Environmental Land Management system: Test and Trials

Model Land Management Plans and Toolkit for southern chalkland farms

Soil Health Management component

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1. INTRODUCTION

There has been considerable discussion of the opportunity to improve agri-environment schemes to replace the CAP provisions after the UK exits the EU. One idea is payment to land managers for outcomes that bring public benefit, rather than subsidies based on land area or agricultural / crop production. The new system will be administered through the Environmental Land Management scheme (ELMS).

Land Management Plans (LMPs) will be designed to help the farming community align their business aspirations with Defra's 25 Year Environment Plan (Defra, 2018) and enable them to access the Environmental Land Management Scheme (ELMS) funding programme.

1.1. Aim and objectives

The overall aim is to progress towards a sustainable farming system on lowland chalk in southern England. The specific objective of this report is to demonstrate that, as a key natural capital asset that both underpins farm businesses and delivers ecosystem goods and services to society, healthy soils should be incorporated into Land Management Plans for these areas. As such, soils should be one of the key building blocks throughout the 'Tests and Trials' programme of Defra's proposed Environmental Land Management scheme. Improving soil health is explicitly mentioned in Defra's 25 year Environment Plan (Defra, 2018).

As recommended by Defra's Environmental Land Management Tests and Trials Thematic Working Group (summary report, July 2020), this report provides a baseline description of the soils and their management on 2 representative estates in the area (Cholderton and Snoddington Manor Farm). This information is then used to develop options for soil management practices that aim (or have been shown) to restore, maintain and improve soil health on the estates. Across the great variety of landscapes and soil types, each land holding will require specific changes in management practice to deliver the desired public goods that align to sustainably produced food. The report recommends how the impact of these practices on soil health could be measured and monitored using indicators of soil health.

1.2. Soil as natural capital

Soils are a key natural capital asset, which underpin the economic, environmental and social viability of all land-based agribusinesses. The quality and quantity of soil assets / stocks vary over space and time. They can be influenced by natural and anthropogenic factors, such as soil management practices. Changes in soil assets / stocks affect the flow of benefits (via ecosystem goods and services) that are provided by soils to individuals and to society. Healthy soils deliver a range of private and public ecosystem services and goods (Figure 1). Beneficiaries of healthy soils include agribusinesses (e.g. farmers, food processors, suppliers, distributors, retailers) and society as a whole (e.g. regulation of water quantity and quality, mitigation of global warming and climate change, provision of cultural services such as recreation, amenity and landscape aesthetics – 'green and pleasant land').

Private and public goods and services delivered by healthy soils

- Production of food (currently valued at market price and CAP Pillar 1 payment), fibre, fodder, forestry and (bio)fuel;
- Production of agrochemical free food
- Mitigation of global warming and climate change (by avoiding and reducing greenhouse gas emissions, such as CO_2 and N_2O; and by plants grown on soil sequestering atmospheric CO_2 and storing it below ground as soil carbon / organic matter). Soils should sequester carbon up to limits compatible with high biological activity and agricultural productivity
- Regulation of water quantity during floods (infiltration and soil water holding capacity) and droughts (water holding capacity and groundwater recharge). Agricultural land should be a major water store in national, regional and local hydrological cycles. Surface water hydrographs should as smoothed and attenuated as possible. Transmission of excess soil water to groundwater should be maximised.
- Improvement of surface- and ground water quality, as fewer inorganic nutrients (fertilisers) and pesticides have to be applied to fertile, healthy soils that already have nutrients available to crops and natural biological predators. Solute and suspended loads in water transmitted from soils to surface and ground water should be minimised.
- Healthy soils are less prone to soil degradation, including soil erosion that depletes soil as a natural capital asset. Off-site damages such as sedimentation and associated dredging costs are avoided.
- Support of wildlife and biodiversity, providing habitat and sustenance to micro- and macro-organisms throughout the food chain
- Protection of cultural services (e.g. recreation and amenity) and the historic environment, including archaeological artefacts
- Conservation of the rich, distinctive and diverse aesthetic value of our ‘green and pleasant land’, associated with notions of beauty, sense of place, identity (within and without protected landscapes), so contributing to human health and wellbeing.

Figure 1. Private and public ecosystem services and goods delivered by healthy soils

These benefits are hampered by ongoing soil degradation as described in the Parliamentary Soil Health Inquiry in 2016. Indeed, current agricultural subsidies can encourage food production and the associated increased use of inorganic fertilisers, with adverse effects on soil quality and subsequent loss of public goods delivered by soils. Continuing with this type of subsidy and farming practice will make intensive farming increasingly bad value for money for society. Future public funds can be used to support good farming practices by being more directly targeted at combinations of private (e.g. agricultural production) and public (e.g. biodiversity) goods, not one at the expense of the other.

EFTEC (2018) concluded that natural capital accounting on farms could be improved by more in-depth analysis of soil quality (and its changes over space and time) to better understand the benefits of improved farming practices on natural soil fertility (and crop production), soil biodiversity, water quality and quantity, and carbon sequestration. A natural capital approach can help to anticipate these dynamic changes and forecast the likely monetary impacts of management actions and decisions.

1.3. **Soil health**

1.3.1. Definitions of soil health

The term 'soil health' has been broadly defined as "the capacity of a living soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health" (Doran, 2002; Doran et al., 1998; Doran, Sarrantonio and Liebig, 1996). However Doran (2002) often uses the terms "soil quality" and "soil health" together, apparently interchangeably and does nothing to distinguish between the two terms. Despite that, the Doran 2002 paper is often referred to for definitions of soil health. Karlen et al. (1997) also uses soil quality and soil halth interchangeably, defined as "the capacity of soil to function, within natural or managed ecosystem boundaries, to sustain plant or animal productivity, maintain or enhance water quality, and support health and human habitation"). Put more simply, soil health is "the capacity of soil to function" or "fitness for use", whether that use is for food production, water regulation, carbon sequestration and storage, or protection and restoration of habitat and cultural assets.

1.3.2. Metrics of soil health

Many metrics have been proposed to measure and monitor soil health. *Meaningful* metrics relate soil properties to soil functions and thus to ecosystem goods and services. In other words, a change in a soil health metric is reflected in a change in soil functioning and the delivery of ecosystem goods and services. e.g. more porosity (less bulk density – a soil physical property) leads to better infiltration of rainfall (a soil function), leading to reduced flood risk (a public good / benefit to society). Similarly, an increase in bioavailable nutrients (a soil chemical property) leads to more assimilation by the plant roots (soil function) and thus higher crop yield quantity and quality (leading to revenue as a private good / benefit to the farmer).

In the 25 Year Environment Plan (Defra, 2018), Defra have pledged to "develop a soil health index (including indicators such as the level of humus and biological activity in the soil) that can be used on farms to check whether their actions are having the desired effect.". To date, this soil health index is still under development[1], but we propose some interim metrics that allow farmers to measure and monitor their soil health cost-effectively.

Numerous studies on soil health / soil quality indicators have been undertaken (e.g. Black

[1] As one example, in consultation with Defra, the Sustainable Soils Alliance (https://sustainablesoils.org/) is currently developing a suite of soil health indicators associated with soil functioning and the delivery of ecosystem goods and services of benefit to society (i.e. 'public goods').

et al., 2002; Merrington et al., 2006; Rickson et al., 2012; Ritz et al., 2009). To summarise much of this work, five essential, interconnected and interdependent soil properties can be shortlisted as candidate indicators of soil health (Figure 2).

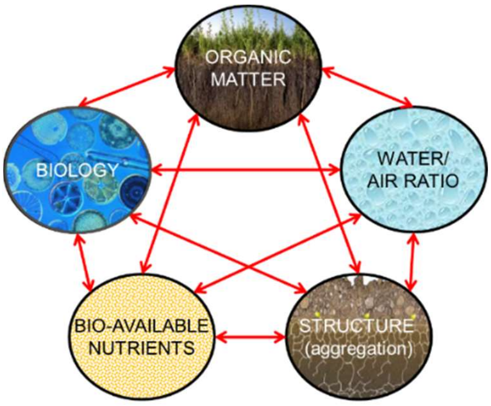

Figure 2. Key indicators of soil health

Having identified some candidate indicators of soil health on scientific grounds, the practicalities of their measurement have to be considered, such as: cost, simplicity / complexity, speed of sampling and subsequent analysis, reliability, accuracy, need for specialist equipment / analyses, etc. It should be noted that many soil properties will vary with season (so consistent time of sampling is important); soil type; current and recent cropping; and stochasty. It should also be recognised that some soil properties change rapidly over space and time: others are more constant. This could determine frequency of measurement / monitoring. Examples of typical minimum data sets (MDSs) are shown in Table 1 and

Table 2.

