SOD BASED ROTATIONS-THE NEXT STEP AFTER CONSERVATION TILLAGE

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ABSTRACT

Conservation tillage techniques have been worked out over the past 30 years for the agronomic crops currently grown in the U.S. Many scientists have shown the value of conservation tillage on different aspects of crop production including economics, soil and water quality, and the environment. The advent of genetic technology for corn, soybean, and cotton increased the transition from conventional tillage (plow, harrow, etc.) to various forms of conservation tillage. This has allowed farmers to farm more land by allowing them to use broadcast sprayers where row tillage or directed sprays were done before. While conservation tillage has resulted in many benefits, farmers still struggle since yields have not necessarily increased by to converting to minimum tillage. There is a next step in increasing yields. Years of research in the southeast have shown that perennial grasses such as bahiagrass can help improve soil structure and reduce pests such as nematodes and increase crop yields, sometimes dramatically. Research in the southeast with perennial grasses grown in rotation with crops has shown higher yields (50% higher peanut yields than under conventional annual cropping systems), increased infiltration rates (more than 5 times faster), higher earthworm numbers (thousands per acre vs. none in some cases), and a more economically viable (potential 3-5 times more profit) cropping system. Diversification into livestock can add another dimension to the farming system making it more intensive and offer risk aversion benefits as well as provide a readily available use for perennial grasses. Verification of this concept is underway and is being moved onto farms.

INTRODUCTION

Conservation tillage has been widely accepted across the U.S. as a way to increase soil organic matter, one of the keys to productive soils, while enhancing water holding capacity, and reducing erosion, fuel and labor use. Sod based rotations should be coupled with conservation tillage for maximum benefits using integrated pest management and genetic technology (Reeves, 1997). The development of precision planters, subsoilers, and varieties resistant to herbicides and insects has enabled widespread adoption of conservation tillage practices in many farming systems. Conservation tillage techniques are still not widely used for peanut production and have had a slower adoption rate than for most of the row crops (CTIC, 1994). Even where conservation tillage has been widely adopted, yields of cotton and peanut have been stagnant for the last 20 or more years with spikes occurring when weather conditions are favorable. Conversion of crop land to perennial grasses in rotation with annual crops provides great potential to mitigate these problems. The native perennials protect the soil from erosion while increasing soil organic matter (SOM). Research efforts have shown several practices that lead to increased SOM or at least slower degradation. These practices include: including perennial grass and legume production in rotation or permanent pastures, manure or other organic additions, year round cover crops, return of high levels of plant residues, crop diversity, reduced tillage, use of stress resistant crops or varieties, and application of needed mineral fertilizer to promote higher yields and increased biomass production. The ultimate goal of agriculture is to be economically profitable while conserving and even enhancing natural resources for future generations. Seldom have all of these practices been used over wide areas. Increased SOM would have a major impact on agriculture by increasing soil fertility, improving water relations and soil structure, and eventually increase productivity and return higher rates of organic matter to the soil. Recent farm programs (Conservation Reserve Program) in the U.S. has led the effort to convert some of these cropped areas and once native grass areas back into perennial grasslands and forests. Diversified farming will become more common in the future which will mean more perennial grasses in rotation with annual crops allowing farmers to maintain or enhance quality of the soil resulting in long term sustainability of SOM and economic viability.

A wide range of grasses have been used for grazing and improving soil structure under different soil conditions. These include drought and salt tolerant wheatgrass (*Agropyron spp*.), flood tolerant reed canarygrass (*Phyalaris spp*.). Adapted perennial grasses generally develop a deep rooting system which can improve soil conditions. Pavlychenko (1942) noted that native grasses such as porcupine grass (*Stipa spartea Trin*) and blue grama (*Bouteloua gracilis*) were most effective in improving soil structure at depths of 60 cm as compared to creasted wheatgrass. In the Southeast, much of the farmland suffers from a natural compaction layer starting at 15-20 cm depth and continuing to 30 cm (Kashirad et al., 1967). This results in a shallow root system which confines root development to a small soil volume which is a small reservoir for both water and nutrients and consequently has dramatic effects on crop management and yield. The shallow rooted crops are susceptible to short periods of moisture stress under the sandy conditions typical of the southeast. Perennial grasses such as bahiagrass and Bermuda grass, which are adapted to the southeast, develop a deep root system which penetrates through the compaction layer (Elkins et al., 1977). When the roots die, they decay and leave root channels which positively impacts soil structure, water infiltration and available water (Elkins et al. 1977; Wright et al., 2004). Long and Elkins (1983) compared cotton following 3 years of bahiagrass sod with continuous cotton. They found a seven fold increase in pore sizes greater than 1.0 mm in the dense soil layer below the plow depth. They concluded that the dense soil layer had been penetrated by the bahiagrass roots and that, after the decay of the roots, pores were left that were large enough for the cotton roots to grow through. Perennial grasses can reduce the need for irrigation in the following crop. Elkins et al. (1977) calculated that given an evapotranspiration rate of 0.45 cm of water per day, available water of 2.54 cm per 30 cm of soil, and plant rooting depth of 15 cm, plants will experience water stress after 3 days without rainfall. However, if the rooting depth is 152 cm, the plant would not experience water stress for 30 days without rainfall.

