Soils Report

Amberly Farm

Date: June 2022

Front: Soils for Life soil scientist Daniela Carnovale and Amberly owner John Lilleyman observing the soil profile.

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We acknowledge that the contents of this document do not necessarily reflect the views of these contributors.

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Preface

This document aims to provide a synthesis and summary of soil outcomes at Amberly farm at Tuggeranong in the ACT. The report draws on available information and data from the Lilleymans, and from projects undertaken by ACT NRM and NSW DPI. The collaborative research undertaken as part of this case study combines local, technical, and expert knowledge. Soils For Life value the farmers as researchers who are constantly experimenting based on their knowledge and experience, monitoring the outcomes of their experiments, and adapting their approach when required. Acknowledging the value of both farmer knowledge and specialist technical knowledge, this report draws not only on soil monitoring data, but also on information from interviews and field observations. The data that were provided and generated form a foundation for establishing the patterns of change within the production and ecological systems at Amberly, resulting in a broader understanding of the associated outcomes.

This document is supplementary to the *Amberly Case Study report*, which provides a holistic and integrated account of this change process and the associated outcomes across the property.

Key Findings

- Collaboration with the local NRM organisation was vital for the collation of data to inform decision making on the property.
- Soil data from the 2020 sampling regime show a significant difference in several soil properties between the western side of the property (grazed by pastured chickens) and the eastern side of the property.
- Based on the available information, there is a general trend of increasing soil carbon and increasing soil pH in the Amberly soils as a result of land management practices.
- Moving forward, funding for a long-term soil measurement and monitoring strategy will capture the whole-of-property change over time.
- In the absence of funding, it will be necessary to build farmer capability and knowledge for long-term soil measurement and monitoring.
- Soil biological properties represent a current gap in the available soil data.

Introduction

The landscape

Name	John and Carol Lilleyman		
Enterprise types	Mixed enterprise, including pastured free-range eggs, 20 breeder cattle, market plants (microgreens and succulents), and an on-site music studio	Location	Ngunnawal Country Tuggeranong, ACT
Property size range	105 ha	Annual rainfall	620 mm
Agro-climatic region	Temperate cool season wet	Elevation	587 m
Soils	Kurosols[1] (dominant) and Rudosols[2] (minor occurrences)		
Social Structure	Owners and operators		

Amberly is a 105-ha property located in the urban-rural fringe of the Canberra region, which lies within the upper reaches of the Murrumbidgee River catchment. Annual rainfall is spread over the seasons, with late spring bringing the highest rainfall figures. Vegetation on Amberly includes predominantly exotic grasslands to the west of the property and native grasslands to the east (Figure 1).

Ground-truthing of the soil classifications has not been undertaken, however, according to existing soil mapping (DPIE, 2021), the dominant soils on Amberly are Kurosols, with minor occurrences of Rudosols (alluvial soils)(Figure 2). Kurosols characteristically exhibit a strong texture-contrast between the A and B horizons, and are strongly acidic (Isbell & NCST, 2021).

From discussions with the Lilleymans, it is likely that other soil types occur on Amberly. This assumption is supported by soil landscape mapping for the region, which confirms that the Williamsdale and Burra soil landscapes are dominant on the property (Jenkins, 2000).

The Burra soil landscape is described as ‘undulating to rolling low hills and alluvial fans over the Silurian Volcanics’ (Jenkins 2000, page 44). The Burra soil landscape comprises moderately deep, well-drained Kurosols and Chromosols. Tenosols are present on upper slopes and crests and Kandosols may also occupy the mid and lower slopes (Jenkins, 2000; page 44).

The Williamsdale soil landscape comprises moderately deep Chromosols and Kandosols on the upper rises and fan elements. Moderately deep, poorly drained Sodosols occur on the midslopes and lower slopes (Jenkins, 2000; page 133). The Sodosols are erodible and prone to waterlogging in low-lying areas.

[1] https://www.soilscienceaustralia.org.au/asc/ku/kurosols.htm
[2] https://www.soilscienceaustralia.org.au/asc/ru/rudosols.htm

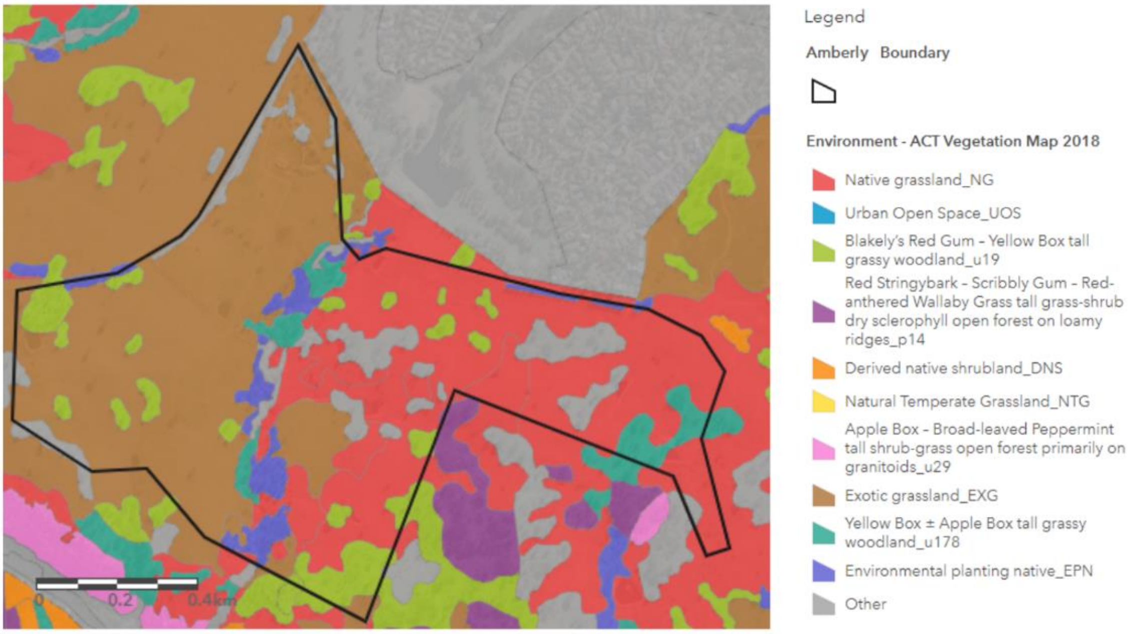

Figure 1: Vegetation map for Amberly, ACT.