Table 1. Key metrics of soil health (example of a minimum data set, MDS)

Soil properties	Soil health metric (minimum data set)	Methods	Comments
Soil chemistry	Soil organic matter / carbon	Walkey Black Loss on ignition Dumas method.	During the Parliamentary Soil Health Inquiry (2016), soil organic carbon content was identified as the one indicator of soil quality that scientists agreed – see letter to The Times (Collins et al., 2017), which stated that soil organic carbon content should be the measure of choice, and that restoring, maintaining or increasing this vital driver of soil health should be financially rewarded. This would benefit farmers' productivity and enhance the environmental benefits provided by soils to the wider community. Different methods for

			measurement are not comparable. Changes slowly over time, and is variable over space and season.
	Bioavailable nutrients (especially N, P and K, and trace elements)	Standard laboratory analyses	Not only total nutrients, but the availability to the crop should be analysed too. Soil pH will affect this.
Soil biology	Earthworm numbers and biomass		Soils are living, a matrix of micro organisms. Bacteria, fungi, tiny invertebrates, earthworms, all living in a complex world based on the decomposition of organic matter, in which they are all active and essential participants.
	Microbial (fungal and bacterial) biomass	Microbial carbon C	
	Microbial (fungal and bacterial) activity	Microbial respiration	CO_2 evolution being a measure of activity
	Fungal/ bacterial ratio	e.g. using Phospholipid fatty acids analysis, PLFA	
	RNA DNA analysis.	Metagenomics	Metagenomic methods are unlikely to be used by farmers. One challenge is data interpretation and the need for a comprehensive data-base of profiles for comparison (e.g. baseline versus desired end point). Currently these methods are very expensive for a routine soil health tool-kit.
Soil physics	Soil structure	Visual Evaluation of Soil Structure (VESS) or Visual Soil Assessment (VSA)	VESS: https://www.sruc.ac.uk/info/120625/visual_evaluation_of_soil_structure VSA: https://core.ac.uk/download/pdf/77086433.pdf N.B. Not statistically robust as results are 'scores' not absolute numbers, but gives a good impression of soil structure (i.e. combination of physical, chemical and biological status). Not available for peat soils
	Bulk density	Undisturbed	Physical soil properties that affect

	/ porosity	samples collected in rings of known volume	processes like infiltration, water holding capacity, water availability to plants, runoff generation and air / water ratio
	Infiltration rates and capacity		
	Soil hydraulic conductivity		

Table 2. Example of a soil health 'scorecard' https://ahdb.org.uk/knowledge-library/testing-the-soil-health-scorecard

Attribute*	Field A; Farm 1	Field B; Farm 2	Field C; Farm 3
SOM (%)	3.4	2	2.2
pH	6.7	6.9	7.0
Ext. P (mg/l)	40.6	59.6	37.2
Ext. K (mg/l)	158	106	148
Ext. Mg (mg/l)	82	89	144
VESS score	2	2	2
Earthworms (Number/pit)	13	8	1

Investigate   Monitor   No action needed

*SOM: Soil Organic Matter – comparison to 'typical' levels for the soil type & climate; Partnership project 2 **ahdb.org.uk/greatsoils**

Ext. P, K & Mg: Extractable Phosphorus, Potassium and Magnesium; See 'The Nutrient Management Guide-RB209' for specific crop advice, **ahdb.org.uk/nutrient-management-guide-rb209**

VESS: Visual Evaluation of Soil Structure – limiting layer score; **sruc.ac.uk/info/120625/visual_evaluation_of_soil_structure**

Earthworms: total number of adults and juveniles; >8/pit = 'active' population for arable or ley/arable soils; Partnership project 2 **ahdb.org.uk/greatsoils**

2. BACKGROUND TO SOILS AND SOIL HEALTH ON THE 2 MODEL ESTATES

The locations of the Cholderton and Snoddington Manor Farm estates are shown in Figure 3.

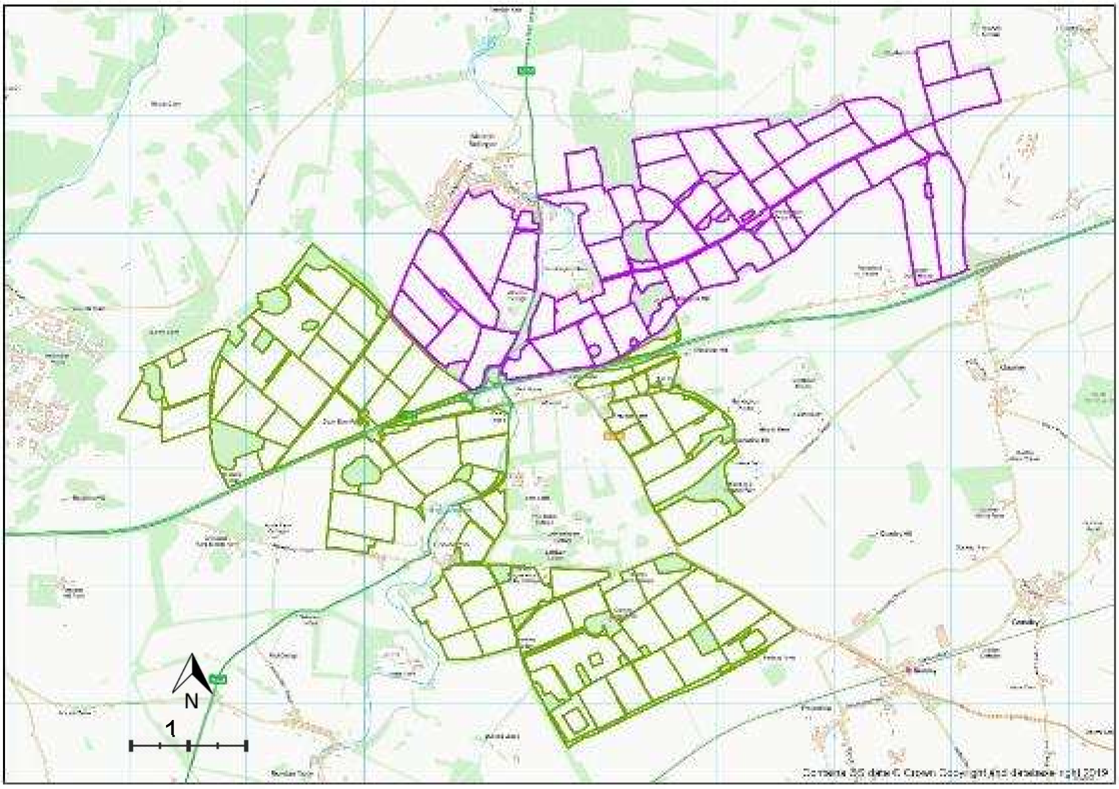

Figure 3. Land holdings on the Cholderton (green lines) and Snoddington Manor Farm (purple lines) Estates.

The soils of the two estates are shown in Figure 4 and Figure 5. The broad topsoil texture classes are shown in Figure 6. Descriptions of the different Soil Associations are given in Table 3. Further details are available within Cranfield University's Land Information System, LandIS (https://www.landis.org.uk/).

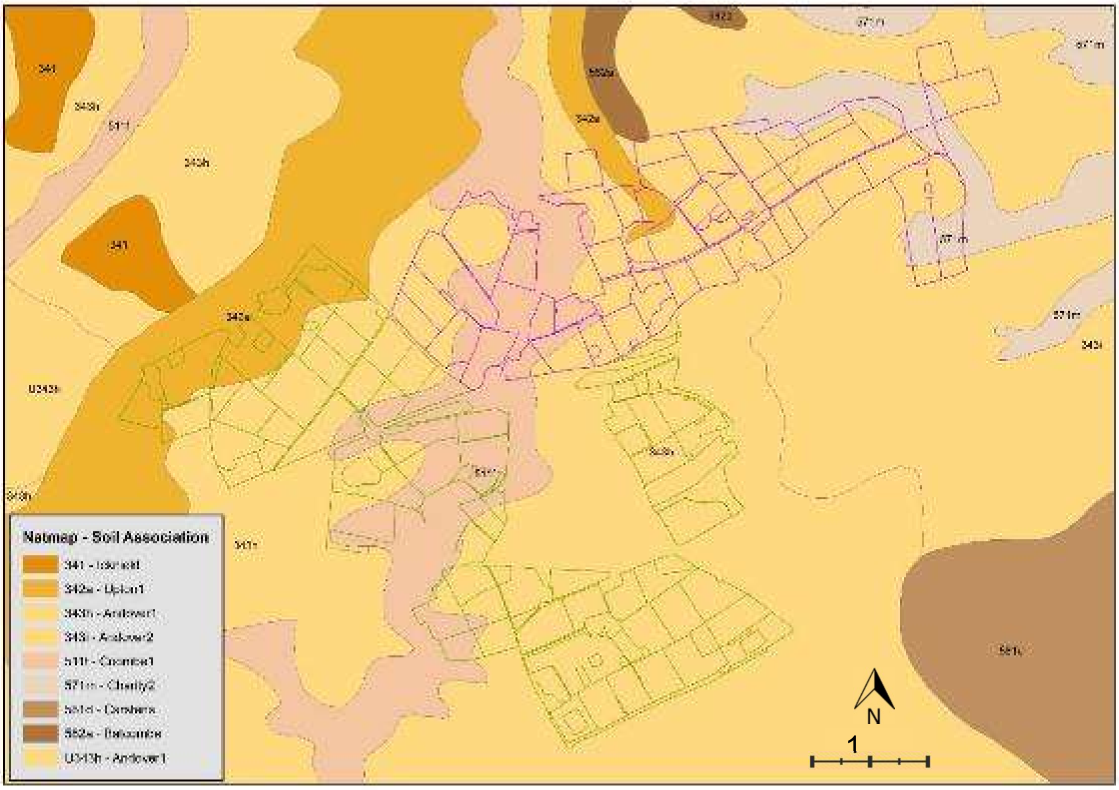

Figure 4. Soil Associations for the two model farm estates © Cranfield University 2020.

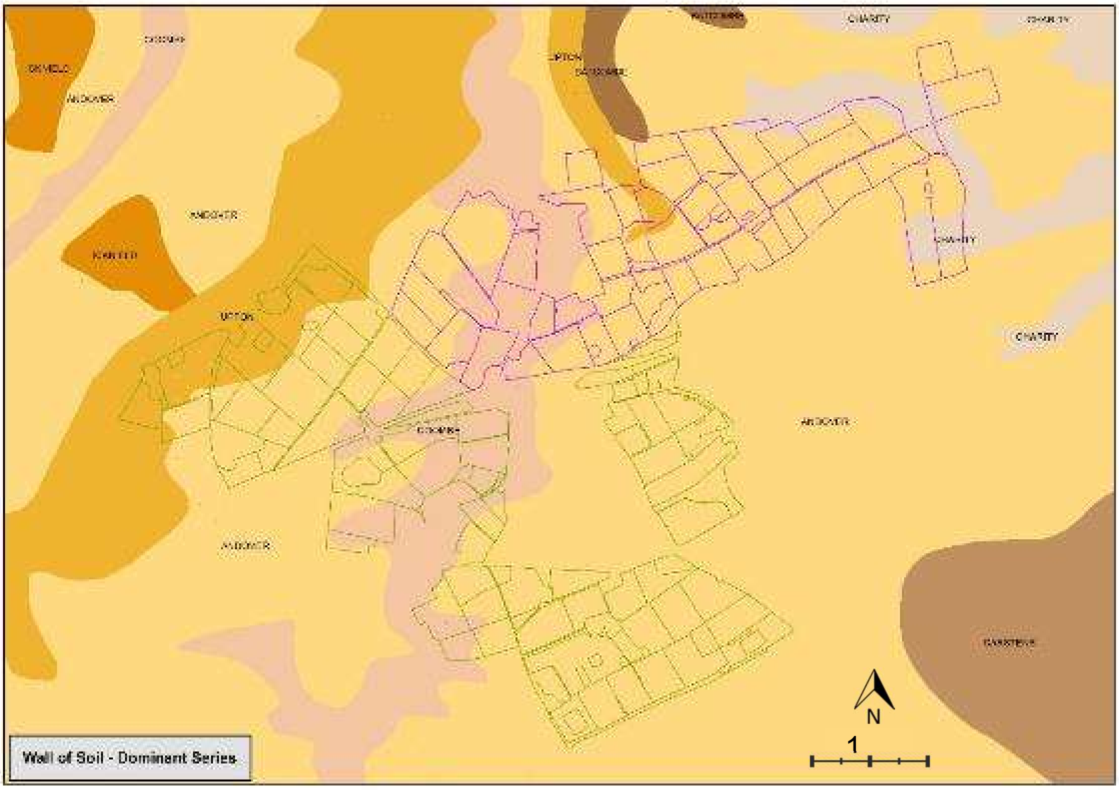

Figure 5. Simplified Soil Associations for the two model farm estates © Cranfield University 2020.

