbial population, which could decrease the rate of invasion by foreign organisms (Cook and Baker, 1983). In many intercropping systems, wind velocity is reduced, which in turn, reduces the rate of pathogen propagation (Keswani and Mreta, 1980). By intercropping species with different above ground morphologies, aeration may be improved, influencing humidity and thermal and gas exchange conditions, and reducing the severity of some diseases.

III. YIELD PERFORMANCE IN INTERCROPPING SYSTEMS

Yield performance in mixtures is well documented. In general, intercropping decreases individual intercrop yields with higher effect on legume crops (Davis et al., 1986). Izaurralde et al. (1990) compared barley/field pea intercropping with the respective sole cropping of the intercrops for grain and N yield. They reported that each intercrop yielded at half its sole rate. Intercropped-barley especially, yielded 35 to 40% lower, but its grain and straw N content were higher than in pure stand. In legume/cereal mixtures, Nyambo et al. (1980) reported a yield reduction of 33-82% for their legume and only 7-37% for cereal intercrops. Even with less disease infection, intercropped sorghum and millet yielded less than their pure stands (Keswani and Mreta, 1980). Peanut yield reduction in mixture with cereals is particularly weel documented (Koli, 1975; IRAT, 1978; Ikeorgu and Odurukwe, 1989).

However, many intercropping systems, particularly cereal/legume combinations, show an overall yield advantage over monocultures (Sanchez, 1976; Fisher, 1977; Nyambo et al., 1980; Ikeorgu and Odurukwe, 1989). Nyambo et al. (1980) reported a 60% overall yield increase in mixtures compared to monocultures. In Sénégal, sorghum/peanut intercropping gave higher overall yields than the individual crops in pure cultures (Schilling, 1965). Yield advantage of intercropping systems depends on the nature of competition among plants, which in turn, depends on resource availability, cropping strategy, and the nature of the crops in association (Barker and Francis, 1986).

IV. EFFECT OF RESIDUE MANAGEMENT ON SOIL PROPERTIES

No-tillage and residue mulches are efficient strategies for soil and water conservation (Okigbo, 1969; Lal, 1975). Crop residue mulches absorb the kinetic energy of raindrops, protecting surface soil aggregates from break down and dispersal. Consequently, surface sealing or crusting, water runoff and soil erosion are reduced (Russelle and Hargrove, 1989). In addition, crop residue mulches reflects solar radiation, reducing thermal fluctuations, and forestalling water evaporation (Lal, 1975; Harrison and Lal, 1979). Reduction of thermal amplitudes by a stubble layer was efficient enough to limit self-mulching effect of a vertisol (Dexter et al., 1982). Crop residues also behave as refuge and/or food resource for soil-dwelling animals, whose activities improve soil macroporosity and hydraulic conductivity (Kemper et al., 1987). Earthworms and termites also contribute to soil mixing and aggregate stabilization.

In contrast to no-tillage, conventional tillage encourages surface crusting, resulting in greater water runoff and soil loss (Russelle and Hargrove, 1989). Although conventional tillage may loosen the soil for better plant rooting, its tendency to reduce water infiltration and its lack of a moisture conserving surface mulch may significantly reduce soil plant-available water in dry areas, and cause greatly diminished yields.

Regardless of tillage, nutrients are recycled when crop residues are returned to the soil (Thompson et al., 1985). When crop residues are removed, a practice common in many parts of Africa, nutrient recycling is not only prevented, but many of the advantages obtained with a reduction in tillage systems are also eliminated. No-tillage with residue removal speeds up soil degradation, and quickly reduces crop production (Hewitt and Dexter, 1980; Dexter et al., 1982; Utomo and Dexter, 1981). Hewitt and Dexter (1980) showed that soil bulk density throughout the growing season was greater in burned no-tillage than in conventional tillage, burned or not.

Under no-tillage, roots were heavily concentrated in the upper 15 cm, presumably due to soil compaction. Although it is widely practiced, no-tillage with residue removal has received little attention from researchers, and information is lacking about the effect of such practices on crop production in intercrop systems.

V. LEGUME NITROGEN FIXATION AND USE EFFICIENCY

Nitrogen is a critical element in plant nutrition. Nodulated legumes can symbiotically fix a substantial amount of atmospheric nitrogen (McGuire et al., 1989; Gibson et al., 1977). A portion of this fixed N typically becomes available to non N-fixing crops grown in association with legumes (Russelle and Hargrove, 1989; Fyson and Oaks, 1990; Hargrove, 1986). Nitrogen derived from N fixation amounted to about 33% in soybean and cowpea (Sisworo et al., 1990). Suwanarit et al. (1986) reported that 55-66% of the N produced by peanut and soybean was fixed. Plant nitrogen fixation is higher in N-poor soils especially when plants are inoculated with effective bacterial symbionts. However, recycling of legume-N recovered by non-legume crops depends on a number of factors including the rate of mineralization, the quality of the residue (lignin and N content, C/N ratio), and the soil moisture status (Sisworo et al., 1990). This percentage also reflects the subsequent cereal crop N-use efficiency (NUE) from legumes (NUEL), which is typically far lower than the NUE from fertilizer (NUEF). For example, it has been shown that only 10 to 30 percent of legume-N was recovered by the following crop (Ladd and Amato, 1986; Harrison and Hesterman, 1987), compared to recoveries from fertilizer N of 30 to 70 percent (Stanford, 1987). Typically, high NUEF's arises because fertilizer N is readily available for plant uptake. In contrast, a large portion of legume-N remains in the soil organic matter and biomass pools, and only becomes available after mineralization.

The estimation of NUE that is based on data from a single season, favors fertilizers, and tends to discourage the use of legumes as a reliable N source. This concern was raised by Bezdicek and Granatstein (1989) who suggested that the efficiency of both N sources be evaluated over a longer time period to develop a total N budget of inputs (N fertilizer, N2 fixation, or N deposition), and outputs (harvest, leaching, volatilization, denitrification). Meisinger (1984) also suggested that estimation of changes in N pool sizes (e.g., organic matter, microbial biomass, inorganic N, etc.) be made when comparing NUE between legumes and fertilizers. Taking into account changes in soil N that take place when legumes are used for many years could drastically increase estimates of NUEL and drastically improve the adoption of legume N sources for crop production.

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CHAPTER 3

EFFECT OF INTERCROPPING AND TILLAGE/RESIDUE MANAGEMENT ON PLANT ROOT GROWTH.

ABSTRACT

Plant competition for below ground resources is controlled by numerous factors that interact dynamically. The complexity of these interactions complicates the determination of compatible crops for association under varying conditions. In tropical areas, lands are traditionally intercropped under a variety of tillage and residue management practices with a corresponding variation in yield. The effect of intercropping sorghum [Sorghum bicolor (L.) Moensh, cv. "Pioneer 8230"] with peanut [Arachis hypogaea L., cv. "Southern Runner"] or velvet bean [Stizolobium deeringianum (Bort), cv. "Early Speckled Velvet Bean"] on root growth under different tillage/residue management practices was studied in Griffin, Georgia, during the summers of 1991 and 1992 using a split-plot design in randomized complete blocks. Three tillage management systems were examined: conventional tillage (CT), no-tillage with residue cover (NTC) and no-tillage bare (NTB). Root growth was examined as an indicator for crop competition for below ground resources. The experimental design was a

randomized split-plot, with tillage/residue management as the main plot and crop treatment as the sub-plot. Root samples were taken from the middle of inter-row spaces at 0-10 cm and 20-30 cm soil depth. Results indicated that root growth was reduced in CT compared to NTC and NTB, and this was in accordance with the measurements of soil water content. Sorghum produced significantly more roots than either legumes under all tillage/residue management systems. Root production in mixtures was intermediary between the corresponding sole crops. Based on these results, intercropping appeared to favor sorghum over the legumes for water and nutrient uptake. For all main treatments, both root length density (RLD) and root dry weight (RDW) were higher at the 0-10 cm than at the 20-30 cm soil depth. Despite the reduced rainfall recorded during the 1992 growing season, crops produced more roots in comparison to 1991, and this was attributed to probable stimulative effect of the water shortage and reduced soil fertility. The ratio of RDW to the RLD suggested that finer roots were produced in 1992 compared to 1991.

INTRODUCTION

Plant water and nutrient uptake is influenced by root morphology and physiology (Gregory 1988; Klepper, 1992). In general, monocotledons, such as cereal crops, have extensive fibrous root systems. This permits them to explore a large volume of soil, thereby increasing their ability to compete for below ground resources (Russell, 1977; Klepper, 1992). Sorghum root growth, can extend beyond 135 cm soil depth, with maximum root density within the top 15 cm depth (Gregory, 1988; Doggett, 1988; Roder et al., 1989). Dicotyledons, including legumes, have root systems ranging from fibrous to centralized taproot (Russell, 1977; Klepper, 1992). Peanuts in particular, have a deep taproot and fine lateral roots with maximum root density within the top 15 cm of soil (McCloud, 1974; Lenka and Misra, 1973; Kenneth et al., 1982; Pandey et al., 1984). Excluding the taproot, peanut root distribution was found to be uniform below the row and laterally 46 cm from the row (Robertson et al., 1979). Rooting depths to 200 cm often have been reported for peanut (Hammond et al., 1978; Robertson et al., 1980). Kenneth et al. (1982) reported deeper rooting depths for Florunner peanuts on a sandy soil. In contrast to peanut, the rooting pattern of velvet bean has not been fully investigated. Hulugalle (1984) sampled velvet bean roots randomly to only 30 cm depth and reported a greater root density in the top 10 cm than in deeper depths. During the same experiment, velvet bean produced more roots than cowpea but less than corn.

Plant root growth is controlled by soil physical and chemical properties, which often are affected by tillage and crop residue management practices (Mosher and Miller, 1972; Cooper, 1973; Hulugalle et al., 1984; Blevins et al., 1984; Phillips, 1984; Shopart, 1987; Payne and Gregory, 1988; Gregory, 1988; Haynes and Knight, 1989; Klepper, 1992; Zobel, 1992).

Changes in these properties may influence niche-breath overlap and crop competition for below ground resources. Soil physical properties that affect plant rooting include soil temperature, water content, compaction and air-porosity (Mosher and Miller, 1972; Cooper, 1973; Klepper, 1992; Phillips, 1984). An extensive review of the role of soil temperature on root growth is provided by Cooper (1973). A recent review by Klepper (1992) showed that both the number and pattern of root branching are partially controlled by temperature. Mosher and Miller (1972) found that warmer temperatures caused vertical root elongation, while cooler temperatures stimulated horizontal orientation. In general, mulched soils, such as no-tillage with residue cover (NTC), have cooler temperatures than soil under conventional tillage (CT) and no-tillage with residue removed, i;e, no-tillage bare (NTB) (Lal, 1975; NeSmith et al., 1984; Phillips, 1984; Gupta et al., 1984; Shopart, 1987; Payne and Gregory, 1988). With regard to results of Mosher and Miller (1972), the cooler temperatures in the NTC may suggest greater horizontal root development and therefore, increased root density in the inter-row spaces in NTC as compared to CT or NTB.

Although soil compaction is a common root growth limiting factor in no-tillage systems (Voorhees, 1992), increased soil water content in NTC (NeSmith et al., 1987; Lal, 1975; Phillips, 1984), can favor greater root growth compared to CT and NTB (Hamblin, 1985). However, complex interactions from numerous other factors can also result in non-linear responses of root growth to soil moisture content (Klepper, 1992; Zobel, 1992). For instance, water stress imposed to peanut at different growth stages resulted in increased root growth as compared to optimal moisture treatment (Meisner and Karnok, 1992). Also, in extreme moisture conditions, soil aeration is reduced, limiting root growth (Brady, 1974). Prihar et al. (1989) reported that water and nutrients also can substitute for each other.

Soil chemical properties controlling root growth in the field include soil pH, aluminum toxicity and nutrient availability (Tisdale et al., 1985; Wilkinson and Duncan, 1989; Shuman et al., 1990; Zobel, 1992; Voorhees, 1992; Foy, 1992). The impact of each of these factors on root growth is species dependent (Gregory, 1988; Roder et al., 1989; Foy, 1992). Wilkinson and Duncan (1989) indicated that soil pH below 4.8 results in H^+ ion toxicity for sorghum grown on acid soils in Georgia. Below pH 4.5 aluminum toxicity becomes more important than H^+ toxicity (Shuman et al., 1990; Foy, 1992). Peanut, on the other hand, can tolerate soil pH levels as low as 4.3 (Laurence, 1973). Morris and Pierre (1949) reported high tolerance of peanut to Al and Mn toxicity.

Soil chemical properties are also greatly influenced by tillage and residue management practices (Lal, 1977). Nutrient cycling processes and microbiological activities are different when comparing CT, NTC and NTB (Wilson and Hargrove, 1986; Monchoge and Mwonga, 1988; Smith and

Sharply, 1990). Whether residues are incorporated, like in CT or left on the surface, like in NTC, nutrients are recycled, and organic matter is returned to the soil with more rapid turn over in CT (Lal, 1977; Wilson and Hargrove, 1986; Smith and Sharpley, 1990; Guertal et al., 1991). Rapid release of plant nutrients in CT may be sufficient to reduce inter-crop competition. Also, the return of organic matter to the soil may contribute to reduce soil acidification (Blevins et al., 1984). When crop residues are removed from the field as in NTB, large quantities of cations such as Ca^{2+} and Mg^{2+} are also removed, which can eventually result in increased soil acidity and aluminum toxicity. Changes induced by tillage and residue management practices may be significant enough to affect plant root growth and competition for below ground resources. The above discussion clearly substantiates the multiciplicity and complexity of root growth factors and their interactions. Despite the wide use of intercropping in the tropics, intercrop competition for below ground resources has not been fully investigated. Information is still limited regarding intercrop competition of many commonly used mixtures being grown under usual tillage and crop residue management systems. According to Russell (1977), plant root growth is forced by increased intra-crop competition with rows to extend to the inter-row spaces for more uptake, making it possible to measure inter-crop competition for below ground resources by sampling soil in the middle of the inter-row space for available nutrients, soil moisture content, or root density.

This paper provides measurements for the effect of intercropping grain sorghum [Sorghum bicolor (L.) Moench,cv. "Pioneer 8230"] with peanut [Arachis hypogaea L., cv. "Southern Runner"], or velvet bean [Stizolobium deeringianum Bort. cv. "Early Speckled velvet bean".] on root growth under three tillage management systems: CT, NTC, and NTB.

MATERIALS AND METHODS

Experimental design

A field study was conducted in summer 1991 and 1992 on a Cecil sandy clay loam at Griffin, Georgia. Following a long fallow during which grasses were the predominant vegetation, the soil was planted to potato for one year, then wheat for 2 years prior to this experiment. In the summer of 1990, wheat residues were removed, and soil was conventionally tilled to 30 cm soil depth before planting forage sorghum over the entire area. This was done to reduce spatial differences and further depress soil nutrients in order to better observe treatment effects. After harvest in early October 1990, the experiment was laid out as a split-plot design in randomized complete blocks with 3 replicates. Main-treatments, which were immediately applied consisted of conventional tillage (CT), no-tillage bare (NTB), and no-tillage cover (NTC). Main treatments were re-applied about two weeks after harvest in 1991 for the 1992 experiment. Subplot treatments were applied at planting, and consisted of pure stands of fertilized (SF) and unfertilized (S) grain sorghum [Sorghum bicolor (L.) Moench, cv. "Pioneer 8230"], peanut [Arachis hypogaea L., cv. "Southern Runner"] (G), velvet bean [Stizolobium deeringianum Bort, cv. "Early Speckled velvet bean] (V), and mixed stands of sorghum/peanut (SG), and sorghum/velvet bean (SV). Grain sorghum and peanut were used because: 1) they are very important as food and cash crops and 2) they are often intercropped in tropical Africa. Velvet bean was used because of its potential for fixing nitrogen and producing heavy biomass for soil improvement (Scott, 1946; Burle et al., 1992). NPK fertilizer was hand broadcasted in SF treatment respectively at rate of 90 kg N/ha, 45 kg P_2O_5/ha, and 67 kg K_2O/ha about 20 days after emergence. Crops in mixtures were planted in alternate double rows. Each subplot consisted of 8 rows, 75 cm apart and 12 m long. Plants were about 10 cm apart within row. Plant populations for all crops averaged 200,000 and 100,000 plants per hectare in pure and mixed stands respectively. Weeds were controlled as needed during the growing season by hoeing and during the winter period by application of 0.56 kg/ha paraquat (1,1′ dimethyl-4,4′-bibyridinium ion).

Crops were planted on June 1 and on June 15 in 1991 and 1992 respectively (figure 1). Annual rainfall was 1126 and 14790 mm for 1991 and 1992 respectively, indicating a 31% difference between the two years. However, daily rainfall distribution presented in Figure 1, Chapter 3 for both growing seasons clearly show an early water shortage recorded from mid June to mid July 1992, compared to 1991, indicating that crops were advantaged in 1991 compared to 1992.

Root sampling

Soil was sampled at depths 0-10 cm and 20-30 cm using a 5.5 by 10 cm stainless steel ring. Two soil cores were taken randomly in the middle of inner-most intercrop row space of each subplot and combined to make a composite sample. Samples were taken at approximately 25, 55 and 80 days after planting during each growing season. These dates correspond respectively to the 2nd (collar of fifth leaf visible), 5th (maximum growth: booting, maximum leaf area, peduncle elongation), and 8th (3/4 of grain dry-matter accumulated) growth stages of sorghum (Duncan, 1983). Samples were immediately stored at -15^{oC} until processing. Prior to root washing, samples were allowed to thaw completely at room temperature. Roots were washed by the hydropneumatic elutriation system (Smucker et al., 1982) and hand cleaned with care to separate dead roots and trash from the fresh roots. A computer controlled digital scanning microdensitometer (Voorhees et al., 1980) was used to measure root length index, which was converted to actual root length using a computer program. For better scanning, roots were stained in methyl violet solution for at least 24 hours. Data were statistically analyzed by analysis of variance by year, by date of sampling, by tillage/residue management system, by intercrop and by depth (SAS Institute, 1985).

RESULTS AND DISCUSSION

The data presented in Tables 1, 2, 3 and 4 clearly show that all crop combinations produced more roots in 1992 than in 1991. Although root growth is commonly believed to be enhanced by soil water and nutrient availability (Tisdal et al., 1985, Gregory, 1988), mild water or nutrient stresses also can stimulate root production for more uptake (Nobel, 1991). Reduced rainfall during the first half part of the 1992 growing season (Figure 1) might have induced extensive root production for greater water uptake. In addition, soil nutrient content decreased after the first season (Chapter 5), presenting another possible reason for increased root growth. Despite the increased root growth in 1992, the ratio of the root dry weight (RDW) to the root length density (RLD) tended to be lower for 1992 compared to 1991

(Table 5), indicating that more fine roots were produced in 1992 compared to 1991.

RLD and RDW were significantly higher in NTC and NTB than in CT. NTC and NTB often were not significantly different. Similar differences were observed when these tillage/residue management systems were compared for soil moisture content (Chapter 4), indicating that soil moisture was a leading factor in root growth. According to Mosher and Miller (1972), warmer soil temperatures stimulate vertical orientation of root growth while cooler temperatures favor horizontal orientation. Since residue cover reflects solar radiation and high moisture content increases the specific heat coefficient of the soil, mulched soils in NTC would normally have cooler soil temperatures compared to bare soils in CT or NTB (Lal et al., 1977; Shopart, 1987; Gupta et al., 1984; NeSmith et al., 1987; Payne and Gregory, 1988). If this was the case during this experiment, this may have contributed to observed differences in plant root densities between CT and NTC. However, no measurements of soil temperature was taken to substantiate the above speculation. Insignificant difference found between NTC and NTB further confirms the predominant role played by soil moisture content.

When crops were compared (Tables 1 and 2, and Figure 2), the sorghum RLD was significantly higher than that for either legumes, agreeing with numerous previous reports on cereal/legume root production (Gregory, 1988; Klepper, 1992). The difference between sorghum and legume RLD was particularly true when the sorghum was unfertilized. Reduced sorghum root proliferation in the fertilized treatment may be due to reduced competition for added nutrients. The greater biomass and grain yield production caused by fertilization (Chapter 5) suggests that the sorghum plants invested less on root growth in favor of yield production in the presence of the added nutrients.

Velvet bean RLD was insignificantly higher than that for peanut. Intercropping sorghum with either legumes resulted in intermediate average root proliferation compared to the corresponding sole crops. This was particularly true under NTC or NTB in both years. In CT, however, all crop treatments were comparable with regards to RLD except for peanut monocrop which remained significantly inferior to the other treatments.

