Proposed Amendments to Eligible Management Activities for 2021 Soil Carbon Methodology

A submission to the Clean Energy Regulator

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Summary

Human activity has resulted in the loss of 50 to 75% of soil carbon matter in impacted land around the world (Richardson et al, 2019 [xi]**)**. In Australia, this represents a significant contribution to greenhouse gases, a major loss of system climate resilience and an important opportunity for carbon sequestration. At the same time, both the agronomic practices leading to soil carbon accumulation, and their economic viability are widely debated.

Clean Energy Regulator's 2021 Soil Carbon Methodology draft (SCM21 DRAFT) lists a number of 'Eligible Management Activities' (EMA) available for use by farmers. This paper has proposed modifications by comparing,

- the list of current approved EMA's in the SCM21 DRAFT and the FAO's 2020 "A protocol for measurement, monitoring, reporting and verification of soil organic carbon in agricultural landscapes – GSOC-MRV Protocol" (FAO PROTOCOL)
- Identifying major areas of differences.
- Exploring peer reviewed evidence to assess applicability under Australian conditions
- Proposing appropriate wording for additional activities.

The SCM21 DRAFT includes 13 activities, however 2 sets of 2 are closely related. In contrast, the FAO PROTOCOL includes 13 activities which are somewhat wider in scope,

The following modifications and new Eligible Management Activities are proposed:

- Activity 7.2 (x) be more focussed on soil surface modification, to cover
  - Modifying landscape or landform features to remediate land;
  - Note: This may include, but is not limited to, practices implemented for erosion control, surface water management or drainage/flood control, water ponding or other means.
- Activity 7.2.(xi) in the SCM21 DRAFT be broadened to include,
  " .. Implementing practices specifically targeted at improving, or maintaining soil physical structure including by not limited to;
  - Deep ripping to break up soil hard pans,
  - the addition or redistribution of soil using mechanical means (including through clay delving, clay spreading or water ponding)
  - Planting deep rooted crops, such as tillage radish, safflower, sunflower, cotton, ...
  - Controlled traffic farming.
- Modify Activity 7.2 (xiii) to broaden it as follows;
  "Diversification of crop rotations, including but not limited to integration of legume species, pasture systems and livestock production"
- A new EMA added covering, " Soil health improvements with beneficial microbes such as N fix bacteria, phosphate solubilizing bacteria, mycorrhizal fungi demonstrated to increase nutrient and moisture uptake"
- That the limit on addition of non-synthetic fertilizers be;
  - Raised to 500kg.
  - The carbon content should be assessed and this be accounted for by a deduction of the carbon credited in the subsequent accounting period

All EMA's need to be reviewed for technical and economic fit under local conditions, and then included in a land management plan, prepared by a qualified person.

Proposed List of Eligible Management Activities.

The CMI Soil Carbon Taskforce proposes the follow amended list of Eligible Management Activities be included in the 2021 Soil Carbon Methodology.

(i) applying nutrients to the land in the form of a synthetic or non-synthetic fertiliser to address a material deficiency;

(ii) applying lime to remediate acid soils;

(iii) applying gypsum to remediate sodic or magnesic soils;

(iv) undertaking new irrigation;

(v) re-establishing or rejuvenating a pasture by seeding or pasture cropping;

(vi) establishing, and permanently maintaining, a pasture where there was previously no pasture, such as on cropland or bare fallow

(vii) altering the stocking rate, duration or intensity of grazing;

(viii) retaining stubble after a crop is harvested;

(ix) converting from intensive tillage practices to reduced or no tillage practices;

(x) Modifying landscape or landform features to remediate land;

Note: This may include, but is not limited to, practices implemented for erosion control, surface water management, drainage/flood control, water ponding or other means.;

(xi) Implementing practices specifically targeted at improving, or maintaining soil physical structure

Note: This may include by is not limited to,
- Deep ripping to break up soil hard pans,
- Using mechanical means to add or redistribute soil through the soil profile, including clay delving, clay spreading or inversion tillage
- Planting deep rooted crops, such as tillage radish, safflower, sunflower, cotton, ¶
- implimenting controlled traffic farming;

(xii) using a cover crop to promote soil vegetation cover or improve soil health, or both;

(xiii) Diversification of crop rotations, including but not limited to integration of legume species, pasture systems and livestock production;

(xiv) Soil health improvement with beneficial microbes such as N fix bacteria, phosphate solubilizing bacteria, or other organisms supported by peer reviewed and field research.

Furthermore, Restricted Activity 12 (6) pertaining to non-synthetic fertilizer, be amended to.

(a) The content of the restricted non-synthetic fertiliser must be measured to assess carbon measured by dry matter weight; and
(b) it is applied at a rate lower than 500kg per hectare per year on average.
(c) The added carbon is deducted from the carbon account in the subsequent accounting period.

Introduction

The accumulation of soil carbon holds potential for both mitigating global climate change, but also remediating the significant impact humans have had on the soil itself. As stated by Richardson et al [(ix)]

> *"It is well recognised that anthropological influences (e.g. land-use change, deforestation, agricultural production, urbanisation) have caused a major decline in SOM content throughout the world. Some 50 to 75% of the antecedent total SOM content is estimated to have been lost due to agricultural practice with higher rates of loss occurring in recent times"*

The loss of this organic matter from Australia's agricultural soil has not only contributed to atmospheric carbon dioxide, but as organic matter is critical in storing and buffering soil moisture and nutrients, has also reduced significantly the ability of our agricultural systems to adapt to future climate change. It is therefore critical that farmers are given the means to reverse soil carbon loss, while remaining economically viable as they help feed our country and region.