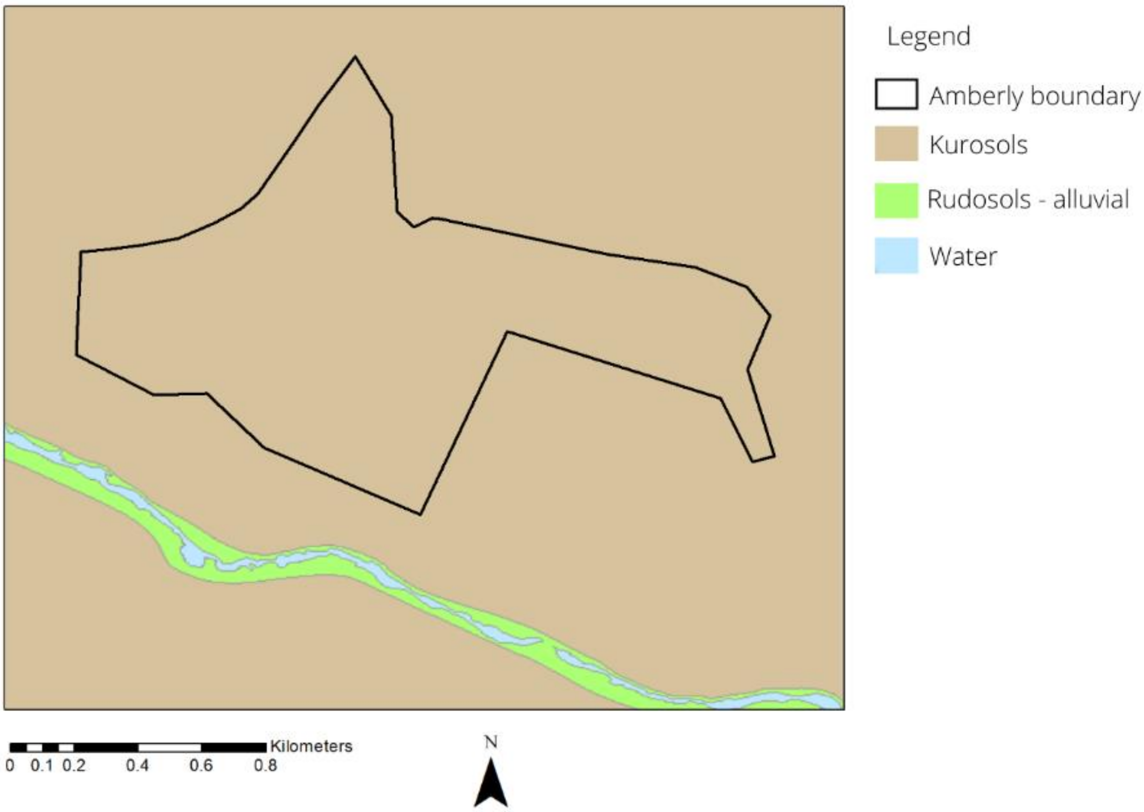

Figure 2: Soil map (Australian Soil Classification) for Amberly, ACT.

Property management

Amberly was purchased by John and Carol Lilleyman in late 2012. Prior to this time, the property had a history of set-stock cattle grazing, which the Lilleymans continued for two years. In 2014, the Lilleymans transitioned to cell grazing with the assistance of an ACT Rural Grant administered by ACT NRM under Australian Government funding. This involved the splitting of larger paddocks into smaller paddocks by installing permanent electric fencing and investing in a reticulated water infrastructure. The property is now divided into 13 paddocks (Figure 3). A large, incised creek divides the property into the paddocks to the east and the paddocks to the west of the creek. The paddocks to the east are referred to as the Tuggeranong paddocks and are less productive due to the landscape topography and soils. The Tuggeranong paddocks are higher in the landscape and include the shallow, stony soils that do not occur elsewhere on the property. The paddocks to the west, referred to as the Kambah paddocks, are lower in the landscape and include deeper, more productive soils, making them ideal for pastured chickens. Chickens were introduced to the Kambah paddocks in 2017 to improve soil health by contributing to the nutrient cycling in the farming system. The Tuggeranong paddocks to the east of the property are used for cattle grazing and two of the Tuggeranong paddocks, T1 Creek and T1 Top (12 ha), have undergone Whole of Paddock Restoration (WOPR). The WOPR was undertaken with the support of the ACT Government and Greening Australia and involved the planting of 830 native trees. From 2015 to 2020, the Lillymans undertook multiple revegetation plantings (see Figure 3), which are discussed further in the Amberly Case Study report.

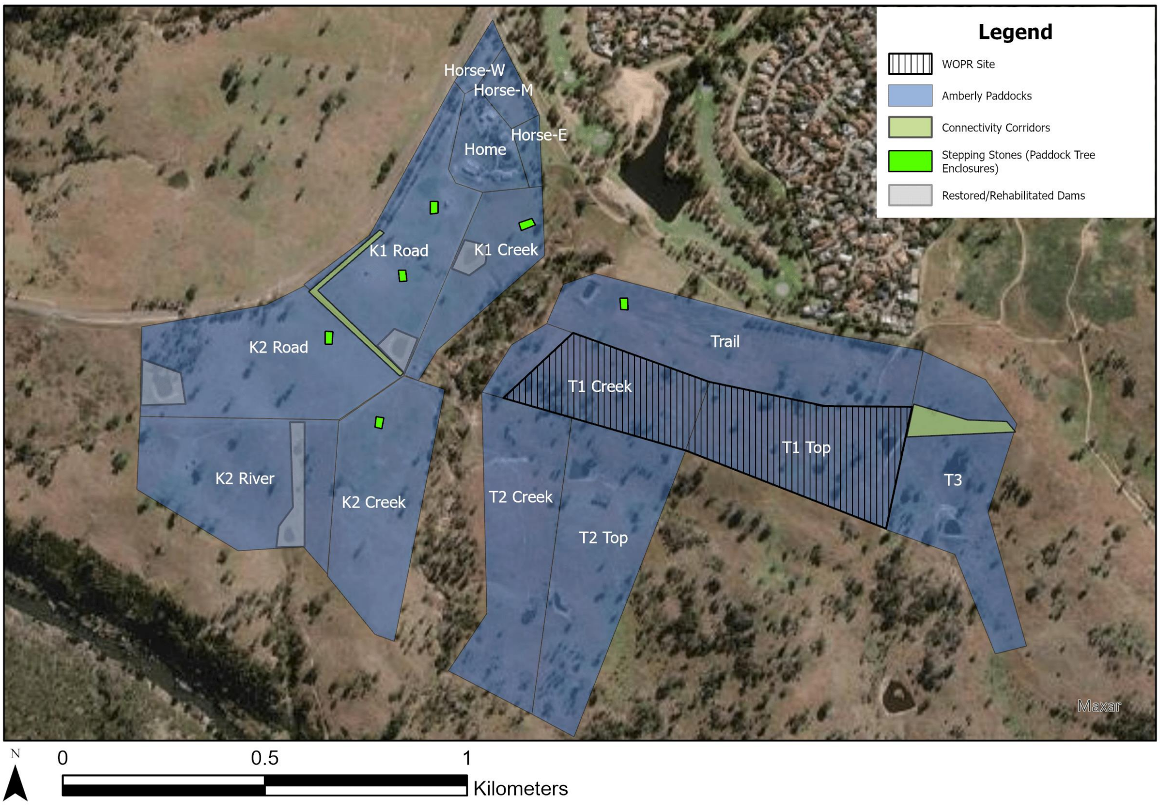

Figure 3: Paddocks and revegetation (tree plantings) from 2015 to 2020.

Paddock treatments

Prior to introducing pastured chickens in 2017, the Lilleymans applied single superphosphate until 2017 and Molybdenum in 2015. To address acidic soil conditions (pH 5.73 average from 2013-2015), lime was applied in March 2015 at a rate of 1000 kg/ha. Since the introduction of chickens to the Kambah paddocks, the Lilleymans no longer use additional fertiliser inputs. The only input into the system has been in the form of chicken feed and the concentration of nutrients in the chicken manure.

Table 1: Kambah paddock treatments at Amberly since 2014.