The high competitiveness of intercropped cereal species often has been attribute to their extensive rooting systems (Lai and Lawton, 1962; Mays, 1980; Caradus, 1980). However, the apparent rooting advantage of intercropped cereals has not been clearly substantiated. The ratios of RLD in pure stand to the RLD in the mixture (Table 4) can provide an indication of the competition pressure resulting from sole cropping compared to intercropping ($CP_{S/I}$). A high $CP_{S/I}$ such as that observed for sorghum may be indicative of 1) neutralism (neither crop affects the other), 2) amensalism (one crop is inhibited and the other is not affected) 3) mutualism (both crops may be affected to some extend as a result of obligatory interaction)

(Francis, 1986). Also, the root growth was so low for the legumes compared to sorghum that even an enhancement in the mixture may not be detected by use of the $CP_{s/l}$ alone. Therefore, a protocooperation (interaction favorable to both crops) also could have prevailed. The same interpretation can be made regarding the reduced $CP_{s/l}$ for the legumes (Table 4). However, the actual measurements in the mixtures tended to be less than the averaged mean values of the intercrop components (Table 1) indicating that some inhibitory factors prevented maximal intercrop root growth. The reduced yield for both intercrops (sorghum/peanut mixtures) or for one of the intercrops observed in this experiment (Chapter 5), as also reported by numerous authors for various cereal/legume intercropping systems (Lai and Lawton, 1962; Reddy et al., 1980; Hikam et al., 1992) also seems to corroborate the existence of root growth reducing factors in the mixtures. However, similarity in the interpretation of the $CP_{s/l}$, the resulting effect of all of the possible interactions indicated above may be opposite for the sorghum anr the legumes. Assuming that RLD is an index of the degree of plant competition, a high $CP_{s/l}$ for sorghum would indicate that inter-crop competition pressure was reduced for sorghum in the mixture, compared to the intra-crop competition pressure in the pure stand. In other words, sorghum was favored by intercropping compared to monocropping. The same reasoning would lead to the conclusion that the legumes were rather disadvantaged by intercropping compared to monocropping. Again, assuming that root growth is the major parameter for measuring competition pressure, the comparison of the $CP_{S/l}$ permits to state that sorghum was favored over either legumes in the mixtures.

The combined effect of high soil water and nutrient content near the soil surface in NTC and NTB (Chapter 4 and 5) probably resulted in significantly greater root growth in the 0-10 cm than in the 20-30 cm soil depth in both years (Table 2). However, soil compaction also may have been an important factor in the soil profile root distribution. In the CT where soil was loosen and mixed in the plow layer, a greater proportion of the roots was observed in the 20-30 cm soil depth, compared to NTC and NTB. This may have been further encouraged by the dry condition of soil surface in CT (Chapter 4). Similar results have been reported for a variety of crops (Gregory, 1988; Arora et al., 1991; Meisner and Karnok, 1992).

CONCLUSION

Results from this study further confirmed the effect of tillage/residue management on crop root growth. RLD and RDW were higher in NTC and NTB than in CT, and this was in accordance with the soil moisture status of these main treatments. Regardless of the crop combination, root growth was significantly greater within the top 10 cm depth than deeper. Sorghum produced more roots followed by velvet bean and peanut. Intercropping resulted in intermediary root proliferation compared to component sole crops, and tended to favor sorghum over the legumes. Despite the reduced rainfall, the root growth was greater in 1992 compared to 1991 where rainfall was high. This was attributed to stimulative effect of the water shortage and changes in soil fertility. The ratio of root weight to root length density suggested that finer roots were produced in 1992 compared to 1991.

Table 1. Effect of intercropping and crop residue management on plant root growth for year 1991 and 1992.[a]

CROP TREATMENT[b]	CT[c] RLD	CT[c] RDW	NTC[c] RLD	NTC[c] RDW	NTB[c] RLD	NTB[c] RDW	Average RLD	Average RDW
1991								
SF	2.16a (b)	3.37a (a)	4.10ab (a)	5.07a (a)	3.43a (ab)	3.83a (a)	3.23a	4.09a
S	2.35a (b)	3.89a (a)	4.30a (a)	4.06a (a)	3.05ab (ab)	4.06a (a)	3.19a	4.11a
$\underline{SG}$	1.31b (a)	2.32b (a)	2.40bc (a)	3.08bc (a)	1.43c (a)	1.93c (a)	1.71b	2.44b
SG	1.46	2.61	2.66	3.20	1.70	2.55	1.92	2.84
G	0.56c (ab)	1.33c (ab)	1.01cd (a)	2.34c (a)	0.34c (b)	1.03b (b)	0.64c	1.56b
$\underline{SV}$	1.16bc (a)	2.31b (a)	1.38cd (a)	2.25c (a)	1.69bc (a)	2.24b (a)	1.41bc	2.27b
SV	1.58	2.89	2.42	2.91	1.97	3.01	1.97	2.99
V	0.80bc (a)	1.89bc (a)	0.54d (a)	1.75c (a)	0.88c (a)	1.96b (a)	0.74c	1.87b
Average	1.35b	2.47ab	2.17a	3.02a	1.74ab	2.40b	--	--
1992								
SF	1.56b (b)	2.51a (b)	4.12b (a)	3.31bc (b)	4.04b (a)	4.57abc (a)	3.24bc	3.44b
S	2.10ab (b)	2.70a (b)	10.63a (a)	5.54a (ab)	17.04a (a)	6.99a (a)	9.93a	5.08a
$\underline{SG}$	2.23ab (a)	2.29a (a)	5.62ab (a)	4.08ab (a)	2.53b (b)	3.09bc (a)	3.46bc	3.15b
SG	1.10	1.59	5.45	3.33	9.58	4.72	5.38	3.22
G	0.09b (b)	0.48b (a)	0.27b (ab)	1.12c (a)	2.11b (a)	2.44c (a)	0.82c	1.35c
$\underline{SV}$	3.14a (a)	2.99a (a)	3.31b (a)	3.15bc (a)	8.51b (a)	5.35ab (a)	4.99b	3.83b
SV	2.16	2.75	6.38	4.22	10.64	5.93	6.36	4.07
V	2.22ab (a)	2.80a (a)	1.92b (a)	2.89bc (a)	4.24b (a)	3.47bc (a)	2.79bc	3.05b
Average	2.09b	2.38b	4.35ab	3.41a	6.19a	4.29a	--	--

[a]Means within column for each year with same letter without parentheses are not significantly different (α = 0.1).
Means within row with same letter in parentheses are not significantly different (α = 0.1).
[b]SF = fertilized sorghum; S = unfertilized sorghum; SG = sorghum/groundnut mixture; etc.
[c]CT = conventional tillage; NTC = no tillage with crop residue; NTB - no tillage with residue removed.
$\underline{SG}$ = mean for sorghum and groundnut monocrop; G = groundnut monocrop; V = velvet bean monocrop
$\underline{SV}$ = mean for sorghum and velvet bean intercrops; RLD = root length density; RDW = root dry weight

Table 2. Plant root growth parameters at two depths under different tillage and residue management systems for year 1991 and 1992.

	CT		NTC		NTB		Average***	
Depth #	RLD*	RDW**	RLD	RDW	RLD	RDW	RLD	RDW
				1991				
0-10 cm	1.56a (a)	2.73a (a)	3.32a (a)	3.90a (a)	2.74a (a)	3.23a (a)	2.54a	3.29a
20-30 cm	1.14a (a)	2.20a (a)	1.03b (a)	2.15b (ab)	0.75b (a)	1.58b (b)	0.98b	1.98b
Average***	1.35b	2.47ab	2.17a	3.02a	1.74ab	2.40b	--	--
				1992				
0-10 cm	1.93a (b)	2.11a (b)	7.88a (ab)	5.38a (ab)	11.18a (a)	6.68a (a)	7.0a	4.72a
20-30cm	2.24a (a)	2.66a (a)	1.20b (a0	1.45b (a)	0.8b (a)	1.90b (a)	1.42b	2.0b
Average***	2.09ab	2.38b	4.35ab	3.41a	6.19a	4.29a	--	--

* Density expressed in $cm/cm^3 \times 10^{-3}$

** Dry weight express in 10^{-2} mg/cm^3

*** Means for tillages have been separated independently from others in columns.

Note: Means within columns with same letter are not significantly different (α = 0.05).
Means within rows in parentheses with same letter are not significantly different (α = 0.05).
RLD = root length density; RDW = root dry weight

Table 3. Effect of intercropping on plant root growth for year 1991 and 1992.

Root Growth Parameter	Depth	SF	S	SG	G	SV	V	Average
				1991				
RLD*	0-10 cm	4.85a (a)	4.40a (a)	2.49a (b)	0.88a (c)	2.15a (bc)	0.86a (c)	2.54a
	20-30 cm	1.61b (a)	1.98b (a)	0.93b (b)	0.39b (c)	0.67b (bc)	0.62a (bc)	0.98b
RDW	0-10 cm	5.40a (a)	5.07a (a)	2.96a (b)	1.96a (b)	2.92a (b)	2.09a (b)	3.89a
	20-30 cm	2.78b (a)	3.15b (a)	1.92b (b)	1.16b (c)	'1.61b (bc)	1.64a (bc)	1.98b
Average	RLD	3.23a	3.19a	1.71b	0.64c	1.41bc	0.74c	--
	RDW	4.09a	4.11a	2.44b	1.56b	2.27b	1.87b	--
				1992				
RLD	0-10 cm	5.57a (bc)	18.03a (a)	4.94a (bc)	1.30a (c)	8.51a (b)	4.17a (bc)	7.0a
	20-30 cm	0.91b (ab)	1.80b (a)	1.98b (a)	0.34b (b)	1.46b (ab)	1.41b (ab)	1.42b
RDW	0-10 cm	5.15a (b)	7.29a (a)	4.01a (b)	1.74a (c)	5.71a (ab)	4.15a (b)	4.72a
	20-30 cm	1.74b (bc)	2.86b (a)	2.30b (ab)	0.96b (c)	1.95b (abc)	1.96b (abc)	2.0b
Average	RLD	3.24bc	9.92a	3.46bc	0.82c	4.99b	2.79bc	--
	RDW	3.44b	5.08a	3.15b	1.35c	3.83ab	3.05b	--

* Root density expressed in 10^{-3} cm/cm^3 and root weight expressed in 10^{-2} mg/cm^3.

Note:

Means within column for each item having same letter without parentheses are not significantly different*.

Means within row with same letter in parentheses are not significantly different (d = 0.05).

Overall means for depth and intercrops have been separated independently.

RLD = root length density; RDW = root dry weight

Table 4. Overall all averages of root length density (RLD), root dry weight (RDW), relative competition pressure ($cp_{s/i}$), and ratio of RDW to RLD (RDW/RLD) for 1991 and 1992.

	1991				1992			
	RLD*	$CP_{s/i}$	RDW**	RDW/RLD	RLD	$CP_{s/i}$	RDW	RDW/RLD
SF	3.73a		4.09a	1.27	3.24bc		3.44b	1.06
S	3.19a		4.11a	1.30	9.93a		5.08a	0.51
SG	1.71b	7.86(S)	2.44b	1.43	3.46bc	2.87(S)	3.15b	0.91
G	0.64c	0.36(G)	1.56b	2.44	0.82c	0.24(G)	1.35c	1.65
SV	1.41bc	2.26(S)	2.27b	1.61	4.99b	1.99(S)	3.83b	0.77
V	0.74c	0.52(V)	1.87b	2.53	2.79bc	0.56(V)	3.05b	1.09

* Density expressed in $cm/cm^3 \times 10^{-3}$

** Dry weight express in 10^{-2} mg/cm^3

Note: Means within columns with same letter are not significantly different ($\alpha = 0.05$).
RLD = root length density; RDW = root dry weight

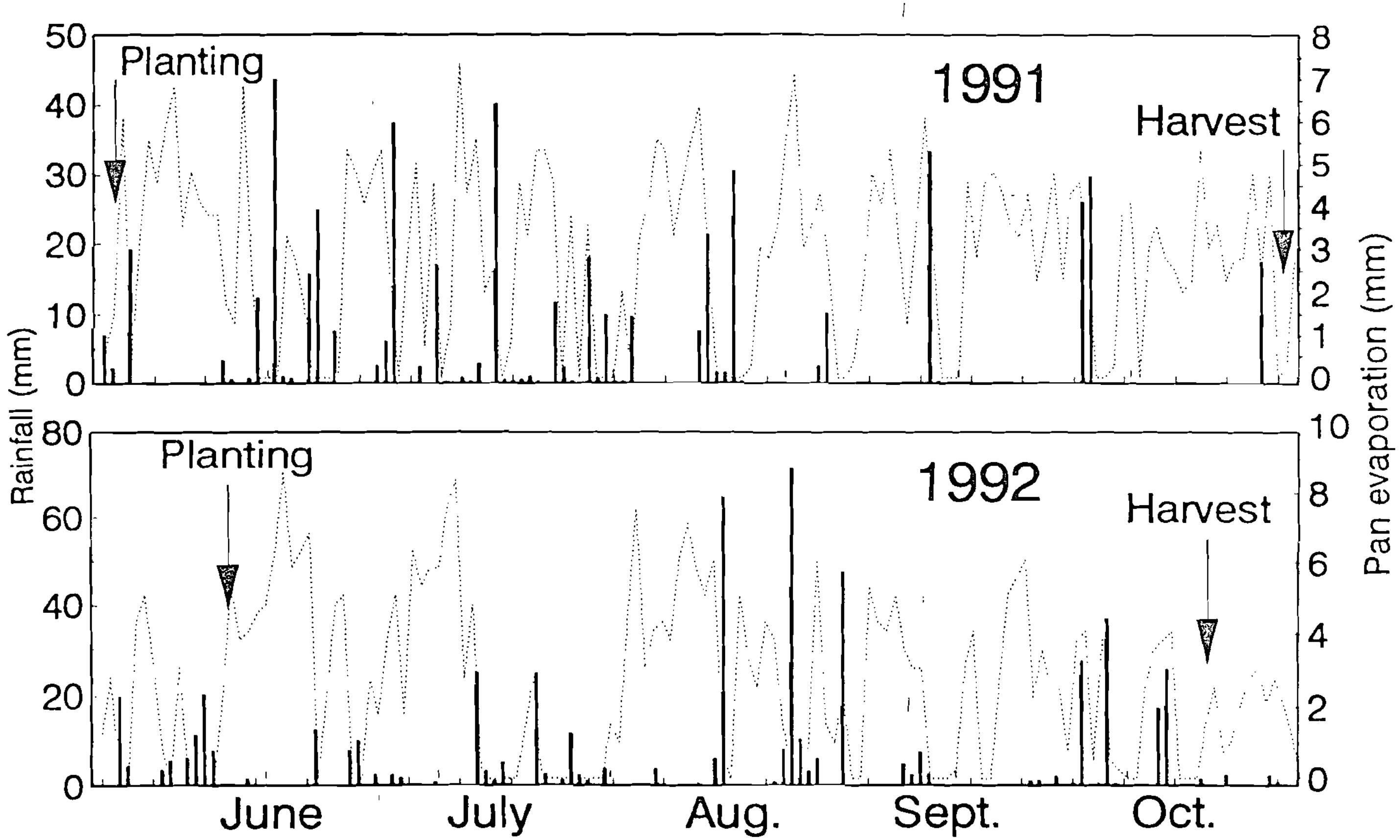

Figure 1: Daily rainfall and pan evaporation during the growing seasons. Dot lines represent pan evaporation; Bars represent rainfall.

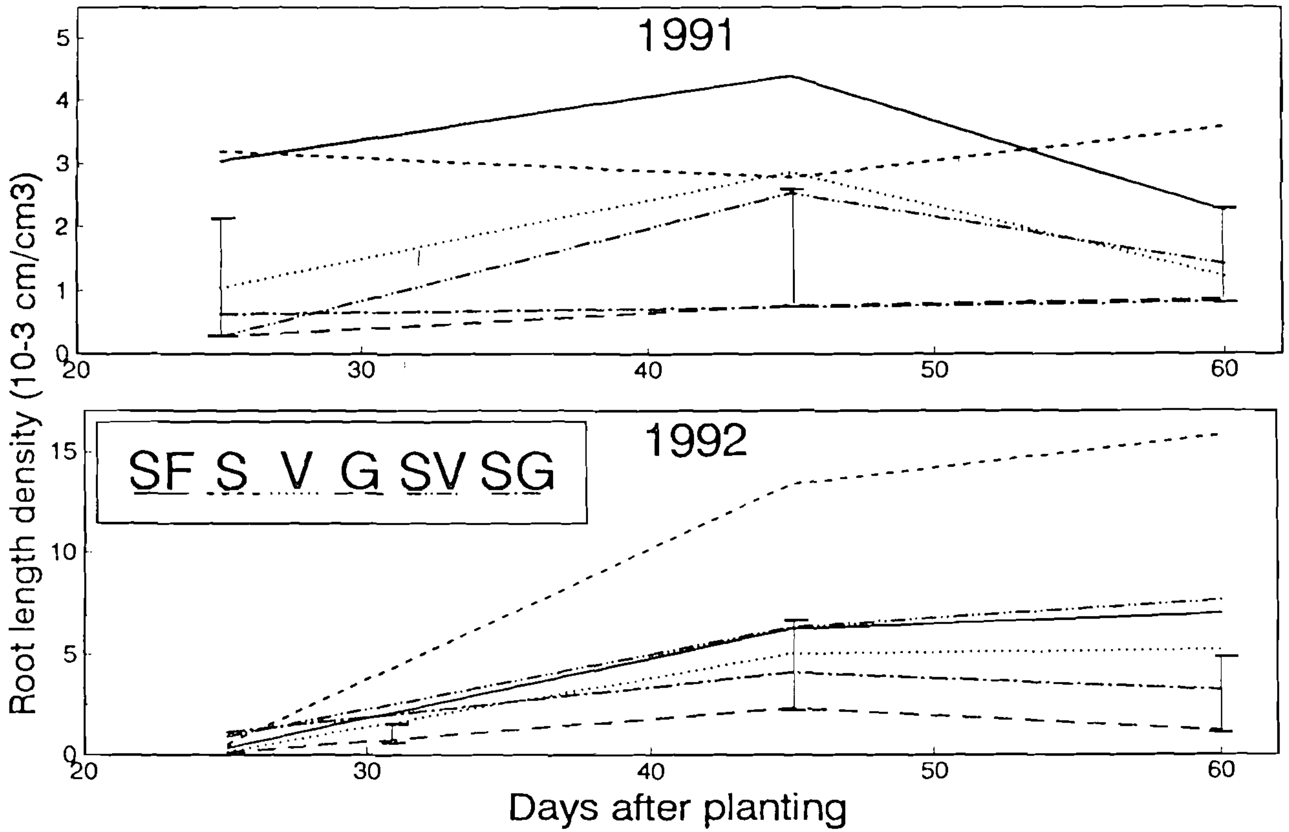

Figure 2: Effect of intercropping on plant root growth.
Error bars indicate LSD(0.05).

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CHAPTER 4

EFFECT OF INTERCROPPING AND TILLAGE/RESIDUE MANAGEMENT ON PLANT COMPETITION FOR WATER.

ABSTRACT

Small-holding farmers in the tropics have traditionally intercropped their lands under different tillage and residue management practices. Yet, little quantitative information is available about water use by intercropped species grown together under varying tillage and residue management practices. A split plot design was used on a Cecil sandy clay loam soil in Griffin, Georgia, in summer 1991 and 1992 to study the effect of intercropping grain sorghum [Sorghum bicolor (L.) Moench,cv. "Pioneer 8230"] with peanut [Arachis hypogaea L., cv. "Southern Runner"], or velvet bean [Stizolobium deeringianum Bort, vc. "Early Speckled Velvet Bean"] in conventional tillage (CT), no-tillage with residue cover (NTC) and no-tillage bare (NTB) on soil water content. Soil water content was measured by time domain reflectrometry (TDR) at 6 depths from 0 to 90 cm in 15 cm increments during the growing seasons. Greater water content was observed with NTC compared to CT. The NTB was intermediary but

significant different from both NTC and CT in 1992. Rain acceptance measured by use of a sprinkler infiltrometer showed greater water infiltration in NTC compared to NTB and CT, explaining the moisture advantage of NTC. Water infiltration in no-tillage velvet bean monocrop was particularly improved at the end of the experiment. Intercropping tended to enhance soil water use compared to sorghum monocrop. There was significant interaction between intercropping and tillage/residue management systems, suggesting careful selection of intercrops and soil management systems for satisfactory crop production. Despite differences between years, most treatment comparisons were unaffected.