Richardson et al . [(ix)] set out a range of potential farming practices proposed to support carbon accumulation including.

- *"increased return of crop residues and bio-solids (manures, composts and other wastes) to soil,*
- *minimisation of soil disturbance,*
- *more continuous ground cover,*
- *a strengthening of nutrient recycling and a more positive nutrient balance,*
- *enhanced biodiversity and use of more diverse crop rotations, and*
- *a reduction in losses of water and nutrients from soils through erosion and leaching."*

Despite these suggestions, farmers have found many implementation challenges and struggle to make substantial impact including;

- The cost of implementing new practices, many of which come at the expense of financially productive farming practices. Due to moisture limitations, often a choice must be made between maximising yield and soil carbon accumulation.
- The cost of re-investing in the nutrient removed when historic carbon was depleted. Richardson et al (2014)[i] estimated that this nutrient reinvestment cost associated with sequestering 1 tonne of soil carbon using C-rich wheat stubble to be as much as $150/ha (at 2014 prices).
- Carbon generating practice often disrupts or complicates important farm programs, such as weed, disease or animal management.

The first Soil Carbon Methodology promulgated by Australia's Clean Energy Regulator held the promise of incentivising the accumulation of soil carbon by farmers, thus helping to address at least some the economic challenges faced by farmers. Continued revision has ensured that the method has steadily improved both in terms of scientific accuracy and its compliance framework thus remaining one of the most sophisticated methodologies in use around the world.

The methodology requires that in order for farmers to set up a scheme, they must start and maintain a new 'eligible management activity' (EMA) deemed likely to increase Soil Organic matter. The 2018 Soil Carbon methodology (SCM18) lists 11 EMA's of practices, with no detailed information on the actual implementation of the farming practices (see Column 1, of Table 1). The 2021 Soil Carbon Methodology Draft (SCM21 DRAFT) modifies and expands this list to 13 EMA's. (see Table 1, Column 3).

This list of EMA's is still somewhat limited in scope and does not cover the wider range of practices proposed by for example, Richardson et al [(ix)], as well as the widely referenced, recently released FAO document "GSOC MRV Protocol: A protocol for measurement, monitoring, reporting and verification of soil organic carbon in agricultural landscapes".[ii] (the FAO PROTOCOL). This document provides a broad checklist of activities that have been considered as useful for carbon accumulation around the world (see Table 1, Column 2)

This review will compare the SCM21 DRAFT with the FAO PROTOCOL.

Table 1 compares the activities in the SCM21 DRAFT and the FAO PROTOCOL and finds that,

- 6 activities in the SCM21 DRAFT are closely aligned with the FAO PROTOCOL.
- 2 activities in the SCM21 DRAFT do not appear in the FAO document.
- 6 activities are partially aligned, with 3 that might be consider for amendment to better alignment.
- Only 1 FAO PROTOCOL activities does not appear in the SCM21 DRAFT in any way.

This paper will review the last two categories for opportunities to broaden the range of approved activities in the SCM21, based on available peer reviewed data, commercial activities and experienced with particular reference to Australia.

The Author

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Richard obtained a Bachelor's degree in Forest Science at the University of Melbourne and a Master of Science in Agriculture degree at the University of Sydney, focussing on satellite mapping of soils. Richard has worked in state government agricultural extension in New South Wales and Victoria, and then undertook a 20-year international career in agribusiness, which involved postings to France, Singapore, Japan, China and Germany. Returning to Australia, Richard worked in New Business Development and Public and Government Affairs developing sustainability programs seeking to better demonstrate the critical need for modern technology to address the twin challenges of food security and environmental responsibility.

Table 1: Soil Carbon enhancement activities: Comparison of ERF 2018, 2021 Exposure SCM21 DRAFT with FAO 2020 GSOC FAO PROTOCOL