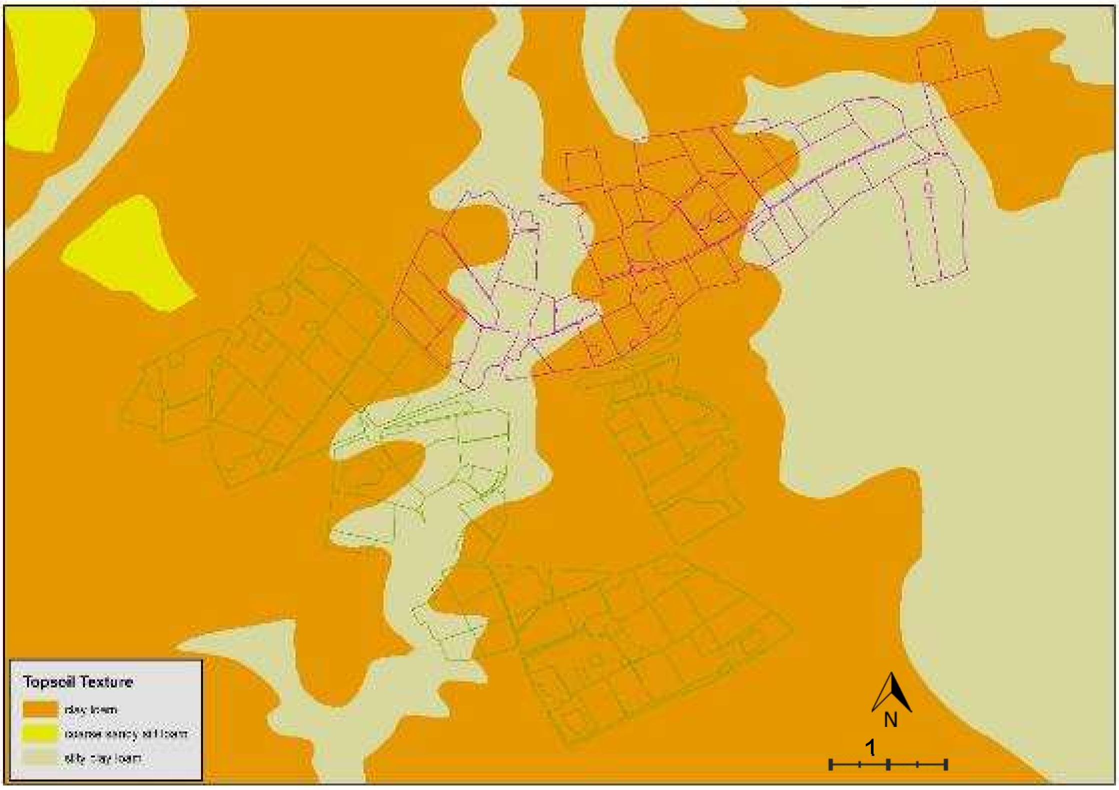

Figure 6. Predominant topsoil texture classes for the two model farm estates © Cranfield University 2020.

Table 3. Soils of the two model farm estates and their general descriptions (taken from the Soils Guide, LandIS: © Cranfield University 2020. Available at www.landis.org.uk)

Soil Association		Summary	Soil and site characteristics	Geology	Predominant cropping and land use
343h	Andover 1	Shallow lime-rich soils over chalk or limestone	Shallow well drained calcareous silty soils over chalk on slopes and crests. Deep calcareous and non-calcareous fine silty soils in valley bottoms. Striped soil patterns locally.	Chalk	Winter cereals and short term grassland with dairying and stock rearing; some woodland.
342a	Upton 1	Shallow lime-rich soils over chalk or	Shallow well drained calcareous silty soils over chalk.	Chalk	Permanent grassland rough grazing and woodland

		limestone	Mainly on moderately steep, sometimes very steep land. Deeper fine silty calcareous soils in coombes and dry valleys.		on scarps; cereals and short term grassland on gentle slopes; recreation.
511f	Coombe 1	Freely draining lime-rich loamy soils	Well drained calcareous fine silty soils deep in valley bottoms, shallow to chalk on valley sides in places. Slight risk of erosion by water.	Chalky drift and chalk	Winter cereals, cereal and grassland rotations with dairying; some horticultural crops.
343i	Andover 2	Shallow lime-rich soils over chalk or limestone	Shallow well drained calcareous silty soils over chalk. Associated with deeper non-calcareous variably flinty well drained fine silty and fine silty over clayey soils.	Chalk and clay-with-flints	Winter cereals; cereal and grassland rotations with dairying and stock rearing; woodland.
571m	Charity 2	Freely draining slightly acid but base-rich soils	Well drained flinty fine silty soils in valley bottoms. Calcareous fine silty soils over chalk or chalk rubble on valley sides, sometimes shallow	Flinty and chalky drift over chalk	Cereals; cereal and grassland rotations permanent grassland and some deciduous woodland on steep valley sides

2.1. **Soil management at Cholderton Farm estate.**

The Cholderton Estate includes land reaching the fringes of Salisbury Plain in the north and Grateley Station to the south. Much of the ground is Grade 4 with some Andover series soils of Grade 3. There is some historical evidence of unsustainable soil management practices, with loss of natural fertility on the Estate. Soil was running off the fields when it rained to such an extent that it was necessary to load the accumulated silt from the tracks and roads and take it back to fill in the exposed fissures in the fields. Analysis demonstrated that these fields lacked soil organic matter and carried infestations of Cereal Cyst and Brassica Root Eel Worms. However, current activities as described below appear to be restoring, maintaining and improving soil health, and delivering associated ecosystem goods and services.

The current cropping plan at Cholderton is shown in Appendix 1.

2.1.1. Land use planning and management

The estate is a mixed farm, with about half the land area in any given year split between arable and livestock enterprises (two dairy herds, and a sheep flock). This allows the traditional method of fertilising the cropped fields with the manures from the grazing livestock, eliminating the need for inorganic, fossil-fuel dependent and CO_2 emitting chemical fertilisers. Organic manures increase soil organic matter and the associated benefits this has on other indicators of soil health (Figure 2).

All Grade 4 shallow chalk soils on steep inclines have been taken out of arable farming, due to the high risks of runoff generation (potential flooding downslope) and soil erosion in these areas. On such shallow soils, loss of soil depth due to erosion will affect soil water holding capacity, nutrient availability and potential rooting depths, with direct impact on soil fertility.

Some 600 acres (243 ha) out of 2,500 acres (1012 ha) have reverted from arable to grassland. The remaining 1900 acres (769 ha) (less the woods and hedges) is under a 10 year rotation – 6 years grass and herb rich leys, followed by 4 years of arable crops.

2.1.1. Rotational cropping

A rotational system is used, utilising deep rooting nutritious leys incorporating a high leguminous content. The leys are generally established by under sowing in a Spring Barley crop. This is achieved by incorporating the grass seed after the barley has been sown. The leys incorporate leguminous mixtures of Sainfoin, Lucerne, White & Red Clover with Timothy, Meadow Fescue and Cocksfoot as the grass component. These were managed by grazing sheep and cattle. The legumes, particularly Sainfoin and Lucerne are very drought tolerant with extensive root systems that can exploit water and nutrients at depth. The herb rich leys are extremely important because they are deep rooted – plants like Hampshire Sainfoin, with roots deeper than the plough layer, which penetrate the interface between soil and chalk. The roots create fissures in the fractured chalk substrate, a weathering process that encourages soil formation.

The roots also develop good soil structure (an essential metric of soil health, see 1.3.2), by increasing the number and range of pore sizes (micro-, meso- and macro-pores). These pores contribute to increasing infiltration (so reducing surface runoff, flooding and soil erosion), water holding capacity (bringing resilience to drought periods), and soil microbial mobility and activity. Soil aggregation (a key indicator of soil susceptibility to erosion (Bryan, 1968)), and carbon and nitrogen sequestration from the atmosphere are also improved by the increasing levels of soil organic matter from the above and below ground biomass.

After a period of 5 years or so, the ley may begin to lose productivity and it is then inverted by the plough, either during the autumn or in the early months of the year. This action places the turf 5 or 6 inches below the soil level where it forms a moisture retaining mat of organic material. This will be broken up and dispersed amongst the shallow soil profile over the next 2 years. The soil nearest the surface will be densely packed with roots, micro fibres and nitrate rich leguminous rhizobia. These will render the soil friable and rich in fertility. This forms an ideal medium in which to grow a cereal crop. This newly turned soil will be relatively free from arable weed seeds because they lose their viability over the duration of ley. Thus is natural fertility engendered by a process long understood, but often now virtually forgotten, due to the complete reliance placed by some farmers on agrichemicals today.

