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Differences in soil carbon sequestration and soil nitrogen among forages used by the dairy industry

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ABSTRACT

Forages cover extensive areas of agricultural land in Australia, but only limited data is available on the potential of these different forages to sequester soil organic carbon (SOC) under best practice management. This study was undertaken on a brown dermosol in the warm temperate climate of Camden, Australia, over three years, to evaluate a range of perennial and annual forages for their impact on SOC and soil nitrogen (N). The C_4 perennial forages kikuyu (*Pennisetum clandestinum* Hochst. ex. Chivov.) and paspalum (*Paspalum dilatatum* Poir.) increased ($P < 0.05$) SOC by 7 g/kg from 27 g/kg initially over the three years which was equivalent to an annual increase of approximately 2.6 t C/ha. For the other forage species, the SOC did not change ($P > 0.05$). The high productivity of legumes led to high mean estimate of N fixation of up to 726 kg N ha/year over the three years. However, as most of the legume shoot production of the forage species was removed there, was a negligible increase in soil N levels. This study has shown that the choice of forage has a large impact on the amount of carbon that can be sequestered into the soil.

1. Introduction

The sequestration of atmospheric carbon dioxide into soil organic carbon (SOC) to mitigate greenhouse gas emissions may become an important farm management strategy in the future. In fact, the global SOC pool (1550 Gt) is twice as large as the atmospheric carbon pool, with the temperate and tropical grassland contribution to the global SOC pool being some 560 Gt (Franzluebbers, 2010). The SOC pool also has an important role to play in nutrient cycling, with increased SOC leading to increased cation exchange capacity, soil water holding capacity and improvements in soil structure which can reduce soil erosion (Conant et al., 2002; Franzluebbers, 2010).

The primary factors affecting SOC are climate, plant productivity, soil texture and agricultural management practices (Paul et al., 1997). Historically, the conversion of native vegetation to intensive cultivation for cropping around the world has resulted in a decline in SOC and the release of carbon into the atmosphere (Heenan et al., 2004; Lal et al., 2003). Whilst a change from conventional systems (tillage and stubble burning) to conservation tillage (no-till and stubble retention) has reduced the rate of SOC losses, it has not always led to a detectable increase in SOC over a 20 year period in Australia (Heenan et al., 2004). In contrast, pasture improvement in Australia, achieved by increased phosphorus application, has been associated with an increase in SOC (Chan et al., 2010). Likewise in the United States, permanent pastures, composed of either switchgrass (*Panicum virgatum* L.) or Bermuda grass (*Cynodon dactylon* L.) have been shown to increase SOC (Franzluebbers et al., 2001; Sanderson et al., 1999). However, in Australia there is little information available on the potential of various forage species used in the dairy industry, to sequester carbon or the possible extent of their impact down the soil profile.

After water, nitrogen (N) is usually the primary nutrient limiting plant growth. The recent international spikes in spot prices (mid 2008) of granular urea of up to US $800, was over four times the price paid a year earlier (IRM, 2010), highlighting the importance of alternative N sources for sustainable and profitable dairy production. Legume pastures, by fixing N from the atmosphere, can substantially reduce reliance on expensive N fertilisers. The amount

Abbreviations: SOC, soil organic carbon; N, nitrogen; ET_o, potential evapotranspiration.

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of N fixed from the atmosphere depends on the proportion of legume in the sward and ranges from 13 to 682 kg/N ha/year (Ledgard and Steele, 1992). The potential N fixing capacity of pure legume pastures suitable for dairy production in Australia has not been extensively documented, particularly under irrigation.

The objective of this study was to evaluate the capacity of a range of forage species to improve soil fertility under optimum and deficit irrigation regimes, relative to perennial ryegrass the dominant dairy forage in Australia, to test two hypotheses. Firstly, whether there are differences between forage species in their ability to sequester SOC. Secondly, whether legumes lead to greater increases in soil N compared to grasses and herbs.

2. Materials and methods

2.1. Site

This study was conducted on the University of Sydney farm, 'Mayfarm' at Camden (34°3′S, 150°39′E), New South Wales, Australia, from September 2003 to December 2006. The site was on an alluvial soil (Brown Dermosol) (Isbell, 2002), with a clay loam A horizon up to 0.3 m thick, overlying a light clay B horizon that gradually changes in texture to a medium clay. Some of the relevant soil properties are listed in Table 1. Additional basic soil chemistry properties are listed in the 'Initial value' row in Tables 4–6. The site was selected for uniform soil characteristics, with blocking down the slight slope. Prior to the experiment the area was sown to long season Italian ryegrasses and grazed by a herd of milking cows.