Kambah Paddocks								
Date	**Treatment**	**Application rate**	**K1 Road**	**K1 Creek**	**K2 Road**	**K2 Creek**	**River**	**Horse**
March 2014	Single Super	125 kg/ha	X	X	X	X	X	X
March 2015	Single Super (+ trace Molybdenum)	125 kg/ha	X	X	X	X	X	X
March 2015	Lime	1000 kg/ha	X	X	X	X	X	X
April 2016	Single Super	125 kg/ha	X	X	X	X	X	X
April 2017	Single Super	125 kg/ha	X	X	X	X	X	X
September 2017	Chickens	500	X		X	X	X	
2018	Chickens	1000	X		X	X	X	
2019	Chickens	1500	X		X	X	X	
September 2020	Chickens	3000	X		X	X	X	
November 2021	Chickens	4500	X		X	X	X	

A history of soil sampling

Since purchasing Amberly in 2012, the Lilleymans have been undertaking soil sampling and monitoring on a regular basis. Initially this started off as undertaking targeted sampling and analysis to support the application of inputs such as single superphosphate and inform decisions on the application of lime. As time has progressed, the Lilleymans have partnered with ACT NRM and NSW DPI on a range of projects to better understand the outcomes of their management decisions. In total, there have been eight sampling events at Amberly between 2013 and 2021 (see Table 2 and Figure 4 for details).

Table 2: Soil sampling at Amberly from 2013 to 2021 showing the depth (cm) of sampling for analysis.

Sample ID	Date	Sampling Site Reference[1]	Depth (cm)						
			0-10	0-5	5-10	10-20	10-15	15-20	20-30
1A	1/1/2013	Horse-E	X			X			
1B		Horse-M	X			X			
1C		K1 Creek	X			X			
2A	2/2/2015	K2 River	X						
2B		K2 Creek	X						
2C		K2 Road	X						
2D		Control (off-farm)	X						
3A	4/5/2015	Trail 1	X						
3B		T2	X						
4A	27/9/2017	K2 Road	X						
5A	5/2/2019	Trail 2		X	X	X			X
5B		K2 Creek		X	X	X			X
6A	20/5/2019	K1 Road (Garlic)	X						
7A	30/9/2020	K2 Creek (H)		X	X		X	X	X
7B		K2 Creek (L)		X	X		X	X	X
7C		Trail 3		X	X		X	X	X
7D		T1 Creek (WOPR)		X	X		X	X	X
8A	6/11/2021	K1 Road (H)	X						
8B		K1 Road (L)	X						
8C		K2 Road (H)	X						
8D		K2 Road (L)	X						

[1] Other than the Control, the "Sampling Site Reference" reflects the paddock from which the sample was collected, and/or the treatment. For example, T = Tuggeranong, K = Kambah, (H) = high exposure to chicken manure (in the path of the chicken trailer), (L) = low exposure to chicken manure (grazed by chickens, but not in the path of the chicken trailer).

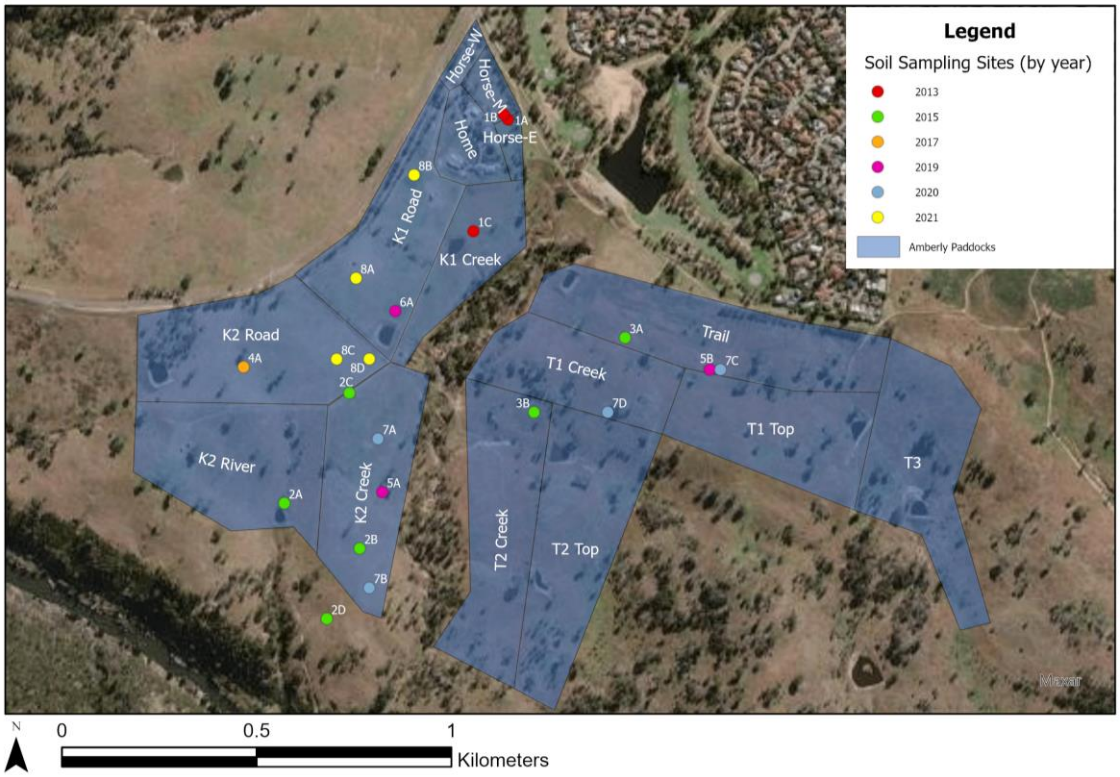

Figure 4: Soil sampling locations at Amberly from 2013 to 2021.

Soil sampling methods

The methods used during each sampling event have varied, and this includes sampling at a range of soil depths from 5 cm to 30 cm (Table 2). John and Carol Lilleyman conducted the sampling in 2013, 2015, 2019, and 2021, using a core sampler to a soil depth of up to 20 cm. Several individual samples were collected over a 10 m^2 area at each location and combined into a bulk sample. A smaller sample was then collected from the bulk sample and forwarded to the laboratory for analysis.

The Lilleymans partnered with ACT NRM, who coordinated and conducted soil sampling events for various programs on Amberly during 2015, 2017, 2019, and 2020. The most comprehensive of these was sampling events occurred in 2020, when deeper soil coring to 30 cm was undertaken for a paired paddock program. The 2020 sampling event was primarily to understand changes in soil organic carbon, pH, sulphur, and other soil chemical properties at different sites, and was useful in exploring the effects of manure addition versus revegetation at Amberly.

Table 3 Soil sampling and analysis methodology.