Item	Australian Soil Carbon Methodology 2018	FAO GSOC FAO PROTOCOL - 2020	Australian 2021 Soil Carbon Methodology Draft	Comment
1	(i) Applying nutrients to the land in the form of a synthetic or non-synthetic fertiliser to address a material deficiency	b) Balanced fertilizer applications with appropriate and judicious fertilizer application methods, types, rates and timing, following the International Code of Conduct for the Use and Management of Fertilizers (FAO, 2019b);	(i) Applying nutrients to the land in the form of a synthetic or non-synthetic fertiliser to address a material deficiency; => Note: This may include, but is not limited to, use of compost or manure.	FAO PROTOCOL and SCM21 DRAFT aligned, similar definition.
2	(ii) applying lime to remediate acid soils;	d) Effective use of inorganic amendments (e.g. lime or gypsum to remediate acid soils, gypsum to remediate sodic soils), following the International Code of Conduct for the Use and Management of Fertilizers (FAO, 2019b); integrated soil fertility management (combined application of inorganic and organic nutrient resources/fertilizers);	(ii) applying lime or other ameliorants to remediate acid soil	Aligned, similar definition.
3	(iii) applying gypsum to remediate sodic or magnesic soils;		(ii) applying gypsum to remediate sodic or magnesic soils;	
4	(iv) undertaking *new irrigation*;	a) Increase in biomass production by managing water availability for plants with soil water conservation practices and adequate and efficient irrigation management;	(iv) undertaking *new irrigation*;	Definition reasonably aligned.
5	(v) re-establishing or rejuvenating a pasture by seeding		(v) re-establishing or rejuvenating a pasture by seeding or pasture cropping;	Covered by item (j) of the FAO PROTOCOL
6	(vi) establishing, and permanently maintaining, a pasture where there was previously no pasture, such as on cropland or bare fallow		(vI) establishing, and permanently maintaining, a pasture where there was previously no pasture, such as on cropland or bare fallow	Aligned via Item (g) of the FAO PROTOCOL, covering cover cropping.
7	(vii) altering the stocking rate, duration or intensity of grazing;	j) Grazing management to promote soil vegetation cover (stocking rate, grazing duration and intensity); rejuvenating pastures by seeding;	(vii) altering the stocking rate, duration or intensity of grazing (or any combination of such activities) to promote soil vegetation cover or improve soil health, or both;	Aligned, similar definition.
8	(viii) retaining stubble after a crop is harvested;	f) Crop residue management: applying organic residues, mulches or providing the soil with permanent cover;	(vii) retaining stubble after a crop is harvested;	Aligned. Broadly similar, though addition of mulch (c.f. compost) is not included.
9	(ix) converting from intensive tillage practices to reduced or no tillage practices;	h) Reduction of tillage events and or the adoption of residue management techniques, minimum or no-tillage;	(ix) converting from intensive tillage practices to reduced or no tillage practices;	Aligned, similar definition.
10	(x) modifying landscape or landform features to remediate land.	l) Landscape management modification such as those implemented for erosion control (such as terraces), surface water management, and drainage/flood control;	(x) modifying landscape or landform features to remediate land; Note: This may include, but is not limited to, practices implemented for erosion control, surface water management, drainage/flood control, or alleviating soil compaction. Practices may include controlled traffic farming, deep ripping, water ponding or other means.	Partly aligned: SCM21 DRAFT definition includes a) changing landscape form to manage water flow and b) changing soil profile characteristics.
11	(xi) Using mechanical means to add or redistribute soil through the soil profile;	i) Implementation of practices oriented to prevent and/or alleviate soil compaction (e.g. controlled traffic operations;	(xi) using mechanical means to add or redistribute soil through the soil profile;	Partly Aligned: Related definition but considering comments above, can be improved.

Item	Australian Soil Carbon Methodology 2018	FAO GSOC FAO PROTOCOL - 2020	Australian 2021 Soil Carbon Methodology Draft	Comment
		'bio- drilling' by using tap-root species; judicious subsoiling labours);	Note: This may include, but is not limited to, clay delving, clay spreading or inversion tillage.	
12		c) Effective use of organic amendments (such as animal manure, plant residues, compost, digestates, biochar), following the International Code of Conduct for the Use and Management of Fertilizers (FAO, 2019b);	*Non synthetic fertilizer* may be added, where *non-synthetic fertiliser* means any biologically-derived solid or liquid substance that: … and (ii) enhance plant growth and soil fertility... (iii) add or stimulate microbial or other life in soils.. ..) contains more than 5% organic content; and .. does not include: non-biodegradable substances, such as plastics, rubber or coatings; or biochar.	Partly Aligned: Compost Included in 2021 SCM21 DRAFT, via the reference in point (1) to non-synthetic fertilizer and it definition. Biochar from within the CEA can be added, as well as limited (100kg/ha) from outside the CEA) .
13		e) Soil health improvement with biofertilizers (beneficial microbes), such as mycorrhiza, phosphate solubilizing bacteria, bio-inoculants and bio- inducers;	*Non synthetic fertilizer* may be added, where *non-synthetic fertiliser* means any biologically-derived solid or liquid substance that: … and (ii) enhance plant growth and soil fertility... (iii) add or stimulate microbial or other life in soils.. ..) contains more than 5% organic content; and .. does not include: non-biodegradable substances, such as plastics, rubber or coatings; or biochar.	Broadly Aligned via Non synthetic fertilizer definition.
14		g) Use of cover crops or green manure, and/or perennials in crop rotations; establishing a pasture in croplands or bare fallow;	(xii) using a cover crop to promote soil vegetation cover or improve soil health, or both	Partly Aligned. Perennials not really relevant in Australian Cropping systems at present.
15		k) Implementation and diversification of crop rotations, integration of production systems (for example, crop-livestock, silvopastoral, agroforestry), use of improved species (such as deep rooting and tap rooting crops);	(xiii)using legume species in cropping or pasture systems; or	Partly Aligned: Definition narrower in SCM21 DRAFT
16		m) Planting indigenous species (for example, N fixing legumes) adapted to local ecological conditions on degraded or abandoned croplands.		Not included in 2021 SCM21 DRAFT

Item 4. Irrigation and Moisture management

Introduction and discussion.

Both the FAO PROTOCOL and SCM21 DRAFT include activities concerning the water management as an obvious precursor to plant and root growth providing a source of carbon that can be converted to stable soil organic matter. While the SCM21 DRAFT definition focusses on ***new irrigation*** the FAO PROTOCOL introduces wording related to *soil water conservation practices.*

Within the Australian context, given the scarcity of water resources and high evapotranspiration rates, there would be few irrigation farmers that would not be implementing some form of water conservation. In the context of rainfed broadacre agriculture, the widespread adoption of minimum tillage agriculture, including stubble retention, can be consider a significant soil water conservation practice.

Considering the above, there seems little benefit to adding any water conservation wording to the current definition.

Recommendation

Do not change activities (iv) in the SCM21 DRAFT

Item 10. Modifying landform.

