Testing the health of your soil

Summary

We asked members to carry out a series of visual soil tests that were designed primarily for farmers and growers with the aim of adapting them to a garden setting.
Most of the tests were reproduced and adapted with kind permission from the Visual Soil Assessment (VSA) Field Guide by Graham Shepherd and the Visual Evaluation of Soil produced by Bruce Ball *et al* of Scotland's Rural College (SRUC).

The tests included texture, structure (visual structure test, porosity test), aeration (visual aeration test, smell test, surface ponding and crusting test), rooting depth (potential rooting depth test, fork test), biological tests (visual organic matter test, worm counts). Participants found the tests easy and quick to perform (over 90% of participants in all tests) and 70-80% of participants found each test useful.

Feedback from users indicated that the tests encouraged gardeners to pay more attention to aspects of soil health and provided a useful framework for community gardeners and groups to assess their soil at a new or existing site. Experienced gardeners found that the tests confirmed what they already knew about the site.

Although a majority of users found that many of the tests showed that their soil was in good health, some indicated that their soils scored well with some tests, but poorly in others, so it was difficult to draw conclusions. A summary score of Texture, Structure, Aeration, Biological activity and Rooting depth with accompanying recommendations would provide more focus and help to translate the tests into practical action.

Users were also questioned on their soil management practices. The key findings were:

- 83% used home compost in their garden
- 33% grew green manures every year, 42% grew them some of the time
- 70% practised minimal digging and cultivations

Those that grew green manures were more likely to have good soil structure and porosity than those that never grew them. As the majority of the group carry out good organic soil practices, it would be interesting to open it out to a wider group who carried out a wider range of soil practices.

The next step is to assemble the tests into a guide for gardeners with relevant recommendations.

Background

Many of us are aware that a healthy soil is important for producing healthy crops, but we are not always sure of what we should be looking for when checking the health of our soil. In particular, the physical conditions of the soil are frequently overlooked. Conventional agriculture too often places a heavy emphasis on the chemical components of the soil and fertilizer requirements whilst neglecting the importance of good soil physical and biological properties to allow a healthy root system and biological life to flourish.

Here we examine some of the basic physical properties of the soil and how to assess them, using simple visual tests. There are a number of visual tests available but many may give advice that is more tailored towards farmers. We wanted to adapt these so that they are more applicable to gardeners.

Soil texture

The soil texture refers to the size of the soil particles themselves. There is nothing you can do to change the texture of the soil unless you add soil imported from elsewhere. Particles are classed within three sizes categories: sand, silt and clay. The ideal soil has a mix of all three particles. Soils which are higher in sand content will drain and lose nutrients more quickly but will warm up more quickly in the spring. Soils higher in clay content will hold onto water and nutrients more strongly, but often tend to remain colder and waterlogged. There are a number of ways testing soil texture, which can be done using a simple visual test.

Soil structure

The soil structure refers to how the sand, silt and clay particles are organised into aggregates and crumbs. This is one of the soil properties that the gardener can have most influence on. A good soil structure can mean the difference between thriving plants and those that are struggling. Good soil structure can take a while to build up, through growing green manures and additions of organic matter. It can be destroyed very quickly by digging or walking on the soil when it is wet.
The ideal soil structure has aggregates that are a small crumb structure that readily crumble with the fingers. It will also have a mixture of fine micro pores and larger macro pores to allow movement of air and water to the roots. A poor structure will have large blocky aggregates with very few pores.

Soil drainage

An ideal soil retains water and nutrients under dry conditions but drains freely enough to prevent waterlogging under heavy rain. Ponding on the soil surface or the growth of algae are indications that the soil is draining poorly. The presence of blue-grey colours in clay soils, is an indication that the soil has been starved of oxygen. Badly drained soil might also smell of rotten eggs.