Looked at strategically, the rooting habit of the ley grasses and cover crops (see below) are a form of 'minimum tillage', but without the need for or application of herbicides (such as glyphosate) or pesticides.

2.1.2. Tillage

Apart from the inversion ploughing of the leys after 5 years or so, most cultivations could be classified as minimum till. Shallow ploughs (150 mm depth) are used 4 years in every 10. Disc ploughing is also used, with no inversion of soil, which can expose soil organic matter and nitrogen to the atmosphere leading to CO_2 and N_2O emissions.

2.1.3. Fertilisation / soil nutrient management

Farming is carried out without inorganic fertilisers or any pesticides at Cholderton. Historical records show the increase in nitrate pollution in local waters from 8 mg l^{-1} in 1938 to 22 mg l^{-1} in 1984. This was attributed to the ploughing up pasture land during the war. As stock keeping became less profitable, intensive cereal production (and associated application of highly soluble fertilisers) increased and with further pasture disappearing, nitrate levels rapidly increased to 37.2mg per litre by 1990, approaching the legal limit of 50 mg l^{-1}. This situation is aggravated by the 'leaky' chalk soils and geology.

The Cholderton estate itself contributed around 8% of the nitrate, 5% of which was due to a leaky slurry lagoon. This was remedied leaving the farming activity at Cholderton contributing just 3% or less of the total nitrate loading in the catchment. This has been achieved by a regenerative farming regime that was put in place some 20 years ago.

No nitrogenous fertilisers are currently used: instead each year every field is fertilised with carefully applied composted animal manures. Additional nutrition comes from the herbal leys which produce slow release nitrogen into the soil. Within the rotation, crops are selected to be tolerant of the relatively low soil fertility, for example, winter rye.

2.1.4. Cover crops

In the autumn (September / October), fields needing improvement are disced and sown with a seed mixture of about 80lbs of vetch and 80lbs of rye per acre (≈ 90 kg ha^{-1} and 90 kg ha^{-1} respectively). No spray or fertilisers are used. This cover crop will grow up the following year producing a crop of possibly in excess 20 tons of plant material per acre (=

50.2 t ha^{-1}). This is not to be cut until the late autumn, to encourage maximum rhizobia development by the vetches, which are essential for nutrient cycling and availability to the follow-on crops.

After harvesting, the vetches are followed by a crop of stubble turnip that is grazed by the cattle or sheep over the winter. This adds fertility for the subsequent crop of spring barley. If the break crop is to be used as an entry for winter wheat, then it could be chopped up in September and ploughed in. Otherwise it could be left overwinter providing excellent cover and improved soil structure (to encourage water infiltration, reduce runoff and minimise erosion risk). The cover crop provides soil organic matter and nutrients, and is then chopped in the early spring, followed by spring barley. The farmer reports that the chopped crop is estimated to return 20 tons of organic matter per acre (= 50.2 t ha^{-1}) to the soil, plus the extensive root system of the vetch and rye. Additionally the vetch will be leaving about 140 units of slow release nitrogen per hectare for the following crop. Crimson clover is another autumn sown cover crop that will produce similar results on soil health in the following year, under the same management routine.

2.1.5. Benefits of current soil management practices

Anecdotally, the current soil management practices described above are bringing multiple benefits to Cholderton Estate. The fertile, microbially rich, healthy soils underpin production of meat and arable crops, whilst delivering other ecosystem goods and services. These include clean water (fewer agrochemicals in surface or ground waters); clean air (no nitrous oxide or carbon dioxide emissions from inorganic fertilisers or soil exposure to the atmosphere, and no spray drift from application of herbicides or pesticides); and an outstanding range of wild flowers, grasses, insects and birds, all reliant on healthy soils.

According to EFTEC (2018), Cholderton's farming practices of avoiding inorganic fertiliser, lower stocking rates, and better soil management practices that improve carbon sequestration in soil all bring tangible financial gains compared to a 'typical' local farm managed more intensively (Table 4).

Table 4. Selected items on the natural capital balance sheet related to soil management at Cholderton Estate (adapted from EFTEC, 2018). Values in £'m are present value over 50 years; values in brackets are net costs or losses; non bracketed values are benefits or net gains)

Asset values – benefits from soil as natural capital (monetarised)	Cholderton	Typical farm*	Difference
Food production	(1.3)	1.7	(3.0)
Water treatment costs to Wessex Water	-	(0.6)	0.6
Artificial fertiliser use	-	(1.8)	1.8
Soil carbon sequestration	3.7	-	3.7
Natural capital maintenance	(0.7)	-	(0.7)

Estimated total benefits associated with soil management	1.7	(0.7)	2.4
*A typical (intensive) farm is defined as one which has 1,000 hectares for dairy, but which uses artificial fertilisers, has higher stocking densities than Cholderton and does not invest in soil quality and biodiversity.			

2.2. **Soil management at Snoddington Manor Farm Estate**

The Snoddington Manor Farm Estate is currently an intensive arable farm on the chalk. The soils of the farm are shown in Figure 7 and selected yield maps shown in Figure 8. The Estate has been farmed on a commercial arable basis by the present owner since 1991. The farming system has been based on a profitable arable enterprise with limited capital resources available. Whilst the present BPS payments have enabled farming at Snoddington to be profitable with extensive food production, the consequence has been harm to the environment. It is acknowledged that under the previous farming system that not sufficient attention was paid to soils as part of natural capital and the public benefit associated with this. Until 2020, the principle has been to maximise the wheat production on the holding.

The farming area has expanded from 323 ha (798 acres) to 560 ha (1,384 acres). Part of the development has been to create a more attractive and environmentally friendly estate, coupled with modern day farming techniques. The present system of farming has changed within the last few years in order to prepare for the changes in the agricultural industry that will take place with the exit from Europe and the new approach of using public money to pay for ‘public goods’. The current cropping plan at Snoddington is shown in Appendix 2. Some of the farming practices that impact soil health (and thus the delivery of these public goods) are described below.

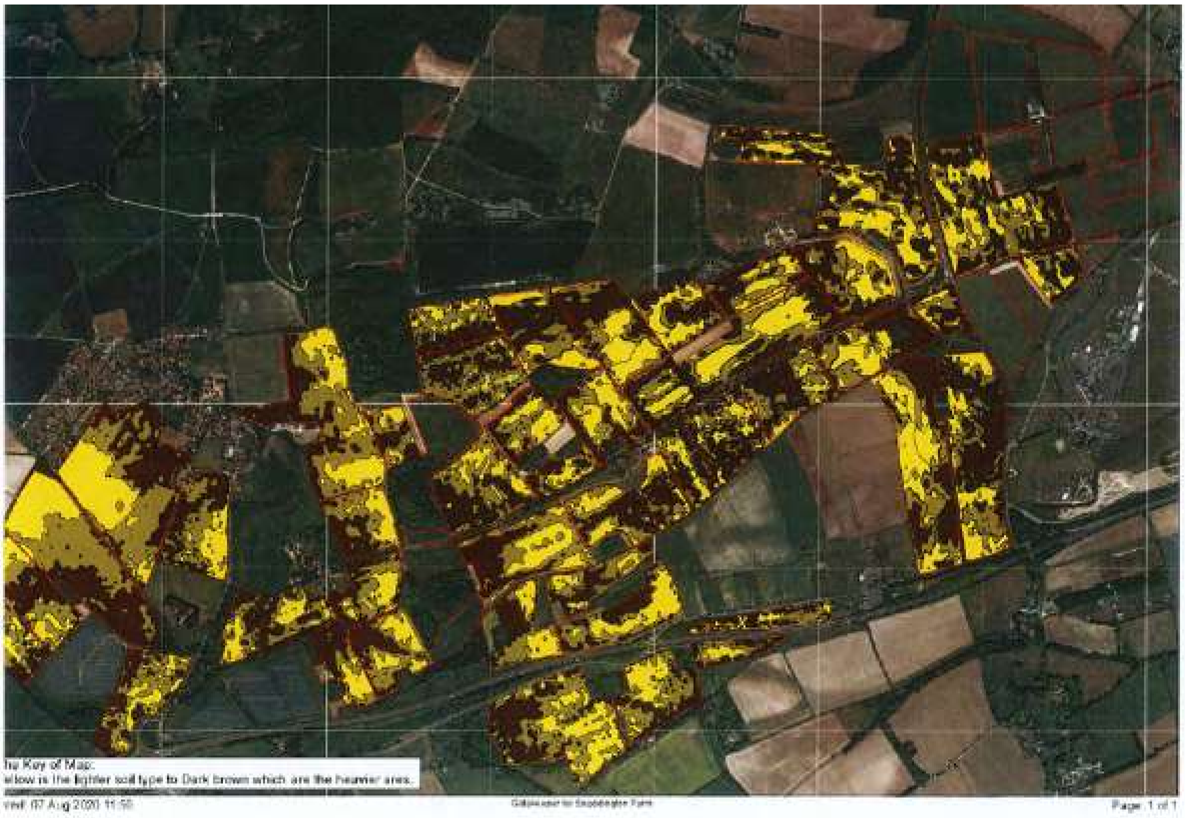

Figure 7. Shallow soil map of the Snoddington Farm Estate

Figure 8. Selected yield maps from Snoddington Farm Estate

2.2.1. Rotational cropping

In order to maximise wheat production, break crops have to be grown in the rotation. This farm like most in the area has grown oilseed rape for many years on a rotation of one in three. Oilseed rape was perhaps the most financially rewarding break crop and there are few alternatives available. However, with the restriction of pesticides and seed dressings, and the fact that farmers have grown too tight a rotation, it is now not possible to grow this product on a commercial basis. Also, oilseed rape is an expensive crop to grow and a high user of nitrogen.

Winter oats have also been grown in the rotation which has enabled the farm to grow approximately 40% wheat production which is the most profitable crop. The current rotation is:

- oilseed rape 40 ha (100 acres)
- winter oats 81 ha (200 acres)
- winter beans 40 ha (100 acres)
- winter wheat 162 ha (400 acres)
- spring barley 81 ha (200 acres)
- spring wheat 40 ha (100 acres)
- winter barley 81 ha (200 acres)

A revised system includes a two year clover mix as a principal break to capture soil fertility. This takes out of production 180 ha (445 acres). At the present time unless livestock are introduced or if these mixes can be made into hay or silage, then there is no economic return for this area. The other break crops include winter oats and 20 ha (49 acres) of winter beans. The restriction on the planting of beans is due to soil type, with the majority of this Snoddington land not being strong enough for a winter bean crop. The rotation for the beans is one year in four.

