SECTION C:

The SOC pasture project 2006-2009

1. Project background

In 2006 NSW Department of Primary Industries (now Industry & Investment NSW) began research in south eastern NSW to find out more about soil carbon stocks under pastures and to evaluate the effects of different pastures and pasture management practices on soil carbon levels.

The project objectives were to:

- quantify SOC stocks under pastures for a range of management practices
- identify management practices that can increase soil carbon under pastures.

To do this we investigated historical SOC data from two long-term field trial sites, and conducted on-farm paired paddock comparisons of SOC under pastures.

The long term trial sites are near Wagga Wagga on the south-west slopes of NSW and both have had pasture systems in place for more than 15 years. We looked at historical soil carbon and agronomic data from the sites to investigate long term trends in SOC under different management practices and as inputs for testing the soil carbon model, ROTHC.

Figure 19. Hydraulic soil corer for obtaining ‘intact’ soil cores used in the project.

2. Long term trial sites

SATWAGL (Sustainable Agriculture Through Wheat and Good Legumes)

SATWAGL was established in 1979 at the Wagga Wagga Agricultural Institute, Wagga Wagga, New South Wales, Australia on a Kandosol. Average annual rainfall at the site was 554 mm. The surface A horizon was brown to greyish brown clay loam which gradually changed to a light to medium reddish brown clay at about 20 cm. Soil pH of the A horizon (0-12 cm) was acidic, about 4.9 in 0.01 M $CaCl_2$. The objective of the experiment was to monitor changes in agronomic performance and soil quality under a range of tillage, stubble management and rotation practices. Soil and plant samples were collected yearly for analyses and archived. The trial was discontinued in 2005 due to lack of funding.

Figure 20. The SATWAGL field trial (1979-2005).

MASTER (Managing Acid Soils Through Efficient Rotations)

The field trial was located at Book Book, 40 km south-east of Wagga Wagga in a 650 mm rainfall zone. The soil was a Subnatric Yellow Sodosol. Two types of pastures, perennial and annual, each with or without limestone, were established in 1992. The perennial pasture was sown to phalaris, cocksfoot, lucerne and subterranean clover. The annual pasture was sown to annual ryegrass and subterranean clover. Lime was applied to maintain an average pH_{Ca} of 5.5 in the 0-10 cm depth over the six year liming cycle. Phosphorus (P) was applied at 15 kg P/ha as single superphosphate every year. Pastures were grazed with a 2½-week grazing period and a five week spell throughout the year except for the period of the autumn break when annual species emerged and the period of rapid growth in spring where a one week grazing and two week spell regime was used. The stocking rate was adjusted to achieve the optimum pasture and animal productivity. More information about the trial is available at: www.dpi.nsw.gov.au/agriculture/resources/soils/acidity

Figure 21. The MASTER long term trial at Book Book, close to Wagga Wagga, NSW.

3. Soil carbon under pasture survey

In this survey we compared SOC in paddocks on 23 farms from Gulgong in the north to south of Albury (Figure 22). We undertook five different comparisons as shown below.

1. Native perennials vs introduced perennials
2. Annual vs perennial pastures
3. Continuous grazing vs rotational grazing management
4. Pasture cropping vs control
5. Improved vs unimproved pastures

We selected 4-5 paired-paddocks for each of these comparisons based on the following criteria to minimise variability and ensure that variations in SOC were due to the factors being studied.

The paired paddocks had to have:

- the same soil type
- the same aspect
- similar slope and topography
- at least 10 years history under the particular management
- be near each other (preferably across the fence).

However, we encountered some difficulties during site selection.