Sample ID	Date	Sampling Site Reference[1]	Sampling method
1A 1B 1C	1/01/2013	Horse-E Horse-M K1 Creek	Sampling was undertaken by the Lilleymans using a core sampler at 0-10 cm and 10-20 cm soil depth. Samples were collected in the vicinity of each sampling location (within about a 10 m^2 radius). Samples were analysed by Nutrient Advantage.
2A 2B 2C 2D	2/02/2015	K2 River K2 Creek K2 Road Control (off-farm)	Sampling was undertaken by ACT NRM from 0-10 cm using a manual core sampler. More than 20 samples were collected along transects and then bulked into a single sample from each site. Samples were analysed by EAL.
3A 3B	4/05/2015	Trail 1 T2	Sampling was undertaken by the Lilleymans using a core sampler at 0-10 cm depth. Samples were analysed by Nutrient Advantage.
4A	27/09/2017	K2 Road	Sampling was undertaken by ACT NRM with support and training provided by NSW DPI as part of a larger project. Samples were collected with a manual core sampler from 0-10 cm depth in the soil. Samples were analysed by NSW DPI environmental laboratories and Nutrient Advantage. In addition, Clover spp. in the area where soil sampling was undertaken were identified and sampled and the nodules on each plant were counted and ranked in terms of health. This work aimed to understand if legume nodulation on the clover species was negatively impacted by low soil pH; and to understand whether pasture legumes such as clover species in ACT pastures were fixing nitrogen or drawing-down the soil nitrogen pool due to poor legume nodulation and reduced nitrogen fixation.
5A 5B	5/02/2019	Trail 2 K2 Creek	Sampling was undertaken in collaboration with ACT NRM and NSW DPI. A petrol-powered soil corer was used to collect samples from 0-5 cm, 5-10 cm, 10-15 cm, 15-20 cm, and 20-30 cm soil depths. Samples were analysed by Nutrient Advantage. Note: this project initially aimed to return to sites sampled during the Millennium Drought in the early 2000s as part of the Murrumbidgee CMA *Healthy Soils, Healthy Landscapes* project looking at changes in soil chemistry and soil health. Given it was difficult to locate the *Healthy Soils, Healthy Landscapes* sampling sites, this 2019 sampling program was expanded to include landholders who had not participated in the *Healthy Soils, Healthy Landscapes* program.

Sample ID	Date	Sampling Site Reference[1]	Sampling method
6A	20/05/2019	K1 Road (Garlic)	Sampling was undertaken by the Lilleymans using a core sampler. One sample was taken from 0-10 cm depth, the results of which would inform a decision for a garlic trial on the property.
7A 7B 7C 7D	30/09/2020	K2 Creek (H) K2 Creek (L) Trail 3 T1 Creek (WOPR)	Sampling was undertaken by ACT NRM. The project aim was to better understand the impact of chicken manure on soil chemical properties and other land management activities. A petrol-powered soil corer was used to collect four replicate samples at 0-5 cm, 5-10 cm, 10-15 cm, 15-20 cm, and 20-30 cm soil depths for each treatment. Samples were analysed by Nutrient Advantage.
8A 8B 8C 8D	6/11/2021	K1 Road (H) K1 Road (L) K2 Road (H) K2 Road (L)	Continuing the theme to better understand the impacts of chicken manure, John Lilleyman undertook sampling at 0-10 cm soil depth using a core sampler. Approximately 35 core samples were collected in the vicinity of each sampling location and combined (bulked). Samples from the bulked sample were analysed by DPI environmental labs. This sampling was undertaken as part of a training program delivered by South East Local Land Services aimed at building farmer skills in sampling soils and interpreting soil test results.

[1] Other than the Control, the "Sampling Site Reference" reflects the paddock from which the sample was collected, and/or the treatment. For example, T = Tuggeranong, K = Kambah, (H) = high exposure to chicken manure (in or near the path of the chicken trailer), (L) = low exposure to chicken manure (grazed by chickens, but not in the path of the chicken trailer).

Data Enquiry Method

The extensive soil sampling and testing undertaken for Amberly, and the willingness of the Lilleymans and ACT NRM to share the resulting soil data, has allowed Soils for Life to better understand the changes in the soil properties over time and the general soil condition at Amberly. All available data from the existing soil sampling have been consolidated into one database.

A visual assessment of the combined dataset was made to determine whether any further analysis should be undertaken. This visual assessment confirmed a range of tests had been performed at different sampling depths in any given year, and over several years. A total of 28 soil properties were measured across several sampling events for a number of different projects. Samples were submitted to different laboratories depending on the project, and some soil properties were analysed by different methods and reported in different units. A summary of the soil properties measured and the units of measurement from 2013-2021 at Amberly is shown in Appendix 1.

Based on the visual assessment of the dataset, only the samples collected at 0-10 cm depth provided enough data for a meaningful comparison to be made. To determine any change in soil properties over time, only the soil properties analysed using the same laboratory method were compared across sampling years. A visual observation of the trends over time in the soil data was gained by plotting the results by year, and the data were also visualised spatially using ArcGIS.

The 2020 dataset, representing a replicated trial with different treatments, was also analysed separately to the other soil data derived from soil sampling at Amberly. This dataset allowed for a deeper enquiry into the soil properties according to site, soil depth, and treatment. The one-way analysis of variance (ANOVA) test determined whether there were significant differences in the soil properties between all four sites:

- K2 Creek (H), receiving high manure inputs.
- K2 Creek (L), receiving low manure inputs.
- WOPR, whole-of-paddock restoration (of vegetation)
- Trail 3 (no treatment).

Results

All sampling years

A limited number of measured soil properties could be compared across the multiple sampling time periods. This is attributed to different methods being used to measure different soil properties over the years. Also, because fewer soil samples were collected and analysed from soil depths between 10 cm and 30 cm, little insight into changes in the soil properties below 10 cm depth could be made.

0-10 cm

The available data for 0-10 cm soil depths across the property appears to show an increasing trend over time for soil pH, sulphur, and carbon (C). No such trend over time is obvious for total nitrogen or phosphorus (Figure 5). In relation to sulphur, which has historically been a limiting nutrient for pasture growth at Amberly, the results from soil sampling in 2020 and 2021 are an early indication that sulphur levels are increasing on the western side of the property in the Kambah paddocks. This is likely due to the chicken manure inputs in these paddocks.

The Phosphorus Buffering Index (PBI) approximates the soil's ability to chemically absorb or 'fix' phosphorus (P). Soils with a high PBI will lockup phosphorus fertiliser, rendering it unavailable to plants. Low PBI soils cannot absorb phosphorus, leaving most applied phosphorus available for plant uptake. The PBI at Amberly has decreased slightly over time. Continued analysis of the PBI will provide an indication if this is a long-term trend (Figure 5).

Cation exchange capacity (CEC), which is a measure of a soil's ability to hold exchangeable cations, was analysed by two methods. Samples collected from 2013 to 2019 were tested using the ammonium acetate (NH_4OAc) method, and samples collected from 2020 to 2021 were tested using the barium chloride/ammonium chloride ($BaCl/NH_4Cl$) method. As such, CEC could not be confidently compared across all sampling events. Disregarding the different

CEC methods used, a trend of increasing CEC over time is evident in the samples collected from 0-10 cm depth in the soils (Figure 8).

Differences in results were observed when comparing the Kambah paddocks (the western side of the property) with the Tuggeranong paddocks (the eastern side of the property). Generally, the soils in the Kambah paddocks with the chickens had higher pH and total nitrogen levels.

Despite the cessation of superphosphate applications in 2017, phosphorus in the 0-10 cm soil samples has generally increased in the paddocks where the chickens have grazed. Soil phosphorus levels are now considered to be conducive to good pasture growth.

The Tuggeranong paddocks to the east, which are mostly under native revegetation, are periodically grazed by cattle and have lower soil phosphorus levels. The low phosphorus levels will suit the native vegetation, which is not well-adapted to high levels of phosphorus in the soil. Soil carbon is variable and no clear trend across the property could be made for the samples collected from 0-10 cm soil depth.