2.2. Experimental design

The study comprised factorial treatments arranged in a fully randomised incomplete block design with three replicates (a total of 284 plots). Treatments comprised 32 forage species and one of three irrigation treatments (I1, maintaining optimal soil water status; I2, 66% of water applied to I1; and I3, 33% of water applied to I1). Due to cost of soil analyses, only a selection of the forages were sampled, consequently this paper only presents soil fertility data for 11 forages (i.e. eight perennial and three annual species) (Table 2). Many of the annual forages were excluded as they were rotated with other annual forages. Forages expected to show SOC and N differences (e.g. kikuyu, ryegrass, lucerne) were initially chemically analysed. However given the lack of significant differences between irrigation treatments and depths below 0.1 m meant there was little benefit in conducting extensive and expensive soil analysis below 0.1 m depth. Consequently, full-depth carbon sequestration analyses were not possible due to incomplete sampling of soil from 0.4 to 0.5 cm, 0.9 to 1.0 m, 1.4 to 1.5 m, and 1.9 to 2.0 m. A plot size of 5 m by 5 m was used with plant and soil measurements taken from the central 2 m by 2 m area for all forages, except sorghum which used an 8 m by 8 m plot with plant and soil measurements taken from the central 3 m by 3 m area.

Table 1
Proportions of sand, silt and clay and selected physical and chemical properties for soil layers at the study site.

Depth (m)	Sand %	Silt %	Clay %	Bulk density (g/cm^3)	pH $CaCl_2$	EC (dS/m)
0–0.1	41.5	35.7	22.8	1.39	6.1	0.37
0.4–0.5	25.8	27.0	47.2	1.68	6.8	0.19
0.9–0.10	8.3	35.9	55.8	1.65	7.7	0.36
1.4–1.5	14.3	34.7	51.0	1.69	7.9	0.49
1.9–2.0	15.2	40.9	43.9	n/a	8.2	0.44

2.3. Meteorological data

Meteorological conditions and measurements were fully described by Neal et al. (2009), suffice that conditions were described as being a warm temperate environment, characterised by having warm humid summers and cool wet winters. Rainfall, temperature, humidity, wind speed, and radiation were recorded on site at hourly intervals from an automatic weather station (model ET106, Campbell Scientific, Logan, UT, USA). These values were used to calculate reference evapotranspiration (ET_o) using a modified Penman–Monteith equation (Allen et al., 1998).

2.4. Establishment of forage species

Prior to establishment of the irrigation infrastructure, the soil was deep ripped to 0.4 m depth, followed by scarifying. Prior to the each sowing, Roundup CT® (glyphosate 450 g a.i./L) at 4 L/ha was sprayed and 5 days later, the soil was rotary hoed. Plots were hand-sown, with the first sowing of perennials in late August 2003. Sowing rate was based on the germination percentage, adjusted to give a seeding rate (Table 2) that would be expected to achieve a plant population to maximise yield. Chicory and paspalum had to be re-sown in March 2004 to achieve the required plant population. The perennial ryegrass, prairie grass, and tall fescue plots were over-sown in March 2004 to improve plant density. The cool season annuals were sown on about the 11 March each year. The warm season annuals were sown on about 27 October in years 2 and 3. Periodically, a range of herbicides were used to control weeds where possible. Kamba M® (MCPA 340 g a.i./L and Dicamba 80 g a.i./L) at 4 L/ha was used to remove broad-leaf weeds from grasses, and Fusilade® (212 g a.i./L Fluazifop-p) at 2 L/ha was used to control grass weeds in herbs and legumes. Buttress® (2,4-DB 500 g a.i./L) at 1–3.2 L/ha was used to remove broad-leaf weeds in lucerne. To reduce summer grass problems, the pre-emergent herbicide Gesaprim® (600 g a.i./L atrazine) at 3 L/ha was irrigated in after sorghum was sown.

2.5. Irrigation scheduling

Irrigation scheduling was fully described by Neal et al. (2011b) for perennials and Neal et al. (2011a) for annuals. Suffice that conditions were described as non-limiting irrigation for forage growth for the I1 and reduced irrigation for I2 and I3.

2.6. Fertiliser management

At the commencement of the study, an initial dressing of 50 kg phosphorus (P)/ha, as single superphosphate, and 50 kg potassium (K)/ha, as muriate of potash, was applied to the entire site. At sowing each year, grass and herb plots received 454 kg ha^{-1} of a mixed fertiliser product (22:4:23:10 + 1.9 Mg, Incitec Pivot, Brisbane, Australia) [nitrogen (N):P:K:sulphur (S) + magnesium (Mg)], except for sorghum, which received 681 kg ha^{-1}, respectively. After defoliation, the equivalent amount of nutrient (P, K and S, and 80% of N) removed in harvested herbage was replaced as the mixed fertiliser product (22:4:23:10 + 1.9 Mg). At sowing, legumes received 206 kg ha^{-1} of a blended fertiliser consisting of a 60/40 mix of muriate of potash (50% K)/single superphosphate (9% P and 15% S). This blended fertiliser was then used to replace the P, K and S removed by each legume species at each harvest. To check that nutrients were not limiting growth, plant tissue analysis was conducted seasonally, and soil nutrients tested annually, to determine the adequacy of fertiliser application. Lime was applied twice at 1.5 t ha^{-1} to the perennial grass and herb plots during the