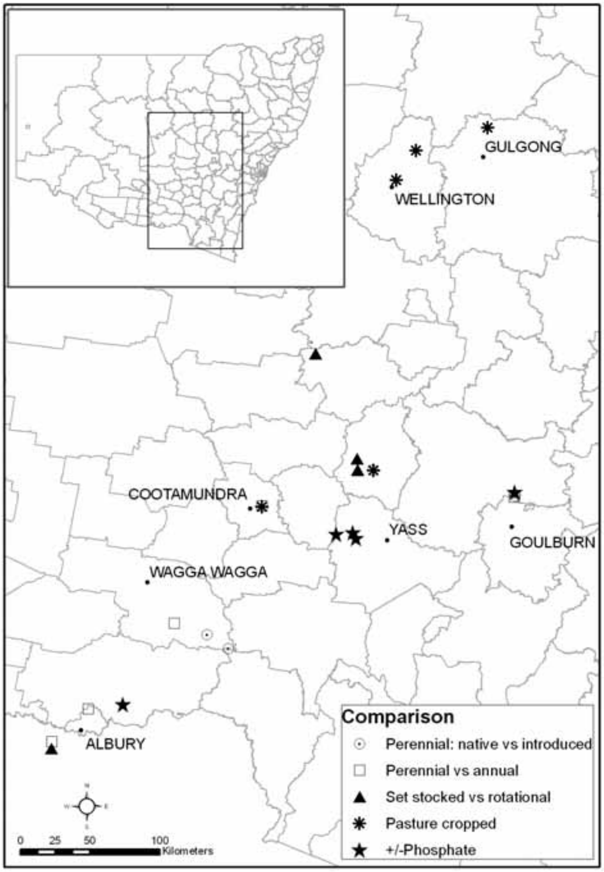


Figure 22. Location of the paired sites for the SOC survey.

Difficulties in site selection

Pasture types

Pastures were rarely pure. Both native and introduced perennial pastures generally also contained some annual grasses and clovers, particularly annual ryegrass and subterranean clover.

Annual pasture sites

Long-term annual pastures were rare on arable land, so one of the annual pastures sampled was under 10 years old.

Fertiliser and grazing management

Grazing management comparisons were inevitably made across-boundary-fences between neighbouring farmers, and therefore potentially confounded by differences in fertiliser history. We initially targeted set-stocking vs rotational grazing, but in practice some set-stockers proved to be loose rotational grazers. In all cases however, we compared relative non-grazed periods.

Pasture cropping sites

Pasture cropping comparisons were particularly problematic. In some cases, the pasture based cropped paddocks were compared against their un-cropped pasture counterparts. In one instance, we compared two pasture areas, each with the same cropping history with one area 'traditionally farmed' (disc plough) and the other pasture cropped. In another, both areas had been cultivated initially and the perennial pasture component was still very low. The final comparison was on a strong bothriochloa pasture with both areas pasture-cropped in the first year, with one area pasture-cropped every year thereafter and the other area just under pasture. In most cases, the history of pasture cropping was less than five years.

Improved pasture sites

Improved pastures were defined as those having a history of superphosphate and subterranean clover. Some of the unimproved pastures may have been fertilised with superphosphate in the past, but not for many years.

4. Soil sampling and analysis

Following the advice of a biometrician we adopted the following sampling scheme.

1. A uniform sampling area (20 m by 20 m) was selected from each side of the paired sites as shown below (Figure 23).
2. Each sampling area was subdivided into four 10 m x 10 m squares.
3. Within each square, 2 soil cores to 40 cm depth were taken at random with a hydraulic device (Figure 24).
4. Each core was individually cut into five depth increments of 0-5, 5-10, 10-20, 20-30 and 30-40 cm (Figure 25). Samples from the two soil cores of each 10 m x 10 m square were combined by depth intervals to form five composite samples.

This means that for each sampling area we took eight composite soil cores with a total of 20 soil samples for analysis.

Figure 23. Soil sampling at each paired site.

Figure 24. Soil sampling using a hydraulic soil corer.

Figure 25. Intact soil core to be sectioned into 0-5, 5-10, 10-20, 20-30 and 30-40 cm increments.

Laboratory analysis

In the laboratory, all the soil samples were tested for total organic carbon using the Leco method. Bulk density of all the soil sections was also calculated.