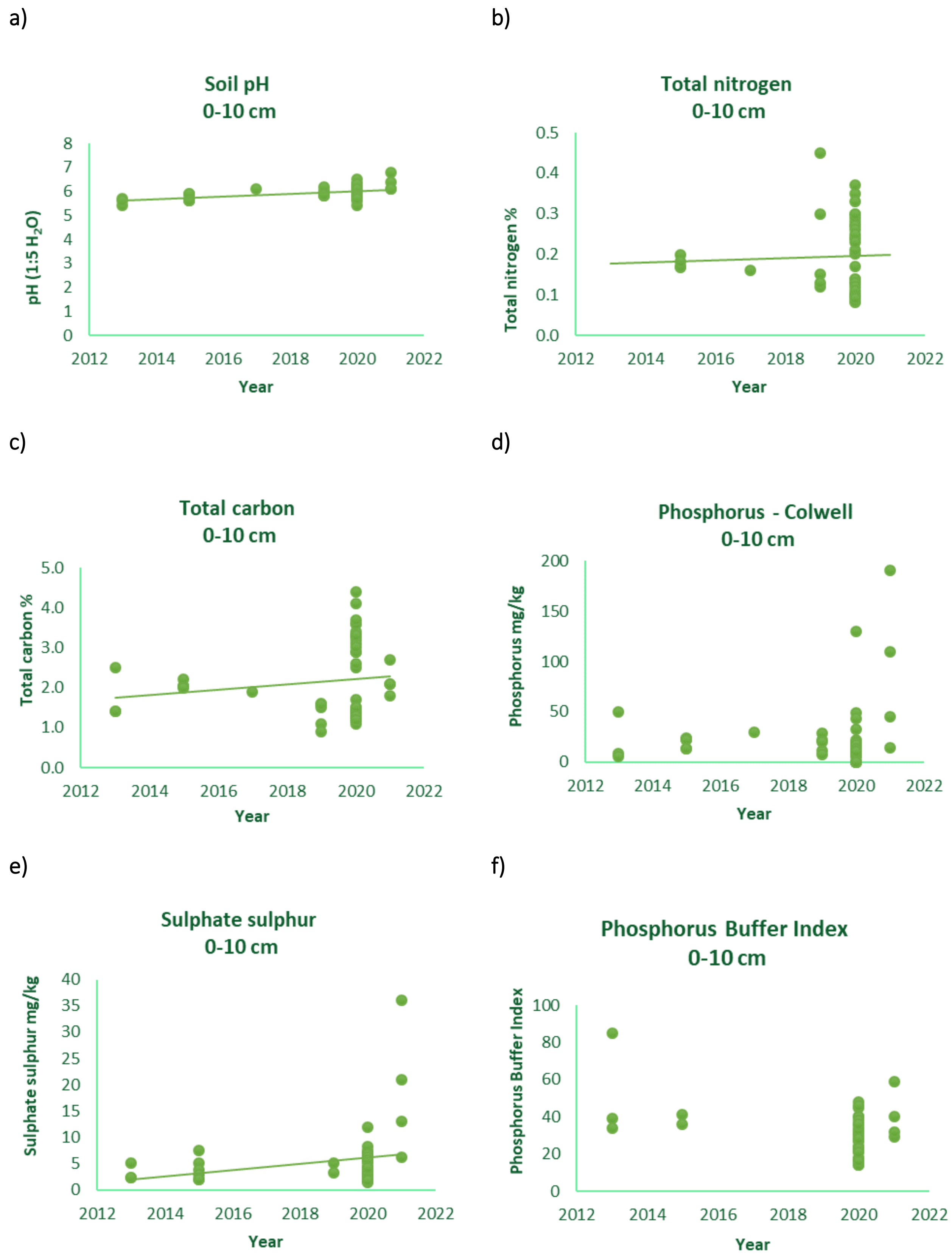

Figure 5: Soil properties a) pH (H_2O), b) Total nitrogen (combustion), c) Total carbon (combustion), d) Phosphorus (Colwell), and e) Sulphate sulphur (KCl_4O), in the top 0-10 cm of soil at Amberly from 2013 to 2021. Only soil properties measured using consistent analytical methods over multiple years are shown.

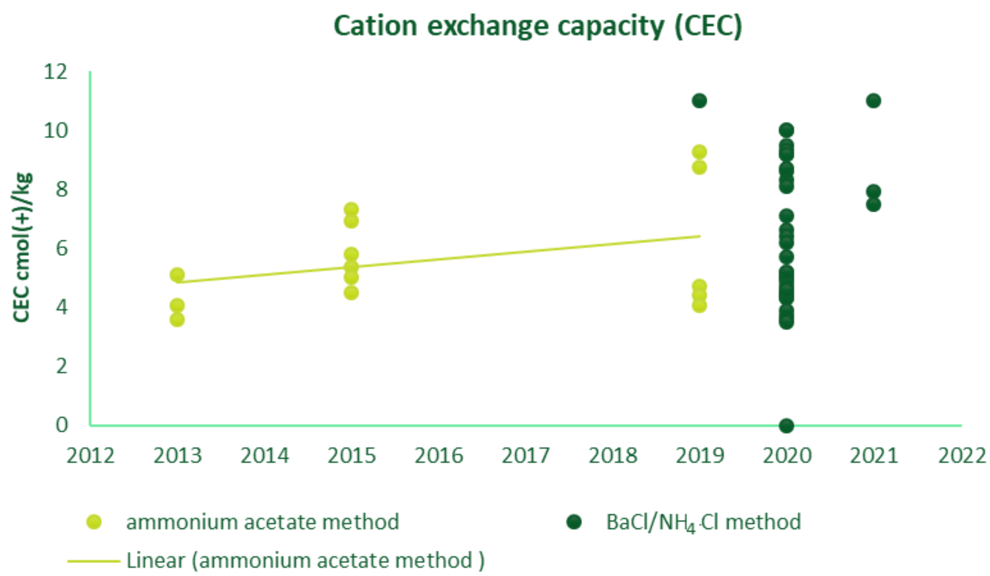

Figure 6: Cation exchange capacity of soil samples collected from 0-10 cm at Amberly from 2013 to 2021, analysed using the ammonium acetate (NH_4OAc) method or the barium chloride/ammonium chloride ($BaCl/NH_4Cl$) method.

10-20 cm

Sampling at 10-20 cm soil depth was undertaken in 2013, 2019 and 2020. Due to the limited dataset (only three timepoints and three different sample sizes), a statistical analysis was not performed. The only soil properties measured consistently for these years were pH and electrical conductivity (EC) (Figure 8).

Looking at the averages for each year, there is a trend of increasing pH from 2013 to 2020. However, this trend should be taken with caution due to the limited numbers of samples tested in 2015 (4 samples) and 2019 (2 samples). The remaining 16 samples were collected and tested in 2020.

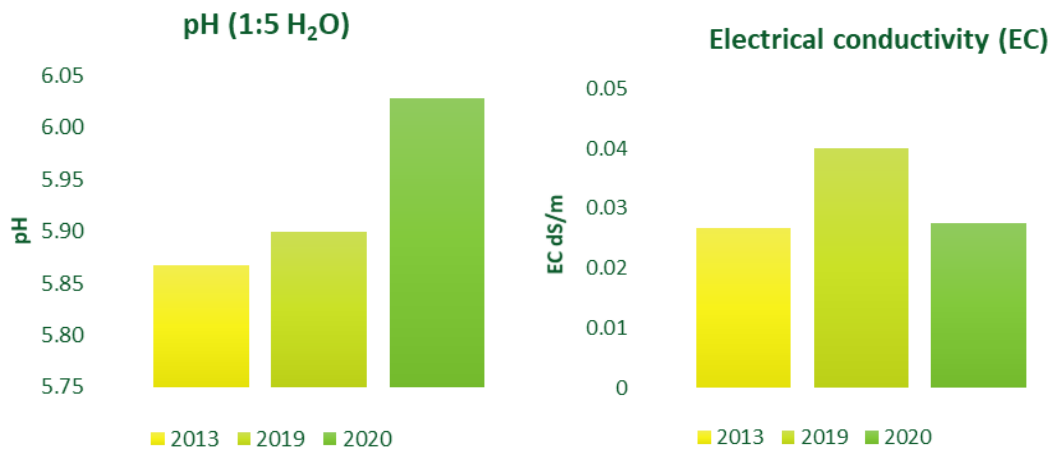

Figure 7: Average pH and EC in 2013, 2019 and 2020 at 10-20 cm soil depth.