Thus the revised arable rotation is:

- Clover
- Clover
- Winter Wheat
- Oats/Beans
- Spring Wheat

There have been no livestock on the arable land at Snoddington for 40 years. It is accepted that the introduction of livestock on the holding would be beneficial. However, one barrier to the reintroduction (despite the benefits to soil health) is the significant infrastructure costs of fencing, water supply, handling systems and dedicated buildings. Also, new skill sets are needed to manage livestock. According to the owner, a more economic and sensible approach would be to let the leguminous grass mixes on a grazing licence to sheep grazers who will use temporary fencing. It is not likely that a rent will be received, but the sheep will improve soil fertility, although it is anticipated this could take

15 - 20 years going round the farm.

2.2.2. Tillage and cultivations

The drilling is now being carried out on a zero-till basis, saving substantially on cultivation costs and the number of passes that take place. This benefits soil health as there is less soil disturbance, more organic matter, less carbon and N loss to atmosphere, and lower runoff and soil erosion risk.

2.2.3. Fertilisation / soil nutrient management

Soil fertility is low on the estate in general and without the application of nitrogen it would not be possible to obtain the levels of quality for milling wheat. It is also probable that malting barley will have protein levels too low for modern day maltsters. Soil fertility is improved through a variety of nutrient applications. Despite the current reliance on chemical fertilisers, there is interest in reducing nutrient applications, particularly of nitrogen.

Human manure has been used on part of the holding and has increased the phosphate levels without using artificial manure. Phosphate is as important to the growing of the crop as nitrogen. An application every four years maintains P levels and also provides the benefit of a small amount of nitrogen and potash. Without this application the levels of phosphate, potash and magnesium will fall significantly within a two-year period.

Compost has been investigated, but the cost of transport results in a charge per acre of £60. Also, unless the compost is topped up four years later the benefit falls. Compost from anaerobic digester (A.D.) plants is proving successful and the cost of transport is not charged, as the A.D. producers require their waste to be spread on agricultural land.

2.2.4. Cover cropping

A cover crop is grown prior to the spring wheat. There are plans for the introduction of phacelia/clover cover crops for all spring crops.

2.2.5. Field margin management

There are plans to create non-production field margins on around 60% of the fields (not currently in agri-environmental schemes).

2.2.6. Hedgerow management

Hedgerows play an important role in promoting soil health. When the farm was purchased, the fields had been enlarged with the removal of hedgerows during the 1960's 1970's and 1980's. Original field boundaries with hedgerows have been re-established and on the rented farm this has been encapsulated by the creation of beetle banks and other margins. Planting of 3000 metres of hedges has occurred in the last ten years (with no government support). Hedges are known to promote soil health, bringing benefits to the adjacent cropped area. Holden et al. (2019) found that soils under hedgerows, which should be conserved, can provide important functions on farmland including storing organic carbon, promoting infiltration and storing runoff, increasing earthworm diversity and hosting distinct arbuscular mycorrhizal communities.

2.2.7. Non-agricultural use of soils

There is provision for a two acre area for allotments, to be let on ten year lease at peppercorn rents. This is an intensively managed land use (e.g. high nutrient levels), but without the heavy machinery associated with soil compaction and land degradation. Whilst this may imply improvements to soil health through intensive husbandry, some concerns as to levels of contaminants on allotments have been raised in the literature (e.g. see Woods et al., 2007; Weeks et al., 2016).

Over the last 20 years, with no government support, there has been some recreation of chalk downland over some 20 acres. Eighty acres have been taken out of production for the construction and operation of a solar park. The possible effects of such a change in land use on soil health including plant–soil C cycling are poorly researched and for which there is no evidence (Armstrong et al., (2014).

Planting of three new 1 acre plantations has been completed in the last 15 years. These land use changes for environmental improvement are shown in Figure 9.

2.2.8. Constraints on land / soil management decisions

The decision to adopt soil management practices to improve soil health will be dependent on immediate and short term practical and financial considerations, as well as the longer term environmental benefits these measures may bring. Taking into consideration the ownership of machinery and equipment, and the employment of staff, it is estimated that the economic size of unit for the arable farm lies between 526 ha (1300 acres) and 647 ha (1600 acres). This then increases to 1,214 ha (3,000 acres). The size of any arable unit in the future is going to be an important aspect if there is to be financial success, and this in turn will influence the management decisions made by the farmer.

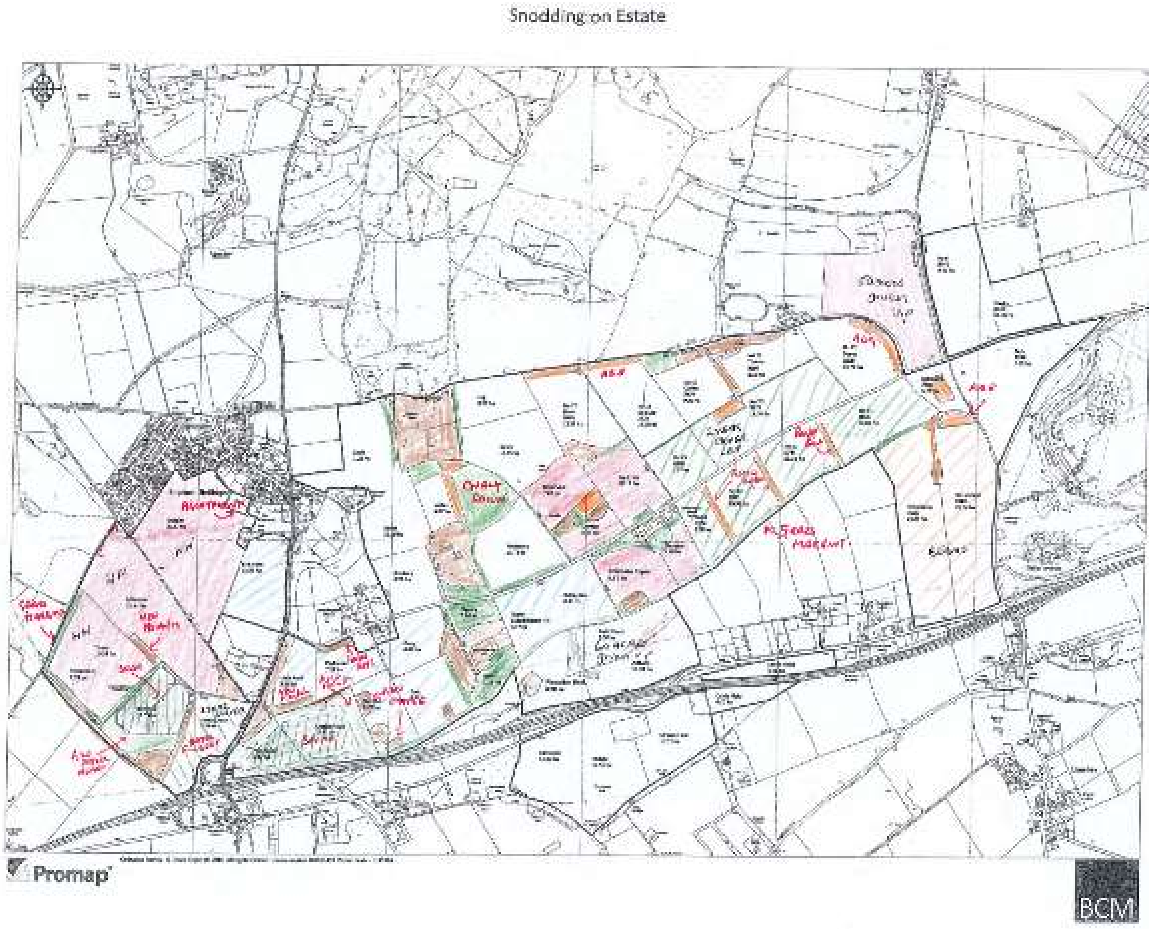

Figure 9. Environmental improvements at Snoddington Manor Farm

3. INPUT TO A MODEL LAND MANAGEMENT PLAN (LMP)

The purpose of drawing up a Land Management Plan (LMP) is to ensure the restoration, maintenance and improvement of natural capital on each farm, so that vital ecosystem goods and services can be delivered in the short, medium and long term. In turn, these goods and services will underpin farm financial viability (i.e. production), as well as deliver benefits to the whole of society such as water regulation, climate change mitigation and protection of biodiversity and cultural assets. In this way, a Land Management Plan could be the basis of a Delivery Contract for ELMs, to align farm business needs with the 25 Year Environment Plan objectives.

The current soil management practices (and their outcomes) as described in Section 2 will form the basis of the LMPs for these 2 representative estates and for other lowland chalk farms in the area.

3.1. **Determining the baseline**

Defra's Environmental Land Management Tests and Trials Thematic Working Group (summary report, July 2020) recommend a baseline to be included in a LMP to help determine the starting point of the farm or holding: this would enable the farmer or land manager to gain an understanding of 'where they are' today regarding the health of their soils, what soil management opportunities and options exist on the farm, how these practices could deliver healthier soils, and what progress is being made towards more sustainable soils. This benchmarking would account for the unique nature (and starting point) of each farm and would recognise where a farm is already performing and delivering.

The baseline would refer to:

a) soil health metrics that reflect the current state of soil health, possibly in comparison with a baseline 'best value' for similar soils / land management system.

b) soil management practices already carried out on the farm to enhance soil health.