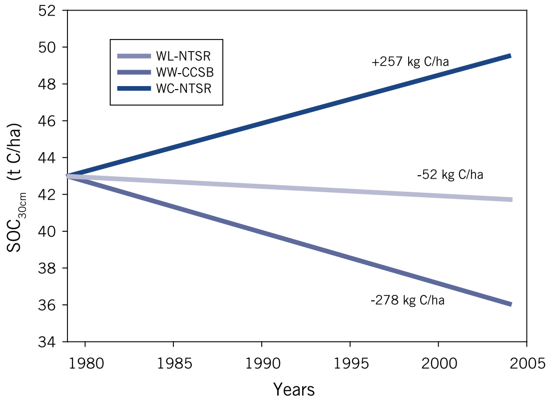
From these data, soil carbon stocks per ha to 30 cm depth were calculated from the data of each of the sampling squares.

Soil carbon stocks between paired comparisons were then compared statistically to see if they were different.

5. Key findings

Key Finding 1: Pastures maintain and increase SOC

SATWAGL long term trial (1979-2004)



NT = no tillage
TT = traditional tillage (3 passes)
SR = stubble retention
SB = stubble burnt
WL = wheat/lupin rotation
WW = continuous wheat
WC = wheat/clover rotation

Figure 26. Changes in SOC stocks with time for three contrasting management systems in SATWAGL long term trial.

In this long term trial, we found SOC stocks varied with the kind of rotation, tillage and stubble management practices (Figure 26).

Declining SOC

Under continuous wheat cropping with stubble burning and traditional tillage (three passes), SOC declined at a rate of 278 kg/ha/yr.

Static SOC

Under wheat/lupin rotation, even with the most conservative management, no tillage and stubble retention, at best SOC remained relatively unchanged.

Increasing SOC

Under wheat/clover rotation (1:1), we found SOC actually increased at a rate of 257 kg C/ha/yr when no tillage and stubble retention were practised under cropping and pasture was mown and returned.

These findings highlight the importance of the pasture phase in sequestering carbon.

MASTER long term trial (1992-2004)

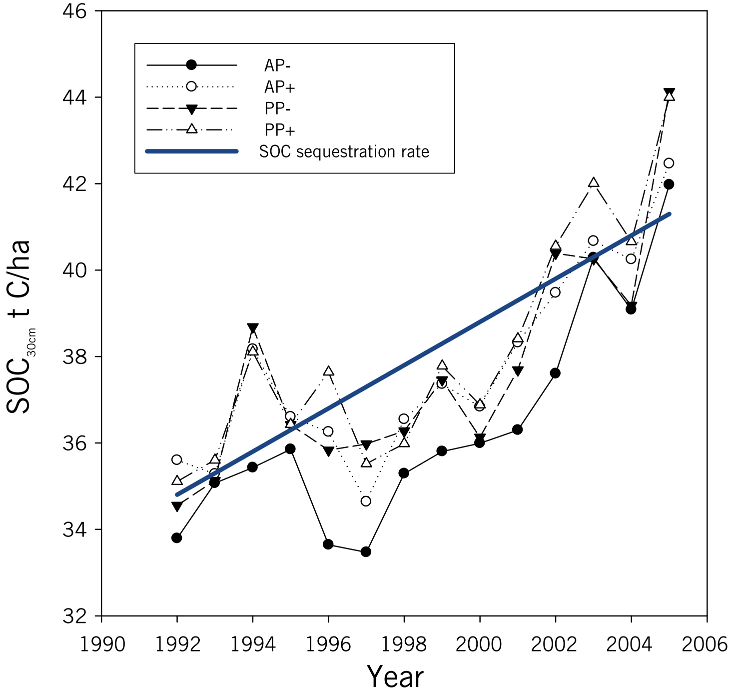


Figure 27. Changes in SOC stocks (to 30 cm depth) with time under different pastures and lime treatments in MASTER long term trial
(AP = annual pasture PP = perennial pasture - = unlimed + = limed)

Before the trial commenced, the site was a degraded pasture, but in the 15 years since then, SOC has increased at a rate (when averaged over all treatments) of about 500 kg C/ha/yr. The increase was due to improved management of the pastures, which increased annual dry matter production from 4 t/ha before the trial to a mean of 6 t/ha. There was no statistically significant difference in SOC stocks between pasture types (PP vs AP) or lime treatment (unlimed vs limed).