Soil organic matter content
Organic matter is derived from compost, broken down leaf litter, plant residues and animal manures. It is a vital component for a healthy soil. It helps to improve soil structure on both sandy and clay soils, retain moisture and nutrients and provides food for biological life in the soil. Generally, soils that are high in organic matter are darker in colour, whereas soils that are light grey are devoid in organic matter.

Biological life
A healthy soil should be teaming with biological life that does much to help plants thrive. Fungi, bacteria, other microbes and larger organisms all help to break down organic matter, releasing nutrients into a form that plants can take up. Earthworms help to mix up organic matter into the soil, and create pores to help the passage of water and nutrients. Mycorrhizal fungi add to the root system extending its reach by an order of magnitude. Without biological life, a plant has to work much harder to merely function.
A soil that is rich in biological life should have a sweet earthy smell like compost. You should also see plenty of earthworms.

Visual Soil Tests
We asked members to carry out a series of visual tests that were designed primarily for farmers and growers with the aim of adapting them to a garden setting. Many of the tests listed here have been reproduced and adapted with kind permission from the Visual Soil Assessment (VSA) Field Guide by Graham Shepherd and the Visual Evaluation of Soil produced by Bruce Ball et al of Scotland's Rural College (SRUC).

The VSA methods were devised by Graham Shepherd for arable and livestock farmers in New Zealand. A number of characteristics are assessed by comparing the soil to photos and giving them a rating of:
0 = Poor, 1 = Moderate, 2 = Good

If you score 0 or 1, you might want to take some of the suggested steps to improve your soil.

The rating system is deliberately simple, so that the categories are easily distinguishable and can be carried out by anybody.
The characteristics used include: texture, structure, porosity, aeration, organic matter, earthworms, smell, ponding, surface crusting and potential rooting depth.
You can find out more about this system here
https://www.bioagrinomics.com/visual-soil-assessment
Despite its simplicity, the methodology is based on scientific research and extensive testing has shown that farmers and growers are able to use the tool to accurately assess soil physical characteristics. Many soil physical characteristics, especially aggregate size distribution, saturated hydraulic conductivity and air permeability showed strong correlations with the visual assessment scores (Shepherd, 2003).

The VES methods were devised by the Scotland Rural College. The aim is to take a soil sample, and match it to the category that most closely resembles the characteristics in the photos on the chart.
The soils are given a structural rating in one of 5 categories:

Sq1 = Friable, Sq2 = Intact, Sq3 = Firm, Sq4 = Compact, Sq5 = Very compact

You can find out more about this assessment here:
https://www.sruc.ac.uk/info/120625/visual_evaluation_of_soil_structure

After carrying out the tests we asked participants to assess:

- How useful they found it (1-4) where:
  1 = No use at all, 2 = Not very useful, 3 = quite useful, 4 = very useful
- How easy they found it to do (1-4)
  1 = Very difficult, 2 = Quite difficult, 3 = Quite easy, 4 = Very easy
- How long it took them to do the test
  1 = A very long time (over 30 mins), 2 = Quite a long time (15 - 30 mins)
  3 = Not very long (5 - 15 mins), 4 = Very quick (Less than 5 mins)

At the end of each section are a few general practical tips that address the results of each test. These will be developed further when we have gathered in results and comments.

Aims of this experiment

To evaluate various simple visual methods of checking soil health and adapt them to produce tailored recommendations for gardeners.

Observations

Participants were advised to carry out tests in early spring when the soil was moist but not waterlogged. We present the general findings from people's soil assessments and also their evaluations of the tests.

Results

Response rate

A total of 373 people signed up to do this experiment, making it the most popular experiment in 2019. Of these, 124 people returned results, giving a response rate of 33%.