Item 10 in the SCM18 aligned closely to the FAO PROTOCOL item (i), pertaining to modify the soil surface of the land, principally with the objective of managing water flow to avoid water erosion and flood damage. These activities are very important to avoid loss of soil, and it's associate organic matter, and to make best use of high flow events.

Item (x) in SCM21 DRAFT adds the following note;

> "This may include, but is not limited to, practices implemented for erosion control, surface water management, drainage/flood control, or alleviating soil compaction. Practices may include controlled traffic farming, deep ripping, water ponding or other means."

This note adds some confusion as it introduces and mixes practices targeting the soil profile (i.e. under the surface). We believe these elements would better be transferred to a rewritten ITEM (xi), which should focus on practices targeting the soil profile. (i.e. beneath the surface)

Recommendation

Activity 10 be focussed on soil surface modifications as follows;

> (x) modifying landscape or landform features to remediate land;
> Note: This may include, but is not limited to, practices implemented for erosion control, surface water management, drainage/flood control, ~~or alleviating soil compaction. Practices may include controlled traffic farming, deep ripping,~~ water ponding or other means.

Item 11. Improvement or maintenance of the soil profile.

Introduction and discussion.

It is well established that improving the overall soil physical environment, reducing compaction and physical barriers can aid accumulation of fresh organic matter. Related factors include better water infiltration, better drainage, less water logging and deeper root penetration. (Brevik et al, 2002) [iii]. Both the FAO PROTOCOL and SCM21 DRAFT activities cover improvement of physical structure of the soil profile.

The SCM21 DARFT activity 7.2.(xi) pertains to using mechanical means to add or redistribute soil through the soil profile, including clay delving, spreading and inversion tillage. While restricted to in scope, it is clear that such 're-distribution' generally should lead to significant improvement in soil drainage, subsoil compaction and root growth which are significant problems across large areas of sodic and duplex soils in Australia. The FAO PROTOCOL definition is broader, adding 'bio-drilling' with deep rooted plants and the highly important preventative measure of Controlled Traffic Farming (CTF).

'Bio-drilling', with specialised deep-rooted crops, such as the Daikon radish ("tillage radish") has been trailed by many farmers and found to open channels deep into the soil. Other deep-rooted species, including wheat grasses, cotton and hemp plants can also achieve similar results.

Yunusa and Newton (2003)[iv] proposed that "primer plants" could modify sub-soils in SE Australia. Nutall et al (2008) [v] compared a variety of deep-rooted plants before wheat and found a up to 15% yield increase, which they suggested was due to the creation of deep pores for the following wheat crop to exploit.

Controlled Traffic Farming, while long adopted in Europe, has seen recent increased adoption in Australia, for reasons of intra-season crop entry, easier trafficability and substantial reduction in soil compaction (Blackwell 2017)[vi]. Benefits include,

- Reduced input costs by minimising application overlaps
- Better traction and floatation in wet conditions with machinery running on firm tracks
- Less waterlogging
- **Improved crop water and nutrient use efficiency**
- More agronomic opportunities, such as using chaff decks for weed control and inter-row sowing
- Less fuel use
- **Lower GHG emissions. (GRDC, 2017)** [vii]

A recent survey by DPIRD in W.A. indicated that knowledge of the importance of soil compaction was broad, with widespread interest in CTF. It was further stated that CTF is estimated to approximately double farm profit when the benefits are calculated using conservative costs and yield effects."

In summary, beyond physical disruption of the soil profile, there are a broad suit of activities aimed at improving the soil profile and physical structure. Equally important are activities aimed at preserving the benefit of such activities by preventing compaction. We suggest that EMA 11 be broadened to reflect this.

Recommendation

That activity 7.2.(ix) in the SCM21 DRAFT be broadened as follows,

Implementing practices specifically targeted at improving, or maintaining soil physical structure including by not limited to,

- Deep ripping to break up soil hard pans,
- Using mechanical means to add or redistribute soil through the soil profile;
  Note: This may include, but is not limited to, clay delving, clay spreading or inversion tillage,
- Planting deep rooted crops, such as tillage radish, safflower, sunflower, cotton, ¶
- Implementing controlled traffic farming;

Item 12. Manure and organic amendments.

Introduction and discussion.

It is well established that direct addition of manure to a soil is perhaps the most rapid way to raise soil carbon levels. Along with directly adding a source of carbon, the amendments can also significantly buffer soils and improve soil microbial balance. The SCM21 DRAFT allows addition of manure from approved waste streams (e.g. intensive animal production, feedlots, etc), including human effluent, or if it is sources from within the project area (CEA).

The addition of amendments from other areas, sources such as industrially produced bio-fertilizers, is allowed, but only at a rate of 100kg/ha, presumably to avoid the issue of transferal and double counting of carbon.

Acknowledging the need to avoid double counting, the 100kg limit is low relative to the normal rate of compost application, which limits an important means of improving soil health and nutritional status and raising soil carbon.

Recommendation

That the limit on addition of non-synthetic fertilizers be,

- Raised to 500kg.
- The carbon content should be assessed, and this be accounted for by a deduction of the carbon credited in the subsequent accounting period

Item 13. Improvement of soil biological health.

Introduction

The FAO PROTOCAL includes item (e), "Soil health improvement with biofertilizers (beneficial microbes), such as mycorrhiza, phosphate solubilizing bacteria, bio-inoculants and bio-inducers". The SCM21 DRAFT incorporates a general reference to these additives within the definition of n*on synthetic fertilizers*, which 'add or stimulate microbial or other life in soils'.