3.2. **Soil health metrics to reflect the current state of soil health.**

A soil sampling / surveying scheme would need to be designed and executed to capture baseline soil health on the 2 model estates. Deciding on the sampling resolution over space and time is not within the scope of this report and ideally would require advice from geo-statisticians. According to Natural England (2008), there can be no precise instructions on how to split up a field for sampling and how many hectares can be represented by one sample. Natural England (2008) state that to obtain a good representation of an area of land (at field scale) at least 25 individual cores should be taken and bulked together to give a single soil sample for analysis of half to one kilogram in weight. These cores should be taken by walking the field in a 'W' or other representative pattern and taking cores from equally spaced sampling points, the distance apart depending on the field size (Figure 10). It should be noted that bulking the samples will not show spatial variation or "sample error". Bulking together in small spaces works, but not in large areas where the spatial variation can be high. Only analysis of all the individual samples will identify variation within the field. Locations should be recorded with GPS coordinates to ensure consistent sampling in space and time when subsequent sampling takes place.

Other guidance includes sampling to the correct depth: e.g. on arable land that is regularly ploughed, samples should be taken to a depth of 0-20 cm. It should be noted there may be considerable variation in some soil properties within this 20 cm (e.g. organic matter, soil biology), especially in areas where inversion tillage has not been practiced. Occasionally ploughed fields (e.g. arable fields normally direct drilled or shallow cultivated but ploughed occasionally) must be sampled to the full plough depth or anticipated plough depth. This may be deeper than 0-20 cm. This also applies to long leys and permanent grassland about to be ploughed and reseeded. Long term leys (less than ten years) and permanent pasture samples should be taken to a depth of 0-7.5 cm. Results can be misleading if sampled to other depths.

According to Natural England (2008), as a 'rule of thumb', if the field is about four hectares, 25 m spacing is "about right", but strictly speaking according to robust statistical analysis, this will depend on the observed variability in the soil property being surveyed. Various designs of field and farm soil sampling campaigns are available, such as Black et al. (no date); Church and Skinner (1986)

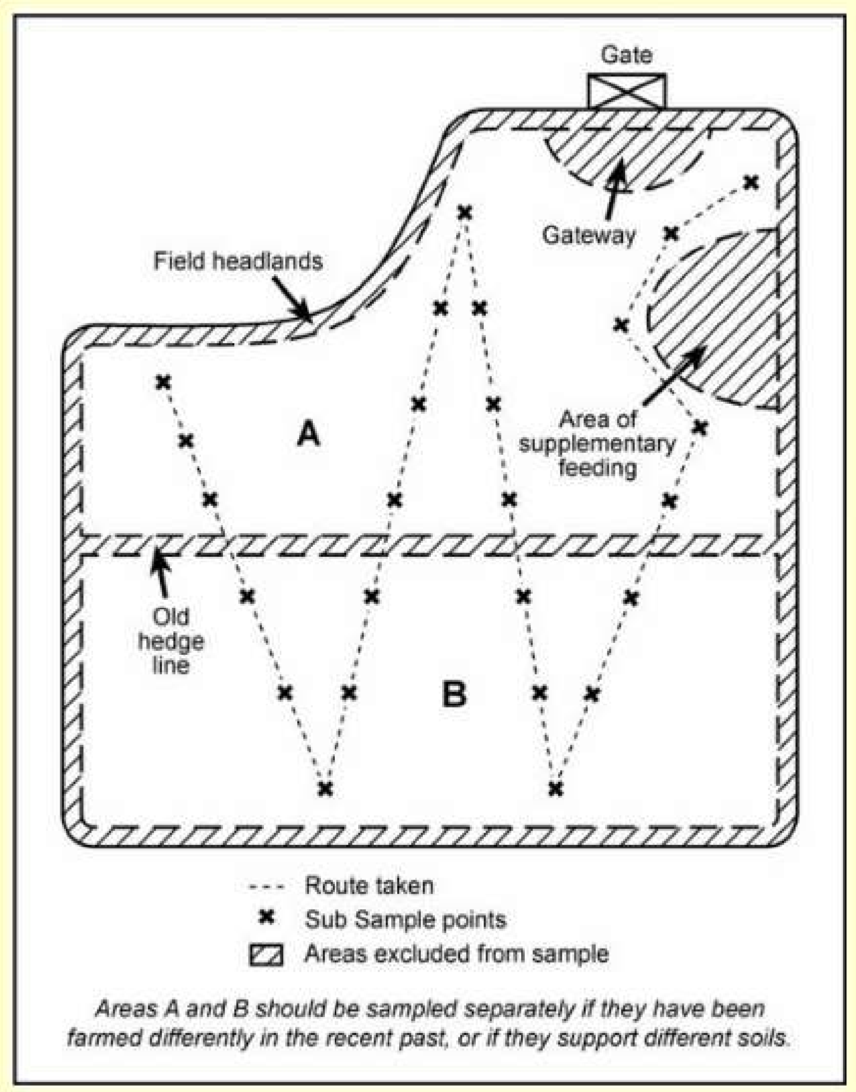

Figure 10. Recommended soil sampling pattern to determine representative soil health readings (from http://adlib.everysite.co.uk/adlib/defra/content.aspx?id=2RRVTHNXTS.8OLLNPPRZXY3T

Candidate indicators of soil health to be measured and monitored are given in Table 1 and

Table 2, which provide examples of minimum datasets of soil health metrics that will capture the salient physical, chemical and biological soil properties. These indicators can be used to evaluate the changes in soil health over space and time on each farm.

Unfortunately, no baseline of soil health metrics has been undertaken to date. Visual observations of sample fields during a visit to the 2 farms in March 2020 showed the status of soil health on the 2 farms as a result of the soil management practice employed.

3.3. **Soil management practices to restore, maintain and improve soil health**

Under the proposed ELMs, there will be three tiers, which broadly address desired outcomes at different scales (Table 5)[2]. This report considers how each Tier could include soil management practices that contribute to the restoration, maintenance and improvement of soil health. LMPs can then be written to facilitate the adoption of these different soil management practices and bring about improvements in soil health compared to the baseline condition. It is acknowledged that across the great variety of landscape and soil types (e.g. see Figure 4 to see the range of different soil types alone for both Cholderton and Snoddington), each farm / estate will require specific changes in management practice to deliver the desired public goods aligned to sustainably produced food. The practices in Table 5 could be options rather than prescriptions.

Defra's Environmental Land Management Tests and Trials Thematic Working Group report that in all 3 current tests of the ELMs scheme, it is essential for advisors to work collaboratively with farmers when drawing up their individual LMPs.

Table 5. Soil management practices for improved soil health under the proposed three tiers of the ELMs (adapted from AHDB website, https://ahdb.org.uk/news/new-details-on-elms-design; accessed 14/08/20)

ELMs Tier	Description	Examples of relevant practices to be incorporated into a LMP for lowland chalkland farms that will improve soil health to deliver private and public goods and services / benefits
Tier 1	The first tier will focus on farm-level improvements by paying farmers to adopt or continue **practices that achieve environmental benefits and improve sustainability, such as cover crops or wildflower margins.** There will be a focus on practices that are most effective when delivered at scale.	1. Arable land Avoiding arable land on steep slopes (e.g. ALC Grade 4) for arable production (soil erosion risk) Reversion of arable lands to pasture permanently or within the rotation Introduction of mixed farming practices Extending the arable rotation to

[2] From https://ahdb.org.uk/news/new-details-on-elms-design. Defra is currently considering the benefits of grouping different options together (particularly in Tier 1) into packages which applicants could choose between. This would aim to simplify a very broad range of potential options, and packages would be tailored to farm type, land type or particular outcomes.

		include grass / herb rich leys Sowing leguminous seed (to improve natural nitrogen fixing to soils) e.g. crimson clover, sainfoin, lucerne, white & red clover with timothy, meadow fescue and cocksfoot, phacelia/clover cover crops for all spring crops Use of deep rooting species to 'bioengineer' the soil to provide better soil structure and organic matter content Avoid inversion ploughing (except after period (? 5 years?) of ley grasses) Use shallow and reduced / minimum (e.g. disc) / zero tillage Reduce inorganic nitrogenous fertilizers Increasing the managed return of farm waste (including animal and organic manures) to the soil Reduce use of pesticides Use of cover crops between main crops Taking field margins and corners out of production Retain and protect existing areas of in-field trees Tree planting Hedge planting Use beetle banks
		2. Pastureland Retain permanent pasture where possible.

		Avoid overstocking Improve species diversity of grassland through species management, and nitrogen-fixing legumes Rotational grazing based on leguminous mixes with Lucerne, Sainfoin and Clover Retain and protect existing areas of in-field trees Tree planting Hedge planting
Tier 2	This tier will focus on locally targeted environmental outcomes, taking into account **priorities in the local area. Collaboration between land managers will be important** for achieving outcomes in this scheme, so there will be mechanisms to encourage and reward join-up between farmers, foresters and other land managers.	Collaboration of arable, livestock and mixed enterprise farmers, for financial and environmental 'economies of scale'. For example: a) Leasing land to livestock owners to reintroduce grazing into the arable rotation b) Use of off-farm manures to fertilise soil on arable units c) Use of local AD and composts to improve soil fertility
Tier 3	The UK has committed to achieving net zero carbon emissions by 2050. The third tier of the scheme will focus on **large-scale land-use change** projects that will contribute to this commitment and others. Many projects in this scheme could therefore be expected to focus on **carbon storage**, whether in creating woodlands, restoring peatlands or creating new wetlands and salt marshes. As well as storing carbon, these schemes are expected to deliver additional environmental outcomes, for instance in **biodiversity and flood mitigation**.	Land use change: Reversion of intensive arable to permanent pasture for downland restoration of rare plants and invertebrates. creation of woodlands creation of natural chalk downland

For Cholderton and Snoddington, the baseline soil management practices currently used are described in Section 0.

A system to monitor and audit the adoption of new practices listed in Table 5 now needs to be designed.

3.4. Demonstration of desirable outcomes from changing soil management practices: use of soil health metrics

The efficacy of the soil management practices in achieving the desired outcome of restoring, maintaining or increasing soil health on each farm (and within each field) will be time- and site specific. Thus it will be necessary to measure and monitor soil health metrics following adoption of these practices as compared to the equivalent baseline condition.