These results highlight the importance of improved pasture management in increasing SOC. The results also highlight the year to year variation which can occur within a long-term trend. Short-term changes in soil carbon based on only a couple of samplings can be misleading because they may be very different from changes measured over ten or twenty years (Figure 27).

Key Finding 2: Additional potential for SOC sequestration

The SOC stock under pastures did not vary with rainfall within the rainfall zone studied. Instead, average SOC stocks (0-30 cm) varied between 29 to 55 t C/ha across all sites and at individual sites with the same rainfall, SOC varied by up to 25 t/ha (Figure 28). This therefore indicates considerable additional potential in SOC sequestration under pastures in the region. We need to identify the factors restricting SOC sequestration at some of these sites.

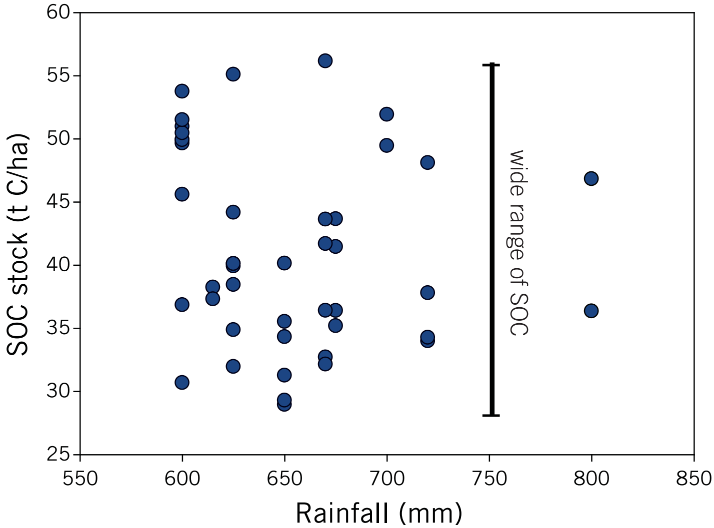


Figure 28. Average soil organic carbon stock (0-30 cm) at all the different sites as a function of annual rainfall.

Key Finding 3: Pasture types do not affect SOC

We found no significant difference in SOC stocks between introduced and native perennial pastures, or between annual and perennial pastures.

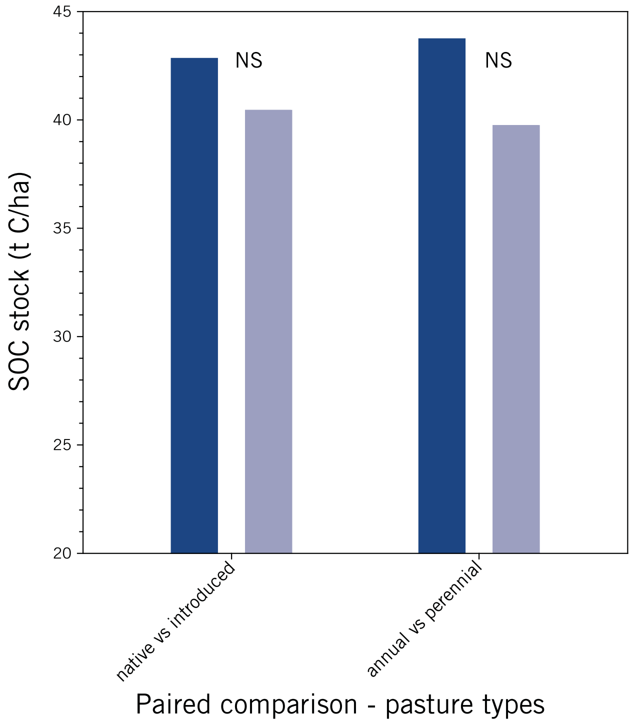


Figure 29. SOC stocks (0-30 cm) between different pasture types.
NS = not statistically different

Key Finding 4: Improved pastures increase SOC

We found significantly higher SOC under pastures improved with P fertiliser application than under unimproved pastures with no history of phosphorus application. Pastures with added P had an average of 10 tonnes of carbon per hectare higher than unimproved pastures.