The topic of soil health is much discussed, but little understood. Below I review information regarding soil additives.

Review of Soil Health additives.

Recent years has seen a steady increase in the number of additives purported to improve soil health. Below I focus on additives which can directly increase a carbon accumulation, or which strengthen key carbon accumulation pathways. Given the difficulty of establishing causal links and whole of system benefits, additives with address disease, or boost root growth through hormonal mechanisms are not prioritized.

Abbott et al, (2018)[viii] conducted and extensive review of the potential roles of biological amendments for profitable Australian grain production, including,

- Biostimulants
  - Chitosan
  - Amino Acid containing substances
  - Humic substances
  - Seaweed extracts
- Organic amendments
  - Animal manure
  - Composted amendments
  - Compost Teas
  - Vermiculture composts
  - Biochars

  - Biochar enhanced products
- Microbial inoculants
  - Legume root nodule bacteria
  - Plant growth promoting rhizobacteria (PGPRs) and generalist microbial inoculants
  - Arbuscular mycorrhizal fungi

Several additives have modes of action not directly linked to soil carbon constraints or accumulation including **chitosan** (disease protection), **amino acids** (drought resistance) and **seaweed extract** (disease, drought and foliar disease resistance).

Regarding **humic** substances, Abbott et al. states, "because of differences in composition and multiple chemical functional groups, effects of humic substances may vary according to environmental conditions and with plant species. Effects also depend on the rate, time and location of application but these details are generally poorly described. Therefore, the extent of plant growth promotion associated with humic substances can be inconsistent and unpredictable."

Animal manure and composted amendments are dealt with above under item 12.

There has been little use of **vermicompost** in production agriculture in Australia and must be further studied. Very limited studies of **compost teas** have indicted possible advantages in terms of reduced incidence of disease, improved soil and plant health, increased root growth and penetration, and reduced pesticide requirements. To date, there has been some use made in high value horticulture and organic systems, however again, more study is required to answer question regarding standardise preparation methodology, recommendations for use, biological impact and economic benefits.

Biochar has been widely studied and discussed and Abbott finds a wide range of results and proposed benefits. The clearest benefit relates to improved soil structure, porosity and water holding capacity. One potential development area may be the use of 'improved' biochar by using it as a carrier to deliver micro or other nutrients. Again, issues of consistency in formulae, manufacture, application methodology and economics pose significant challenges to widespread adoption and must be further studied.

The area of greatest potential identified by Abbott is that of **microbial inoculants**. Much of the rationale for their use relates to addressing the 'stoichiometric challenge', (see box on the right), which means that the building soil carbon will require a substantial capture and binding of N and P into soil organic matter. This presents a very real economic challenge which bacterial additives may reduce substantially.

Peoples et al (2009) [ix] found following application of **legume root nodule bacteria** that N increased in 31 of 33 legume pre-cropping treatments. Increased N can be a direct driver of microbial diversity and therefore of carbon accumulation (Richardson et al 2020) [x].

Penicillium radicum and Penicillium bilaiae are examples of **plant growth promoting rhizobacteria (PGPRs)** that can have significant benefit via phosphorus solubilisation. (Harvey et al. (2009) [xi], Richardson et al 2011 [xii]). These isolates have been extensively trialled originally by CSIRO in Australia and have shown yield increases even when fertilizer levels were lowered. They are commercially available under the brand names *Jumpstart*[1] and *Tagteam*[1]

Soil Carbon: The 'stoichiometric challenge' (after Richardson et al, 2020)
The elemental nutrient ratio that occur in more stable soil organic matter (i.e. typically 70:6:1:1 for C:N:P:S) is similar to the ratio that is found in the microbial biomass (60:7:1:1 for C:N:P:S), as compared with the wide range of ratios commonly found in plant residue inputs (263:5:0.5:1 C:N:P:S for wheat residue and 102:2:0.3:1 for canola residue). .. "Collectively, this indicates that the processing of FOM to SOM by microorganisms requires a 'concentration' (enrichment) of nutrients (i.e. narrowing of CNPS ratios) to reach that which is present in stabilised SOM (Tipping et al. 2016). The provision of the N and P to create stable humus is a significant economic cost.

[1] Tradename of Bayer Australia limited

Melanised endophytic fungi (MEF) is an emerging areas of high interest and investment in Australia. Mugerwa and McGee demonstrated[xiii] that ascomycete and zygomycete MEF isolates increased within soil aggregates by 17% over 14 weeks. It was earlier hypothesised that fungal organic matter in a melanised form is much more stable due to the "large, complex and irregular chemical structure of these macromolecules , which are composed of phenolic (or indolic) monomers.[xiv] A second factor is the deposition of carbon at the interior of soil aggregates, where it is physically protected. The Soil Carbon Co has attracted some 10m$ in funding and is now testing isolates broadly across Australia, with promising results, which will be reported later this year.

A**rbuscular mycorrhizal fungi** (AMF)have been widely studied however Abbot et al 2009 does not find a clear and consistent benefits at this stage.

In summary, while a wide variety of substances have been proposed to improve soil health in a general sense, currently only microbial inoculants focus on nutrient capture or liberation contribute in a known way to carbon accumulation, and have support in Australian peer reviewed literature. Several other areas are being actively studied (MEF, AMF) and hold promise, but they are not yet widely proven. Other additive may be beneficial but have limited proven linkage to carbon accumulation and no standard format.