20-30 cm

Sampling at 20-30 cm depth was undertaken in 2019 and 2020. As there were only two timepoints and each had a different sample size (two samples in 2019 compared to 16 samples in 2020), a statistical analysis was not performed. No trend over time could be established for the soil properties collected at 20-30 cm depth at Amberly from 2019 to 2020.

2020 soil analysis

In 2020, sampling was undertaken in collaboration with ACT NRM to better understand the impact of chicken manure on soil chemical properties. Two sites were compared, one that received high inputs of chicken manure (H), and one that did not receive high inputs of chicken manure (L). The impact of revegetation (tree planting) on another site was also of interest.

The samples from the site receiving high inputs of manure were collected from an area that had been in the path of the chicken trailer. The samples from the site receiving low inputs of manure (L) were collected from an area that had not been in the path of the chicken trailer.

The other samples were collected from the Trail paddock and T1 Creek (WOPR) paddock on the western side of the property (Tuggeranong paddocks). The Trail paddock was of interest as a baseline for future pasture cropping and the revegetation site (WOPR) had only been established for about a year at the time of the sampling.

Soil properties down the soil profile (0-30 cm)

For each sampled soil depth, statistical analyses (ANOVA and Tukey pairwise tests) were performed to determine any differences between the sites. The results of the statistical analyses are presented in Appendix 2 and a summary is provided in Table 4.

The trends in soil properties down the profile are illustrated in Figure 9 and Figure 10. As soil depth increased, total carbon, total nitrogen and EC decreased. Between sites, there was greater variability in the soil properties in the 0-10 cm samples than in the 10-30 cm samples.

The site receiving high chicken manure inputs (K2 Creek (H)), had higher total nitrogen than the other sites from 0-30 cm depth in the soil profile (Figure 9). In general, there was a narrower range in total nitrogen levels between both the K2 Creek sites and the WOPR and Trail sites.

There was little difference in soil carbon at each sampling depth between sites (Figure 10), with soil carbon being significantly different between the sites at 5-10 cm depth only (Table 4). The difference in soil pH, total nitrogen, and EC for each site decreased with soil depth (Figure 9). As soil depth increased, the differences in Ca^{2+}, Al^{3+}, Mg^{2+}, and K^{+} between the sites were consistent down the profile (Figure 10).

The variability in the measured soil properties between sites is supported by the results of the statistical analyses presented in Table 4 and in Appendix 2.

Historically, the soils of the WOPR site (in the Tuggeranong paddocks on the western side of the property) are less fertile, and this trend is supported by the soil chemistry results from 2020. The WOPR site had significantly lower pH, CEC, Ca^{2+}, total nitrogen, and phosphorus at various depths (see Appendix 2 for further information on the differences within each soil depth range). These paddocks are now only occasionally grazed when the conditions are right, and no additional inputs are used.

0-5 cm

ANOVA was performed to determine any significant differences between the means for the samples collected from 0-5 cm depth at each site. There was no significant difference between sites for total carbon, bulk density, EC, and sodium.

The Tukey pairwise test (for differences between individual sites) showed that the WOPR site was significantly different ($p \le 0.05$) to the other sites for pH, total nitrogen, sulphate sulphur, Al^{3+}, Ca^{2+}, and CEC. Phosphorus in the high manure site (K2 Creek (H)) was higher than all other sites, which were not significantly different to each other. This increase in phosphorus is a result of the high levels of phosphorus in the chicken manure.

Sulphur, which had previously been identified as a limiting nutrient for pasture growth at Amberly, was significantly higher in the high manure site (K2 Creek (H)) compared to all other sites for samples collected at 0-5 cm soil depth (Appendix 2). This indicates that the chicken manure is having a positive impact on sulphur levels.

The CEC of the samples collected from 0-5 cm soil depth ranged from 4.98 to 9.70 cmol(+)/kg (Figure 10 and Appendix 2). The CEC of soils may be influenced by several factors, including soil texture (many of the Amberly topsoils are sandy in nature), clay content (specifically the abundance and type of clay), and organic matter content. The CEC was lowest at the WOPR site (4.98 cmol(+)/kg) compared to the other sites and this may be a result of an increase in organic matter from the chicken grazing.

5-10 cm

ANOVA was performed to determine any significant differences between the means for the samples collected at 5-10 cm depth at each site. There was no significant difference between sites for the soil properties EC, sulphate sulphur, or pH (Table 4).

Total carbon was significantly lower ($p \le 0.05$) at the WORP site than in the high manure (K2 Creek (H)) and low manure (K2 Creek (L)) sites. While further investigation would be needed to confirm the cause, this is likely due to the lower levels of organic matter in the topsoil of the WOPR site as a result of the soil type and land management. The WOPR site also showed lower levels of Ca^{2+}, K^{+}, and Al^{3+}, but higher levels of Mg^{2+} and Na^{+} compared to the other sites (Appendix 2). The high manure site (K2 Creek (H)) had significantly higher total nitrogen and phosphorus levels than all other sites.

10-15 cm

ANOVA was performed to determine any significant differences between the means for the samples collected at 10-15 cm depth at each site. There was no significant difference between sites for the soil properties bulk density, EC, total nitrogen, total carbon, pH, or C:N. There was a significant difference ($p \leq 0.05$) between sites for basic cations, CEC, Ca:Mg, and sulphur (Table 4).

The Tukey pairwise test (for differences between individual sites) provided variable results. Generally, there was a significant difference ($p \leq 0.05$) for basic cations and sulphur between the high manure site (K2 Creek (H)) compared to the WOPR site. The high manure site (K2 Creek (H)) compared to low manure site (K2 Creek (L)) had a significant (negative) effect for sulphur, Mg^{2+}, and Ca:Mg.

Of note is the low sulphur in the samples collected at 10-15 cm depth from the high manure site (K2 Creek (H)), which had the highest sulphur at 0-5 cm depth than any other site. This might be explained by the slower movement of sulphur down the soil profile because of the impact of chicken grazing.

15-20 cm

ANOVA was performed to determine any significant differences between the means for the samples collected at 15-20 cm depth at each site. There was no significant difference between bulk density, EC, total N, total C, Na^{+}, or C:N. There was a significant difference ($p \leq 0.05$) between pH, basic cations, CEC, and Ca:Mg (Table 4).

The Tukey pairwise test (for differences between individual sites) provided variable results with no clear trends. However, there was a significant difference between the high manure site (K2 Creek (H)) compared to the WOPR site for Al^{3+}, Mg^{2+}, and Ca:Mg. In addition, there was a significant difference between the high manure site (K2 Creek (H)) and the low manure site (K2 Creek (L)) for Mg^{2+}, Ca:Mg, and CEC.

20-30 cm

ANOVA was performed to determine any significant differences between the means for the samples collected at 20-30 cm depth for each site. There was no significant difference between the treatments for bulk density, EC, total N, total C, pH, Na^{+}, Al^{3+}, or C:N. There was a significant difference ($p \leq 0.05$) for pH, basic cations, CEC, and Ca:Mg (Table 4).