The estimated long term rate of carbon sequestration due to pasture improvement ranged between 260 – 710 kg C/ha/yr (mean of 410 kg C/ha/yr).

We found no difference in SOC levels between set stocked vs rotational grazing or pasture cropping vs control.

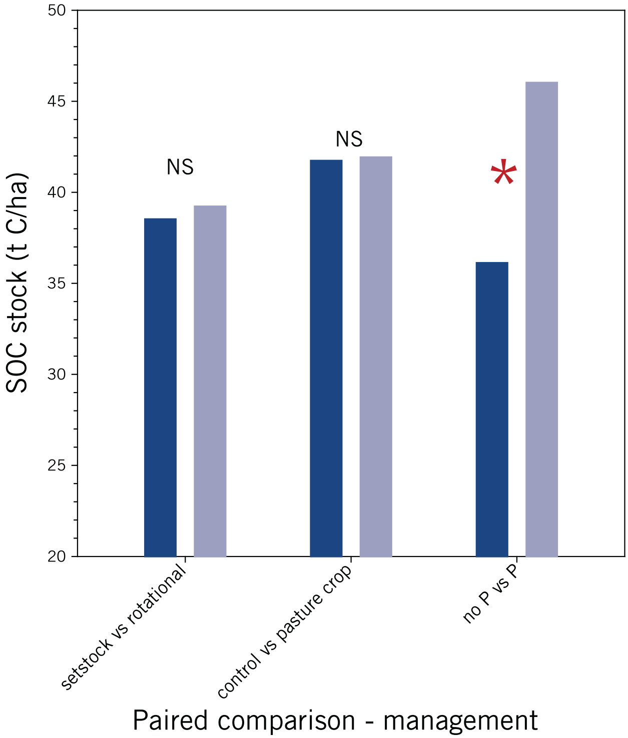


Figure 30. SOC stock (0-30 cm) under pastures of different management practices.
NS= not statistically different
* = statistically different

Key Finding 5: There is potential to store carbon in subsoil

Comparisons of soils with phosphorus and no phosphorus applications showed two distinct patterns in SOC at depth (Figure 31).

At some locations SOC increases were measured down to 30 cm (A) in soils fertilised with phosphorus. At others, increases in SOC were restricted to the top 10 cm (B).

This indicates that there is potential to store SOC in the subsoil layer where it is less prone to decomposition and therefore will stay in the soil for longer.

However, we need more research to understand why the different patterns of SOC sequestration occur.

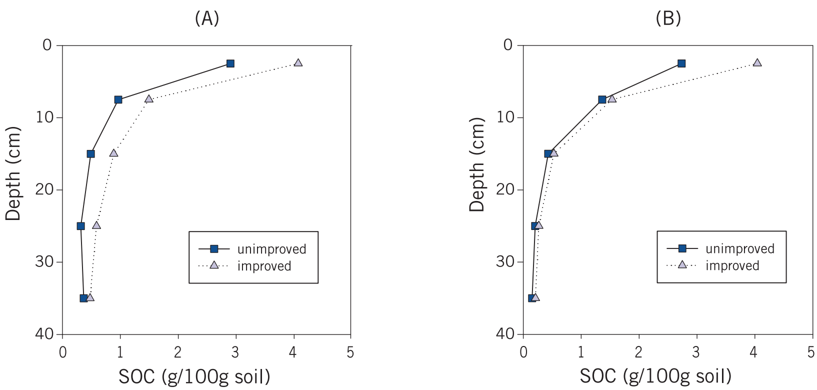


Figure 31. Soils varied in the depths at which they stored SOC. In comparison A SOC increased to 30 cm; in comparison B SOC increases only occurred in the top 10 cm.

Key Finding 6: SOC levels vary across the paddock

Our sampling showed that organic carbon levels vary spatially even in a seemingly uniform area (Figure 32).

Over the small area of 40 m by 40 m sampled, SOC levels varied between a maximum of 2.72% and a minimum of 1.44%. The mean value of the 20 soil samples was 2.02%.

Therefore, by collecting just one sample at random, any SOC value within this range is possible but this would not represent accurately the SOC status of the area.