Recommendation

The CER include in SCM21 a new approved activity such as

> "Soil health improvements with beneficial microbes such as N fix bacteria, phosphate solubilizing bacteria, mycorrhizal fungi demonstrated to increase nutrient and moisture uptake"

Item 14. Use of cover crops or green manure

Introduction and discussion

Cover cropping and green manure has been a long-established agricultural practice in the northern hemisphere. Recent years has seen a move to multi-species mixtures, with 3, 6 or even 10 different species.

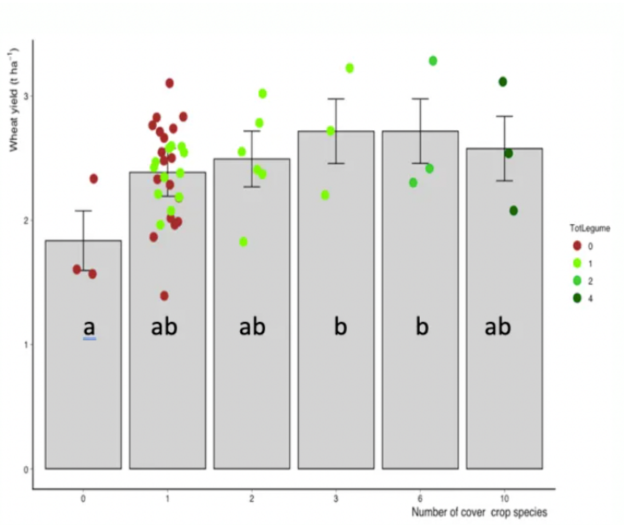
Humbert-Canquii et al (2015)[xv] set outs strong evidence in northern temperate regions, noting that "Cover crops alleviate soil compaction, improve soil structural and hydraulic properties, moderate soil temperature, improve microbial properties, recycle nutrients, and suppress weeds". In addition, "Cover crops increase soil organic C stocks (0.1–1 Mg ha–1 yr–1) with the magnitude depending on biomass amount, years in CCs, and initial soil C level".

The use of cover crops in Australia is a topic of great interest at the moment; no fewer than 4 Nuffield Scholars in 2017 and 2018 addressed cover cropping in some form in their reports (Richard Leask, Grant Pontefex, Alex Nixon and Stuart Tait). Numerous GRDC studies have or are being undertaken. A current multi party project led by the CSIRO is looking at;

- Five species evaluation trials to evaluate cover crop species across different soils and climates, established on a small plot basis
- Nine termination trials testing timing and method of cover trop termination
- Twenty demonstration trials which span from Streaky Bay in the West to Tasmania, and cover the Upper and Lower Eyre Peninsula, Upper and Mid North, Mallee, Kangaroo Island, South-East, Gippsland, and Tasmania. (see: https://research.csiro.au/mixedcovercrops/)

Preliminary data presented at the 2021 GRDC Research update by Farrell et at (2021)[xvi] showed evidence of “biomass production ‘over-yields’ i.e., produces more biomass than that from an equivalent monoculture”, with strong yield increase from 3 and 6 species mixtures.

Earlier GRDC funded work by Erbarcher et al (2020)[xvii] pointed to another critical role of cover crops in moisture retention driven by longer ground cover. This would also have boosted ground cover, the critical importance in maintaining soil carbon (Garland et al (2021)[xviii]).



In parallel, the Horticulture Innovation has invested heavily in cover cropping research and delivery activities from 2017 to 2020, including 13 field sites growing 57 vegetable crops (Montagu, 2020[xix]). This resulted in seven articles, 20 factsheets, six guides, four research reports, six webinars, five podcasts, and five videos, demonstrating a wide array of benefits. Trials in Tasmania showed “Soil C levels, .. showed distinct treatment differences, with both Caliente and ryegrass (*cover crop*) treatments leading to an increase of 0.2-0.4%C (0.4-0.8% OM) compared with the fallow treatment across all 4 years the measurements were made.”

Recommendation

The SCM21 DRAFT includes the new item (xiii)

> “ using a cover crop to promote soil vegetation cover or improve soil health, or both”.

While this wording does not cover the reference to ‘perennials in crop rotations” of the FAO PROTOCOL, these are not commonly use at this stage in Australian cropping rotation systems. The proposed wording is therefore acceptable.

Item 15. Diversification of crop rotations.

Introduction and discussion

Richardson et al [ix] highlight “increasing crop diversity” as supporting increased soil carbon, and the FAO PROTOCOL include the activity “Implementation and diversification of crop rotations, integration of production systems (for example, crop-livestock, silvopastoral, agroforestry), use of improved species (such as deep rooting and tap rooting crops)”.

It is well known that soil organic levels have declined in Australian broad acres systems of over this previous 20 years. It is hypothesised that this is driven by an expected loss of organic matter when converting from pasture to cropping land, exacerbated by the preference for a monoculture system (e.g Wheat on Wheat, or Wheat/Fallow) as they are perceived as lower risk (Collins and Norton 2019)[xx]. They set out the advantages of great diversity include,

- disease management.
- soil nutrient supply and demand.
- soil structure and water supply benefits,
- weed control land management of herbicide resistance

Bell et al (2019)[xxi] noted that some 83% of all cropping farms are mixed farms in some sense. Nevertheless, there has been a dramatic reduction in animal numbers, with the number of sheep dropping from over 120m DSE in 1990 to around 50 million today, (or around 7,000 a day less over the last 30 years).