The Southeast is one of the most diverse crop production areas in the U.S. and has a climate that is conducive to multi-cropping. All of the major crops as well as pasture grasses can be grown. Native vegetation was initially hardwood and pine forest with grass encroachment in cleared areas. As these small patches of bluestem and switch grass were overgrazed, they were replaced with broomsedge and other less desirable grasses. Continuous row cropping has continued to degrade these soils. It is known that rotation with perennial sod crops will increase soil carbon, water infiltration, improve soil structure, and decrease erosion to a higher level than the winter annual cover crops which have been shown to be better than summer annuals. Winter annual cover crops do not do much to enhance soil quality because of their short duration and fast degradation. Living roots have a tremendous impact on soil quality with annual crops only having active roots for about 3 to 4 months each year. Much of the research in the 20th century has looked at cover crops as green manure crops to be turned under for nitrogen benefit or nematode suppression. Perennial grasses all over the world have been shown to have a major impact on yield. Florida farmers will testify that peanut, watermelon, and soybean will all yield substantially higher after bahiagrass. Cooper and Morris, 1973, put it in context when they described a wheat- sod based rotation by saying that the primary function of sod is to put "heart back into the land". Virginia research showed that winter annual cover crops did not contribute to improved water holding capacity while perennial grasses did. Agriculture has a history of depletion of SOM and subsequent loss of soil fertility and productivity as a result of poor management. At times this is a result of lack of knowledge about agricultural practices or a lack of proper resources to maintain productivity. Farmers are often financially strapped to the point of maximizing short term productivity at the expense of long term productivity. There are often other factors such as environmental conditions, marginal soils or marginal crops that result in minimum income resulting in growers doing the minimum to continue farming at the expense of long term productivity. Extensive cultivation done throughout the Corn Belt, Great Plains, and the Southeast Cotton Belt of the U.S. over the past 150 years resulted in loss of high amounts of SOM, soil nitrogen, and influenced atmospheric CO_2 levels as well as resulting in abandonment of large areas due to erosion. Cultivation and cropping resulted in losing ¼ to ¾ of the SOM that was present 100 years ago as seen from long term plots (Magruder, Sanborn, and Morrow plots). Many of these long term fertility sites had a rapid decrease in SOM until the 1940's and 50's when fertilizer use started to become a normal practice resulting in more biomass being produced and returned to the soil. Data from Georgia shows that SOM may be increased when put back into perennial crops but is degraded more rapidly. Soil quality is of major concern to the farming community while SOM or carbon sequestration concerns both agricultural and environmental scientists. A model (Imhoff et. al, 1990) currently in use for SOM by EPA and Natural Resource Conservation Service's Natural Resources Inventory shows a decline between 1910 and 1950 to about one half the original levels. This model predicted some stability until about 1970 and predicted an increase in the next 30 years due to a higher cropping intensity and use of commercial fertilizer. Other reasons for a predicted increase in SOM are government programs that have promoted grass set aside of crop land and economic benefits of conservation tillage. The economic conditions of rising labor and fuel costs are expected to continue indefinitely. Growing continuous annual crops not only results in a decrease of SOM but in a buildup of nematodes and diseases (Dickson and Hewlett, 1989), a depletion of certain nutrients, less organic material left in the soil as compared to perennial crops, and compaction of the soil so roots cannot explore large areas for water and nutrients. Rotation is always at the top of the list as an important component of producing crops profitably (Edwards et. al., 1988). It is generally known that legumes will add nitrogen to the soil and improve soil health.