This highlights the importance of sampling methodology to obtain accurate and verifiable SOC values.

This large field variability tends to mask any small real difference in SOC due to management practice and is probably the reason why we could not detect significant difference in SOC for some of the paired comparisons investigated in this project.

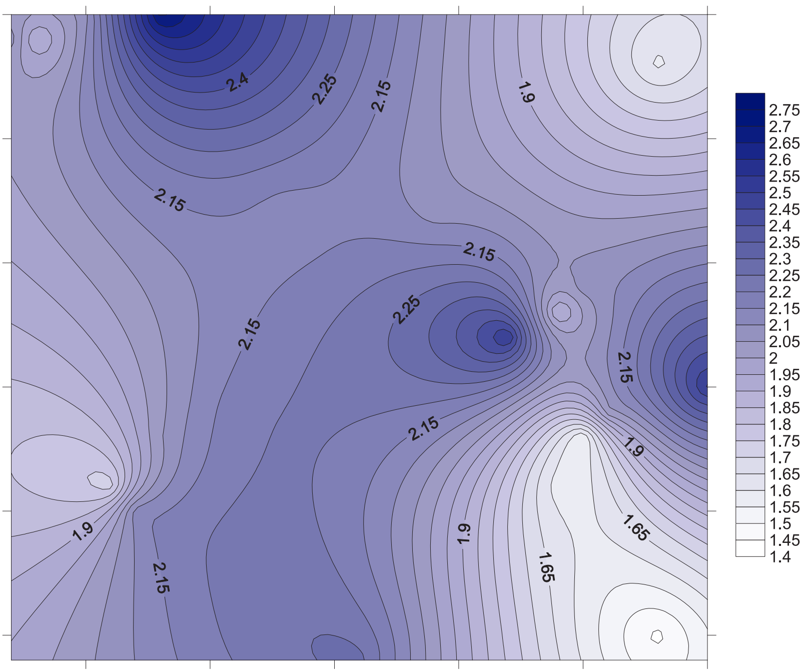


Figure 32. This 40 m x 40 m contour plot shows large variations in SOC concentration (%) as measured in 20 soil carbon samples collected from 0-5 cm depth.

Summary and conclusions

Soil organic carbon is the basis for sustainable agriculture. Increasing SOC of agricultural soil is a win-win strategy because it improves soil fertility and assists in mitigating climate change.

SOC levels are sensitive to management practices.

In agriculture, SOC levels are sensitive to management practices. To turn agricultural soils from a carbon source to an effective soil sink requires adopting improved management practices.

SOC levels are higher under pasture.

In pasture soils, SOC levels are generally higher than those under cropping and so management of pastures offers opportunities to increase SOC sequestration.

Higher rainfall areas have potential to sequester additional SOC.

We have identified considerable additional SOC sequestration potential under pastures in higher rainfall (>600mm) areas in central and southern NSW.

Applying P fertiliser is a useful practice to increase SOC under pastures.

We have also identified the use of P fertiliser on P deficient soil together with legumes to increase pasture production as an effective management practice to significantly increase SOC stocks under pastures. This also results in more productive and hopefully more profitable pasture enterprises.

More research is needed in SOC under pastures.

We did not detect any statistically significant difference in SOC stock due to other management practices included in the investigation, namely native perennial vs introduced perennial; annual vs perennial; continuous vs rotational grazing management or pasture cropping comparisons. Further research using other approaches, such as long term trials, is needed.

SOC levels are highly variable so a good sampling methodology is needed.

Due to high field variability of SOC, an appropriate sampling methodology is required to obtain accurate SOC values, particularly if soil carbon is to be included in carbon trading schemes.

References and further reading

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Glossary

Annual pasture

A pasture with species that complete their life cycle in one year. Typically, annual species germinate from seeds in autumn at the break of season and set seeds at the end of the growing season, normally in late spring. Pastures dominated by annual pasture species, such as annual ryegrass, subterranean clover or annual medics are called annual pastures. The ideal annual pasture should have more than 40% of legume component.