Additions to the soil

We asked participants what they added to the soil and how often they added it. (Table 1)

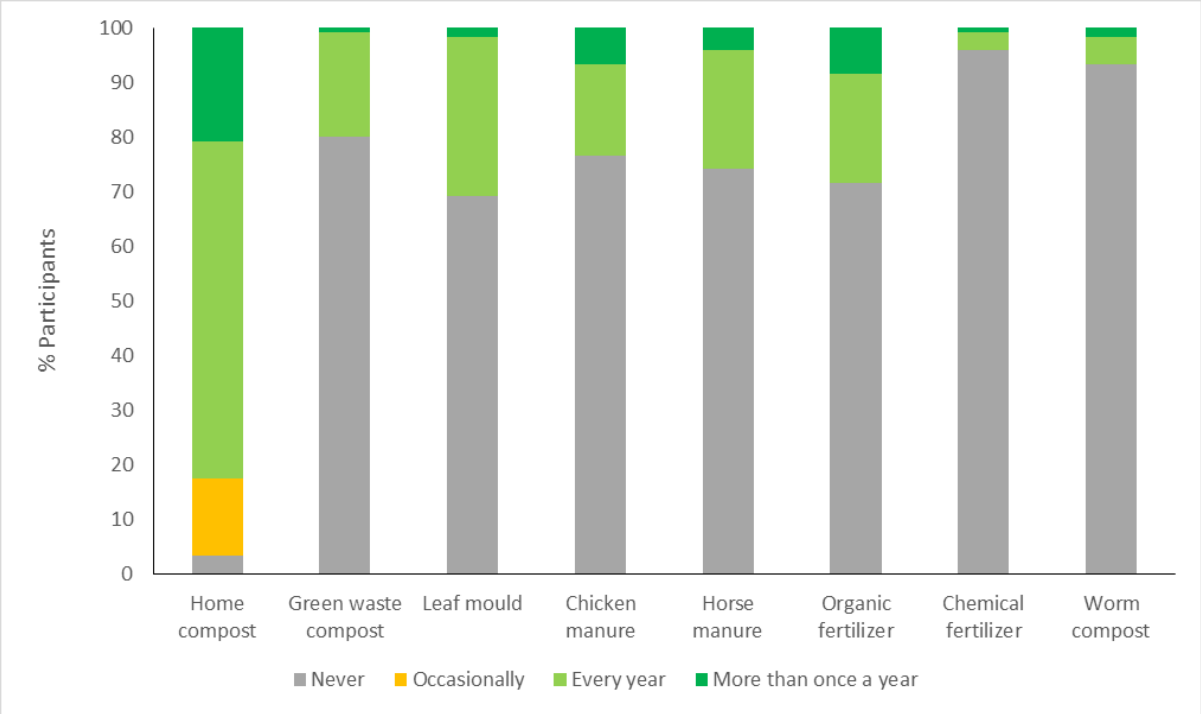

Figure 1 Soil inputs

We have summarised the findings below:

Table 1 Materials used by participants

Material	**% of people using it at least once a year**	**Comments**
Home compost	83	A good source of all round, slow-release nutrients. Closes the nutrient loop and avoids the environmental footprint of transporting bulky materials a long distance
Leafmould	31	Low in nutrients but a good source of organic matter. Again has the environmental benefits of being produced on site.
Organic fertilizer	29	These may be necessary to supplement the soil or containers where there is insufficient fertility generated from composting or growing green manures. Often they have long supply chains and a larger environmental footprint associated with their manufacture and distribution, but they are still preferable to chemical fertilizers. Chicken manure pellets are popular with gardeners, but there are concerns over the welfare standards that they are kept under.

Horse manure	26	A good source of organic matter, but very variable in nutrient content. Users need to be sure that it is not contaminated with herbicides.
Chicken manure	24	Chicken manure is very high in readily available nitrogen so must only be applied sparingly and when well-rotted.
Green waste compost	20	This is good for improving levels of organic matter, but is slower to release nutrients than many composts produced in the garden. Its availability varies in different regions of the country. Some gardeners are concerned over its quality, although samples with PAS 100 certification and a smaller screen size are of reasonable quality.
Worm compost	7	Although rich in nutrients, not many participants used this on their soil. Wormeries generate relatively small amounts of compost, which is generally only useful for small spaces, such as containers.
Chemical fertilizer	4	It is perhaps not surprising that only a few members of an organic gardening organisation are using synthetic chemical fertilizers.