The linkage between crop and animal diversity and increased soil carbon is not generally direct, but is associated with enhances nutrient availability or cycling, and/or, improved microbial activity. Examples include;

- Inclusion of a legume crop in the rotation phase will contribute from 37 to 128 kg N/ha directly to nitrogen availability which is a critical requirement for creation of stable to support carbon accumulation. (Collins and Norton (2019)) (See 'Stoichiometric challenge' in the box on page 11.)
- A rotation with Canola has been shown to liberate phosphorus, due to canola's long roots and higher levels of citrate root exudates under low P conditions. This can liberate P from soil, which should also support accumulation of organic matter. (Collins and Norton, 2019).
- Regarding integration of livestock into cropping systems, perhaps the most important aspect is that this is often associated with a pasture phase, which has been shown to build soil organic matter by 0.3 to 0.6 T C/ha/yr (Richardson, 2019) due it's dense sward, fine roots and associated lack of cultivations.
- In addition, Abbott et al (2009) lists a number of key benefits from animal manure itself, including;
    - Higher soil organic matter turnover and accumulate soil organic C and energy, with an enhancement of biological activity.
    - Enhance soil structure and adsorption properties by reducing their bulk density while increasing their porosity, infiltration rate, water holding capacity, hydraulic conductivity and aggregate stability
    - Nutrient cycling (N, P and S) can be enhanced in soils under manure management and the improved nutrient status has been linked to increased crop yield

Specific mention should also be made of dung beetle research which could greatly accelerate manure integration. Doube (2008) [xxii]demonstrated that significant increase in pasture productivity, permeability, nitrate, available phosphate, carbon and organic matter in the subsoil ". An MLA major ongoing study of dung beetles across Australia will deliver detailed results on soil impacts later in the year.

Bell et al (2019)[xxi] There is now active focus on an array of new practices that can allow easier diversification of cropping systems including,

- Next generation annual legumes
- Perennial grasses in ley pastures
- Dual purpose crops

Recommendation

Modify Activity 7.2 (xiii) to broaden it as follows;

> "Diversification of crop rotations, including but not limited to integration of legume species, pasture systems and livestock production"

Item 16. Planting Indigenous species

Introduction and discussion.

The PROTOCOL include the activities "Planting indigenous species (for example, N fixing legumes) adapted to local ecological conditions on degraded or abandoned croplands." It is our view that this practices is not relevant to Australian conditions, and is largely covered by the proposals 13 and 15 above.

Recommendation

Do not incorporate this activity.

Conclusion

Human activity has resulted in the loss of 50 to 75% of soil carbon matter in impacted land around the world (Richardson et al, 2019 [xi]**)**. In Australia, this represents a significant contribution to greenhouse gases, a major loss of system climate resilience and an important opportunity for carbon sequestration. At the same time, both the agronomic practices leading to soil carbon accumulation, and their economic viability are widely debated.

Clean Energy Regulator's 2021 Soil Carbon Methodology draft (SCM21 DRAFT) lists a number of 'Eligible Management Activities' (EMA) available for use by farmers. This paper has proposed modifications by comparing,

- the list of current approved EMA's in the SCM21 DRAFT and the FAO's 2020 "A protocol for measurement, monitoring, reporting and verification of soil organic carbon in agricultural landscapes – GSOC-MRV Protocol" (FAO PROTOCOL)
- Identifying major areas of differences.
- Exploring peer reviewed evidence to assess applicability under Australian conditions
- Proposing appropriate wording for additional activities.

The SCM21 DRAFT includes 13 activities, however 2 sets of 2 are closely related. In contrast, the FAO PROTOCOL includes 13 activities which are somewhat wider in scope,

The following modifications and new Eligible Management Activities are proposed:

- Activity 7.2 (x) be more focussed on soil surface modification, to cover
  - Modifying landscape or landform features to remediate land;
  - Note: This may include, but is not limited to, practices implemented for erosion control, surface water management or drainage/flood control, water ponding or other means.
- Activity 7.2.(xi) in the SCM21 DRAFT be broadened to include,
  " .. Implementing practices specifically targeted at improving, or maintaining soil physical structure including by not limited to;
  - Deep ripping to break up soil hard pans,
  - the addition or redistribution of soil using mechanical means (including through clay delving, clay spreading or water ponding)
  - Planting deep rooted crops, such as tillage radish, safflower, sunflower, cotton, …
  - Controlled traffic farming.
- Modify Activity 7.2 (xiii) to broaden it as follows;
  "Diversification of crop rotations, including but not limited to integration of legume species, pasture systems and livestock production"
- A new EMA added covering, " Soil health improvements with beneficial microbes such as N fix bacteria, phosphate solubilizing bacteria, mycorrhizal fungi demonstrated to increase nutrient and moisture uptake"
- That the limit on addition of non-synthetic fertilizers be;
  - Raised to 500kg.
  - The carbon content should be assessed and this be accounted for by a deduction of the carbon credited in the subsequent accounting period

All EMA's need to be reviewed for technical and economic fit under local conditions, and then included in a land management plan, prepared by a qualified person.