However, legumes contribute little to the long-term build up of organic matter and soil structure because of the rapid break down of the plant material and the flush of nitrogen available for plant growth (Frye et. al.1985). The U.S. Geological Survey has reported that 63% of North America that was previously in native grasslands is now cultivated. The reason for this is that most of these soils were highly productive and high in SOM when initially cultivated and many of these remain highly productive with ½ as much SOM as they started out with. Temperate grasslands have been estimated to contain 18% of the global SOM reserves (Atjay et al., 1979). This large storage of SOM is attributed to low decomposition rates relative to net production. Perennial grasses contribute little to the immediately available nitrogen pool, but add significantly to the organic base and long-term nitrogen pool as well as well as helping reduce pests normally found in annual grass or legume crops (Boman et.al., 1996, Elkins et. al. 1977). Annual ryegrass has been shown to contribute 3 to 4 times as much organic matter to the soil from its roots as crimson clover or vetch (McVickar, et.al.,1946). The nitrogen concentration of ryegrass roots is 1/3 to ½ that of legumes and yet ryegrass contributes more total nitrogen to the soil because it has considerably more root mass in the soil than any of the legumes. Likewise, animal manure and composts are more effective in building SOM than harvest residue, which is more effective than fresh plant material such as green manure crops. Paustian et al., 1992 showed that when the same rate of residue was added from 4 sources of organic material to the soil, soil organic carbon (SOC) was increased most by peat followed by manure, and then straw which contributed 3 times more SOC to the soil than alfalfa, which degrades rapidly. Likewise, relative soil carbon is 20-40% higher with grass/forage in a rotation as compared to continuous corn or soybean in rotation with corn. Areas with long growing seasons can have two to three crops planted each year adding to the organic matter base of the soil (Wright, et. al., 1998). However, continuous cropping of either annual grass or legume crops can result in nematode or disease build up to damaging levels as well as decreasing SOM. Hagan, et.al.,1995, noted that bahiagrass and to some degree, bermuda grass is resistant to all of the major nematodes of row crops in the Southeast and can contribute significantly to pest control and increased yields. Benefits of sod prior to row crop production can result in dramatic increases in yield at a lower cost of production with less pesticide use and less negative environmental impact than trying to alter all of these factors with chemicals and tillage tools. Water in the soil profile is conserved and utilized by the crops, since rooting depth is often 10 times deeper following bahia, or bermuda, as in conventional cropping systems, reducing irrigation needs from normal applications of about 30 cm of irrigation per year to as little as 5 cm with similar or higher yields. This could result in as little as 1/10 th the current water use for irrigation, alleviating some of the water problems for annual crops.

EXPERIMENTAL PROCEDURES

The multi-state project was has been underway since 2000 in Florida and 2001 in Alabama and Georgia to examine the influence of 2 years of bahiagrass on peanut and cotton as compared to a cotton/peanut rotation. The site at Marianna, FL was under a pivot and has a cow-calf operation in rotation with peanut and cotton and winter grazing after annual crops, while the large site at Headland has stocker cattle on winter grazing after peanut and cotton with the bahiagrass being used for hay in the stocker operation.

Small plots at Quincy, Headland, and Tifton utilized the grass as hay and the winter cover crop for planting the next crop into. Data collected has included water infiltration, soil carbon, soil fertility, bulk density, weed population, earthworm numbers, penetrometer measurements, soil moisture measurements, yields and grades of crops and various other measurements. The first four year cycle of this system was completed in small plots at Quincy in 2004 with data summarized over years and locations. The basic design of the study is shown below:

	Year 1		**Year 2**		**Year 3**		**Year 4**	
Field	Spring	Winter	Spring	Winter	Spring	Winter	Spring	Winter
1	Cotton	Wheat	Peanut	Wheat	Cotton	Wheat	Bahia	Bahia
2	Bahia	Bahia	Bahia	Bahia	Peanut	Wheat	Cotton	Wheat
3	Peanut	Wheat	Cotton	Wheat	Bahia	Bahia	Bahia	Bahia
4	Cotton	Wheat	Bahia	Bahia	Bahia	Bahia	Peanut	Wheat

RESULTS

The results obtained from the study have shown good advantages to the sod based system. Including bahiagrass in the cotton/peanut cropping system increases soil water infiltration rates in both the peanut and cotton phases of the cropping system. Higher infiltration rates reduce runoff and soil erosion and subsequently increase soil water content resulting in less plant stress. The bahiagrass rotation retained more soil moisture as compared to conventional cotton during both the 2003 and 2004 growing season. The increased moisture levels in the bahiagrass rotation were partially attributed to the increased infiltration rates observed in cotton after bahiagrass. Table 1 below shows the influence of the sodbased rotation on peanut with a 30-50% increase in peanut yield in 2003 and 2004 when the system was fully implemented. Bahiagrass was planted late the first year and did not have the advantage of 2 full years of bahiagrass.

Table 1. Peanut yields in a bahiagrass vs. a conventional Cotton/peanut rotation using conservation tillage techniques for both systems.

	2002		2003		2004		Mean	
	Irrigated	Non Irrigated	Irrigated	Non Irrigated	Irrigated	Non Irrigated	Irrigated	Non Irrigated
			(kg ha-1)					
B-B-P-C	3245a	3360a	2829 a	2737 a	3277 a	3287 a	3117a	3128a
C-P-C-C	3300a	3015b	2198 b	1719 b	2245 b	2584 b	2581b	2439b

* Means in columns followed by the same lower case letter are not significantly different.