The soil health metrics (Table 1 and

Table 2) measured in the baseline assessments (see section 3.1) should be resampled at the same locations (using GPS readings if needed), after an appropriate timescale. Some soils scientists argue for a 5 year's sampling period to observe change in soil carbon, but other indicators of soil health may change more rapidly (e.g. biological indicators). If appropriate statistical analysis is used to detect significant and meaningful change in selected soil properties, the results can be used to select an appropriate sampling interval / frequency and evaluate the trajectory of soil health on each farm.

It will be important to reward fields and farms already showing good soil health metrics for their soil type / land management system, even if they are not improving.

Unfortunately, no baseline of soil health metrics has been undertaken to date. Visual observations of sample fields during a visit to the 2 farms in March 2020 showed the status of soil health on the 2 farms.

3.5. Toolkit

The Toolkit will essentially map the process we are adopting.

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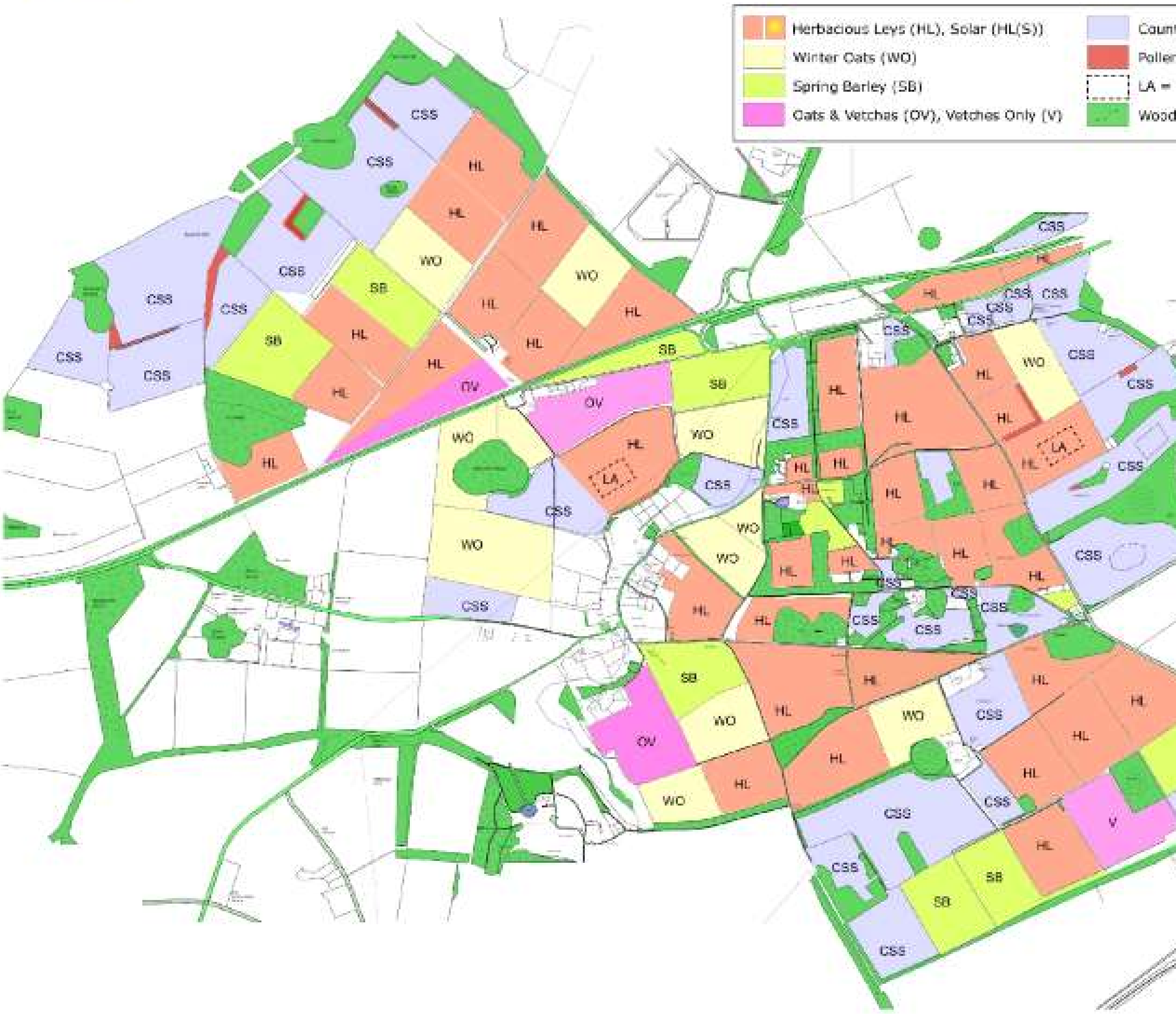
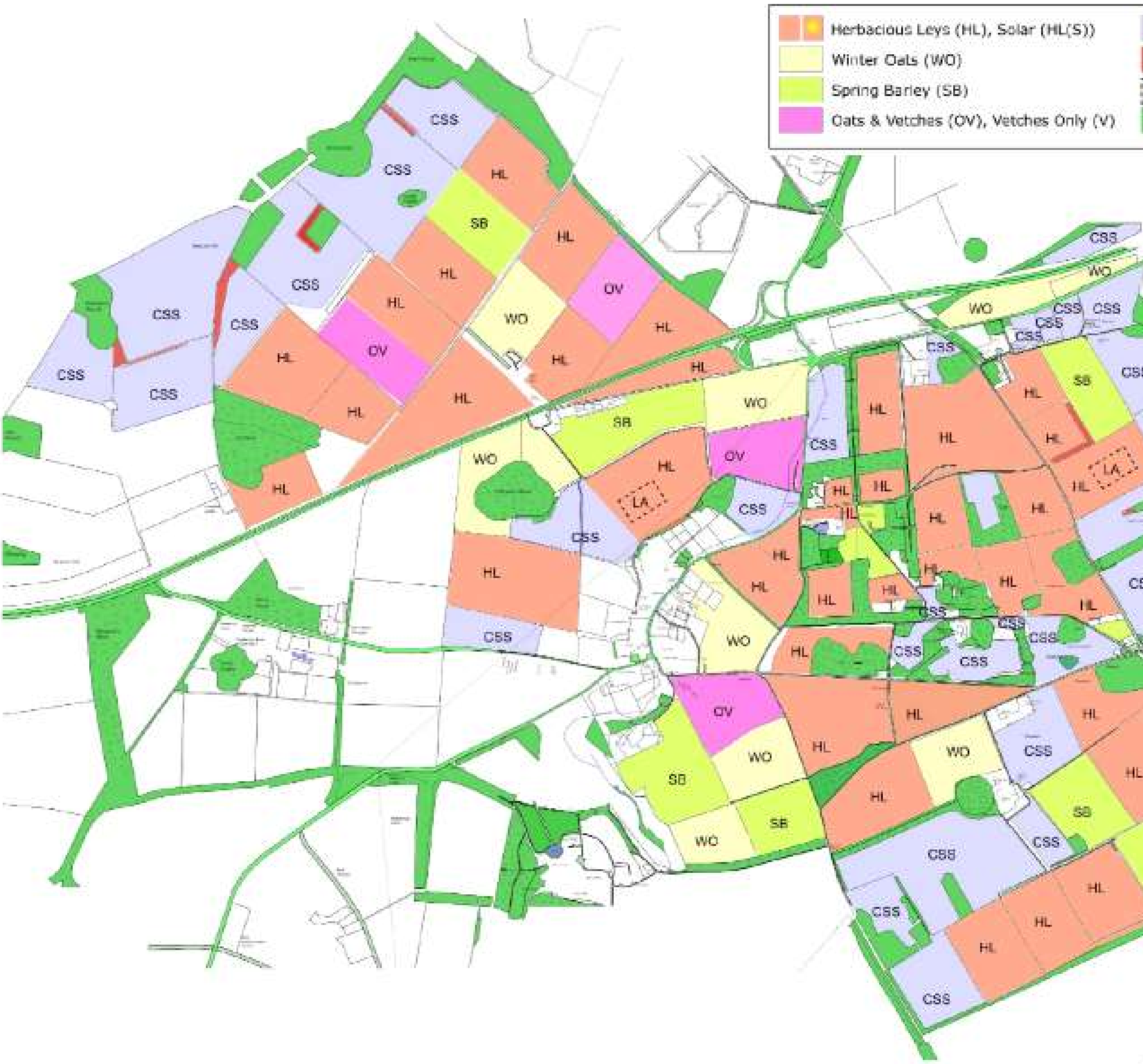
APPENDICES

