Down to Earth:

Estimating Carbon Stocks with Remote Sensing Tools

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Introduction

With the advent of remote sensing from satellites and the rise of digital twin farming tools, it is now easier to gain insights about a farm and its soils from the comfort of the office chair. For soil carbon measurement, a range of new digital tools are becoming available to estimate or model soil organic carbon (SOC) without relying solely on taking soil samples. SoilCQuest tested one such tool developed by Downforce Technologies in 2023 that can estimate SOC at any 10 x 10 m portion of land on earth every ten days. The 10-day cycle corresponds with the orbit of the EU Copernicus Sentinel-2 satellite, which is used for earth monitoring. The satellite images are combined with publicly available soil mapping datasets and other ancillary information to derive models that can estimate SOC% in the 0-30 cm depth.

In 2023, SoilCQuest undertook a small research project to test the application of Downforce Technologies software to estimate SOC% for different farm management practices. The Downforce software was used to assess soil carbon over three properties in NSW from 2017-2022 (Table 1). Cropping and grazing data from each farmer were then analysed to see if inferences could be made between farm management and soil carbon levels during those six years. This 6-year period included a 2-year drought period in 2018-1019, which allowed us to monitor how soil carbon declined during drought and later bounced back when the rains returned. The three properties included two mixed cropping/grazing farms and one cropping farm.

Table 1. Details about the case study farms used to test the Downforce software

	'Pine Valley', West of Parkes, NSW	**'Weemabah', East of Trangie, NSW**	**'Mayfield', East of Forbes, NSW**
Farming system	Mixed	Mixed	Cropping
Annual Rainfall (mm)	562	517	600
Dominant Soil texture	Course Sand 0-15 cm	Clay loam over clay	Clay
Study area size (ha)	1301	1661	962
6-year SOC (%) average and (min-max)	1.18 (1.00-1.58)	1.1 (0.9-1.65)	1.3 (0.9-1.9)

Which farm management practices were influential in building soil carbon?

While rainfall, or the lack thereof, was the main driver of SOC's gain or loss, some farm management showed statistically significant effects, albeit minor ones in absolute terms.

On ‘Pine Valley’ farm, growing lucerne increased SOC% by 6.58 % against a modelled baseline for the cropping paddocks. Data was not available on Pine Valley farm to make inferences on the effect of grazing.

On ‘Mayfield’ farm, fallowing paddocks during the 2019 drought resulted in retention of 9.6% SOC compared to other rotations. Also, growing canola after the break of drought in 2020 resulted in a 5.8% loss in SOC compared to different crop rotations in that year.

On ‘Weemabah’, the main finding was that grazing lands had a 6% higher SOC than cropping paddocks in 2017-2022, which agrees with common knowledge that pasture soils store more carbon than cropping soils.

As a result of this study, SoilCQuest plans to use the Downforce software tool in future carbon farming research.

Soil moisture was the main driver of SOC stocks across the six years, with drought conditions over two years, 2017-2019, reducing SOC stocks by 9% across the three farms. As rains returned, SOC stocks also bounced back quickly, increasing by 16% from 2019-2020, showing that the good times can compensate for the bad times and more. It was interesting to note that 'Mayfield' farm, which, unlike the other two farms, is a purely cropping operation without permanent grazing pastures, lost more carbon per hectare in the drought but gained more carbon when rains returned (Fig. 1). This may be due to the faster growth rate of annual compared to perennial grasses when water is not limited (Garnier et al. 1992).