INTRODUCTION

No-tillage and residue mulches are efficient strategies for soil and water conservation (Okigbo, 1969, Lal, 1975; Russelle and Hargrove, 1989). Crop residue mulches absorb kinetic energy of rain drops, thereby reducing surface crusting, water runoff and erosion (Lal, 1975; Radcliffe et al., 1988; Russelle and Hargrove, 1989; West et al, 1991). They also reflect solar radiation, resulting in reduced thermal fluctuations and water evaporation (Lal, 1975; Harrison and Lal, 1979; Dexter et al., 1982; Shopart, 1987; NeSmith et al., 1987b). In addition, the return of crop residue to the soil enhances the soil organic matter content and nutrient cycling (Okigbo, 1990). Soil organic matter encourages good soil structuring, which improves soil water properties (Boyle et al., 1989). Residue cover also serves as refuge and/or food resource for soil dwellers such as earthworms and subterranean insects (Dexter et al., 1982). Soil invertebrates not only contribute to nutrient cycling, but also are major pedoturbation agents (Lal, 1987; Lavelle, 1988). They also create macro-pores and enhance soil aggregation, which improves water infiltration (Lavelle, 1988; Radcliffe et al., 1988). Hillel (1980) suggested that soil with high macro-porosity looses less water by evaporation because capillary rise of water is not favored by large pore sizes. Consequently, soil invertebrate activity improves both rain acceptance and water conservation. Because of its many advantages in improving soil quality, no-tillage cover has often been mentioned as a component of sustainable agriculture (Russelle and Hargrove, 1989; National research council, 1990). In contrast, conventional tillage and no-tillage with residue removed, two tillage/residue management systems of common practice in the United States and in West Africa respectively, expose the soil surface to the effect of raindrop impact, resulting in soil crusting and compaction (Lal, 1975; Harrison and Lal, 1979; Phillips, 1984; NeSmith et al., 1987a; Lal, 1987; Gajri et al., 1992). This combines with reduced soil macro-porosity to limit water infiltration in favor of runoff and erosion.

Regardless of tillage and crop residue management system, most farmers in Africa have traditionally intercropped their lands to minimize risks associated with monocultures and to assure stable income and nutrition levels (Francis et al., 1975). Advantages associated with intercropping include; 1) yield security in the event of epidemics, water shortage or flooding, 2) reduced inter- and intra-crop competition for resources, 3) high resource use efficiency, 4) yield advantage over monocropping, and 5) reduced rate of soil nutrient depletion (Huxley and Maingu, 1978; Willey, 1979; Ikeorgu and Odurukwe, 1989; Russelle and Hargrove, 1989). Plant competition for resources (light, soil water, nutrients, and carbon dioxide) occurs during all or part of the growing season (Gomez and Gomez, 1983; Russelle and Hargrove, 1989), and the productivity of each companion crop is dependant on its ability to compete.

In general cereal intercrops are favored by their extensive root systems and are more competitive than legumes for below ground resource acquisition (Lai and Lawton, 1962; Wolfe and Lazenby, 1973; Mays et al., 1980; Caradus, 1980; Hart, 1981; Wolfe et al., 1982; Pleasant, 1982). However, the severity of inter-crop competition depends on a number of factors including; 1) soil water and nutrient availability, 2) intercrop planting density and geometry, 3) timing of planting, 4) intercrop species or varieties and 5) extent of nitchbreath overlap (Willey et Reddy, 1981; Gomez and Gomez, 1983; Davis et al., 1986; Ofori and Stern, 1987; Russelle and Hargrove, 1989).

When compatible crops are intercropped, reverse flow of water from deep rooting species which tap water from deep horizons (Gregory, 1988; Nobel, 1991) can permit the survival of the shallow rooting companion crops during drought periods (Hardwood, 1984; Blevins, 1987; Corak et al., 1987). This indicates that intercropping can improve water use efficiency and exhibit yield advantage over monocropping (Reddy and Willey, 1980; Natarajan and Willey, 1980).

The effects of intercropping, tillage and residue management on crop performance often have been investigated separately. In addition, although there are numerous reports concerning plant competition for water and nutrients, many crop mixtures remain untested. The present work was designed to study plant competition for water under conventional tillage, no-tillage with residue mulch, and no-tillage bare when crops are grown in pure or mixed stands.

MATERIALS AND METHODS

Experimental design

A field study was conducted in summer 1990 and 1992 on a Cecil sandy clay loam at Griffin, Georgia. Following a long fallow during which grasses were the predominant vegetation, the soil was planted to potato for one year, then wheat for 2 years prior to the experiment. In Summer 1990, wheat residues were removed, and soil was conventionally tilled to 30 cm soil depth before planting forage sorghum over the entire the area. This was done to reduce spatial differences and to further depress the soil nutrient content in order to increase the potential for observing treatment effects. After harvest in early October 1990, the experiment was laid out as a split-plot design in randomized complete blocks with 3 replicates. Main-treatments, which were immediately applied consisted of conventional tillage (CT), no-tillage bare (NTB), and no-tillage cover (NTC). Main- treatments were re-applied about 2 weeks after the 1991 harvest for the 1992 experiment. Subplot treatments, applied at planting, consisted of pure stands of grain sorghum [Sorghum bicolor (L.) Moench,cv. "Pioneer 8230"] fertilized (SF) and unfertilized (S), peanut [Arachis hypogaea L., cv. "Southern Runner"] (G), velvet bean [Stizolobium deeringianum Bort, vc.

"Early Speckled Velvet Bean] (V), and mixed stands of sorghum/peanut (SG), and sorghum/velvet bean (SV). Grain sorghum and peanut were used 1) because of they are important as food and/or cash crops, and 2) because their are often intercropped in tropical Africa. Velvet bean was used because of its potential for fixing nitrogen and producing heavy biomass for soil improvement (Scott, 1946; Burle et al., 1992). This crop was once popular in Georgia for use as green manure (USDA, 1957; Scott, 1946). Its use declined with decreased cost of inorganic fertilizers. Returning to the use of velvet bean for soil improvement can foster agricultural sustainability. NPK fertilizer (90 kg N, 45 kg P_2O_5 and 67 kg K_2O per hectare) was hand broadcasted in SF treatment about 20 days after emergence. Crops in mixtures were planted in alternate double rows. Each subplot consisted of 8 rows, 75 cm apart and 12 m long. Plants were about 10 cm apart within row. Plant populations for all crops averaged 200,000 and 100,000 plants per hectare in pure and mixed stands, respectively. Weeds were controlled as needed during growing season by hoeing and during winter period by application of 0.56 kg/ha paraquat (1,1' dimethyl-4,4'-bibyridiniumion). Crops were planted and harvested on June 1 and October 28 in 1991, and on June 15 and October 16 in 1992, respectively. A reduced rainfall was observed during the 1992 growing season, compared to 1991 (Chapter 3). For these reasons, crops were disadvantaged in 1992 compared to 1991.

Measurement of rain acceptance

Rain acceptance was measured during the period of 10 to 21 May 1991 and 1992, and 14 to 18 January 1993, respectively 7 and 2 months after tillage/residue management treatments were applied. During the time interval between main treatment application and infiltration measurement several rains events were recorded. In 1993, infiltration measurements followed 22 rains, the largest averaging 43 mm. All measurements were made using a sprinkler infiltrometer (Petersons and Bubenzer, 1986). Rain was simulated over a squared metal enclosure of 0.92 m width for 45 minutes at sprinkler rates of 60, 68 and 63 mmh^{-1} in 1991, 1992 and 1993 respectively. Pounding water was pumped off and the amount recorded every alternate minutes. Enclosure was randomly positioned on a middle row so that it straddles the row. Because nontraffic and traffic inter-rows were alternate, this arrangement allowed both effects to be equally accounted for in the runoff measurements (Radcliffe et al., 1988). Care was taken not to disturb the soil within the enclosure. However, soil was carefully packed against the enclosure inside and outside to avoid preferential side flow along the wall. In all years, measurements concerned only sorghum and velvet bean monocropped plots in NTC and sorghum monocropped plots in NTB and NTC.

Surface cover by forage sorghum residue averaged 27% in April 1991 in NTC. Soil cover by velvet bean and sorghum residues averaged 100% and 48% in 1992, and 100% and 63% in 1993, respectively at the time of rainfall simulation. Residue removal reduced soil cover to less than 12% in the NTB each year. The incorporation of crop residues in CT resulted in zero soil coverage.

Soil moisture measurement.

Soil water content was measured 6 and 8 times during the 1991 and 1992 growing seasons, respectively, from seedling to crop maturity by time-domain reflectrometry (TDR) using a cable tester (Tektronix Inc., Beaverton, Oregon, USA). Measurements were done on relatively dry days where differences among treatments were more likely to be observed. Measurements were done in all main plots and subplots at 6 depths from 0 to 90 cm in 15 cm increments. Six pairs of solid stainless steel welding rods, 0.39 cm diameter, were vertically driven into the soil half-way between rows in the center of the plot, in a single line of increasing depth, and used as transmission lines (Topp and Davis, 1985). Rods in intercrop treatments were installed half-way between rows of intercrops. Rods of each pair were of equal length and were placed 5 cm apart and pairs about 15 cm apart. TDR readings were converted to soil volumetric water content using the following calibration equation (Mulla, 1989):

$$\Theta = -0.053 + 2.92 \times 10^{-2} K - 5.5 \times 10^{-4} K^2 + 4.3 \times 10^{-6} K^3,$$

where $K = (\text{TDR reading/rod length})^2$.

Because vertical rods measure the average water content over their entire length, length weighted averages of the measured water contents were computed to match the 15 cm depth increments. All data were statistically analyzed by year, date of sampling, tillage/residue management system, crop treatment, and depth using the statistical analysis system (SAS) (SAS Institute, Inc.).

RESULTS AND DISCUSSION

General rainfall and soil profile moisture distribution.

Annual rainfall was 1126 and 1479 mm for 1991 and 1992 respectively, indicating a 31% difference between the two years. However, daily rainfall distribution presented in Figure 1, Chapter 3, for both growing seasons show that crops were advantaged in 1991 compared to 1992. A late season drought was observed in 1991 in September, while an early water shortage was recorded in 1992, from mid June to mid July. Crops were planted on June 1 and on June 15 in 1991 and 1992 respectively. Average moisture distribution over all treatments in the soil profile for both growing seasons is presented in Figure 1. Soil water content increased with soil depth. Mean separation among depths within main treatments was consistent in 1991 and 1992 (Table 1) showing that moisture distribution from 0 to 60 cm depths was not affected by seasonal differences in rainfall.

Effect of tillage/residue management on water infiltration

The effect of tillage/residue management on rain acceptance is shown in Figure 2 for all years. Visual observation during the experiment indicated that earthworm population was greatly enhanced by residue cover in NTC, especially under the velvet bean residues. This may have enhanced the soil macro-porosity which added to the surface cover to increase water infiltration in NTC. Water infiltration in the NTC-velvet bean monocrop was significantly greater than that observed in the NTB and CT. Reasons for reduced water infiltration in NTB and CT may include: 1) increased soil crusting and 2) reduced macro-porosity, both resulting from reduced surface cover. The greater water infiltration rate tended to be greater in the NTB than in the CT, corroborateing a report by Wess et al., 1991. This may be attributable to the presence of stubbles, root channels, and preserved soil aggregate stability in the NTB. However, no measurement of soil aggregate stability or root channel effect was made to substantiate the above assumption. Another factor, soil gravimetric water content in the top 7.5 cm soil depth averaged 22-28.5% under NTC-velvet bean compared to 9-11% in CT and 9.5-10.5% in NTB during early and late 1992 infiltration measurement, respectively. Initially dry soil conditions in NTB and CT may have favored slaking-crusting, compounding early and greater runoff compared to NTC.

Effect of tillage/residue management on soil moisture content

Temporal change in soil moisture content in the first 15 cm of soil under the different tillage/residue management systems is presented in Figure 3 for both years. Greater water infiltration rate (Figure 2) added to the residue cover to provide NTC with soil moisture advantage over NTB and CT. In general, differences between CT and NTC were significant in both years and at all depths above 60 cm except at 45 cm depth (Table 1). NeSmith et al. (1987) reported similar ranking of these treatments for moisture content. Likewise, soil water content in NTB and CT corroborates the rain acceptance measurements, confirming several previous reports (Lal, 1975; Dexter et al., 1982; Radcliffe et al., 1988; Miller and Radcliffe, 1992). There was no significant difference between NTC and NTB in 1991 as a result of lack of treatment effect. However, NTB became significantly drier than NTC in 1992 probably due to changes in soil properties.

Effect of intercropping on soil moisture content.

Temporal changes in the average soil water content within the first 60 cm soil depth under pure stands of unfertilized sorghum, peanut and velvet bean are presented in Figure 4 for 1991 and 1992. Behavior of these crops at individual depths for 1991 is shown in Figures 5-8. Within the top 60 cm depth, ranking of these treatments for soil water content was V < S < G (Figures 4, 5 and 7). Sorghum soil water content tended to be the lowest below 60 cm (Figures 6 and 8), confirming its deep rooting habit (Rachie and Majmudar, 1980; Doggett, 1988).

The effect of intercropping sorghum with peanut (SG) or velvet bean (SV) on soil water content in the 0-60 cm depth compared to monocrop sorghum (S) is shown for 1991 and 1992 in Figures 9 and 10, respectively. With the exception of CT in 1991 and NTB in 1992, intercropping resulted in reduced soil water content compared to sorghum monocropping, suggesting a more thorough soil exploration and soil water use by in the intercrops than in the sorghum monocrop. Crop treatment comparison at depth 45-60 cm in 1992 (Table 2) shows a significantly reduced soil water content in both mixtures compared to the pure stands of sorghum and peanut. This finding seems to indicate that the intercrop competition was greater at this depth and suggests a good knowledge of the soil profile water distribution to guide the decision for crop association. The observation of Table 3 and Figures 9 and 10 shows that the comparison among crop treatments was affected by the main treatments, indicating a significant interaction between intercropping and tillage/residue management practice. This sugests a careful selection of intercrops and soil management systems for satisfactory crop production.

CONCLUSION

These results clearly confirmed the differences among the tillage/residue management systems tested. Residue removal and probably an improved soil macro-porosity favored water infiltration and conservation, resulting in greater water content in NTC compared to NTB and CT. The least water infiltration rate and soil water content were observed in the CT. Reduced soil water content in the mixtures suggested a better soil exploration and more thorough use of soil water by the intercrops as compared to sorghum monocrop. Increased competition for water between sorghum and either legume appeared to occur at 45-60 cm soil depth. There was significant interaction between intercropping and tillage/residue management systems, suggesting careful selection of intercrops and soil management systems for satisfactory crop production. Despite differences between years, most treatment comparisons were unaffected.

Table 1. Soil profile moisture (%) status under different crop residue management systems for year 1991 and 1992.

Depth #	Soil Depth	CT	NTC	NTB	Mean
			Year 1991		
1	0 - 15	13.54e (b)	17.14d (a)	17.53d (a)	16.07e
2	15 - 30	16.11d (b)	20.99c (a)	19.27d (a)	18.79d
3	30 - 45	25.91b (a)	26.46b (a)	26.07bc (a)	26.15c
4	45 - 60	23.09c (b)	30.56a (a)	24.92c (ab)	26.19c
5	60 - 75	28.37ab (ab)	31.13a (a)	28.14b (b)	29.21b
6	75 - 90	30.31a (a)	31.71a (a)	35.10a (a)	32.27a
	Mean	22.89b	26.33a	25.17a	
			Year 1992		
1	0-15	13.93f (b)	16.91f (a)	16.94d (a)	15.93d
2	15-30	18.23e (c)	22.94e (a)	20.83c (b)	20.67c
3	30-45	25.92c (a)	25.35d (a)	25.06b (a)	25.44b
4	45-60	22.56d (b)	27.10c (a)	25.21b (ab)	24.96b
5	60-75	32.32b (a)	36.79a (a)	33.38a (a)	34.16a
6	75-90	34.87a (a)	34.18b (a)	32.88a (a)	33.98a
	Mean	24.64b	27.21a	25.72ab	

Note:

Means within columns, for each year, with same letter without parentheses are not significantly different (α = 0.05).

Means within rows, for each year, with same letter in parentheses are not significantly different (α = 0.05).

Table 2. Effect of intercropping on soil moisture depletion for year 1991 and 1992.

Depth	SF	S	SG	G	SV	V
			Year 1991			
0-15	16.24c (a)	16.55c (a)	16.39d (a)	13.54e (b)	16.39d (e)	15.32c (ab)
15-30	17.97c (b)	19.08c (ab)	19.97c (a)	16.11d (b)	19.36c (a)	17.13c (b)
30-45	26.56b (ab)	25.31b (ab)	27.12ab (ab)	25.91b (ab)	27.44b (a)	24.40b (b)
45-60	25.91b (b)	25.91b (bc)	29.46a (a)	23.09c (c)	24.65b (bc)	24.17b (bc)
60-75	26.07b (cd)	28.35b (bc)	25.11b (d)	28.37ab (bc)	33.60a (a)	30.16a (bc)
75-90	33.29a (ab)	34.39a (ab)	28.84a (b)	30.31a (ab)	30.85a (ab)	35.61a (a)
Average	24.34b	24.60ab	24.48ab	25.69a	25.38ab	24.48ab
			Year 1992			
0-15	16.39d (a)	16.52d (a)	15.97d (a)	15.29e (a)	15.25d (a)	16.13d (a)
15-30	20.21c (ab)	21.64c (a)	20.35c (ab)	20.96d (ab)	21.13c (ab)	19.68c (b)
30-45	24.24b (b)	25.32b (ab)	25.90b (ab)	26.94c (a)	25.60b (ab)	24.65b (b)
45-60	25.34b (ab)	26.93b (a)	23.68b (b)	26.48c (ab)	23.74bc (b)	23.56b (b)
60-75	32.08a (b)	32.67a (b)	32.30a (b)	39.40a (a)	33.82a (b)	34.70a (b)
75-90	33.71a (a)	35.25a (a)	34.33a (a)	34.45b (a)	32.29a (a)	33.83a (a)
Average	25.33b	26.39ab	25.42b	27.25a	25.31b	25.43b

Note:

Means within column for each year with same letter without parentheses are not significantly different (α = 0.05).

Means within row, for each year, with same letter in parentheses are not significantly different (α = 0.05).

Table 3. Effect of intercropping and crop residue management systems on soil moisture content for year 1991 and 1992.

Crop Treatment	CT	NTC	NTB	Average
		Year 1991		
SF	24.89a (a)	25.15a (a)	22.98a (a)	24.34b
S	19.87c (c)	28.88a (a)	25.94a (b)	24.60ab
SG	24.10a (a)	24.43a (a)	24.86a (a)	24.48a
G	23.75a (b)	26.60a (a)	26.73a (a)	25.69a
SV	24.27a (b)	26.67a (a)	25.20a (ab)	25.38a
V	22.63b (b)	25.90a (a)	24.85a (a)	24.46b
Mean	23.25b	26.27a	25.09a	
		Year 1992		
SF	24.63ab (a)	26.49a (a)	24.86a (a)	25.33
S	25.43ab (b)	29.18a (a)	24.56a (b)	26.39
SG	24.91ab (a)	25.01a (a)	26.34a (a)	25.42
G	26.16a (a)	27.71a (a)	27.89a (a)	27.25
SV	23.21b (c)	27.62a (a)	25.10a (b)	25.31
V	23.47b (b)	27.26a (a)	25.55a (a)	25.43
Average	24.64c	27.21a	25.72b	

Note:

Means within column, for each year, with same letter without parentheses are not significantly different (α = 0.05).

Means within row, for each year, with same letter in parentheses are not significantly different (α = 0.05).