Table 2: Comparison of SCM21 DRAFT with FAO 2020 GSOC Protocol, including proposed updates

Item	FAO GSOC Protocol – 2020	Australian 2021 Soil Carbon Methodology DRAFT	Recommendation
1	b) Balanced fertilizer applications with appropriate and judicious fertilizer application methods, types, rates and timing, following the International Code of Conduct for the Use and Management of Fertilizers (FAO, 2019b);	(i) Applying nutrients to the land in the form of a synthetic or non-synthetic fertiliser to address a material deficiency; => Note: This may include, but is not limited to, use of compost or manure.	Maintain SCM21 DRAFT proposal
2	d) Effective use of inorganic amendments (e.g. lime or gypsum to remediate acid soils, gypsum to remediate sodic soils), following the International Code of Conduct for the Use and Management of Fertilizers (FAO, 2019b); integrated soil fertility management (combined application of inorganic and organic nutrient resources/fertilizers);	(ii) applying lime or other ameliorants to remediate acid soil	Maintain SCM21 DRAFT proposal
3		(ii) applying gypsum to remediate sodic or magnesic soils;	
4	a) Increase in biomass production by managing water availability for plants with soil water conservation practices and adequate and efficient irrigation management;	(iv) undertaking ***new irrigation***;	Maintain SCM21 DRAFT proposal
5		(v) re-establishing or rejuvenating a pasture by seeding or pasture cropping;	Maintain SCM21 DRAFT proposal
6		(vI) establishing, and permanently maintaining, a pasture where there was previously no pasture, such as on cropland or bare fallow	Maintain SCM21 DRAFT proposal
7	j) Grazing management to promote soil vegetation cover (stocking rate, grazing duration and intensity); rejuvenating pastures by seeding;	(vii) altering the stocking rate, duration or intensity of grazing (or any combination of such activities) to promote soil vegetation cover or improve soil health, or both;	Maintain SCM21 DRAFT proposal
8	f) Crop residue management: applying organic residues, mulches or providing the soil with permanent cover;	(vii) retaining stubble after a crop is harvested;	Maintain SCM21 DRAFT proposal
9	h) Reduction of tillage events and or the adoption of residue management techniques, minimum or no-tillage;	(ix) converting from intensive tillage practices to reduced or no tillage practices;	Maintain SCM21 DRAFT proposal
10	l) Landscape management modification such as those implemented for erosion control (such as terraces), surface water management, and drainage/flood control;	(x) modifying landscape or landform features to remediate land; Note: This may include, but is not limited to, practices implemented for erosion control, surface water management, drainage/flood control, or alleviating soil compaction. Practices may include controlled traffic farming, deep ripping, water ponding or other means.	Modifying landscape or landform features to remediate land; Note: This may include, but is not limited to, practices implemented for erosion control, surface water management, drainage/flood control, ~~or alleviating soil compaction. Practices may include controlled traffic farming, deep ripping,~~ water ponding or other means.
11	i) Implementation of practices oriented to prevent and/or alleviate soil compaction (e.g. controlled traffic operations; 'bio- drilling' by using tap-root species; judicious subsoiling labours);	(xi) using mechanical means to add or redistribute soil through the soil profile; Note: This may include, but is not limited to, clay delving, clay spreading or inversion tillage.	Implementing practices specifically targeted at improving, or maintaining soil physical structure: Note: This may include, but is not limited to; • Deep ripping to break up soil hard pans, • Using mechanical means to add or redistribute soil through the soil profile, including clay delving, clay spreading or inversion tillage,

Item	FAO GSOC Protocol – 2020	Australian 2021 Soil Carbon Methodology DRAFT	Recommendation
			• Planting deep rooted crops, such as tillage radish, safflower, sunflower, cotton, ¶ • Implementing controlled traffic farming;
12	c) Effective use of organic amendments (such as animal manure, plant residues, compost, digestates, biochar), following the International Code of Conduct for the Use and Management of Fertilizers (FAO, 2019b);	**Covered by the Non Synthetic fertilizer definition:** "where n***on-synthetic fertiliser*** means any biologically-derived solid or liquid substance that: … and (ii) enhance plant growth and soil fertility... (iii) add or stimulate microbial or other life in soils.. ..) contains more than 5% organic content; and .. does not include: non-biodegradable substances, such as plastics, rubber or coatings; or biochar."	That the limit on addition of non-synthetic fertilizers be, • Raised to 500kg. • The carbon content should be assessed and this be accounted for by a deduction of the carbon credited in the subsequent accounting period
13	e) Soil health improvement with biofertilizers (beneficial microbes), such as mycorrhiza, phosphate solubilizing bacteria, bio-inoculants and bio- inducers;	**Covered by the Non Synthetic fertilizer definition:** "where n***on-synthetic fertiliser*** means any biologically-derived solid or liquid substance that: … and (ii) enhance plant growth and soil fertility... (iii) add or stimulate microbial or other life in soils.. ..) contains more than 5% organic content; and .. does not include: non-biodegradable substances, such as plastics, rubber or coatings; or biochar."	An item is added, "Soil health improvements with beneficial microbes such as N fix bacteria, phosphate solubilizing bacteria, mycorrhizal fungi demonstrated to increase nutrient and moisture uptake"
14	g) Use of cover crops or green manure, and/or perennials in crop rotations; establishing a pasture in croplands or bare fallow;	(xii) using a cover crop to promote soil vegetation cover or improve soil health, or both	Maintain SCM21 DRAFT proposal
15	k) Implementation and diversification of crop rotations, integration of production systems (for example, crop-livestock, silvopastoral, agroforestry), use of improved species (such as deep rooting and tap rooting crops);	(xiii)using legume species in cropping or pasture systems; or	"Diversification of crop rotations, including but not limited to integration of legume species, pasture systems and livestock production.
16	m) Planting indigenous species (for example, N fixing legumes) adapted to local ecological conditions on degraded or abandoned croplands.		**No clear evidence of relevance in the Australia system.**

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