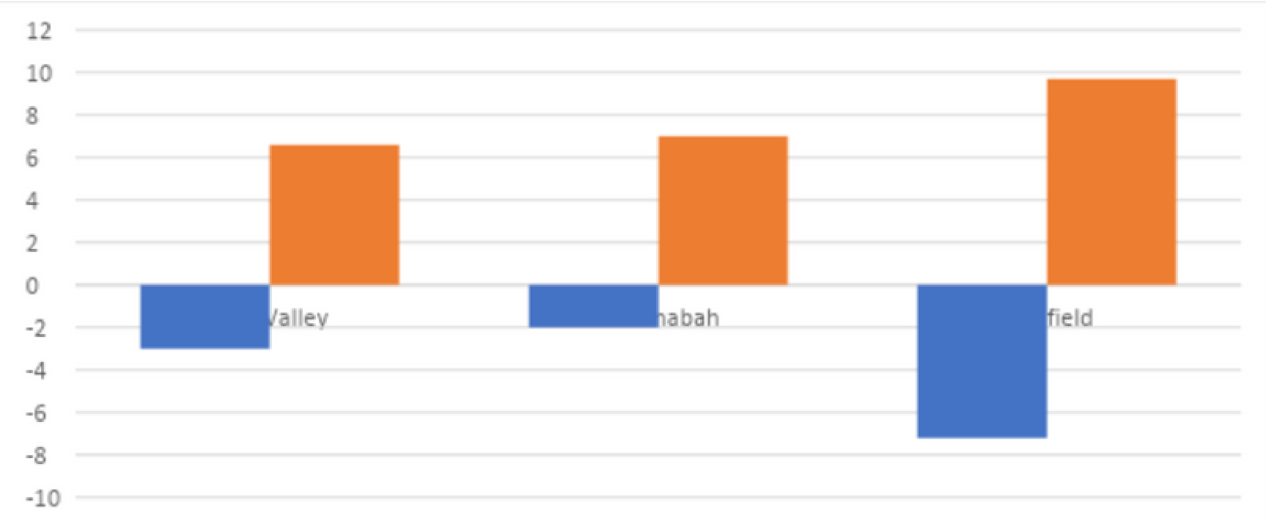


Fig 1. SOC stocks declined and rebuilt during and after the drought of 2018-2019 on the three case study farms.

Common among the three case studies was that paddocks with more trees often had the highest SOC. For example, at 'Pine Valley' farm, the paddocks with the three highest levels of SOC also had more trees (Fig. 2), with approximately 8% more SOC in the paddock with trees compared to the treeless paddock with the lowest SOC content. Agroforestry research confirms that the presence of trees can increase SOC stocks significantly in surrounding soils (Cardinael et al. 2017). Furthermore, a modelling study focussed explicitly on NSW (Gray et al. 2021) predicted that increasing vegetation by 10% would increase SOC stocks by 1.6-15.9 t ha-1 depending on the underlying fertility of the soil, rainfall and the level of existing vegetation on the land. In 2024, SoilCQuest will take further soil samples in paddocks with trees vs. no trees to confirm this trend and estimate the monetary value of carbon sequestration that includes trees in agricultural paddocks.

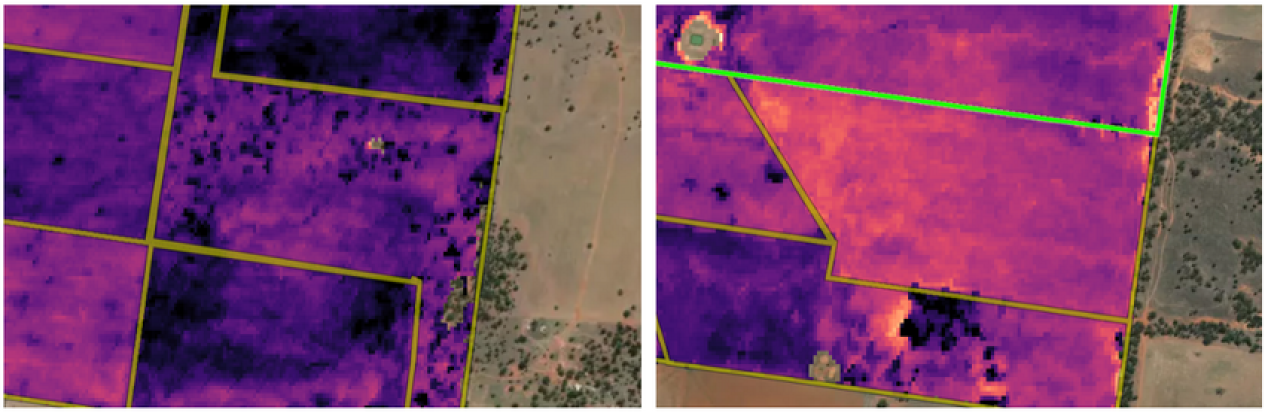


Fig 2. (left) Paddock with highest SOC (1.23% to the left) and Paddock with lowest SOC (1.14% to the right) between 2018-2022 on 'Pine Valley' farm.