Bulk density

The ratio of the oven dried mass of a given soil sample to its bulk volume. The common unit for bulk density is Mg m^{-3}, i.e. tonnes m^{-3} which is numerically the same as g cm^{-3}.

C sink

The parts of the carbon cycle (see Figure 3) that store carbon in various forms are referred to as C sinks. Soil carbon, with a size more than twice that of vegetation is a C sink of considerable size.

Carbon neutral

Refers to achieving net zero carbon emissions by balancing a measured amount of carbon released with an equivalent amount sequestered or offset. The carbon neutral concept may be extended to include other greenhouse gases (GHG) measured in terms of their carbon dioxide equivalence.

CENTURY Soil Carbon Model

Another widely used soil carbon model developed in the US. It is part of a general plant soil ecosystem model which simulates carbon and nutrients dynamics for different types of ecosystems.

Continuous grazing

A grazing system in which little or no opportunity is provided for the pasture system to rest and recover after grazing. This is the traditional management grazing management practice in Australia. This term is used interchangeably with set stocked grazing.

Greenhouse effect

The heating of the surface of a planet or moon due to the presence of an atmosphere containing gases that absorb and emit infrared radiation. Greenhouse gases are almost transparent to solar radiation but strongly absorb and emit infrared radiation. Thus, greenhouse gases trap heat within a system.

Greenhouse gases

There are many gases which cause the atmosphere to retain heat. In order, Earth's most abundant greenhouse gases are: water vapor, carbon dioxide, methane, ozone.

Carbon dioxide from human activity is the greenhouse gas that contributes most of the warming effect. CO_2 is produced by fossil fuel burning and other human activities such as cement production and tropical deforestation.

CO_2 is the standard by which the relative impact of other gases is assessed. For example, methane (CH_4) is approximately 33 times worse than CO_2, so every tonne of CH_4 gas emitted is equivalent to 33 tonnes of CO_2. The worst gas emitted by agriculture is probably N_2O, which has approximately 298 times the warming potential of CO_2; hence 1 tonne of N_2O has a CO_2 equivalent of 298 tonnes.

Improved pasture

Grazing land permanently producing introduced or domesticated native forage species that receives varying degrees of periodic cultural treatment including fertiliser application to enhance forage quality and yields and is primarily harvested by grazing animals.

Overgrazing

Grazing livestock to the point of damage to the land. Overgrazing occurs when plants are exposed to intensive grazing for extended periods of time, or without sufficient recovery periods. It can be caused by either livestock in poorly managed agricultural applications, or by overpopulations of native or non-native wild animals.

Pasture cropping

Pasture cropping refers to an intercropping technique first developed in the Central West of New South Wales and involves the direct drilling of winter-growing cereals into the predominantly summer-growing native perennial pastures.

Perennial pasture

Species that can grow more than two years are called perennial species. Pastures dominated by perennial pasture species are called perennial pastures. Perennial pastures can be established from seeds or vegetative parts.

Perennial pastures can grow all year round depending on the availability of soil moisture. However, many perennial pasture species have mechanisms which provide dormancy when there is a lack of moisture. Perennial pastures can generally use soil moisture from deep in the soil profile and they may respond more quickly to out of season rainfall, such as summer storms.

Root shoot ratio

The ratio of root biomass to shoot biomass of a plant. Different plants have different R/S ratios. In general, grass species have higher R/S ratios than crop and tree species

e.g. Temperate pastures 0.4-3.7; crops 0.1 and trees 0.2-0.3.

Rotational grazing

Rotational grazing refers to the improved practice of scheduled movement of grazing animals from one pasture paddock to another during the year.

Soil carbon stock

The amount of soil carbon stored over a given depth of soil per unit area of land. The unit is t C/ha. Based on Kyoto protocol, the depth refers to 0-30 cm layer of surface soil.

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A farmer's guide to increasing soil organic carbon under pastures

This book is based on findings from a three year project investigating soil carbon levels in pastures under different management practices in south east NSW. It is designed to be of practical use to farmers who want to increase their soil carbon levels. It includes basic information on soil carbon and reports the project's findings regarding the impact of pasture management on soil carbon.

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