Soil water nitrates were determined at the 15- and 30-cm depth in the conventional and bahiagrass rotated cotton. The cotton in the bahiagrass rotation had less soil water nitrate at both depths throughout the growing season. Bahiagrass has deep roots which penetrate through the compaction layer. When the grass dies, the roots decay, leaving root channels. Cotton may have exploited the channels and developed a more extensive rooting system, which utilize more N across a wider soil profile. Higher root biomass, root area and root length were observed in the bahiagrass rotated cotton. As with soil nitrate, the bahiagrass rotation had less ammonium nitrogen compared to the conventional cotton. Higher levels of N above the EPA recommended level have been reported in ground water in most states of the US. High levels of N in ground water are also responsible for algae blooms in fresh water bodies. Hence rotations which reduce N levels can be a good way to protect the environment.

Cotton in the bahiagrass rotation had less residual nutrients including P, Mg and B at the end of the season. The vigorously growing cotton in the bahiagrass rotation utilized more nutrients, leaving less residual nutrients being susceptible to leaching and erosion. However, the bahiagrass rotation had higher levels of both soil nitrate and ammonium at the end of the season. When the cotton roots died the decaying roots would have mineralized and released the NO3 and NH4. This would have resulted in more N being released from the bahiagrass rotation because it had the larger biomass. A solution to this would be to keep the land under crop cover, so that the residual soil N would be utilized. Cotton yields were significantly higher in 2002 and 2004 in the bahiagrass rotation (Table 2). All of the growth parameters were higher in cotton grown after peanuts in the bahiagrass system and yields were significantly higher 2 out of the 3 years.

Table 2. Cotton yields in bahia rotated vs. conventional rotations using conservation tillage techniques.

	2002	**2003**	**2004**	**Mean**
		Lint (kg ha^{-1})		
B-B-P-C	2317 a	1878	1979 a	2058
C-P-*C*-C	1613 b	2099	1829 b	1847
C-P-C-*C*	-	1934	1884 ab	1909

*Means in columns followed by the same letter are not significantly different

Earthworms were more numerous in sodbased rotated cotton by many folds in some cases. Earthworms are known to increase infiltration rates, aeration, soil nutrient cycling and help achieve good soil crumb structure. The higher organic matter and associated higher soil moisture in the bahiagrass rotation may have caused the increase in earthworm densities.

The bahiagrass rotated soils had less soil mechanical resistance compared to both cotton and peanuts in the conventional plots. High mechanical resistance impedes root growth and subsequently reduces cotton grade and yield. Higher mechanical resistance also retards water movement through the soil profile, thereby increasing the chances of water as runoff.

Soil from cotton in the bahiagrass rotation had lower bulk density compared to soil in conventional cotton. Bulk density is defined as the mass (weight) of a unit volume of soil.

Bulk density takes into consideration total pore space and is an indicator of porosity, infiltration and compaction.

Cotton grown after bahiagrass has improved yield component parameters including plant height, plant biomass and LAI in both 2003 and 2004. The cotton in the bahiagrass rotation was taller than cotton in the conventional system and had greater above ground biomass compared to conventional cotton. The taller plants in the bahiagrass rotated cotton also had greater total root length and root area. The more extensive rooting system in the bahiagrass rotation was able to utilize more soil nutrients across a larger volume of soil and in the process recycle nutrients from deeper soil depths. These nutrients would otherwise have been lost from the nutrient cycle.

Cotton in the bahiagrass rotation had higher LAI compared to the conventional cotton. The more developed plant canopy was able to effectively shade the weeds rendering them less competitive to the cotton. The reduced weed pressure in the bahiagrass rotated cotton will mean less herbicide application, thus reduce herbicides costs for the growers and also reduces, the potential for pesticide contamination to the environment. Bahiagrass contributed to the positive aspects of a health soil which in turn resulted in healthier and more vigorously growing plants which were better able to withstand stress conditions.

When combined over years, peanuts in the bahiagrass rotation had higher yields compared to the conventional peanuts at Quincy. Peanuts in the bahiagrass rotation are likely to have benefited from the positive soil health parameters following the bahiagrass, as described above. At Headland, peanuts in the conventional rotational had higher yield compared to the peanuts grown immediately after bahiagrass.

The beef industry has been doing well for the last several years. Forages are the backbone of the industry and the cheapest source of feed for livestock. Including bahiagrass in the traditional peanut/cotton cropping peanut increases the overall acreage of forage and provides risk aversion for that part of the farming operation that is then excluded from growing cash crops. Perennial grasses including bahiagrass can be produced at lower production costs compared to annual forages and row crops. Including bahiagrass in the traditional peanut/cotton cropping system will conserve and protect land from potential degradation. Perennial grasses protect land from erosion and help build up organic matter levels and increase water availability to following crops.

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