How accurate is remote sensing of soil organic carbon?

Soil samples were taken at 0-15cm and 15-30 cm on four irrigated cotton paddocks on 'Weemabah' farm in July 2023. These laboratory-tested results of soil samples were compared with the satellite-modelled data estimated by Downforce in 2022 for the 0-30 cm depth, in essence, 'ground truthing' real soil data with remotely-modelled data. The Downforce data was found to give a good approximation of the physically sampled field soil, the Downforce modelling being within 0.1-0.2 % points of the soil samples (Fig. 3).

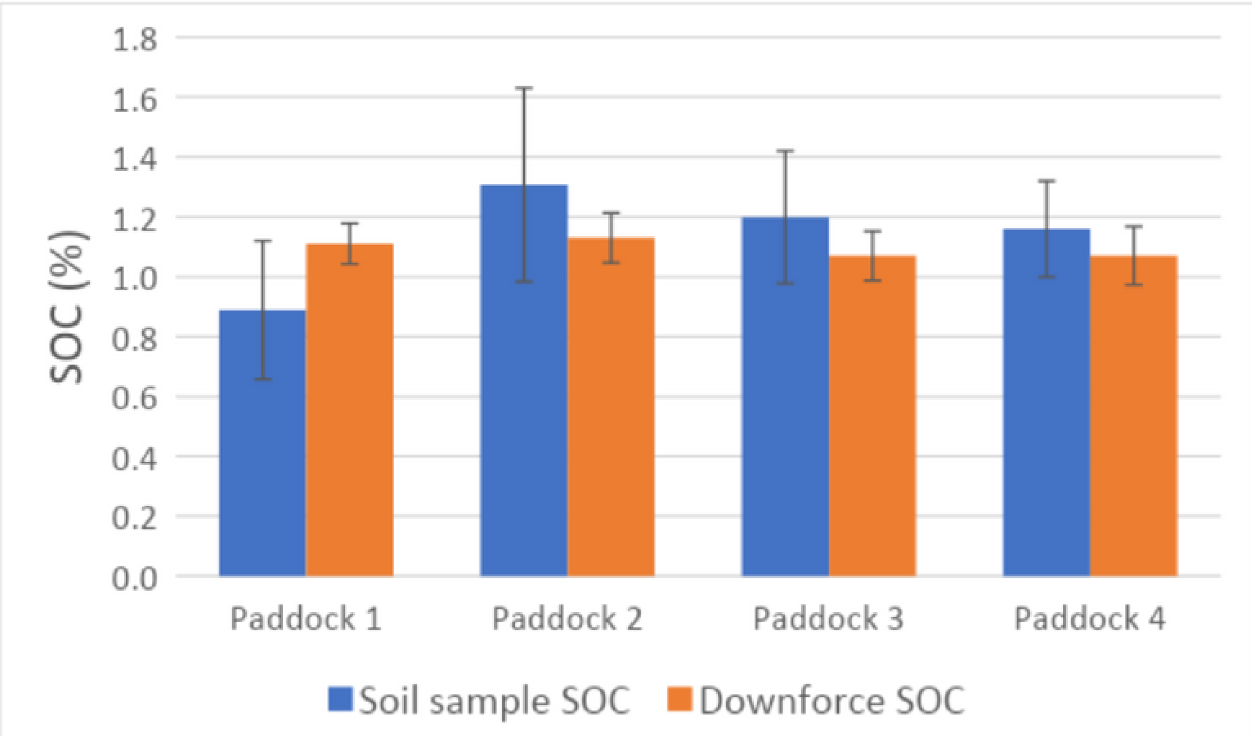
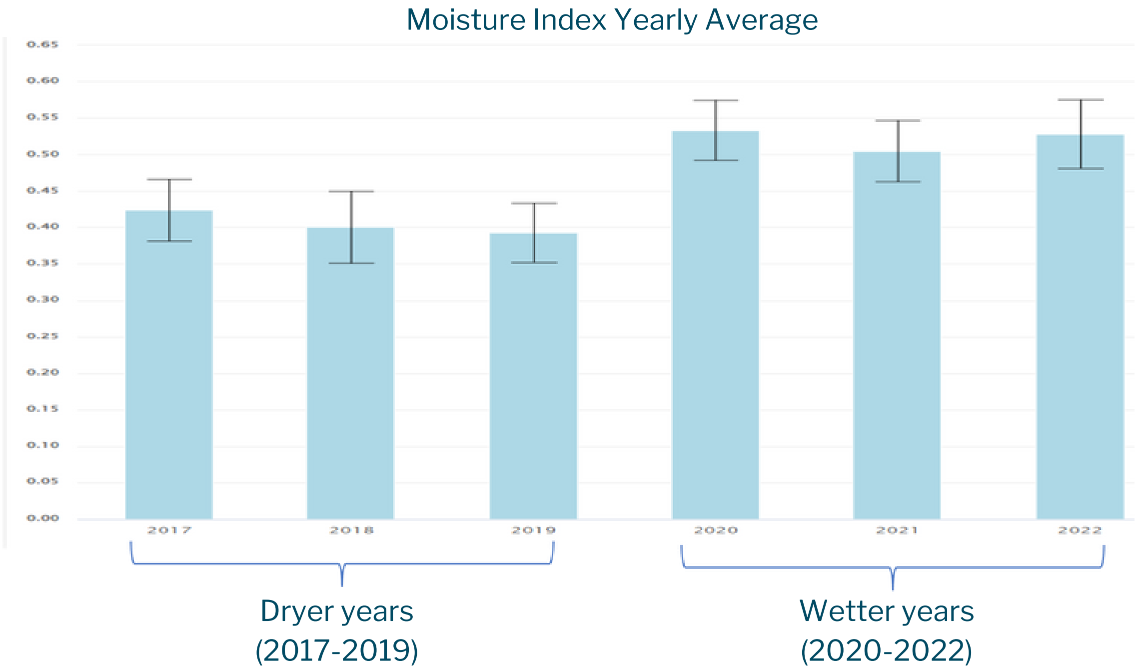