The Tukey pairwise test (for differences between individual sites) provided variable results. There was significant pairwise difference between the high manure site (K2 Creek (H)) compared to the WOPR site for K^{+}, Ca^{2+}, and Ca:Mg (Appendix 2). There was a significant difference (negative) between the high manure site (K2 Creek (H)) and the low manure site (K2 Creek (L)) for Mg^{2+} and Ca:Mg. In addition, pH was significantly higher in the high and low manure sites on the western side of the property (Kambah paddocks) compared to the WOPR and Trail sites on the eastern side of the property (Tuggeranong paddocks) (Appendix 2).

*Table 4: Summary of the results of the statistical analyses between sites for the soil properties at each soil sampling depth. ***= P ≤ 0.001, ** = P ≤ 0.01, * = P ≤ 0.05, NS= not significant P > 0.05*

	Soil Sampling Depth (cm)				
	0-5	5-10	10-15	15-20	20-30
pH (H_2O)	***	NS	NS	*	***
Total N %	*	**	NS	NS	NS
Total C %	NS	*	NS	NS	NS
Phosphorus (Colwell) **mg/kg**	***	***	NS	NS	NS
C:N	*	**	NS	NS	NS
Potassium **mg/kg**	***	**	NS	NS	NS
Sulphate Sulphur mg/kg	***	NS	*	NS	NS
Aluminium %	***				
Aluminium cmol(+)/kg		***	*	*	
Calcium cmol(+)/kg	***	***	***	***	***
Potassium cmol(+)/kg	**	*	*	*	***
Magnesium cmol(+)/kg	**	**	**	***	***
Sodium cmol(+)/kg	NS	*	*		*
Ca:Mg	***	***	***	***	***
CEC cmol(+)/kg	***	22	***	***	***
Bulk density	NS	*	NS	NS	NS

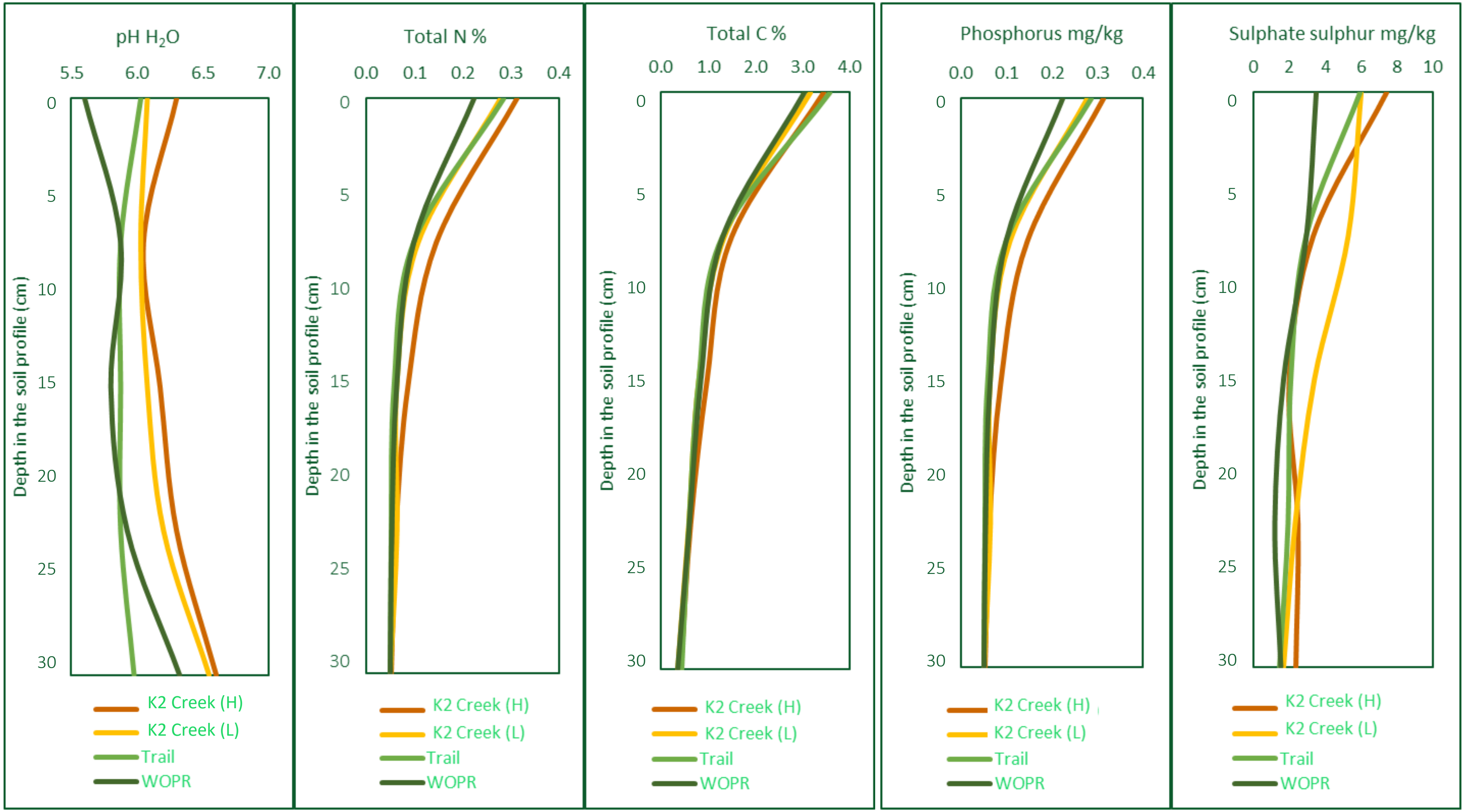

Figure 8: Trends in soil properties from 0-30 cm depth in the soil (2020).