Cultivations

We asked participants about their soil cultivation practices. The vast majority of participants (69.7%) stated that they did a minimal amount of cultivation or forking when needed. Only a small proportion (12.6%) said that they were no dig. Many people are becoming aware of the benefits of no dig, but perhaps are not convinced that it will work for them, or lack the time or resources to change their established growing practices. No dig gardening does require access to a plentiful supply of compost which may be a barrier to some. A significant minority (17.6%) admitted to turning the soil over to at least a spade's depth very year. From our experience, fewer growers that we encounter at Garden Organic are still using the standard practice of turning the soil over in the autumn and allowing the frost to break up the aggregates. With mild wet winters, this advice is often not appropriate. Firstly, there are fewer frosts that will break up the aggregates. Secondly cultivating the soil in the autumn encourages organic nitrogen to be released into more soluble forms (mineralisation) (Silgram & Shepherd, 1999) which will be washed out by any rainfall, especially if there are no plants to take it up.

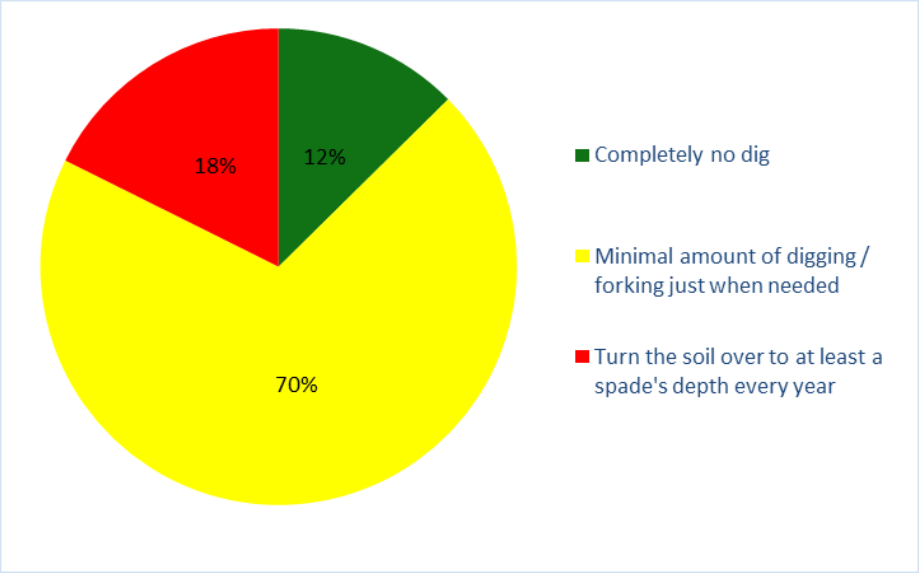

Figure 2 Cultivations carried out

Use of green manures

Only a third of growers (33%) used green manures every year, with 42% occasionally growing them. A quarter of the growers (25%) never used them.

At Garden Organic, our experience is that green manures are often low on the priority list for gardeners. Many focus on looking after food crops without seeing growing green manures as an investment in future food crops. Many find the choice of which species to grow and when to grow it, bewildering or they may intend to grow one over the winter, but miss the narrow autumn window for sowing after harvesting summer crops. A guide to choosing green manures is compiled by Garden Organic https://www.gardenorganic.org.uk/green-manures