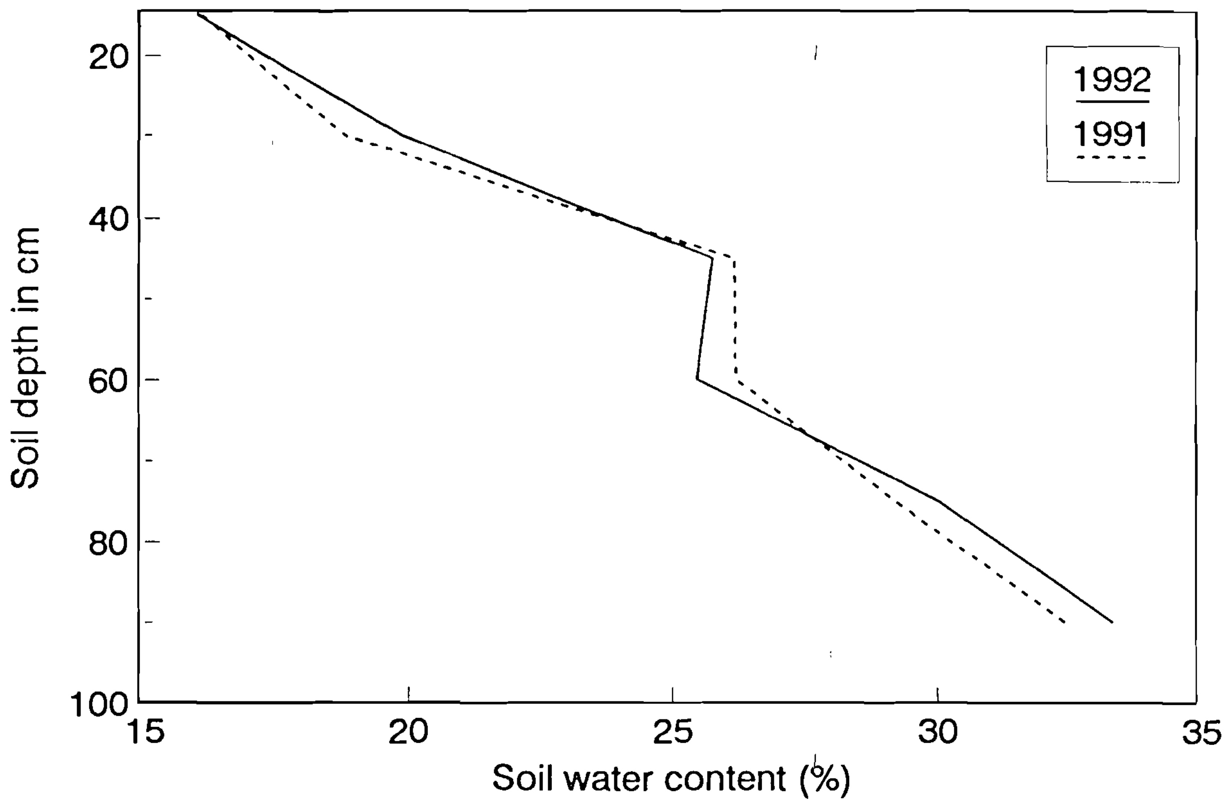
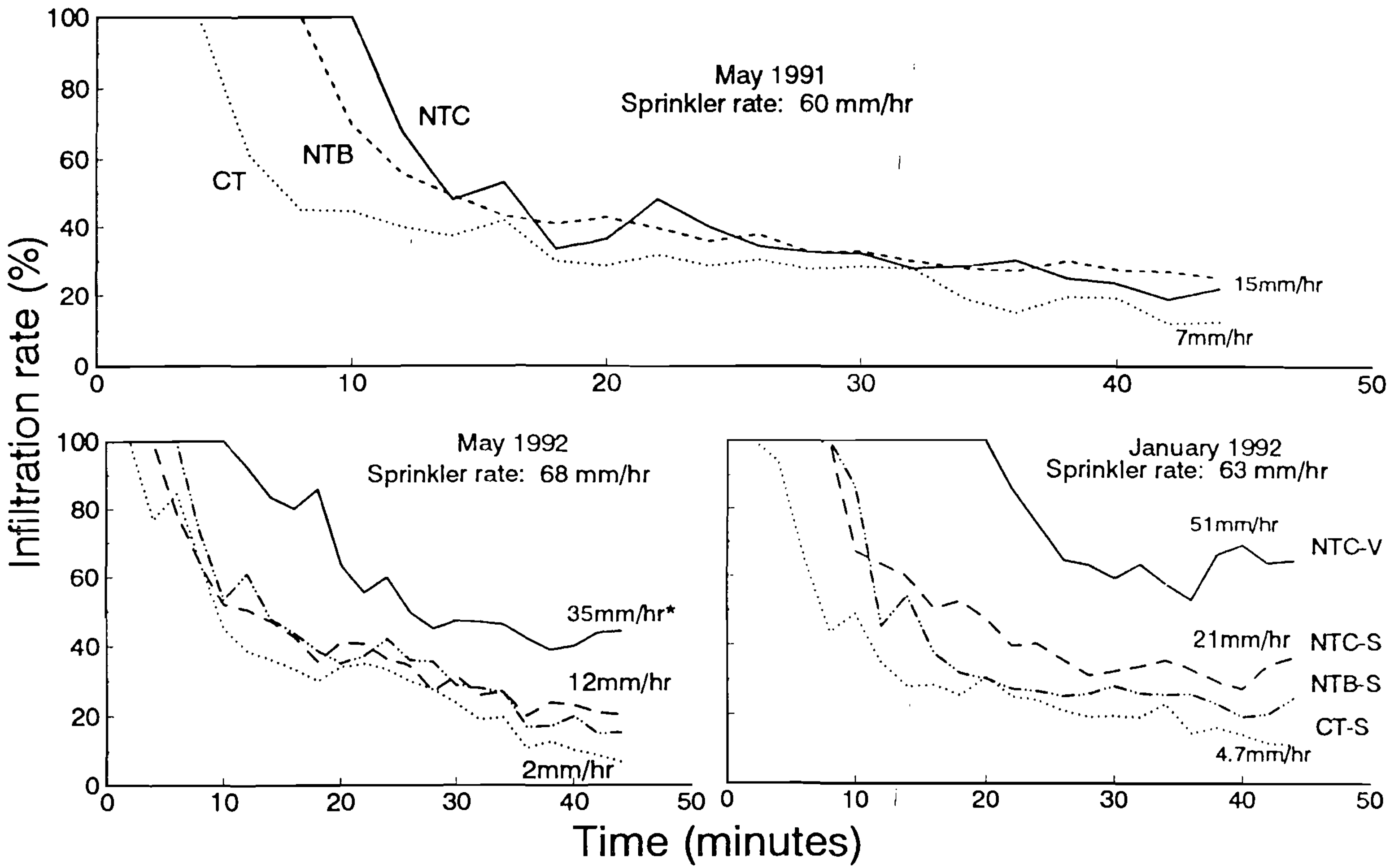


Figure 1: Average seasonal soil profile water content over all treatments in 1991 and 1992.



Fugure 2: Infiltration rate with time.
NTC-V = No-till velvet bean cover; NTC-S = No-till sorghum cover
NTB-S = No-till sorghum bare; CT-S = Conventional tillage sorghum
* Final infiltration rate is presented for NTC-V, NTC- S and CT-S

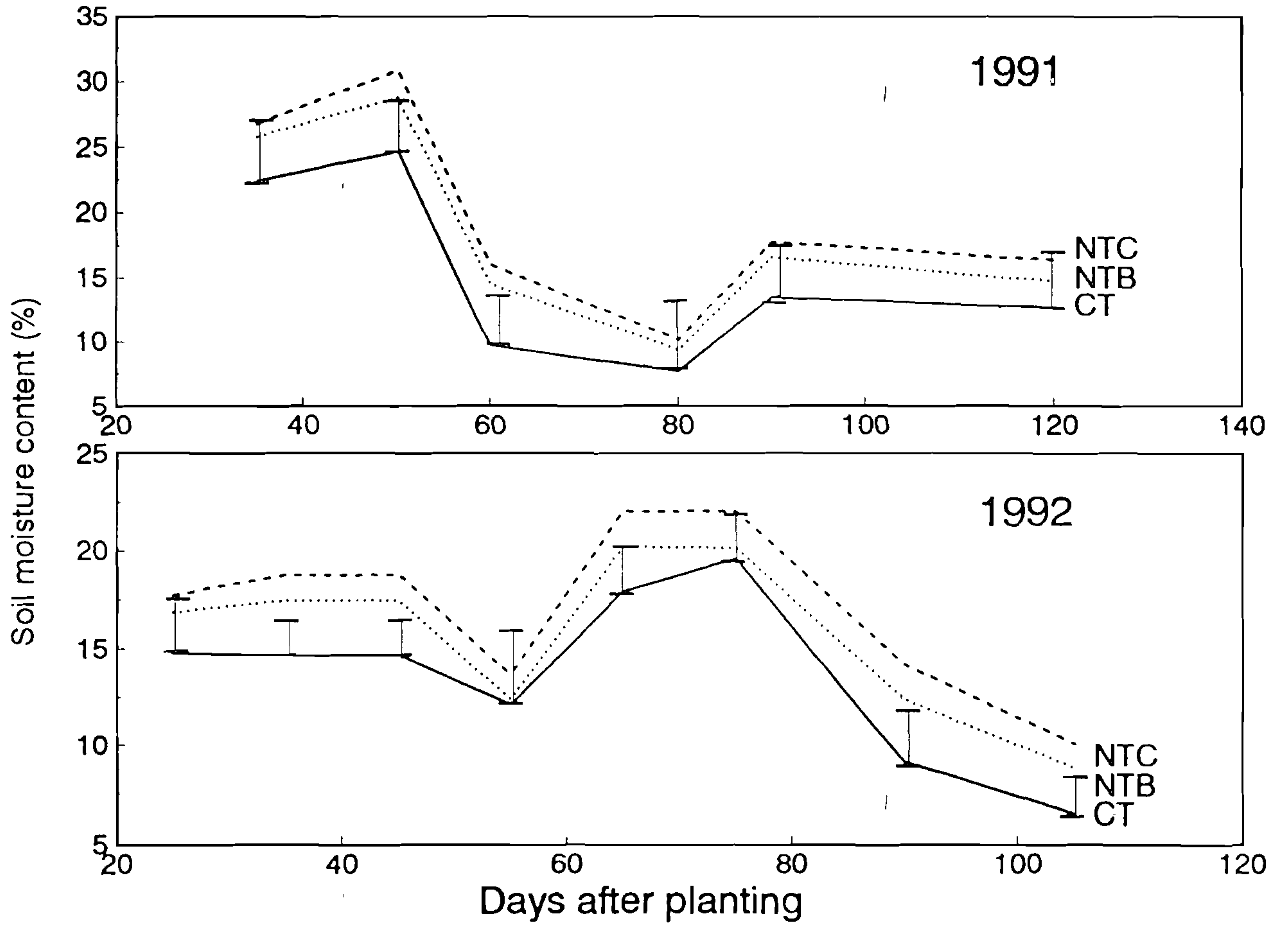


Figure 3: Effect of tillage/residue management practices on soil water content in the top 15 cm soil depth. Error bars indicate LSD(0.05).

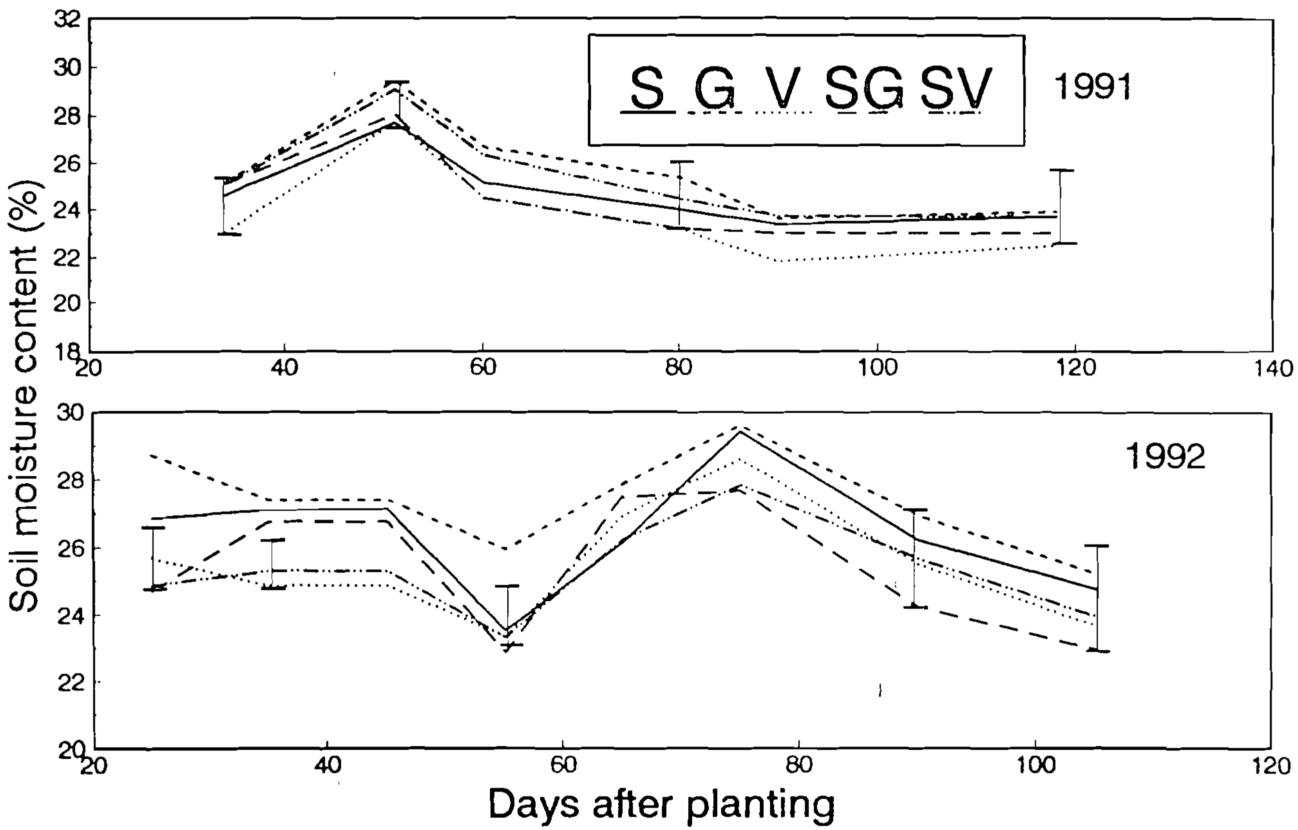


Figure 4: Effect of crop treatments on soil water content within the 0-60 cm depth during the growing season. Error bars indicate LSD(0.05).

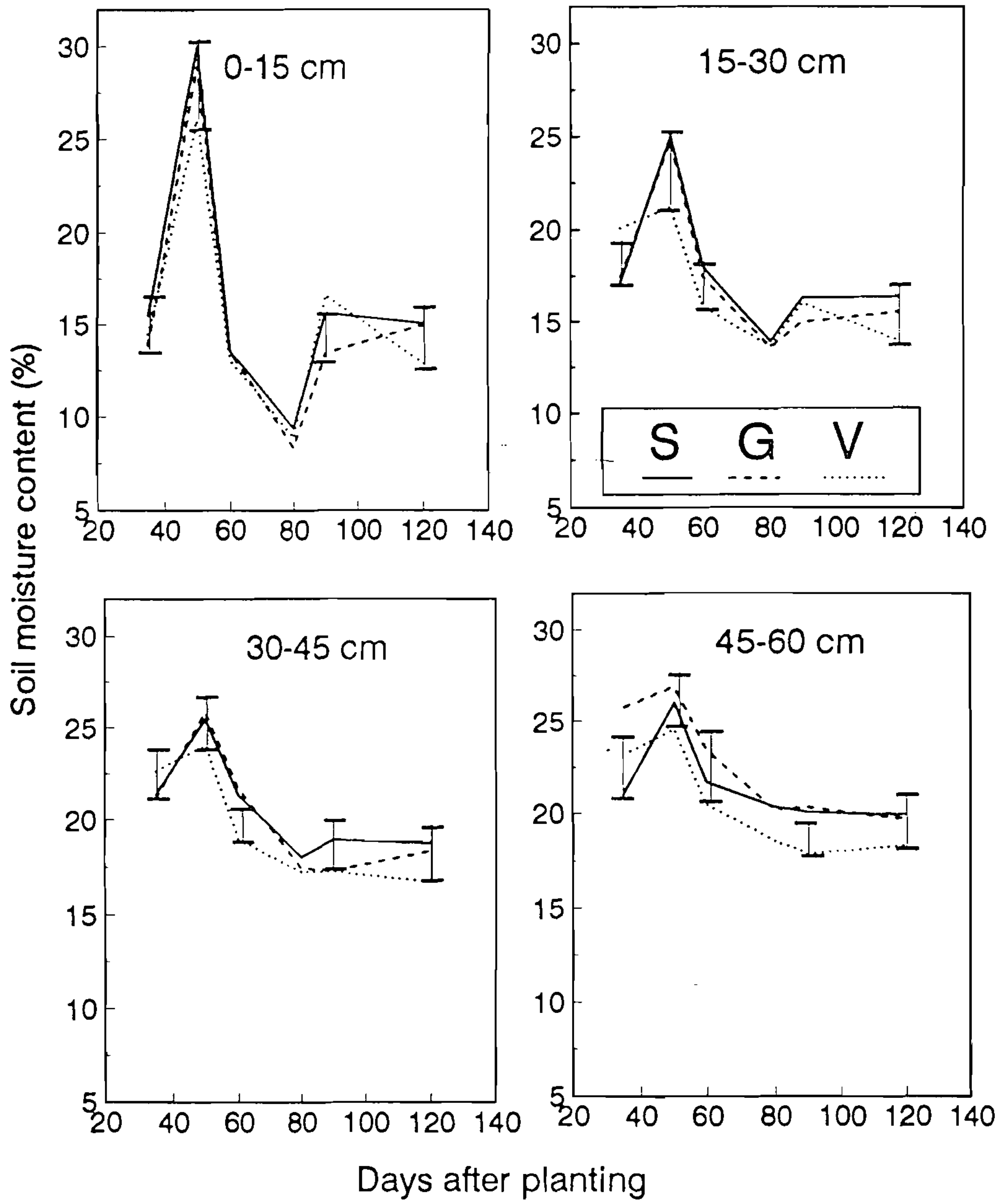


Figure 5: Effect of crop treatment soil water content at different soil depth during 1991 growing season. Error bars indicate LSD(0.05).

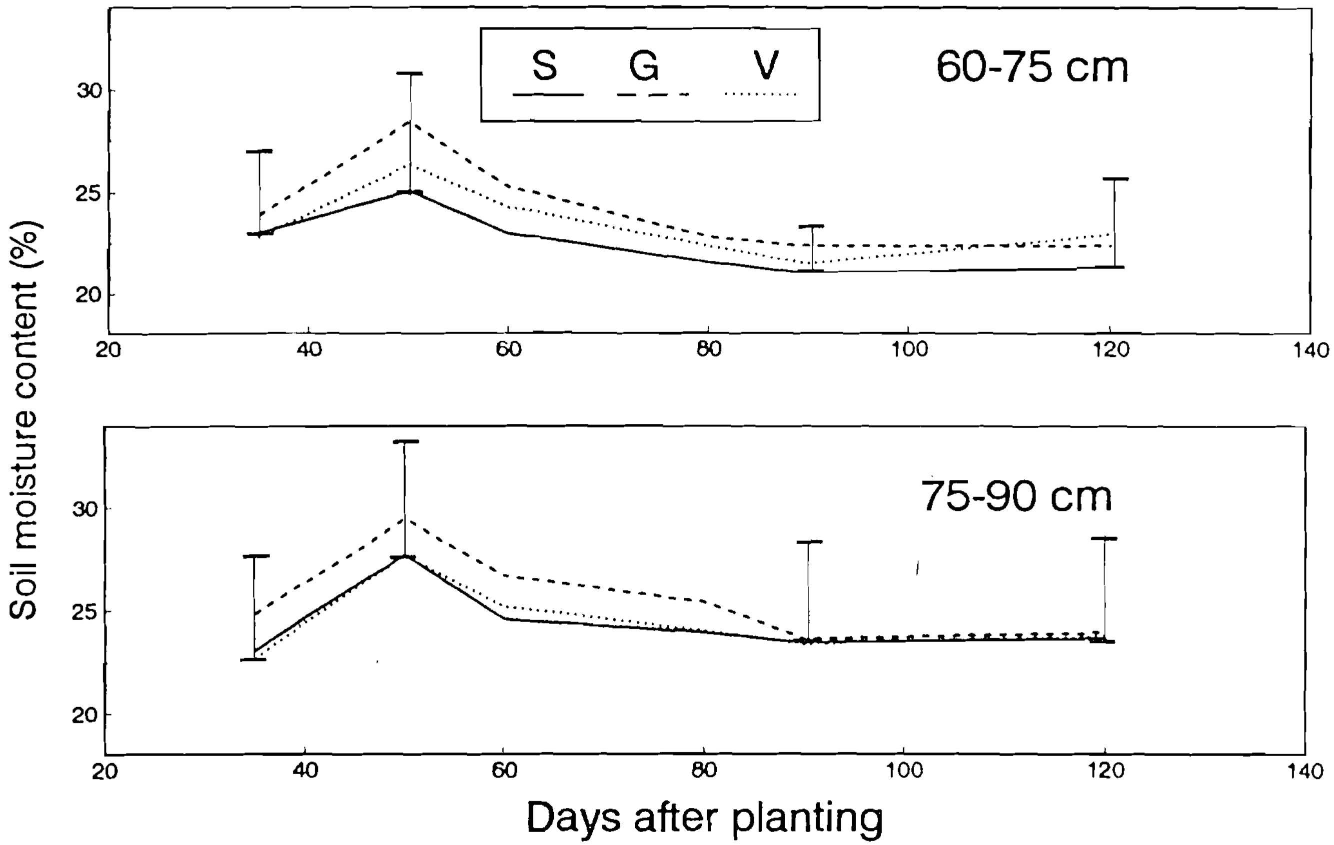


Figure 6: Effect of crop treatments on soil moisture content at different soil depths during 1991 growing season. Error bars indicate LSD(0.05).