Fig. 3. Ground truthing of Downforce SOC (%) average in 2022 (n=36), with Soil Sample data from 4 paddocks (n= 2) taken in July 2023. Error bars are the standard deviation for Downforce and Min-Max for Soil Samples.

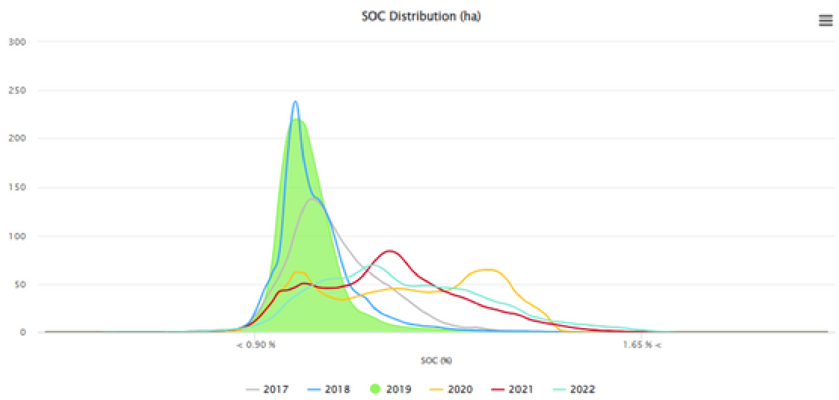
One of the benefits of using Downforce to estimate SOC is that the high frequency of measurements (every ten days) combines to give a good average for the whole year and allows SOC trends to be tracked over many years. With conventional soil carbon sampling, a particular point of time in the season has to be picked, which can lead to either an under or overestimate for SOC for that specific year. Soil carbon in no-till soils can vary by up to 10% depending on when a soil sample is taken in the season (Wuest et al. 2014).