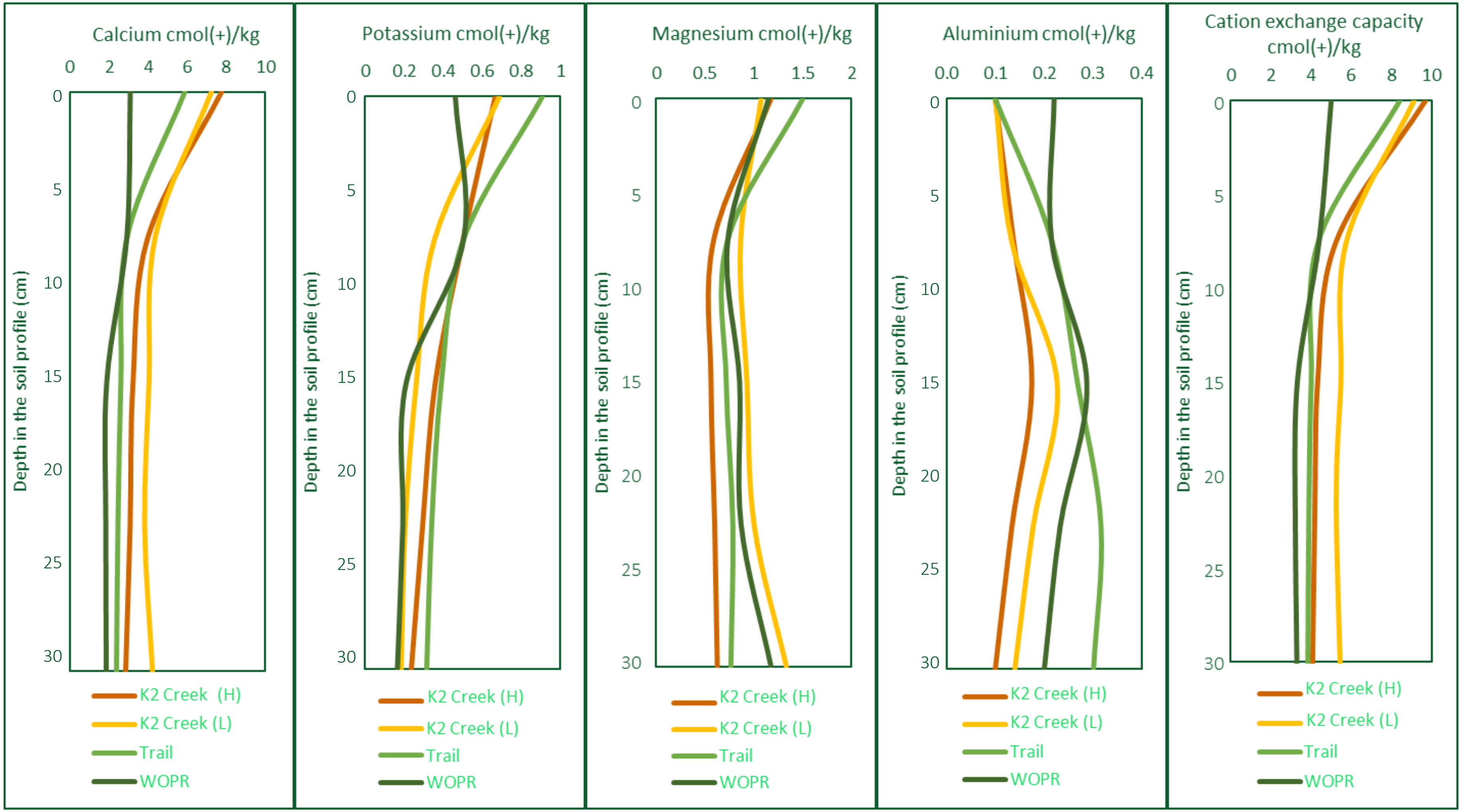

Figure 9: Trends in soil properties from 0-30 cm depth in the soil (2020).

Soil Insights

Value of partnerships in undertaking soil monitoring

The soil investigations at Amberly are a testament to the Lilleymans and ACT NRM, who have collaborated to explore the differences in the soils on the property. Without relationships such as this, the soil sampling and monitoring regime undertaken at Amberly would not have been possible.

Additional collaboration with Soils for Life has allowed further analysis, interpretation, and consolidation of the existing data, which has highlighted useful trends and insights. Moving forward, more benefits will be gained from long-term relationships, including the opportunity to undertake soil sampling, measuring, and monitoring over multiple years to confirm changes in soil properties over time.

In addition to external collaborations, there is a need to build farmer capability and knowledge to undertake ongoing sampling for the purpose of monitoring soil health at Amberly. This will be particularly important if external project funds are not available for such activities in the future.

The soil sampling and testing of the Amberly soils has covered a range of soil chemical and physical properties. Additional value may be added to these data by collecting information on other soil physical properties, such as soil structure, and soil biological properties, many of which are useful indicators of soil health.

The measuring and monitoring of these additional properties may be achieved through a combination of farmer-led field assessments (e.g. earthworm or total soil macroinvertebrate counts) and laboratory assessment of microbial biomass, the ratio of fungi to bacteria, microbial community composition, or enzyme activities. Other measures that can provide insights into soil health and condition include ground cover assessments and soil water infiltration, which can be estimated in the field without engaging specialists.

Soil trends across Amberly

There are clear differences in the soil chemical properties on the eastern part of the property (the Tuggeranong paddocks) compared to the western part of the property (the Kambah paddocks). The soils to the east have lower pH, total N, and phosphorus. This reflects both the differences in soil type (e.g. the occurrence of sandy, stony soils in the Tuggeranong paddocks) and the management practices. The grazing and manure inputs of the chicken rotations on the Kambah paddocks are likely to be contributing to increased levels of total nitrogen and phosphorus in the soils of these paddocks. This has been explored and discussed in more detail in the insights from the 2020 sampling events.

Changes over time

The soil data collected since 2013 have allowed the Lilleymans to better understand the changes in the soil properties on their property. While the available soil data do not show statistically significant changes in the soil properties over time, the information gleaned from the data provides trends and insights that are supporting innovation on Amberly.

The cessation of inputs such as superphosphate and lime have had limited effect on pH and phosphorus levels according to the sampling undertaken after 2017, and the addition of the chickens appears to have had a positive impact on total nitrogen and phosphorus in the grazed pasture paddocks. Though there is a trend of increasing pH and total carbon, ongoing monitoring using the same sampling design and sample analysis methodology will assist in confirming this trend.

Key insights from the 2020 sampling

The sampling undertaken in 2020 provided more detailed insights into the variability in soil properties, including the effect of the chicken manure. The greatest impact on soil properties between the sites was observed in the samples collected at 0-5 cm depth, with diminishing effects on soil properties as soil depth increased.

The impact of high inputs of chicken manure on the soil chemical properties included a significant increase in phosphorus and nitrogen for the samples collected at 0-5 cm depth. This is not unexpected as fresh chicken manure can contain between 0.5% and 0.9% nitrogen, and 0.4% and 0.5% phosphorus.

Between sites, there were significant differences in cations and CEC deeper in the soil. These differences are likely due to soil type rather than a manure treatment effect. Longitudinal studies of manure inputs at Amberly could confirm this conclusion.

Soil properties such as total nitrogen, total carbon, phosphorus, C:N ratio, and potassium did not differ significantly between sites at soil depths greater than 10 cm. Changes in these soil properties beyond 10 cm depth in the soil typically require longer timeframes, particularly in temperate environments.

For future soil projects, it would be interesting to explore the nutrient cycling and emission rates under the chicken trailer compared to the surrounding pasture paddocks, and whether there is capacity in these systems to increase soil carbon sequestration rates.

Need for a soil monitoring plan

While being opportunistic leads to insights on certain aspects of soil monitoring, the Lilleymans are keen to develop a more strategic soil monitoring plan going forward. Some useful things that the Lilleymans can consider when planning long term soil monitoring include:

- Following a fit-for-purpose sampling procedure, including sampling at consistent soil depth intervals for easier comparisons across sampling events.

- Undertaking sampling and monitoring to 30 cm (or deeper) to explore the potential for soil carbon farming (following the approved procedures for measuring SOC).
- Accurately recording the locations of sampling sites by GPS, or establishing more permanent monitoring sites to allow for repeat sampling events at the same locations. Soil properties will vary within the paddock and sampling at the same location will reduce this variability and allow for a direct comparison of the results.
- Introducing sample replicates at each location to assist in accounting for the variability in soil properties and allow for more confident interpretation of any observed changes.
- Measuring bulk density as part of the sampling program to calculate the soil carbon stocks to explore the potential for soil carbon farming (the calculation of the carbon stock is necessary for carbon trading). Bulk density is also an indicator of soil texture (including organic matter content) and soil physical properties relating to soil structure.
- Establishing a minimum dataset of soil properties to measure and monitor. Consistent measuring and monitoring of fewer soil properties (selected based on the Lilleymans' objectives) may prove more useful than a larger dataset collected at different times and using different methods.
- Deciding on a sampling regime that can be viably maintained in the absence of additional external grants or funding.

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