Appendix 1. Cholderton Cropping Plan

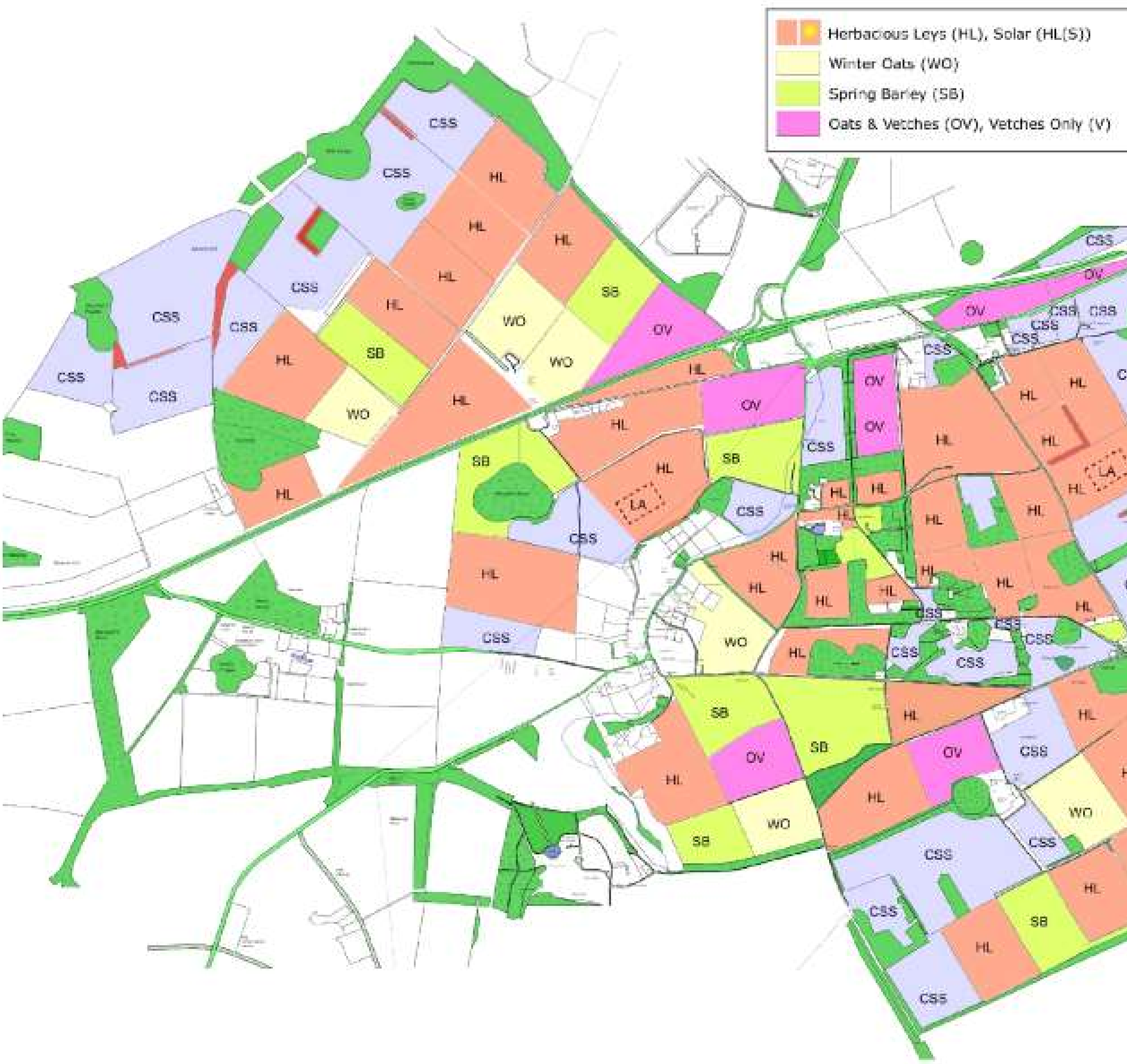
Cholderton Crop Rotation 2017



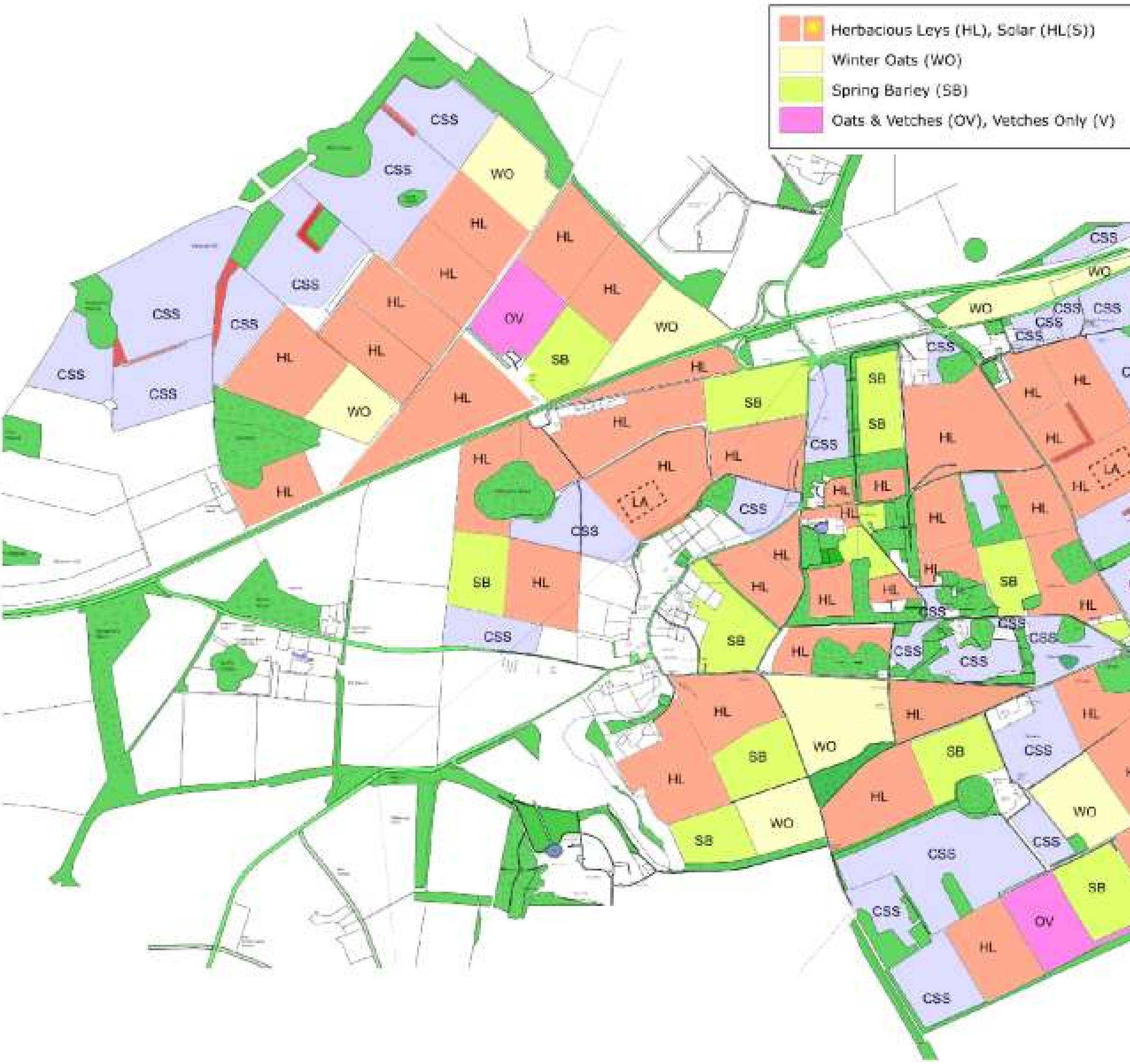
Cholderton Crop Rotation 2018



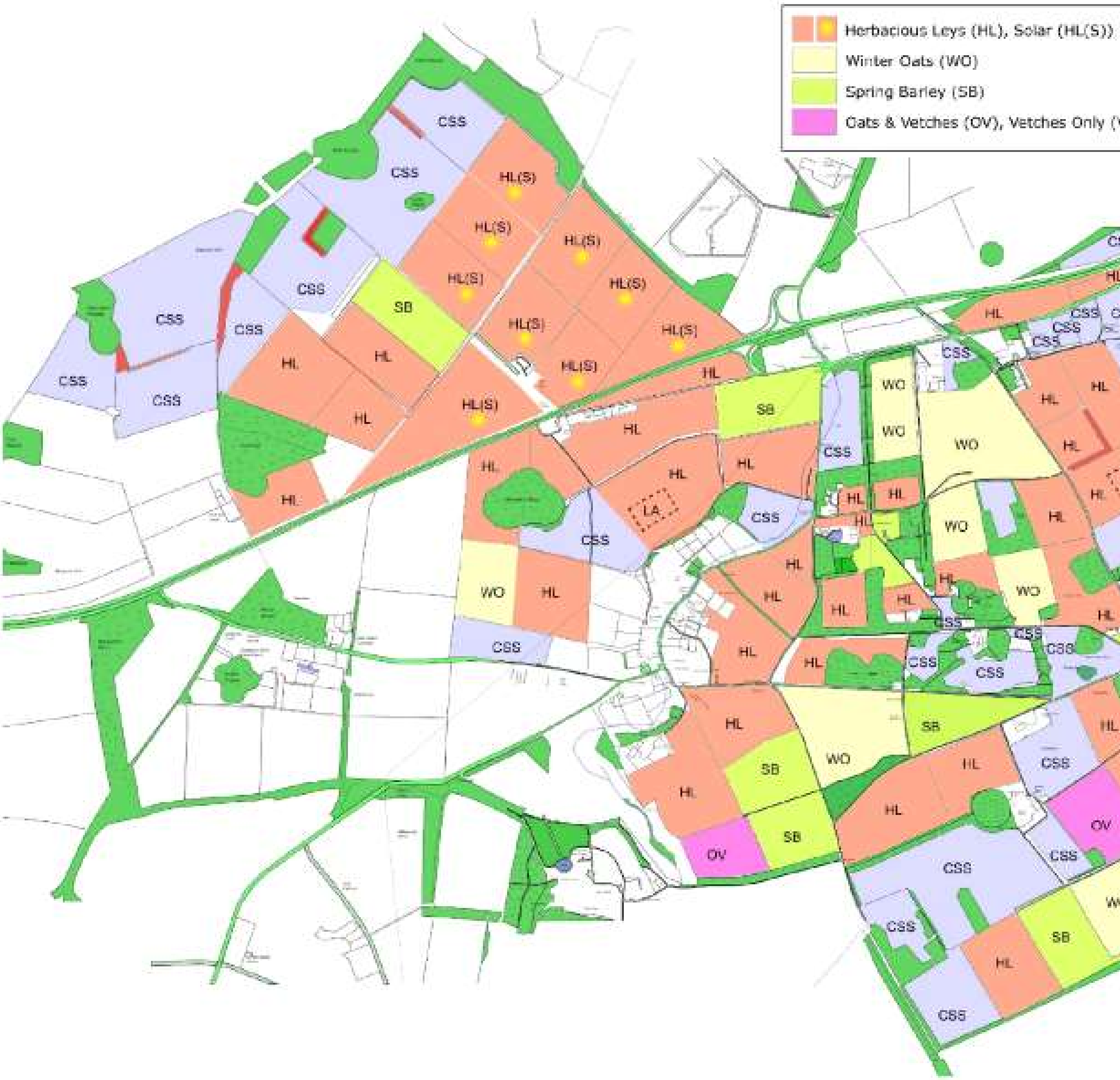
Cholderton Crop Rotation 2019



Cholderton Crop Rotation 2020



Cholderton Crop Rotation 2021



Appendix 2. Snoddington Estate Cropping Plan