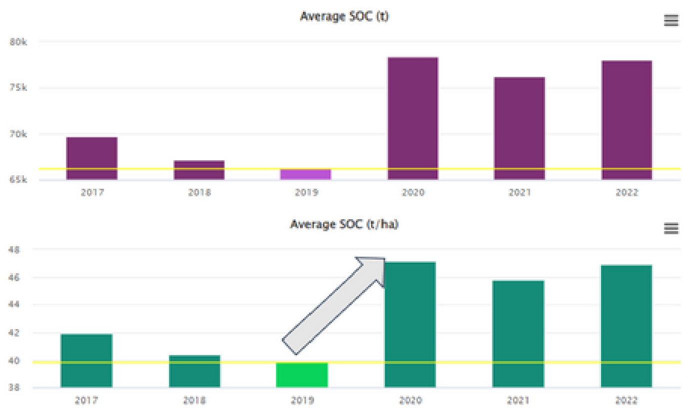
Case Study Findings:
Weemabah, NSW 2017-2022

1. Soil Moisture index was notably lower in 2017-2019 (drought)



2. SOC stocks as much as 7 t/ha lower in 2019 compared to 2020





Case Study:
Weemabah, NSW 2017-2022

Statistical analysis

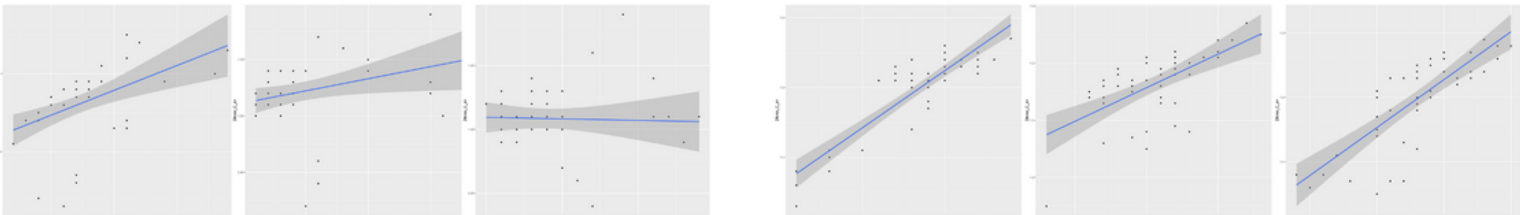
- Considering the management insights within Downforce are limited, the SoilCQuest case studies focused on combining Downforce data (SOC % and Soil Moisture Index) analysed against paddock data and records.

- In each year, we labelled whether a paddock had a crop and which one was grazed.

- We also segmented only grazing paddocks and looked at correlations with grazing indicators and SOC (%) and Soil Moisture Index.

- Correlation and Regression analysis were conducted using R Software and the LME package.

3. SOC% was significantly correlated with Soil Moisture Index (SMI) in all years except for the drought year of 2019



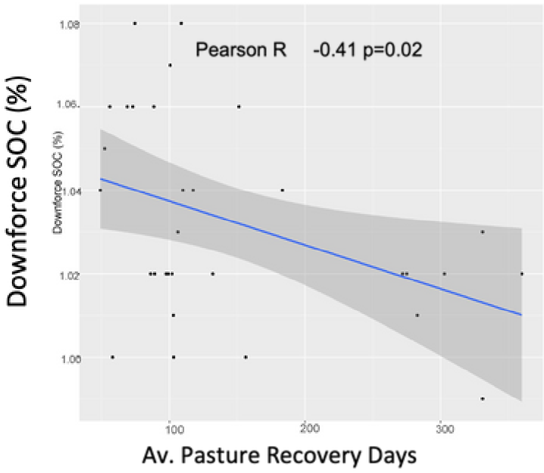
Pearson R 0.5 p<0.01 | 0.31 p=0.02 | -0.03 n.s | 0.89 p<0.01 | 0.64 p<0.01 | 0.79 p<0.01

- We need more insight into whether there are autocorrelation effects between the SMI and Downforce SOM%.

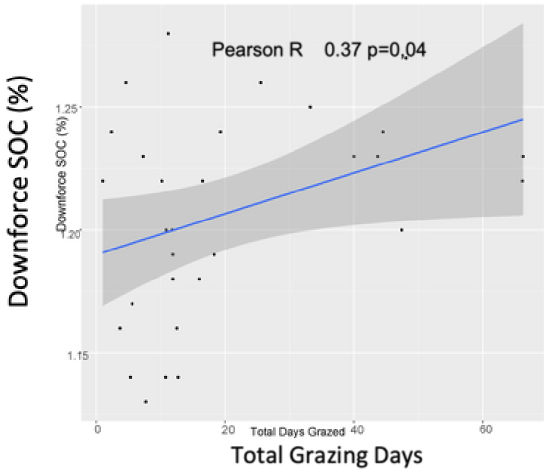
- Is the SMI derived from the same dataset used to model SOC, or is it independent?

Case Study:
Weemabah, NSW 2017-2022

4. Grazing variables that were significantly correlated with Downforce SOC (%)



In drier years (2017-19), SOC% was negatively correlated with the number of pasture recovery days



In wetter years (2020-22), SOC% was positively correlated with the number of total grazing days

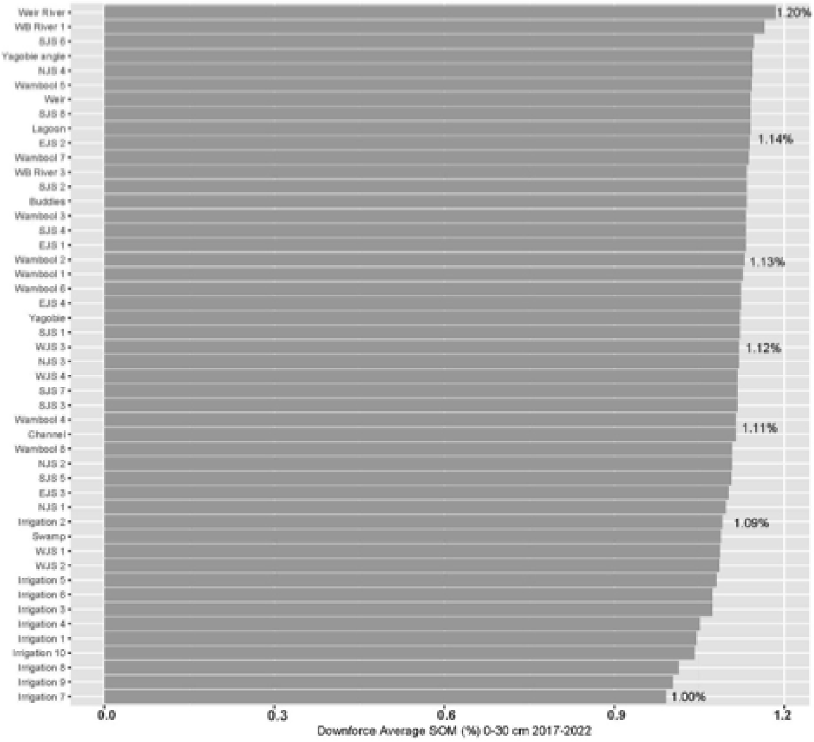
Regression analysis

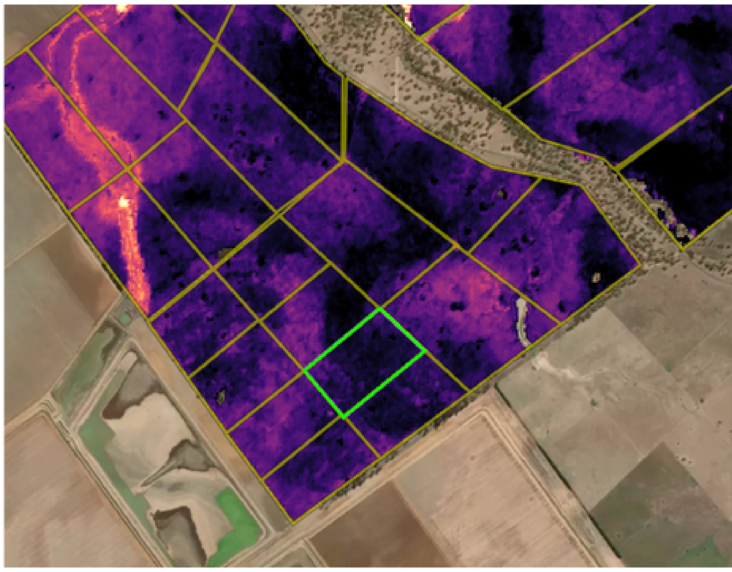
- The table featured here lists variables that had a significant influence on SOC%.
- Soil Moisture was the most critical variable (by order of magnitude) for Downforce SOC (%) across 2017-2022.
- Grazing paddocks had 6% higher SOC than cropping paddocks in 2017-2022.
- Surprisingly, a cover crop in 2021 led to a 4.2% less SOC%.
- Paddocks in Fallow had ~5-6% more SOC % across all years compared to other management practices.

	Coefficient	Std error	p	% change
Intercept	-0.34	0.03		
2018	-0.02	0.01	<0.01**	**-1.7**
2019	-0.03	0.01	<0.001***	**-2.5**
2022	0.03	0.01	<0.001***	**2.8**
2020	0.02	0.01	0.02*	**2.3**
2021	0.02	0.01	<0.01**	**2.1**
Av. Soil Moisture Index	0.85	0.05	<0.001***	**134.7**
Grazing	0.06	0.02	0.014*	**6.0**
Fallow in 2018	0.05	0.02	<0.01**	**5.5**
Fallow in 2019	0.10	0.02	<0.001***	**10.9**
Fallow in 2020	0.11	0.02	<0.001***	**12.1**
Cover crop in 2021	-0.04	0.02	0.03*	**-4.2**
Fallow in 2021	0.05	0.02	0.02 *	**5.1**
Fallow in 2022	0.06	0.02	<0.01**	**6.0**

Case Study:
Weemabah, NSW 2017-2022

Which paddock performed best?





Best and worst soil carbon paddocks

There was a tight average SOC% range between all paddocks - between 1-1.2%

Highest 5 Soil Carbon paddocks

1. Weir River
2. WB River 1
3. SJS 6
4. Yagobie Angle
5. NGS 4

Lowest 5 Soil Carbon paddocks

1. Irrigation 7
2. Irrigation 9
3. Irrigation 8
4. Irrigation 10
5. Irrigation 1

References

Cardinael, R., Chevallier, T., Barthès, B. G., Saby, N. P. A., Parent, T., Dupraz, C., Bernoux, M., & Chenu, C. (2015). Impact of alley cropping agroforestry on stocks, forms and spatial distribution of soil organic carbon - A case study in a Mediterranean context. Geoderma, 259–260, 288–299. https://doi.org/10.1016/j.geoderma.2015.06.015

Garnier, E. Growth analysis of congeneric annual and perennial grass species. 1992. Journal of Ecology, 80, 665-675.

Gray, J., Karunaratne, S., Bishop, T., Wilson, B., & Veeragathipillai, M. (2019). Driving factors of soil organic carbon fractions over New South Wales, Australia. Geoderma, 353(July), 213–226. https://doi.org/10.1016/j.geoderma.2019.06.032

Wuest, S. (2014). Seasonal Variation in Soil Organic Carbon. Soil Science Society of America Journal, 78(4), 1442–1447. https://doi.org/10.2136/sssaj2013.10.0447

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