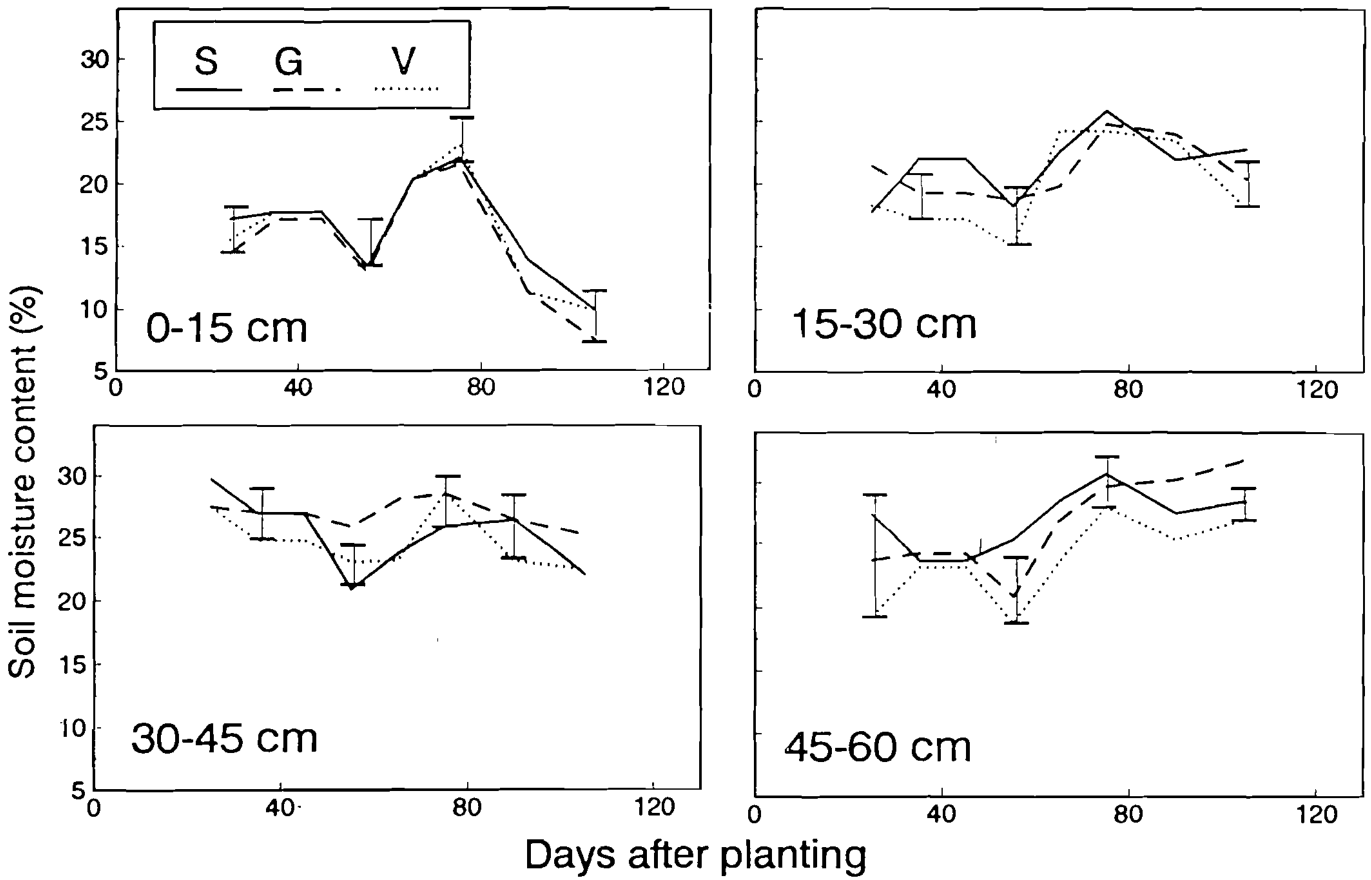


Figure 7: Effect of crop treatments on soil moisture content under different soil depths during the 1992 growing season. Error bars indicate LSD(0.05).

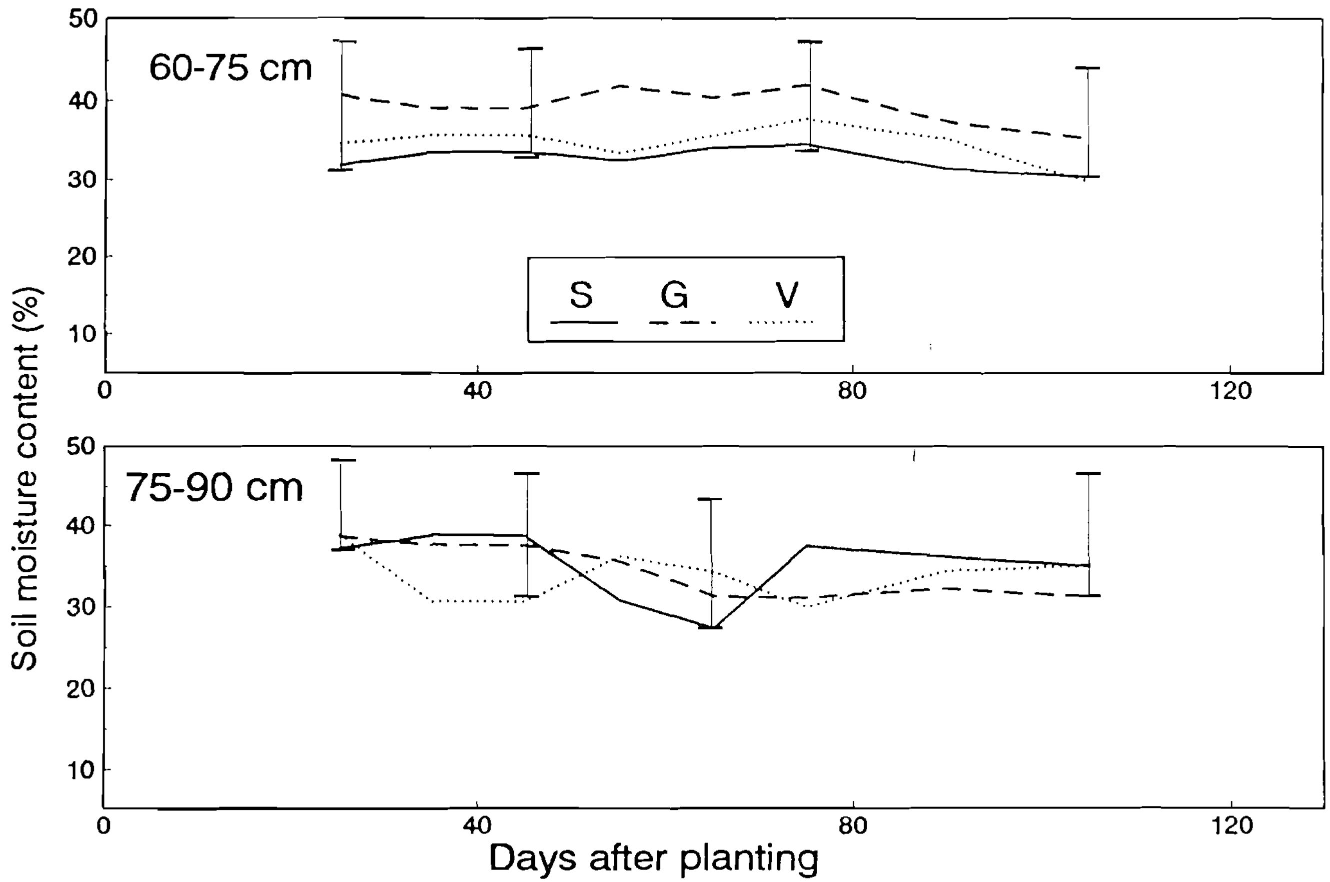


Figure 8: Effect of crop teatment on soil moisture content at different soil depths during 1992 growing season. Error bars indicate LSD(0.05).

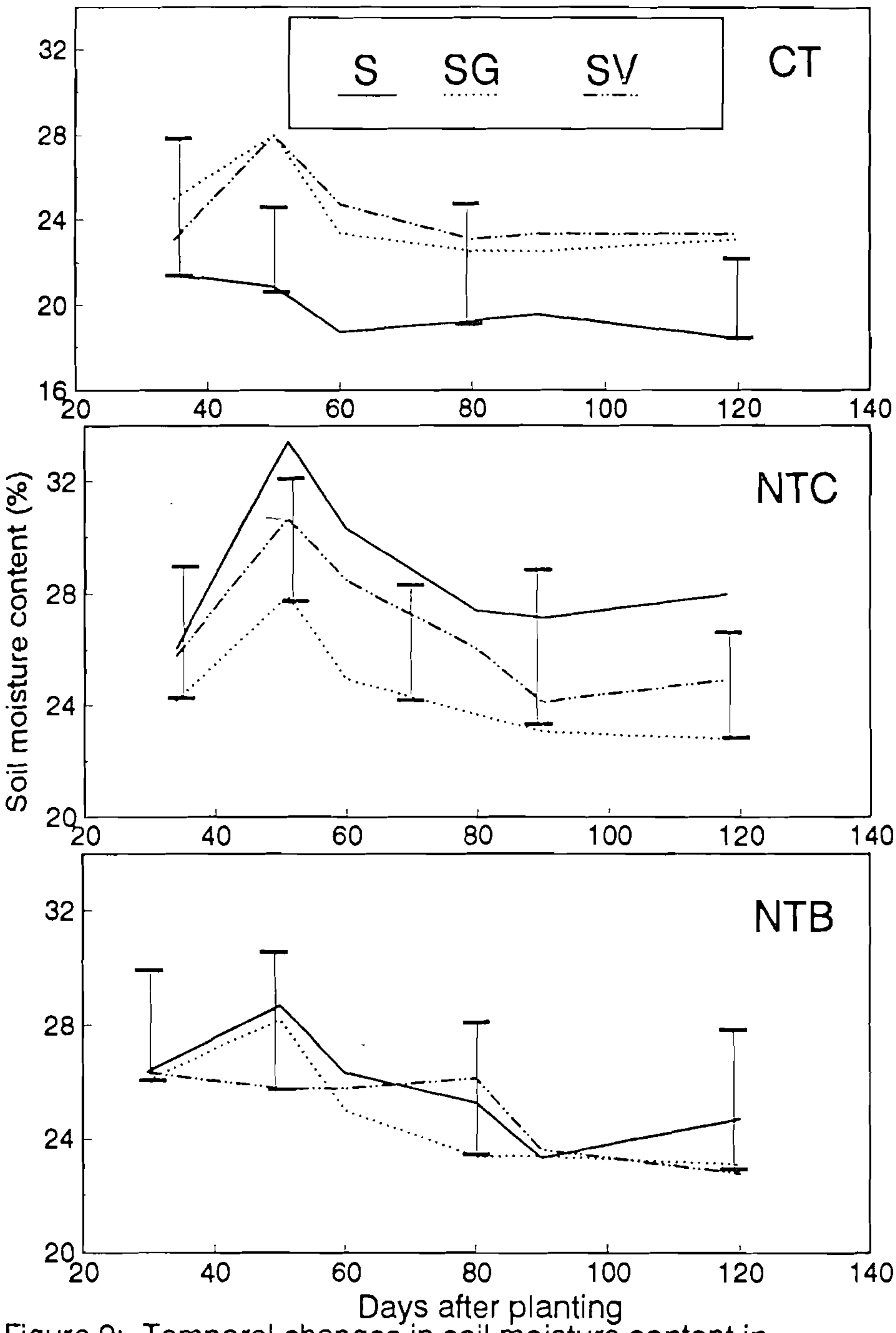


Figure 9: Temporal changes in soil moisture content in the first 60 cm soil depth during 1991 growing season. Error bars indicate LSD(0.05).

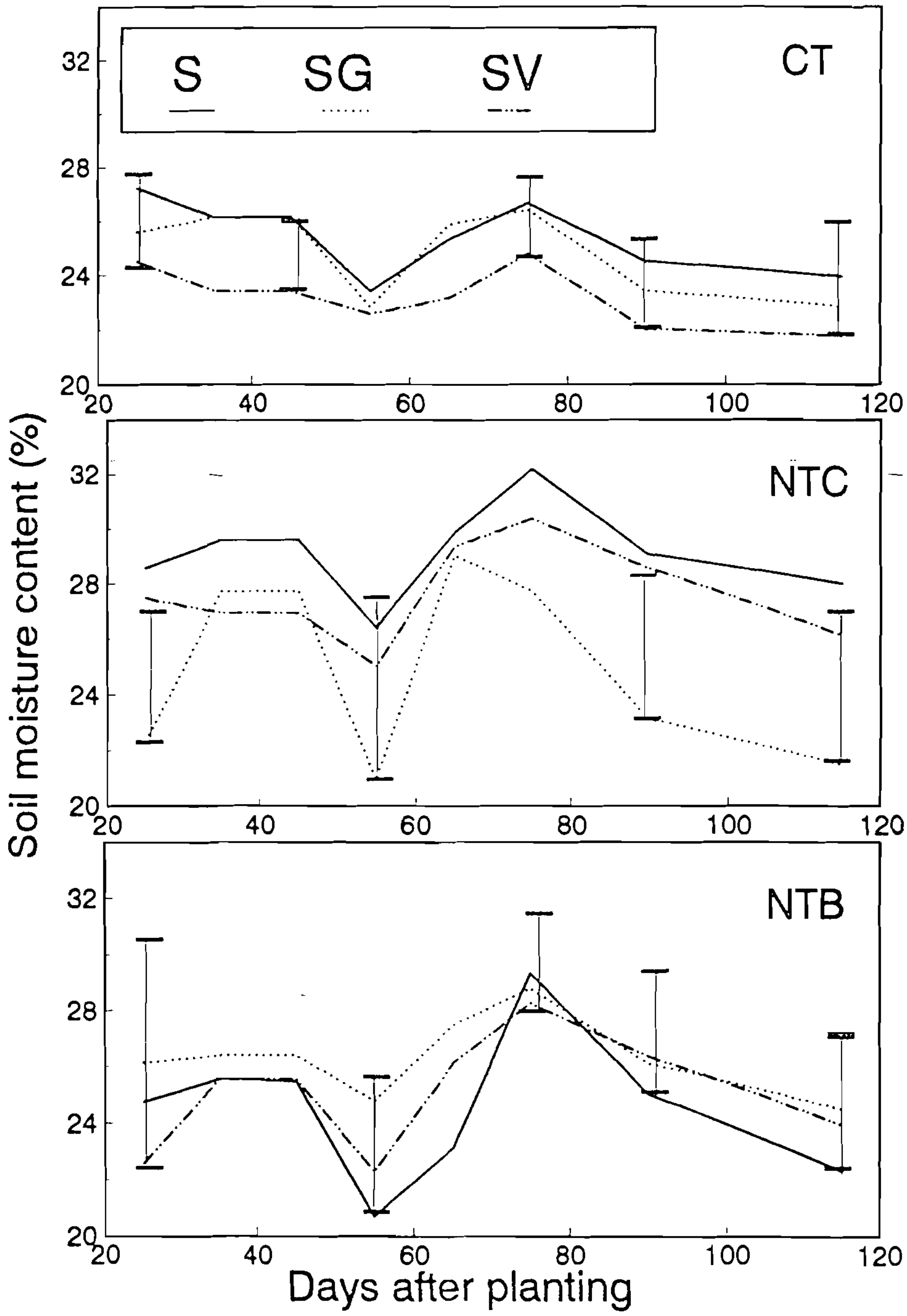


Figure 10: Temporal changes in soil moisture content in the first 60 cm soil depth during 1992 growing season. Error bars indicate LSD(0.05).

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CHAPTER 5

EFFECT OF INTERCROPPING AND TILLAGE/RESIDUE MANAGEMENT ON PLANT BIOMASS PRODUCTION, NUTRIENT UPTAKE AND GRAIN YIELD.

ABSTRACT

Intercropping is a traditional crop production method in the tropics. Yield from intercropping practices are affected by inter-species competition for water and nutrients. The availability of water and nutrients, in turn, is affected by tillage and crop tillage/residue management practices. To study the effect of intercropping and residue management practices on plant nutrient biomass and yield production, and on the soil chemical properties, an experiment was conducted on a Cecil sandy clay loam in Griffin, Georgia during the summers of 1991 and 1992 using a split plot design in randomized complete blocks. Grain sorghum [Sorghum bicolor (L.) Moench, cv. "Pioneer 8230"] was intercropped with peanut [Arachis hypogaea L., cv. "Southern Runner"], or velvet bean [Stizolobium deeringianum Bort, vc. "Early Speckled"] under three tillage/residue management practices: conventional tillage (CT), no-tillage with residue cover (NTC) and no-tillage bare (NTB).

In general, plant biomass production, nutrient uptake and grain yield drastically decreased in the second year of the experiment as a result of unfavorable rainfall distribution, late planting and reduced soil nutrient content. On the average, CT favored plant biomass production, nutrient uptake and yield in 1991 where rainfall distribution was satisfactory. NTC was advantageous under the drier conditions in 1992 due to its moisture advantage. Velvet bean yielded significantly more biomass and nitrogen than sorghum and peanut showing promise for improving soil properties. The amount of biomass and nutrient uptake in the intercropping systems was intermediary between the corresponding sole crops. In general, intercropping improved the residue quality and provided an overall yield advantage over monocultures. Interaction between intercropping and tillage/residue management was generally significant and complex. Changes in soil nutrient content and pH in NTB suggested that residue removal may lead to a long-term soil infertility.

INTRODUCTION

Intercropping or the simultaneous growing of different crops at proximate stands, is an efficient crop production strategy with potential for enhancing agricultural sustainability (Francis, 1986). When associated crops are compatible, intercropping can reduce niche-breath overlaps, minimizing plant competition and improving resource utilization and yield (Gomez and Gomez, 1983; Davis et al., 1986; Sanders, 1989; Ikeorgu and Odurukwe, 1989; Russelle and Hargrove, 1989; Okigbo, 1990). Numerous factors control inter-crop competition and these factors interact dynamically, making it difficult to predict the performance of untested mixtures in varying field conditions (Gliessman, 1986; Trenbath, 1986; Russelle and Hargrove, 1989). Among these factors, below ground resources availability is particularly important, increasing inter-plant competition as these resources become limiting (Willey and Reddy, 1981; Gliessman, 1986; Izauralde et al., 1990). The availability of below ground resources is highly influenced by tillage and residue management practices (Phillips, 19884; Blevins et al., 1984; Haynes and Knight, 1989). In many parts of the tropics where intercropping is widely practiced, inadequate tillage and residue management practices often result in reduced yield and rapid soil degradation. Improving tillage and residue management practices therefore, can further enhance agricultural sustainability especially if adequate intercropping systems such as cereal/legume mixtures are used. Although cereal/legume crop associations often result in a yield depression of the component intercrops compared to the monocrops, with a greater effect on the legumes (Nyambo et al., 1980; Davis et al., 1986; Reddy et al., 1988; Izaurralde et al., 1990), especially peanut (Koli, 1975; IRAT, 1978; Ikeorgu and Odurukwe, 1989), many cereal/legume intercropping systems show an overall yield advantage compared to the monocultures (Sanchez, 1976; Fisher, 1977; Nyambo et al., 1980; Ikeorgu and Odurukwe, 1989). Nyambo et al. (1980) reported a 60% increase in the total intercropping productivity over monocropping. In Sénégal, sorghum/peanut intercropping provided an overall yield advantage compared to the monocultures (Schilling, 1965). Yield advantage of intercropping systems depends on the nature of competition among plants, which in turn, depends on the resource availability, the cropping strategy, and the nature of the crops associated (Barker and Francis, 1986).

Nodulated legumes can symbiotically fix a substantial amount of atmospheric nitrogen (McGuire et al., 1989; Gibson et al., 1977), especially on soils with reduced nitrogen content (Elowad and Hall, 1987). For instance, soybean and cowpea derived 33% of their nitrogen from fixation (Sisworo et al., 1990). Suwanarit et al. (1986) reported that 55-66% of plant nitrogen was fixed by peanut and soybean. A portion of this fixed N eventually becomes available to companion cereals, enhancing their dry matter production and grain yield (Russelle and Hargrove, 1989; Fyson and Oaks, 1990; Hargrove, W.L. 1986). An important source of N transfer to non-legumes in mixtures may be through the mineralization of sloughed-off and dead nodules (Walker et al., 1954). Agboola and Fayemi (1972) also suggested that excess nitrogen also may be excreted by legume roots in favor of cereal intercrops. Heichel and Henjum (1991) reported that 36% of grass N was transferred from intercropped legumes. Izaurralde et al. (1990) reported greater grain and straw N content in barley intercropped with field pea than in pure stands. Greater amounts of legume nitrogen can be recovered by cereals when intercrop positions are rotated the subsequent season (Sinnadurai, 1980; Power, 1987; Hargrove, 1986; Burle et al., 1992).