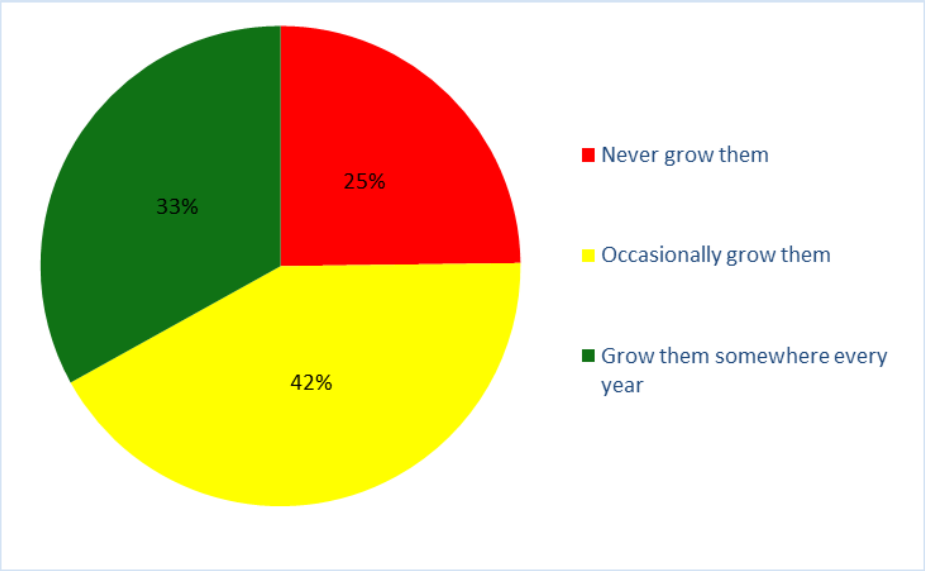

Figure 3 Use of green manures

We asked participants to carry out the visual tests on their soil then evaluate them as to

i) How useful they found them
ii) How easy they were to perform
iii) How quick they were to perform

We have presented scores for

i) Use - % of participants that found them quite useful or very useful
ii) Ease - % of participants that found them easy or very easy to perform
iii) Speed - % of participants took less than 15 mins to do the test

Soil texture

Soil texture could be thought of as the most fundamental test, as it is a key indicator as to how your soil will behave. Both these tests were a modified version of a traditional hand texture test, of which many variations exist already. The VES test had more categories of soil texture than the VSA test. The VSA test aimed to simplify the texture test, and put soils intro categories from poor to good. Loam soils with a balanced mixture of soil particles were given the best rating, then soils with a higher proportion of clay and silt slightly lower, then the sandiest soils most poorly.

Table 2 Soil texture assessment using VSA test

Soil texture (VSA score)	Silt loam (2)	Clay loam (1.5)	Loamy silt (1)	Sandy loam (1)	Silty clay / clay (0.5)	Loamy sand (0)	Sandy (0)
Participants (%)	18	18	19	21	7	13	3

Table 3 Soil texture assessment using VES test

Soil texture	Organic	Sandy	Loamy sand	Sandy loam	Silt loam	Sandy clay loam	Clay loam	Sandy clay	Silty clay	Clay
Participants (%)	18	3	29	15	8	10	10	0	5	2

Most participants found the visual soil tests useful or very useful, with little or no preference given to the VSA or VES methods given.
VSA test: Use: 75%, Ease: 83%, Speed: 98%
VES test: Use: 75%, Ease: 78%, Speed: 99%

Soil structure

Soil structure test

The soil structure gives a good indication of the physical and biological health of the soil. The VSA structure test categorises soil structure into 3 simple categories: good, moderate and poor. The VES test has five categories: Sq1 = Friable, Sq2 = Intact, Sq3 = Firm, Sq4 = Compact, Sq5 = Very compact. Some people commented that they preferred the 'higher resolution' of the VES test.
People categorised their soils in a similar way, using both tests:

Table 4 Soil structure using VSA test

	Good condition VSA2	Moderate condition VSA1	Poor condition VSA0
% of participants	83	15	2

Table 5 Soil structure using VES test

	Friable Sq1	Intact Sq2	Firm Sq3	Compact Sq3	Very compact Sq4
% of participants	59	24	15	1	1

Generally people had good soil structure, with few people having structural problems. Using both tests, 83% of people categorised their soil as having good (VSA2 or Sq1/2) soil structure. 15% categorised their soil as moderate or firm, and only 2% as poor or compacted.

VSA test: Use: 79%, