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Crop and cattle production responses to tillage and cover crop management in an integrated crop–livestock system in the southeastern USA

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ABSTRACT

Integrated crop–livestock systems can help achieve greater environmental quality from disparate crop and livestock systems by recycling nutrients and taking advantage of synergies between systems. We investigated crop and animal production responses in integrated crop–livestock systems with two types of winter cover cropping (legume-derived N and inorganic fertilizer N), two types of tillage [conventional disk (CT) and no tillage (NT)], and whether cover crops were grazed by cow/calf pairs or not. The 13-ha field study was a modification of a previous factorial experiment with four replications on Ultisols in Georgia, USA. Recurring summer drought severely limited corn and soybean production during all three years. Type of cover crop had little influence and grazing of cover crops had minor influence on crop production characteristics. Cattle gain from grazing of winter cover crops added a stable component to production. No-tillage management had large positive effects on corn grain (95 vs. 252 g m^{-2} under CT and NT, respectively) and stover (305 vs. 385 g m^{-2}) production, as well as on soybean grain (147 vs. 219 g m^{-2}) and stover (253 vs. 375 g m^{-2}) production, but little overall effect on winter wheat grain (292 g m^{-2}) and stover (401 g m^{-2}) production. Our results suggest that robust, diversified crop–livestock systems can be developed for impoverished soils of the southeastern USA, especially when managed under no tillage to control environmental quality and improve resistance of crops to drought.

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1. Introduction

Contemporary, industrialized agricultural systems typically rely on simplification of the production environment to control undesired influences so that consistently high production can be achieved. Such an approach has led many to question the long-term sustainability of this domination (Kirschenmann, 2007; Ikerd, 2009). Valid environmental concerns can be levied against such simplification – poor nutrient recovery, water pollution, soil quality deterioration, accelerated emission of potent greenhouse gases, loss of biodiversity, etc. (Franzluebbers, 2007; Russelle et al., 2007).

A committee on 21st century agricultural systems concluded that "...if U.S. agricultural production is to meet the challenge of maintaining long-term adequacy of food, fiber, feed, and biofuels under scarce or declining resources and under challenges posed by climate change and to minimize negative outcomes, agricultural production will have to substantially accelerate progress toward the four sustainability goals. Such acceleration needs to be undergirded by research and policy evolution that are designed to reduce tradeoffs and enhance synergies between the four goals and to manage risks and uncertainties associated with their pursuit" (NRC, 2010). The four goals outlined by NRC (2010) were: (1) satisfy human food, feed, and fiber needs, and contribute to biofuel needs, (2) enhance environmental quality and the resource base, (3) sustain the economic viability of agriculture, and (4) enhance the quality of life for farmers, farm workers, and society as a whole. One of the recommendations of NRC (2010) was to implement a transformative approach toward agricultural research, such as "identifying and researching the potential of new forms of production systems that represent a dramatic departure from (rather than incremental improvement of) the dominant systems of present-day American agriculture". Integrated crop–livestock systems that rely on the synergies between crop and animal production systems, but that may create limitations to optimize either system fully are one such approach toward transformation of agriculture.

The southeastern USA region has typically poor soils (highly weathered Ultisols with mineralogical features not ideal for water

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Table 1
History of experimental manipulations of the field site near Watkinsville, GA, USA.

Characteristic	Year of evaluation		
	1982–2002	2002–2005	2005–2008
Experimental emphasis	Tall fescue genetics and fertilization	Integrated crop–livestock (summer vs. winter)	Integrated crop–livestock (low vs. high N)
Treatments	K31 + LF + LN (Plots 2-11-17)	CT + SGWC (Plots 4-6-11-18)	CT + CC/C-W/S + Low (Plots 4-8-11-13)
	K31 + LF + HN (Plots 5-10-18)	NT + SGWC (Plots 1-10-16-17)	NT + CC/C-W/S + Low (Plots 1-7-15-16)
	K31 + HF + LN (Plots 4-7-13)	CT + WGSC (Plots 5-8-12-13)	CT + CC/C-W/S + High (Plots 5-6-12-18)
	K31 + HF + HN (Plots 1-8-15)	NT + WGSC (Plots 2-7-9-15)	NT + CC/C-W/S + High (Plots 2-9-10-17)
	J + LF + LN (Plots 3-12-16)	Perennial pasture (Plots 3-14)	Perennial pasture (Plots 3-14)
	AUT + LF + LN (Plots 6-9-14)		
Plot size	Each 0.7 ha	Grazed split plot 0.5 ha	Grazed split plot 0.5 ha
		Ungrazed split plot 0.2 ha	Ungrazed split plot 0.2 ha
Key reference	Belesky et al. (1988)	Franzluebbers and Stuedemann (2007)	This article

K31 is Kentucky 31 tall fescue, J is Johnstone tall fescue, AUT is Auburn University Triumph tall fescue, LF is low fungal endophyte infection, HF is high fungal endophyte infection, LN is low nitrogen rate, HN is high nitrogen rate, CT is conventional tillage, NT is no tillage, SGWC is summer grain/winter cover crop, WGSC is winter grain/summer cover crop, CC/C–W/S is cover crop/corn–wheat/soybean 2-year rotation, Low is clover/rye cover crop without N fertilizer, High is ryegrass/rye cover crop with N fertilizer.

and nutrient storage), but abundant precipitation throughout the year (Franzluebbers, 2007). Unfortunately though, excess precipitation occurs in the winter and deficit precipitation occurs in the summer, resulting in frequent occurrence of drought with high evapotranspiration demand in the summer. A widespread approach to overcoming drought in the region has been implementation of conservation-tillage management (minimal soil disturbance combined with winter cover cropping) (Edwards et al., 1988; Langdale et al., 1990; Rhoton et al., 1993; Endale et al., 2002).

Franzluebbers and Stuedemann (2007) reported on a study aimed at assessing the impact of cover crop grazing and tillage management on performance of summer and spring crops. Beneficial soil-surface organic matter characteristics were maintained with NT during the initial years of this study and were lost with CT (Franzluebbers and Stuedemann, 2008a). Soil under cover crops grazed by cattle sometimes resulted in surface compaction (Franzluebbers and Stuedemann, 2008b), and this compaction appeared to have had an occasional negative impact on summer crop yield.

Summer crops [e.g. cotton (*Gossypium hirsutum* L.), corn (*Zea mays* L.), and peanut (*Arachis hypogaea* L.)] tend to have much greater economic return potential in the region, yet suffer from drought susceptibility. Spring crops [e.g. wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), and canola (*Brassica napus* L.)] are relatively stable from year-to-year due to low evapotranspiration demand during the winter and spring, yet suffer from moderate yield potential, unattractive economic return, and poor weather conditions during harvest. Crop yields in the study by Franzluebbers and Stuedemann (2007) were often improved with no tillage (NT) compared with conventional tillage (CT), except for winter cereals, which tended to be somewhat inhibited by the lack of tillage. A review of crop yield response to NT compared with CT in the southeastern USA revealed that corn and cotton were most often positively impacted by NT, and that with increasing number of years of NT there was increasingly greater chance of greater yield with NT (Franzluebbers, 2005).

Some studies of economic and environmental benefits of integrated crop–livestock systems have been initiated in the southeastern USA (Katsvairo et al., 2006; Franzluebbers and Stuedemann, 2007), yet much more research is needed to fully understand the suite of complex interactions that can occur, not only biophysically in the field, but also socio-economically within regional landscape settings. Our general objective was to increase knowledge of how crop and livestock components interact to achieve sustainability. Specifically, we wanted to test the choice of winter cover crop (inorganic fertilization of grass mixture or low-input management of clover–grass mixture), how cover crops were managed (ungrazed or grazed), and the effect of tillage system (CT or NT) on crop and animal production characteristics in a typical 2-year crop sequence of cover crop/corn–wheat/soybean [*Glycine max* (L.) Merr.].

2. Materials and methods

The experiment was located near Watkinsville, Georgia, USA (33°62′ N, 83°25′ W) on Cecil sandy loam and sandy clay loam soils [Acrisol (FAO Taxonomy), fine, kaolinitic, thermic Typic Kanhapludults (USDA Taxonomy)] with 2–6% slope. Soil was moderate to strongly acidic (pH 5–6). Long-term mean annual temperature is 16.5 °C, precipitation is 1250 mm, and pan evaporation is 1560 mm.

The experiment conducted from 2005 to 2008 was a continuation of a field experiment managed with the same tillage and cover crop harvest treatments, but with different cropping system (Table 1). Previous experimental design was a factorial arrangement of (1) tillage (CT and NT) and (2) cropping system with four replications. These 16 main plots were split into grazed (0.5 ha) and ungrazed (0.2 ha) cover crop treatments. The experimental design from autumn 2005 to the end of summer 2008 remained the same for tillage and cover crop management, but the cropping system portion was changed to: (1) low N input via a crimson clover (*Trifolium incarnatum* L.)/rye (*Secale cereale* L.) cover crop that was unfertilized prior to corn and (2) high N input via a ryegrass (*Lolium multiflorum* Lam.)/rye cover crop that was fertilized with ~50 kg N ha^{-1} in late winter. The cropping system in both of these treatments was a 2-year rotation of cover crop/corn–wheat/soybean. In 2008 following two years of sub-performance of corn under drought conditions, we substituted pearl millet [*Pennisetum glaucum* (L.) R.Br.] for corn. In the autumn of 2008, all plots were planted to wheat to initiate another phase, but the project ended in summer 2009 due to various financial and management constraints.

Tillage systems were: (1) conventional disk tillage (CT) following harvest of each grain and cover crop and (2) no tillage (NT) with glyphosate to control weeds prior to and just after planting. Tillage treatments were initiated in May 2002 and managed consistently on the same plots throughout the experiment lifetime. Plowing to a depth of 15–20 cm with a cutting disk occurred two to several times between crops, depending on amount of residue present and with a smoothing disk (10–15 cm depth) to prepare the seedbed. Glyphosate was applied in NT to control weeds once pre- or immediately after-planting and sometimes a few weeks after emergence when using glyphosate-tolerant crops (Table 2).

Cover crop management was: (1) no grazing and allowing plants to reach early flowering prior to termination and (2) grazing with cattle to consume ~90% of available forage during a 2–5 week period once forage reached ~30 cm tall. Cover crops were stocked with cow/calf pairs in the spring of 2006, 2007, and 2008. Ungrazed