The percentage of N recovered by non-legume crops generally depends on two major factors: 1) the rate of N mineralization which in turn, depends on a) the soil moisture and temperature status (Nyhan, 1976; Stott et al., 1986; Voroney et al., 1989), b) the quality of the residue (lignin and N content, C/N ratio) (Smith and Douglas, 1968; Reinertsen et al., 1984;

Berendse, 1987) and c) the placement of the residue (Parker, 1962; Frankenberger and Abdelmagid, 1985), and 2) the N-use efficiency (NUE) from legumes (NUEL) of the cereal species grown on the legume soil or intercropped with a legume (Sisworo et al., 1990). The NUEL is typically far lower than the NUE from fertilizers (NUEF) because fertilizer N is more readily available than legume-N for plant uptake. As a result, short term measurements of NUE tend to discourage the use of legumes as a reliable N source in favor of chemical fertilizers (Bezdicek and Granastein, 1989; Meisinger , 1984). For example, it has been shown that only 10 to 30% of legume-N was recovered by the following crop (Ladd and Amato, 1986; Harrison and Hesterman, 1987), compared to recoveries from fertilizer N of 30 to 70% (Stanford, 1987). This prompted Bezdicek and Granatstein (1990) to recommend that the two N sources should be evaluated over an extended period to develop a complete N budget of inputs (N fertilizer, N2 fixation, or N deposition), and outputs (harvest, leaching, volatilization, denitrification). Meisinger (1984) also proposed that the changes in N pool sizes (e.g., organic matter, microbial biomass, inorganic N, etc.) be considered when comparing NUE between legumes and fertilizers. Taking into account changes in soil N that take place when legumes are used for many years , could drastically increase estimates of NUEL, and encourage the adoption of legume N sources for crop production. Interplanting legumes with cereals in particular, may not only improve NUEL, but also forestall soil nutrient depletion and contribute to sustainable crop production.

The changes in soil N discussed above are often influenced by tillage and crop residue management practices. In general, these changes are greater when residues are incorporated as in CT than when residues are maintained on the soil surface as in NTC. This is due to differences in soil water and physical properties (Hargrove, 1986; Costa et al., 1990). Differences in soil properties among tillage and residue management systems may not only affect the NUEL, but also the intercrop competition for nitrogen. The present work was designed to determine the effect of intercropping grain sorghum with peanut or velvet bean under conventional tillage, no-tillage with residue mulch and no-tillage with residue removed on plant nutrient uptake, dry matter and yield production, and on the soil chemical properties.

MATERIALS AND METHODS

Experimental design

A field study was conducted in summer 1991 and 1992 on a Cecil sandy clay loam in Griffin, Georgia. Following a long fallow during which grasses were the predominant vegetation, the soil was planted to potato for one year, then wheat for 2 years prior to the experiment. In Summer 1990, the wheat residues were removed, and soil was conventionally tilled to 30 cm soil depth before planting forage sorghum over the entire the area. This was done to reduce spatial differences and to further depress soil nutrients in order to increase the potential for observing treatment effects. After harvest in early October 1990, the experiment was laid out as a split-plot design in randomized complete blocks with 3 replicates. Main-treatments, which were immediately applied, consisted of conventional tillage (CT), no-tillage bare (NTB), and no-tillage cover (NTC). Main treatments were re-applied two weeks after the 1991 harvest for the 1992 experiment. Subplot treatments, applied at planting, consisted of pure stands grain sorghum [Sorghum bicolor (L.) Moench,cv. "Pioneer 8230"] fertilized (SF) and unfertilized (S), peanut [Arachis hypogaea L., cv. "Southern Runner"] (G), velvet bean [Stizolobium deeringianum Bort, vc. "Early Speckled Velvet Bean"] (V), and mixed stands of sorghum/peanut (SG), and sorghum/velvet bean (SV). Grain sorghum and peanut were used 1) because of their high importance as food and/or cash crops, and 2) because they are often intercropped in tropical Africa. Velvet bean was used because of its potential for fixing nitrogen and for producing heavy biomass for soil improvement. This crop was once popular in Georgia for use as green manure (USDA, 1957; Scott, 1946), but its use declined with decreased cost of inorganic fertilizers. Return to the use of velvet bean for soil improvement can foster agricultural sustainability. NPK fertilizer (90 kg N, 45 kg P_2O_5 and 67 kg K_2O per hectare) was hand broadcasted in SF treatment about 20 days after emergence. Crops in mixtures were planted in alternate double rows. Each subplot consisted of 8 rows, 75 cm apart and 12 m long. Plants were about 10 cm apart within row. Plant populations for all crops averaged 200,000 and 100,000 plants per hectare in pure and mixed stands, respectively. Weeds were controlled as needed during growing season by hoeing and during winter period by application of 0.56 kg/ha paraquat (1,1′ dimethyl-4,4′-bibyridiniumion). Crops were planted and harvested on June 1 and October 28 in 1991, and on June 15 and October 16 in 1992, respectively. Also, reduced rainfall was observed during the 1992 growing season (Figure 1, Chapter 3) indicating that the crops were disadvantaged in 1992 compared to 1991.

Soil pH and nutrient analysis

Soil samples were taken each year at 0-7.5, 7.5-15, 15-30, and 30-45 cm soil depths for pH and nutrient analysis at planting and harvest. These samples were allowed to air dry for several days, ground to pass a 2 mm stainless steel screen, and hand mixed to ensure a representative sample during analysis. Samples were kept in soil sample bags until laboratory analysis for pH, N, P, K, Ca, and Mg. Soil water and buffer pH were determined on a 1:1 soil/liquid suspension. Soil total N was determined by a micro-Kjeldahl method which included nitrate [salicylic acid-sodium-thiosulfate modification (Bremner and Mulvaney, 1982)]. Soil samples were also extracted with 1 M KCl for the remaining nutrient analysis.

Plant dry matter and yield.

Plant biomass and grain yield samples were harvested over 2 randomly located 1 m2 (velvet bean) or 1 m row (peanut and sorghum) samples from inner-most rows. Samples were dried at 90^{oC} for at least two weeks then weighed. Samples were then ground to pass 1mm screen and analyzed for nutrients as described above for soil samples. Nutrient uptake was calculated by multiplying nutrient concentration by total dry matter. Biomass, nutrient uptake and yield data were analyzed by year, date of sampling (when needed), tillage/residue management system, intercrop and crop, by statistical analysis system (SAS Institute, Inc., 1985). Soil chemical properties were analyzed by date of sampling, tillage/residue management practice, crop treatment and depth, also using the SAS program.

RESULTS AND DISCUSSION

Plant biomass production.

Mean separation among intercrops is presented in Table 1 for each tillage/residue management system for 1991 and 1992. In general, overall biomass production was lower in 1992 than in 1991 (Table 1, Figure 1), probably due to 1) unfavorable rainfall distribution, 2) late planting, 3) reduced nutrient uptake, and 4) reduced soil nutrient content in 1992 compared to 1991. Overall final crop biomass production was comparable between CT and NTC in 1991, and between NTC and NTB in 1992. The least biomass production was obtained from NTB in 1991, and in CT in 1992. Mean separation among crops was not affected by tillage/residue management practices (Table 1), indicating that interaction between intercropping and tillage/residue management was insignificant. Of the three monocrops, the biomass production was the highest for velvet bean, followed by sorghum and peanut (Table 1, Figure 1). Biomass production by velvet bean was more rapid than that by sorghum or peanut all through the season, with greater growth rate after about 60 days post emergence (Figure 1), and resulted in early ground cover by the canopy. Velvet bean residue dry weight averaged 11393 kg/ha and 9544 kg/ha in 1991 and 1992 respectively (Table 1). Such high biomass production by velvet bean has been reported by previous workers who suggested the use of this crop for improving soil fertility (Bowen et al., 1988; Malik et al., 1985; Burle et al., 1992). The rapid spread of the velvet bean canopy suppressed weed growth, also supporting its use for weed control (Baryeh, 1987). As a result of intercropping effects, the overall biomass produced in the mixed stands were intermediary between corresponding sole crops (Table 1), presenting an advantage over the less productive intercrop component.

Intercropping tended to depress peanut biomass production compared to peanut monoculture in both years (Figure 1; Table 1). Sorghum biomass production remained unaffected by competition from peanut. In contrast, intercropping favored velvet bean and depressed sorghum biomass production in the sorghum/velvet bean mixture (Table 1). Overcompetition of sorghum by velvet bean may be due to a greater water uptake by velvet bean (Chapter 4).

Plant nutrient uptake

For the same reasons as for biomass production, overall plant nutrient uptake was lower in 1992 than in 1991 in all tillage/residue management systems (Tables 2 and 3, Figures 1 and 2). Figure 1 shows that N uptake was particularly a function of the amount of biomass produced, indicating that intercropping exerted little effect on crop nutrient concentration as shown in Figure 2 for sorghum N content. In general, tillage did not significantly affect nutrient uptake in 1991, because soil fertility was still uniform for all plots. In 1992, nutrient accumulation in residues was significantly greater in NTC than in CT and NTB except for P and Mg (Table

3). In general, residue decomposition is enhanced in CT as compared to NTC due to higher moisture content below the soil surface (Wilson and Hargrove, 1986; Stott et al., 1986; Voroney et al, 1989; Smith and Sharpley, 1990). Reduced nutrient uptake in CT, may be attributable to 1) reduced root growth, 2) reduced soil moisture content [Chapters 3 and 4], and 3) rapid residue decomposition that may have resulted in greater nutrient loss by leaching, immobilization or volatilization as reported Parker (1986) for buried corn residues. Reduced nutrient uptake in NTC may have resulted also from slow residue decomposition due to water shortage on the soil surface. Reduced uptake in NTB may have been compounded by increased nutrient depletion (Figures 3, 4, and 5), as nutrient cycling was reduced by residue removal.

Nutrient accumulation in crop residues was consistently higher in velvet bean monocrop and/or in sorghum/velvet bean intercrop regardless of the tillage/residue management system in both years. In 1991, the unfertilized sorghum monocrop exhibited the lowest uptake of all nutrients except potassium. The N uptake by monocropped sorghum was about 3 to 5 fold less than that of monocrop velvet bean for both CT and NTC in 1991 and for all tillage/residue management systems in 1992 (Table 3). In general, intercropping improved overall residue nutrient content compared to monocrop sorghum (Table 3). This observation is particularly important with regard to nutrient recovery by the subsequent crops and to the long-term soil nutrient status. Cereal residues often have a larger C:N ratio than legumes and decompose more slowly with the risk of a net N immobilization and reduced N recovery by the subsequent crops. In contrast, N recovery from legume residue often is high because of more rapid decomposition and larger amount of N release compared to cereals (Frankenberger and Abdelmagid, 1985; Douglas et al., 1980; Hargrove, 1986; Hargrove et al., 1990). Cereal residue decomposition is slow and often results in a net immobilization, reducing plant N uptake. The rate of decomposition and the amount of N recovered from cereal residue however, can be enhanced by improving the initial soil inorganic N content (Smith and Douglas, 1968). In cereal/legume mixtures therefore, rapid mineralization of legume residues can provide sufficient inorganic N in favor of cereal residue mineralization, if an adequate cereal/legume ratio is used. In any case, resulting mixed residue from intercropping may decompose at an intermediate rate, reducing excessive losses and supplying plants with nutrients at a more optimal rate than monocrop residues. Overall, residue return to the soil from legume-based mixtures can have a long-term buffering effect on cereal nitrogen uptake, contributing to agricultural sustainability.

Grain or seed yield

In crop production, the ultimate aim of all cultural practices is to optimize seed yield. Absolute grain or seed yield was lower in 1992 than in 1991 (Table 4). Reasons for this reduced yield may be the same discussed earlier for reduced biomass production or nutrient uptake. Late planting, resulted in late maturation and reduced velvet bean pod filling due to early frost that occurred in late September. In general, in 1991, yield was higher in CT than in NTC and NTB certainly because of greater nutrient uptake. In 1992, increased water shortage provided yield advantage to NTC except for velvet bean monocrop.

Absolute yield of sorghum was not significantly affected by competition from peanut except in NTB in 1991 and CT in 1992. In contrast, although peanut pod yield was not affected by intercropping in NTC and NTB in 1991, it was significantly depressed in all tillage/residue management systems in 1992. Peanut yield depression by companion cereals has been extensively reported (Koli, 1975; IRAT, 1978; Reddy et al., 1988; Ikeorgu and Odurukwe, 1989). In general, shading effect and more aggressive root competition from cereal companion crops often are cited as reasons for intercropped peanut yield reduction (IRAT, 1978; Reddy et al., 1988; Stirling et al., 1990). In this experiment, short stature sorghum variety was used and intercropping was done in alternate double rows to minimize shading effect. In addition, no major disease or insect infestation was observed during the two years that could have differential impact on crop treatments. Therefore, intercropped peanut yield depression may have resulted essentially from competition from sorghum for below ground resources.

As for the biomass production, intercropping favored velvet bean yield production and tended to depress sorghum yield when the two crops were mixed. Velvet bean is a viney crop that grows fast and produces heavy biomass as shown in Table 1 and Figure 1. Although velvet bean root density may be lower (Chapter 3), its rate of water and nutrient uptake may be higher than that of sorghum, providing it with a superior competitiveness over sorghum. Velvet bean vines were cut when needed to keep them from climbing the sorghum stems. Shading from either intercrop was limited due to 1) the height of velvet bean canopy, 2) the short stature of the sorghum variety used, and 3) the binary planting strategy adopted. As with peanut, only competition for below ground resources may have influenced intercrop yield performance. Reduced yield of monocropped as compared to intercropped velvet bean may have resulted from increase intra-crop competition. The dense canopy in velvet bean monoculture also may have reduced air renewal, promoting air humidity and diseases which can adversely affect flower and pod setting.

Relative yield of intercrops, e.g, actual yield calculated in relation to the percentage of land area allocated to the crop in the mixture, was always lower than the yield in pure stand because individual companion crop plant population was half the plant population in the monoculture. The values of efficiency of yield production (EYP) presented in Table 4 provide a fair comparison between intercrop relative yields and their yield in monoculture. Except for intercropped sorghum in 1991 and intercropped peanut in 1992, EYP's approximated or were greater than 0.5 in all main plots, indicating that intercropping favored yield production of component intercrops. The sums of EYP's of associated crops represents the land equivalent ratios (LER) and were greater or close to unity (Table 5), evidencing an overall yield advantage of intercropping as reported by several previous workers (Fisher, 1977; Nyambo et al., 1980; Ikeorgu and Odurukwe, 1989).

Effect of intercropping and tillage/residue management practices on soil nutrient content.

In general, soil nutrient content was uniform across the experimental plots at the beginning of the experiment in 1991 and decreased with soil depth except for magnesium (Tables 6, 7, and 8). Soil water pH was about 5.7-

6.2 and varied little vertically in the soil profile, indicating that lime/or fertilizers may have been applied in previous years. After two years of treatment application, all soil nutrient content decreased to more than half their initial levels (Tables 6, 7, and 8). A significant loss of N, K from the top 7.5 cm soil depth was observed in CT and NTB, compared to NTC (Table 8). Reasons for this drastic decrease may include 1) plant uptake, 2) slow nutrient turn over, 3) nutrient exportation with harvested grain, and 4) various other sources of losses such as leaching, drainage with runoff water and erosion. In general, NTC tended to exhibit higher Ca and Mg content than CT and NTB (Tables 7 and 8). These differential effect of tillage/residue management practices on soil nutrient content explains the changes in soil pH levels as shown in Tables 7 and 8). As a result of higher nutrient and probably organic matter content, NTC soil exhibited a significantly higher pH than NTB and CT soils at the end of the experiment. However, the status of soil pH and nutrient content observed at the last harvest may be a punctual result from plant uptake during the growing season. Residue return to the soil in CT and NTC resulted in cyclic replenishment of soil nutrients as shown in Figures 3 and 5 for N and K. Soil pH also followed the same trend. Crop residue removal from NTB reduced nutrient cycling, resulting in a continual decrease of soil nutrient content.

Crop treatments exhibited little differences with regards to soil nutrient content (Tables 9, 10 and 11, Figures 3, 4, and 5) due to the short experimental period. Additional nutrient release from the 1992 residues in CT and NTC would probably improve soil nutrient, especially N content in the legume soils, compared to NTB. Although the effect of velvet bean on soil properties was not clearly demonstrated during this experiment, the high biomass production and high N return to the soil by velvet bean, combine with its good soil coverage to make it a crop of choice for soil and water conservation. Velvet bean appeared to provide better soil N advantage than peanut.

CONCLUSION

In general, plant biomass production, nutrient uptake and grain yield drastically decreased in the second year of the experiment as a result of unfavorable rainfall distribution, late planting and reduced soil nutrient content. On the average, CT favored plant biomass production, nutrient uptake and yield in 1991 where rainfall distribution was satisfactory. NTC was advantageous under the drier conditions in 1992. Although NTB differed little from NTC, soil nutrient content and pH in NTB suggested that residue removal may lead to a long-term soil infertility. Velvet bean biomass production and nitrogen yield were interestingly high, encouraging the use of this crop for improving soil properties. In general, intercropping improved the residue quality and provided an overall yield advantage over monocultures. Interactions between intercropping and tillage/residue management systems were generally significant and complex.

Table 1. Effect of tillage and residue management on the amount of crop residue incorporated (CT), removed (NTB), or left on soil surface (NTC) after harvest for 1991 and 1992.

Crop Treatment		CT		NTC		NTB		Mean	
				1991					
SF		8747	b	8862	c	8569	b	8693	c
S		8543	b	9015	c	8626	b	8728	c
SG	*	7339	c	7259	d	7664	c	7421	d
G		6058	d	7130	d	6058	d	6415	e
SV	*	11622	a	10527	b	9059	b	10403	b
V		12020	a	11443	a	10717	a	11393	a
S		8543	a	9015	a	8626	ab	8728	a
S/SG	**	8536	a	8351	ab	9575	a	8821	a
S/SV		9138	a	8193	b	7165	b	8165	b
G		6058	a	7130	a	6058	a	6417	a
G/SG		6142	a	6168	b	5752	a	6021	b
V		12020	b	11443	b	10717	a	11393	b
V/SV		14106	a	12860	a	10953	a	12640	a
Average		9055	a	9040	a	8449	b	8832	
				1992					
SF		8617	b	8071	b	6890	b	7859	b
S		599	d	5752	c	7021	b	6194	c
SG	*	3970	e	5402	c	4484	c	4619	d
G		3565	e	4702	c	4702	c	3988	d
SV	*	6399	c	8710	ab	7934	ab	7681	b
V		9550	a	9700	a	9383	a	9544	a
S		5599	a	7371	a	7021	a	6664	a
S/SG	**	5030	ab	7043	a	6212	b	6095	ab
S/SV		4681	b	5752	b	6802	ab	5745	b
G		3565	a	4702	a	3696	a	3988	a
G/SG		2909	b	3762	b	2756	a	3142	b
V		9550	a	9700	a	9393	a	9544	a
V/SV		8117	b	10050	a	9067	a	9078	a
Average		6283	b	7056	a	6736	ab	6636	

- Means of same set within column with same letter are not significantly different (α = 0.05).

* Means for SG and SV represent averages of combined component intercrop biomass.

** Means for specified component intercrop in indicated mixture (S/SG = sorghum/groundnut mixture).

Table 2. Crop residue nutrient content at harvest (kg/ha) average cover crop treatments.

	CT		NTC		NTB		Average	
Nutrients	1991	1992	1991	1992	1991	1992	1991	1992
N	138.4 a(a)	99.6 b(b)	137.7 a(a)	120.3 a(a)	123.9 b(a)	106.5 b(a)	133.3 (a)	108.8 (b)
P	12.2 a(a)	8.2 a(a)	12.6 a(a)	9.6 a(a)	10.9 a(a)	9.9 a(a)	11.9 (a)	9.3 (a)
K	178.6 a(a)	86.1 b(b)	165.7 b(a)	105.1 a(b)	152.7 c(a)	83.4 b(b)	165.7 (a)	91.6 (b)
Ca	73.8 a(a)	49.7 b(b)	67.2 b(a)	58.9 a(a)	61.4 c(a)	49.3 b(b)	67.5 (a)	52.6 (a)
Mg	28.0 a(a)	16.7 a(b)	26.0 ab(a)	19.5 a(b)	23.3 b(a)	18.4 a(a)	25.8 (a)	18.2 (b)

- Means within row for same year with same letter without parentheses are not significantly different.
- Letters in parentheses represent year separation.

Table 3. Effect of tillage and intercropping on crop residue nutrient content at harvest (kg/ha).

Crop	N			P			K			Ca			Mg		
Treatment	CT	NTC	NTB	CT	NTC	NTB	CT	NTC	NTB	CT	NTC	NTB	CT	NTC	NTB
							1991								
SF	69 c	58 d	112 a	9 a	9 a	9 b	203 a	206 a	205 a	31 d	32 d	30 c	25 a	24 a	20 c
S	47 c	50 d	77 a	9 a	9 a	9 b	207 a	187 ab	191 ab	30 d	29 d	30 c	23 a	24 a	22 bc
SG	111 bc	108 c	91 a	11 a	13 a	10 ab	167 ab	139 b	135 ab	54 cd	55 c	49 c	27 a	29 a	27 b
G	156 b	190 b	110 a	9 a	11 a	10 ab	114 c	138 b	117 b	73 bc	75 bc	74 b	30 a	31 a	33 a
SV	172 b	164 b	118 a	15 a	11 a	13 ab	208 a	181 ab	150 ab	97 b	79 b	72 b	34 a	25 a	19 c
V	270 a	260 a	132 a	18 a	17 a	16 a	155 bc	154 ab	139 ab	156 a	132 a	109 a	125 a	23 a	20 c
							1992								
SF	106 b	90 bc	72 b	14 a	10 a	9 a	108 a	133 a	98 a	148 a	51 bc	97 a	28 a	28 a	18 a
S	56 c	46 c	66 b	8 b	9 a	16 a	60 b	90 a	107 a	88 c	20 c	107 a	16 b	17 a	23 a
SG	61 c	82 bc	67 b	6 bc	7 a	7 a	45 b	75 a	66 a	63 de	34 c	66 a	13 b	13 a	16 a
G	90 b	119 bc	99 b	4 c	6 a	5 a	34 b	75 a	58 a	50 e	45 bc	58 a	18 b	18 a	19 a
SV	107 b	158 ab	140 b	8 b	12 a	11 a	50 b	137 a	88 a	83 cd	78 b	88 a	14 b	21 a	18 a
V	209 a	226 a	221 a	12 a	13 a	13 a	33 b	119 a	98 a	112 b	131 a	93 a	17 b	18 a	18 a

- Means with columns with same letter are not significantly different (α = 0.05).

Table 4. Effect of intercropping, tillage, and crop residue management on absolute seed yield (ASY) (kg/ha) and efficiency of yield production (EYP)*

Crop Treatment	CT		NTC		NTB		Overall Average	
	ASY	EYP	ASY	EYP	ASY	EYP	ASY	EYP
				1991				
SF	5743 a (a)	1.1	5284 a(a)	1.2	5966 a(a)	1.3	5665 a	1.2
S	5302 ab(a)	1	4392 b(b)	1	4707 c(ab)	1	4800 b	1
S/SG	5100 b (a)	0.5	4042 b(b)	0.5	5179 b(a)	0.5	4774 b	0.5
S/SV	4234 c (a)	0.4	4339 b(a)	0.5	3657 d(b)	0.4	4077 c	0.4
G	3106 b (a)	1	2944 a(a)	1	3030 a(a)	1	3027 b	1
G/SG	4772 a (a)	0.8	3752 a(b)	0.6	2991 a(c)	0.5	3838 a	0.6
V	3383 b (a)	1	2950 b(a)	1	3117 a(a)	1	3150 b	1
V/SV	5183 a (a)	0.8	3983 a(b)	0.7	5150 a(a)	0.8	4772 a	0.8
				1992				
SF	4484 a (b)	1.7	5883 a(a)	1.9	5774 a(a)	1.6	5380 a	1.7
S	2646 b (c)	1	3062 b(b)	1	3674 b(a)	1	3128 b	1
S/SG	3412 b (b)	0.6	4505 b(a)	0.7	3587 bc(b)	0.5	3835 b	0.6
S/SV	3084 b (a)	0.6	2996 c	0.5	3499 c (a)	0.5	3193 b	0.5
G	2078 a (b)	1	4702 a(a)	1	2231 a (b)	1	3004 a	1
G/SG	1750 b (b)	0.4	3762 b(a)	0.4	1247 b(b)	0.3	2253 b	0.4
V	2483 b (a)	1	1317 b(b)	1	1733 b (a)	1	1844 b	1
V/SV	3300 a (a)	0.7	3583 a(a)	1.4	3650 a (a)	1.1	3511 a	0.9

- Means within column of same group of crop treatment and having same letter without parentheses are not significantly different ($\alpha = 0.05$).

- Means within row (except for overall average) with same letter in parentheses are not significantly different ($\alpha = 0.05$).

* EYP has been calculated using relative yield value of intercrops, equal half their absolute values, according to component intercrop plant population in mixtures.

Table 5. Effect of tillage and residue management on land equivlent ratios (LER) with regard to seed yield of intercrops.

Intercropping	CT 1991	CT 1992	NTC 1991	NTC 1992	NTB 1991	NTB 1992	Overall 1991	Overall 1992
SG	1.2	1.1	1.1	1.1	1.0	0.8	1.1	1
SV	1.2	1.2	1.2	1.8	1.2	1.5	1.2	1.5

LER = Ma/Sa + Mb/Sb = La + Lb
Where Ma and Mb = Relative yield of crop A and B in mixture respectively.
Sa and Sb = Yield of crop A and B in monoculture respectively.
La and Lb = Efficiency of yield production (EYP) presented in Table 4 for intercrops A and B respectively.

Table 6. Soil profile nutrient status in 1990 and 1992 average over tillage and crop treatments.

Depth	pH H_2O	pH AcOH	N	P	K	Ca	Mg
				7/25/90			
0.75	5.88b	7.66a	0.11a	15.6a	137.2a	619.2b	79.7a
7.5-15	5.86b	7.65ab	0.09ab	13.6a	96.3b	683.6a	86.8a
15-30	6.12a	7.64ab	0.08b	6.3b	54.4c	525.1c	95.6a
30-45	5.99ab	7.62b	0.05c	2.1c	36.6d	360.4d	85.5a
				11/17/92			
0.75	5.81b	7.71a	0.07a	8.3a	52 a	369.5b	39.3b
7.5-15	5.99a	7.70ab	0.06b	7 a	34.4b	417.8a	40.1b
15-30	6.05a	7.68b	0.04c	2.3b	32.1b	338.2c	41.4b
30-45	5.85b	7.64c	0.03d	0.7b	27.3c	280.9d	49.3a

Means within columns with same letter are not significantly different (α = 0.05).

Table 7. Effect of tillage and residue management on soil nutrient content (%). Average over crop treatments and depths.

Tillage	pH H_2O	Buffer pH	N	P	K	Ca	Mg
				7/25/90			
CT	5.95ab	7.6a	0.08a	8.7ab	80a	532a	79a
NTC	6.05a	7.6a	0.08a	8.2b	81a	563a	101a
NTB	5.89b	7.6a	0.08a	11.1a	81a	545a	80a
				11/17/92			
CT	5.85b	7.67b	0.05a	4.5ab	39a	343a	41b
NTC	6.07a	7.71a	0.05a	3.8b	39a	363a	46a
NTB	5.86b	7.68b	0.04b	5.4a	31b	356a	41b

Means within columns with same letter are not significantly different (α = 0.05).

Table 8. Effect of tillage and crop residue management system on soil profile nutrient content (ppm). Average over crop treatments.

pH Nutrients	0-7.5 cm CT	0-7.5 cm NTC	0-7.5 cm NTB	7.5 - 15 cm CT	7.5 - 15 cm NTC	7.5 - 15 cm NTB	15.3 cm CT	15.3 cm NTC	15.3 cm NTB	30 - 45 cm CT	30 - 45 cm NTC	30 - 45 cm NTB
7/25/90												
pH H_2O	5.84a	5.88a	5.90a	5.92a	5.98a	5.70a	6.09a	6.17a	6.09a	5.96b	6.17a	5.85b
Buff pH	7.65a	7.66a	7.66a	7.65a	7.66a	7.64a	7.69a	7.65a	7.63a	7.63a	7.61a	7.62a
N	0.06b	0.07b	0.12a	0.12a	0.09c	0.10b	0.09a	0.08ab	0.07b	0.05a	0.05a	0.04a
P	15 a	14 a	18 a	13 a	12 a	16 a	50 a	5.76a	7.86a	1.95a	1.81a	2.63a
K	133 a	135 a	144 a	98 a	99 a	92 a	50 a	59 a	53 a	41 a	33 a	36 a
Ca	596 a	630 a	630 a	693 a	682 a	677 a	485 b	529 ab	559 a	353 ab	383 a	345 a
Mg	75 a	83 a	80 a	85 a	90 a	85 a	70 a	140 a	76 a	86 ab	91 a	80 b
11/17/92												
pH H_2O	5.87a	5.85ab	5.73b	5.89b	6.08a	6.01ab	5.91 b	6.24a	5.99b	5.74b	6.1 a	5.73b
Buff pH	7.66c	7.75a	7.71b	7.70a	7.71a	7.71a	7.69 a	7.67a	7.67a	7.65a	7.64a	7.65a
N	0.06b	0.09a	0.07b	0.06a	0.06a	0.06a	0.05 a	0.04b	0.04b	0.03a	0.03a	0.03a
P	7.8 a	7.5 a	9.6 a	6.2 ab	5.9 b	9.02a	3.16 a	1.34b	2.29ab	0.77a	0.60a	0.60a
K	47 b	60 a	49 b	41 a	36 b	25 c	39 a	33 a	25 a	29 a	28 a	24 a
Ca	362 a	372 a	374 a	399 a	422 a	433 a	345 a	339 a	331 a	269 b	319 a	285 b
Mg	36 a	44 a	38 a	41 a	40 a	39 a	41 a	44 a	39 a	46 a	55 a	47 ab

Means within columns with same letter are not significantly different (α = 0.05).

Table 9. Effect of intercropping on soil nutrient content (ppm). Average over tillage/residue management systems.

Crop Treatment	pH H_2O	Buff pH	N	P	K	Ca	Mg
				7/25/90			
SF	6.0 ab	7.64a	0.08a	8.43a	83a	553a	83a
S	5.93ab	7.65a	0.08a	11.95a	76a	539a	80a
SG	5.83b	7.64a	0.08a	8.40a	79a	524a	83a
G	5.95ab	7.63a	0.07a	8.70a	82a	535a	81a
SV	5.43ab	7.65a	0.09a	9.18a	83a	552a	80a
V	6.11a	7.64a	0.08a	9.72a	83a	579a	113a
				11/17/92			
SF	5.89bc	7.70a	0.05a	5.98a	38a	348ab	37b
S	6.01ab	7.71a	0.05a	4.88ab	34bc	358ab	45a
SG	6.03a	7.68ab	0.05a	4.26ab	32c	373a	45a
G	5.79c	7.68ab	0.05a	4.35ab	39a	338b	41ab
SV	5.89bc	7.66b	0.05a	3.27b	38ab	347ab	44a
V	5.95ab	7.68ab	0.05a	4.67ab	38a	360ab	44a

Means within columns with same letter are not significantly different (α = 0.05).

Table 10. Effect of intercropping on soil nutrient content (ppm), averaged over depths and tillage/residue management systems.

pH Nutrients	0-7.5 cm SF	S	SG	G	SV	V	7.5-15 cm SF	S	SG	G	SV	V
						7/25/90						
pH H_2O	5.93 a	5.83 ab	5.87 ab	5.87 ab	5.75 b	5.99 a	5.97 a	5.93 a	5.33 a	5.96 a	5.86 a	6.12 a
Buff pH	7.66 a	7.67 a	7.67 a	7.64 a	7.65 a	7.66 a	7.67 a	7.66 a	7.62 a	7.64 a	7.65 a	7.65 a
N	0.09 a	0.06 a	0.10 a	0.08 a	0.10 a	0.10 a	0.11 a	0.10 a	0.11a	0.106a	0.113a	0.101a
P	14.33 a	18.03 a	15.46 a	13.95 a	15.02 a	15.79 a	12.47 a	17.68 a	11.98 a	12.64 a	12.33 a	14.24 a
K	139.65 a	112.28 a	148.49 a	133.93 ab	146.17 a	144.17 a	102.26 a	89.48 a	97.79 a	97.50 a	99.31 a	91.04 a
Ca	641.41 a	590.27 ab	627.63 ab	571.49 b	636.08 ab	647.48 a	706.55 ab	652.56 b	654.87 ab	667.22 ab	676.63 ab	240.44 a
Mg	84.76 a	75.39 a	82.09 a	75.44 a	78.59 a	81.47 a	88.33 a	80.48 a	87.33 a	86.91 a	84.67 a	92.82 a
						11/17/92						
pH H_2O	5.6 c	5.9 ab	5.98 a	5.8 ab	5.77 bc	5.84 ab	6.0 ab	6.07 ab	6.13 a	5.84 b	5.92 ab	6.0 ab
Buff pH	7.72 a	7.73 a	7.72 a	7.70 a	7.70 a	7.70 a	7.72 a	7.70 a	7.72 a	7.69 a	7.68 a	7.73 a
N	0.07 ab	0.06 b	0.06 ab	0.07 ab	0.07 a	0.07 a	0.06 ab	0.05 b	0.06 ab	0.06a	0.06 a	0.06 ab
P	12.99 a	8.74 ab	7.16 b	7.54 b	5.52 b	7.91 b	7.5 a	8.08 a	6.79 ab	6.77 a	5.16 a	7.95 a
K	48.31 bc	46.29 c	46.28 c	54.87 b	51.55 bc	64.68 a	36.19 ab	33.52 ab	31.76 ab	38.43 a	35.81 ab	30.62 b
Ca	338.96 b	401.29 ab	393.27 a	358.92 ab	352.22 ab	372.32 ab	417.56 a	423.94 a	436.33 a	399.86 a	395.49 a	433.62 a
Mg	29.07 b	43.01 a	43.97 a	41.01 a	38.48 ab	40.00	36.33 a	42.06 a	42.32 a	37.41 a	38.58 a	44.11 a

Means within columns with same letter are not significantly different (α = 0.05).

Table 11. Effect of intercropping and tillage/residue management practices on soil pH and nutrient content (kg/ha). Average over depths.

Crop Treat-ment	pH_{water}			N			P			K			Ca			Mg		
	CT	NTC	NTB	CT	NTC	NTB	CT	NTC	NTB	CT	NTC	NTB	CT	NTC	NTB	CT	NTC	NTB
									1991									
SF	5.99a	6.1b	5.9ab	0.09a	0.07a	0.08a	10.8a	7.6a	7.3b	100a	32d	77bc	587a	567a	517bc	79.7a	92.6a	79.2ab
S	5.83a	5.95c	6.00a	0.08a	0.08a	0.09a	8.0a	8.0a	8.8a	66c	29d	70c	473b	550a	608a	74.3a	85.5a	80.3ab
SG	5.97a	6.13ab	5.39b	0.09a	0.08a	0.08a	8.2a	8.9a	8.1b	89ab	79ab	90ab	530ab	556a	486c	85.2a	87.2a	78.1ab
G	5.82a	5.95c	6.14a	0.07a	0.09a	0.07a	7.4a	8.0a	10.6b	81abc	86ab	79bc	473ab	536a	595ab	74.7a	80.9a	87.8a
SV	6.02a	5.85c	5.94ab	0.09a	0.09a	0.08a	9.1a	9.5a	8.9b	70bc	78a	75bc	586a	567a	513c	78.8a	86.5a	74.1b
V	6.09a	6.28a	5.94ab	0.07a	0.08a	0.08a	8.7a	7.4a	13.1ab	73b	78b	97a	573a	604a	561abc	82.4a	73.7a	83.3ab
									1992									
SF	5.87a	6.05b	5.77a	0.05a	0.05a	0.15a	7.4a	5.0a	5.5ab	51a	38bc	25b	357a	368ab	316b	36.9b	43.0bc	31.2c
S	6.00a	6.32a	5.92a	0.05a	0.05a	0.04b	3.1b	3.3b	8.2a	36c	37bc	28b	373a	401a	366ab	44.5a	48.3ab	41.2ab
SG	5.94a	6.11b	5.84a	0.05a	0.05a	0.05ab	4.4ab	3.2b	5.1ab	35c	33c	29b	347b	361ab	344ab	44.5a	50.3a	40.3b
G	5.67b	5.82c	5.89a	0.05a	0.05a	0.05ab	4.4b	4.3ab	4.4ab	37bc	42ab	37a	340ab	327b	348ab	41.3ab	40.8c	40.3ab
SV	5.82a	5.99b	5.86a	0.05a	0.06a	0.05ab	2.8b	4.2ab	2.8b	35c	35bc	28b	308b	362ab	369ab	40.8c	45.6abc	43.8ab
V	5.82a	6.12b	5.92a	0.05a	0.05a	0.05ab	4.7ab	3.1b	6.2ab	41b	50a	37a	332ab	359ab	391a	38.3ab	47.2abc	47.8a

\- Means with columns with same letter are not significantly different (α = 0.01).

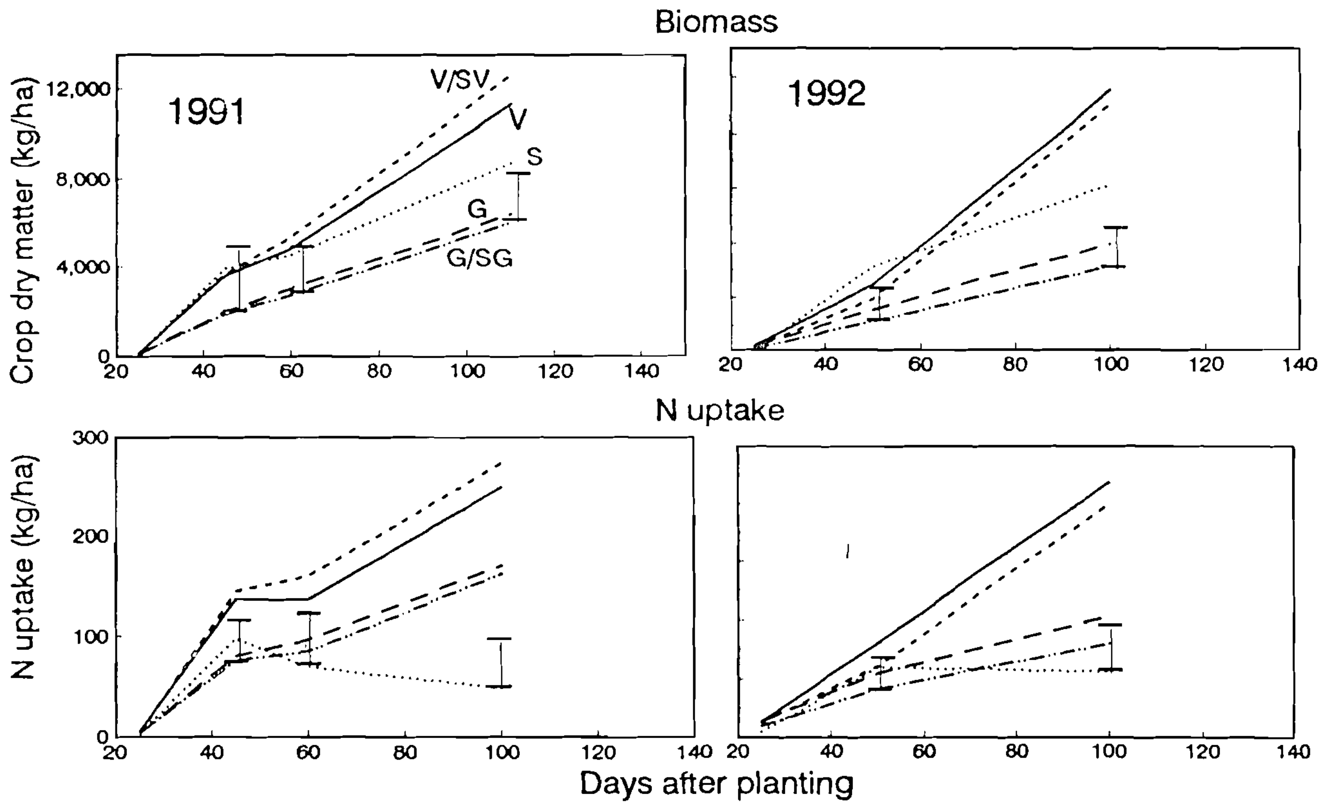

Figure 1: Effect of intercropping on plant biomass production and N uptake.
Error bars indicate LSD(0.05).

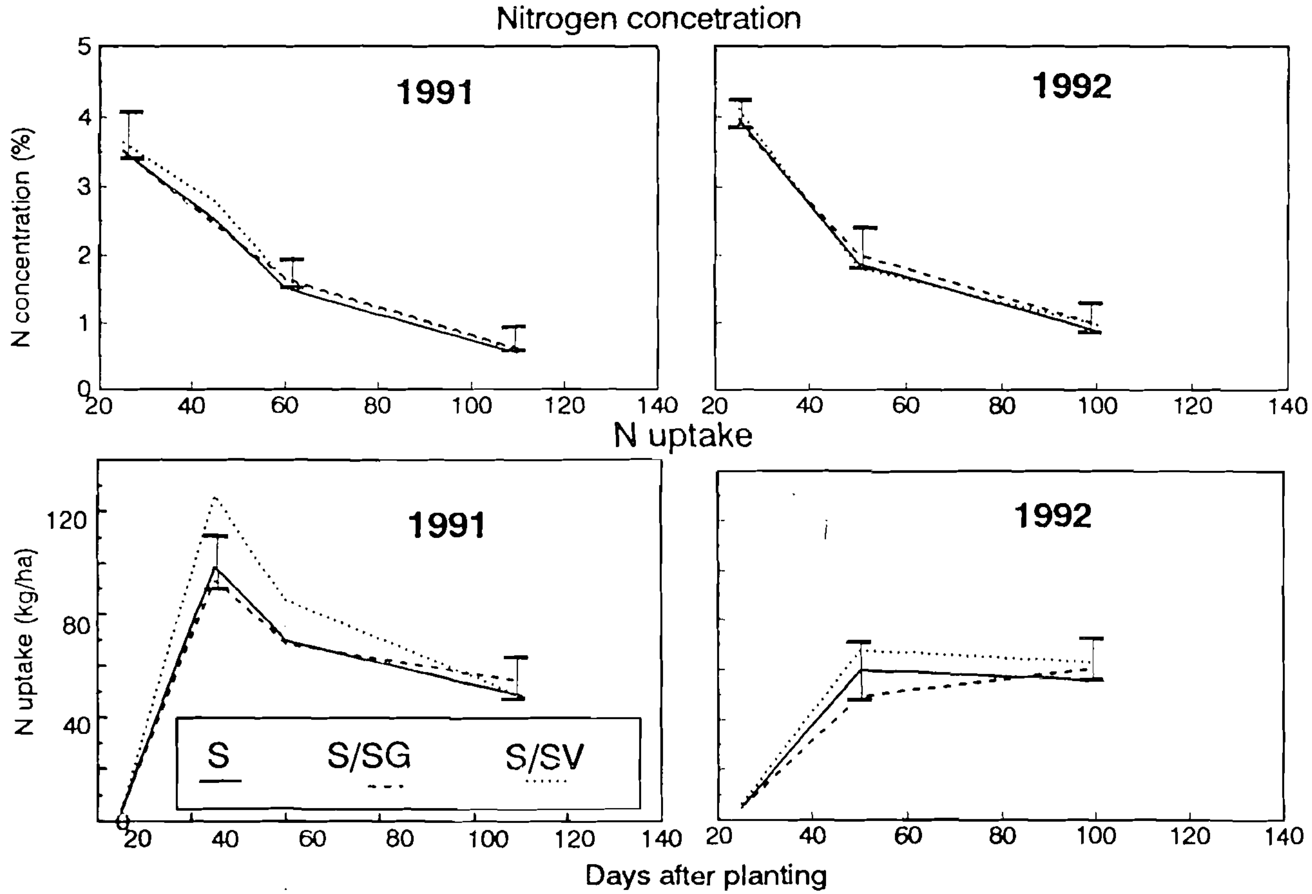

Figure 2: Effect of intercropping on sorghum N concentration and uptake
Error bars indicate LSD(0.05).

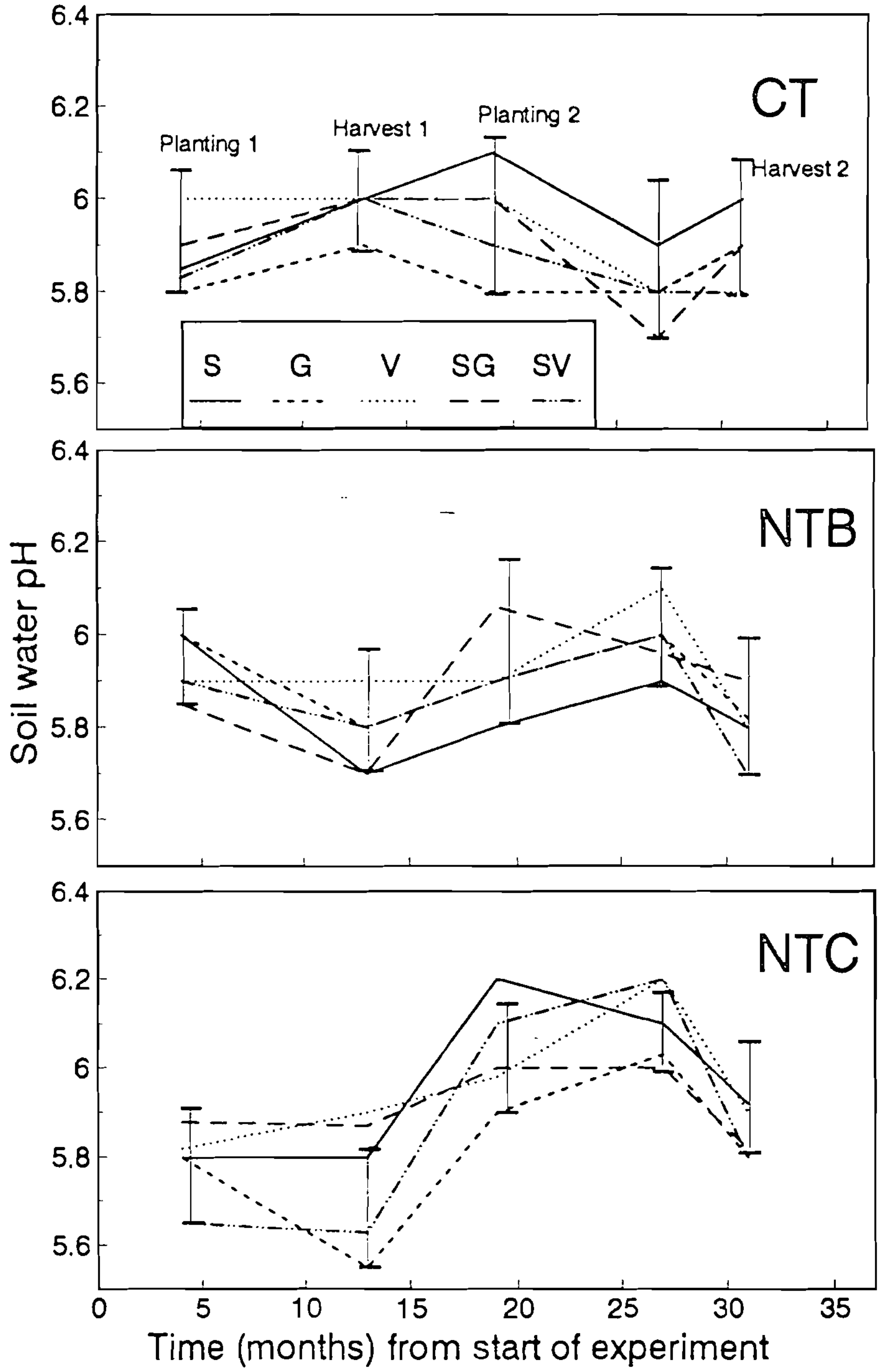

Figure 6: Effect of intercropping and tillage/residue management on soil water pH in the top 7.5 cm soil depth. Error bars indicate LSD(0.05).

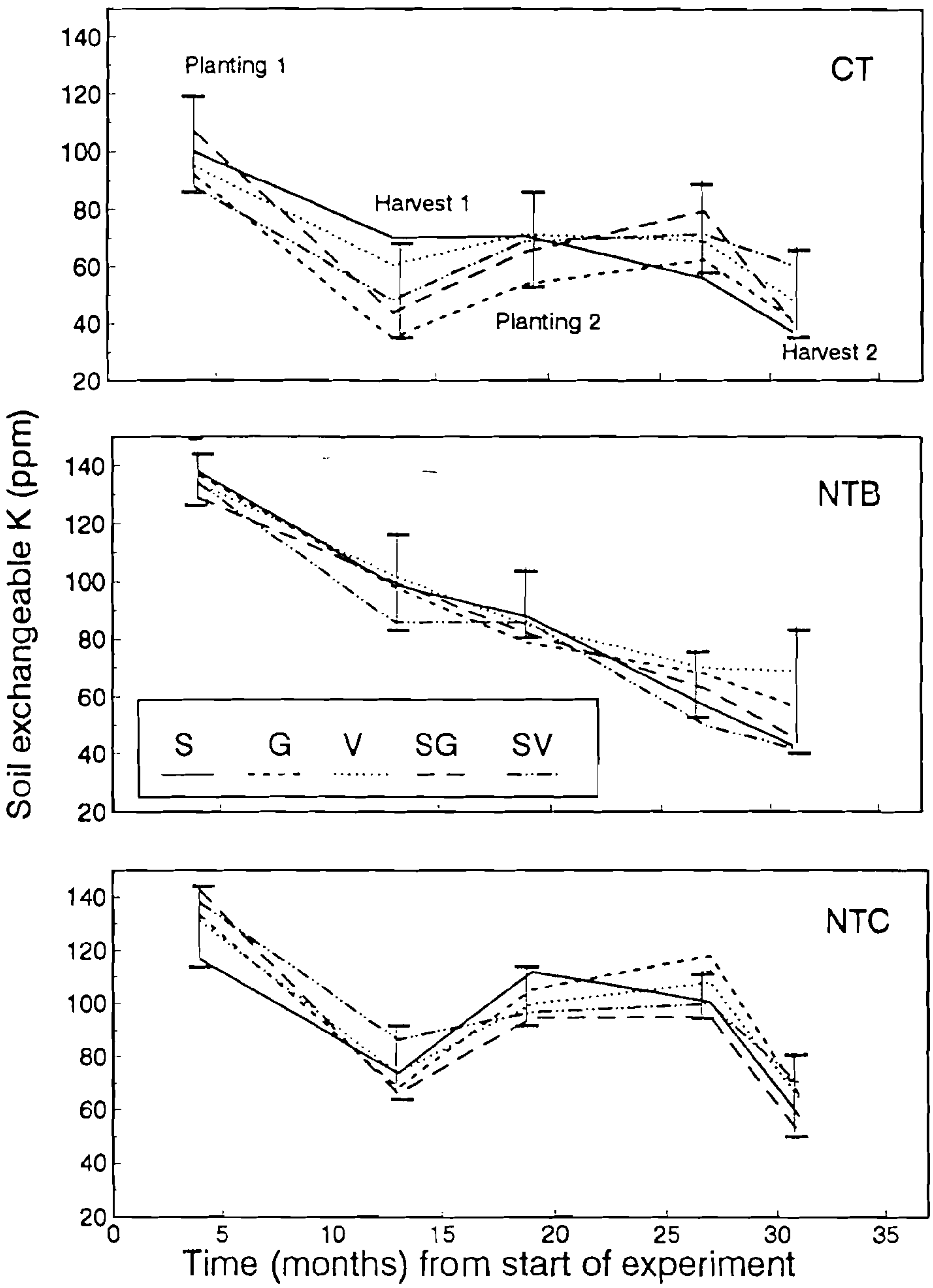

Figure 5: Effect of intercropping and tillage/residue management on soil extractable K level in the top 7.5 cm soil depth.
Error bars indicate LSD(0.05).

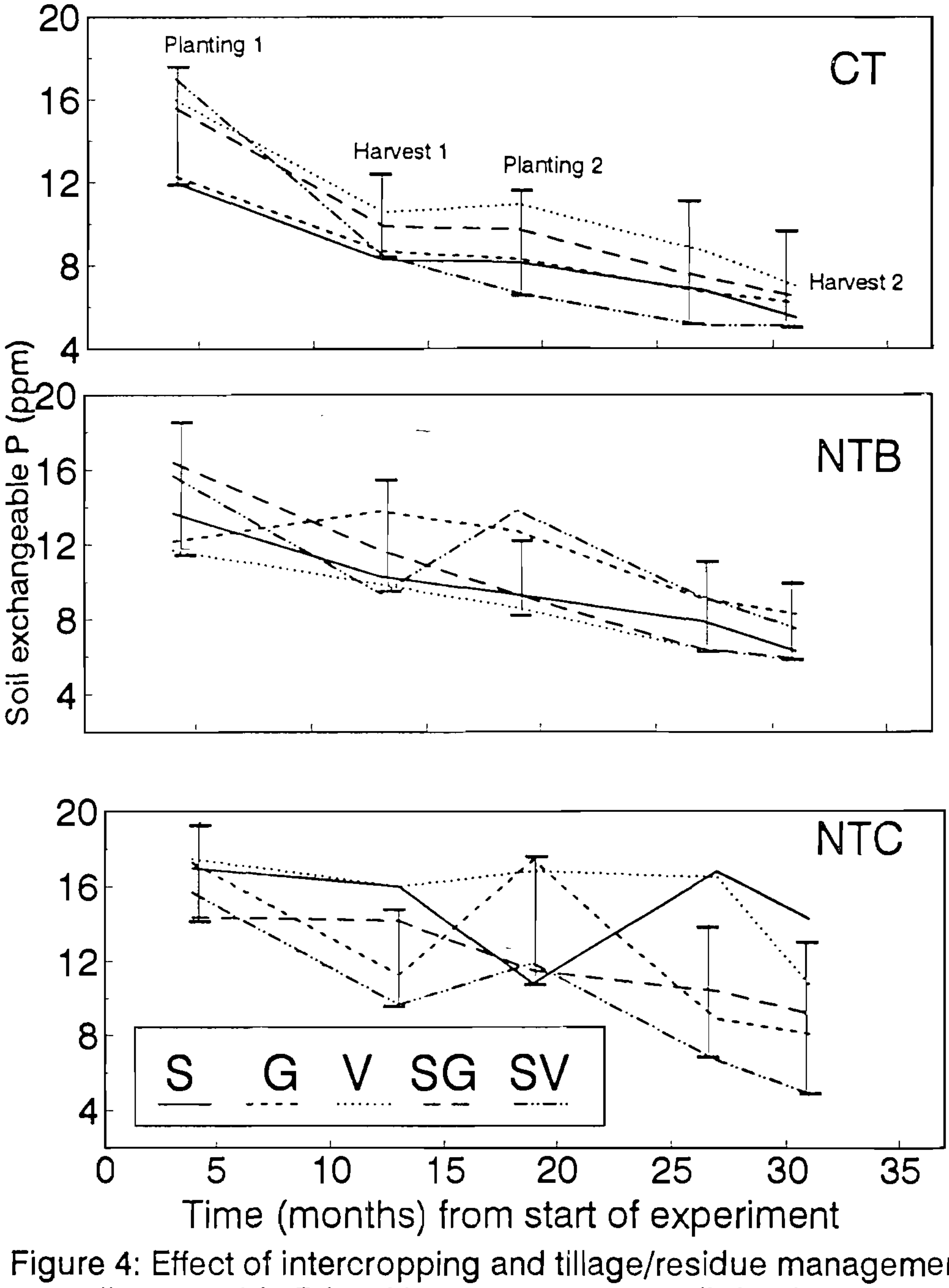

Figure 4: Effect of intercropping and tillage/residue management on soil extractable P level in the top 7.5 cm soil depth. Error bars represent LSD(0.05).

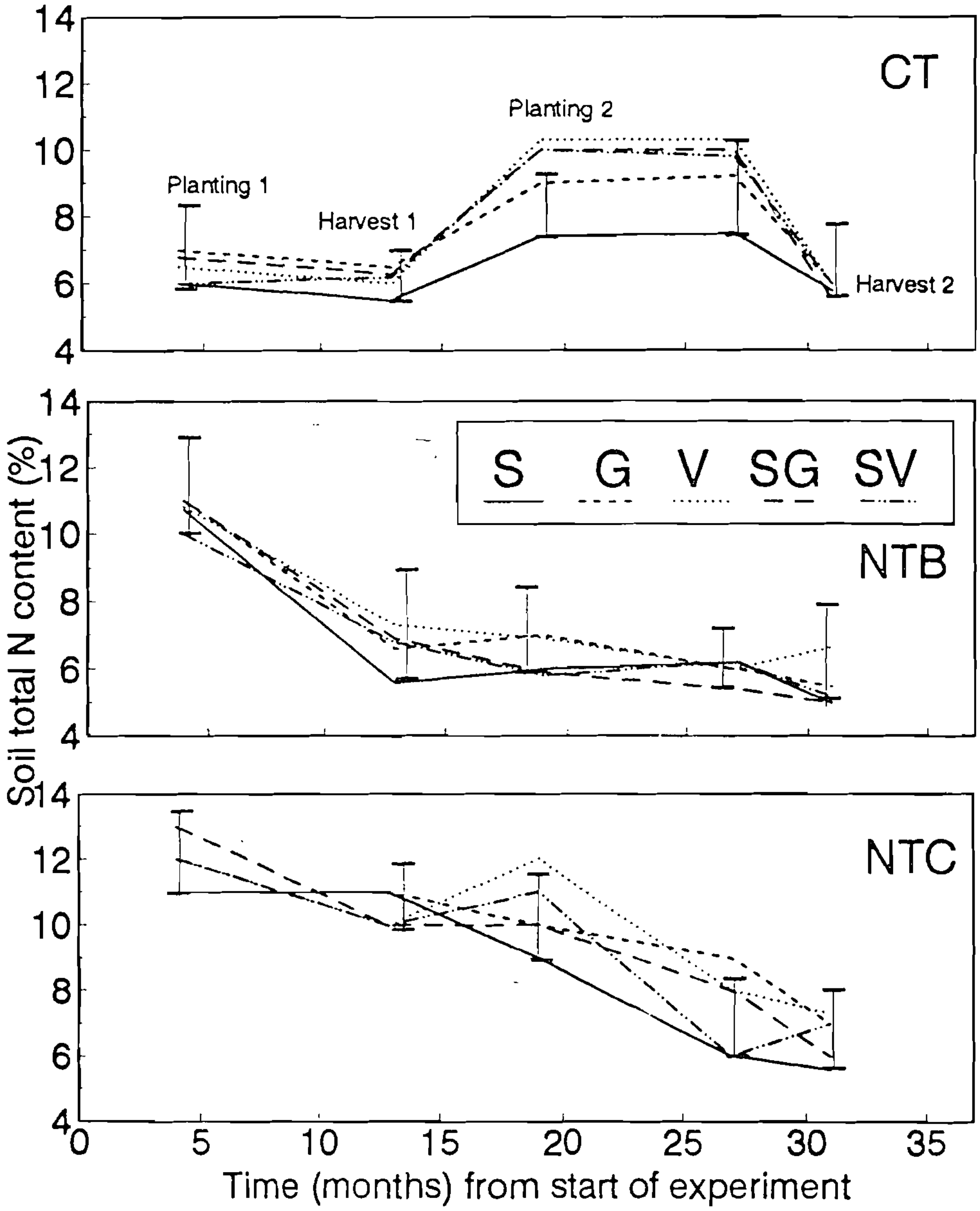

Figure 3: Effect of intercropping and tillage/residue management on soil total N level in the top 7.5 cm soil depth.
Error bars indicate LSD(0.05).

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CHAPTER 6

CONCLUSIONS

Grain sorghum [Sorghum bicolor (L.) Moench,cv. "Pioneer 8230"] was intercropped with peanut [Arachis hypogaea L., cv. "Southern Runner"] or velvet bean [Stizolobium deeringianum Bort, vc. "Early Speckled Velvet Bean"] under conventional tillage (CT), no-tillage with residue cover (NTC) or no-tillage bare (NTB) in 1991 and 1992 to examine the effect of intercropping and tillage/residue management practices on plant root growth, biomass and yield production, soil water content and soil chemical properties.

Results from this study further confirmed the effect of tillage/residue management on crop root growth. Root length density (RLD) and root dry weight (RDW) were higher in NTC and NTB than in CT, and this was largely attributed to higher soil moisture content. All crop treatments produced significantly more roots in the top 10 cm depth than deeper. In the CT, however, a greater proportion of the total root population was observed in the 20-30 cm soil depth as compared to the NTC and NTB. Sorghum produced more roots followed by velvet bean and peanut. Intercropping resulted in intermediary root proliferation between component sole crops, and tended to favore sorghum over the legumes. Root growth was greater in 1992 than in 1991, despite the reduced rainfall in 1992, and this was attributed to possible stimulative effect of the water shortage and changes in soil fertility over time. The ratio of the RDW to the RLD suggested that finer roots were produced in 1992 compared to 1991.

The measurement of soil water content by time domain reflectrometry clearly confirmed the moisture disadvantage of conventional tillage over no-tillage systems. Crop residue removal from no-tillage plots resulted in insignificantly less soil water content than otherwise. These differences corroborate the water infiltration measurements. Reduced soil water content in mixtures suggested a greater soil exploration and a more thorough water use by intercrops when compared to sorghum monocrop. Increased competition for water between sorghum and either legume in the mixtures appeared to occur at 45-60 cm soil depth.

In general, plant biomass production, nutrient uptake and grain yield drastically decreased in the second year of the experiment as a result of unfavorable rainfall distribution, late planting and reduced soil nutrient content. On the average, CT favored plant biomass production, nutrient uptake and yield in 1991 where rainfall distribution was satisfactory. NTC was advantageous under the drier conditions during the 1992 growing season. Although NTB differed little from NTC, soil nutrient content and pH in NTB suggested that residue removal may lead to long-term soil infertility. Velvet bean biomass production and nitrogen yield were interestingly high, encouraging the use of this crop for improving soil properties. In general, intercropping improved the residue quality and provided an overall yield advantage over monocultures.

Despite the differences between years, most treatment comparisons were unaffected. In general, interactions between intercropping and tillage/residue management systems were significant and complex, suggesting a careful selection of intercrops and soil management systems for satisfactory crop production.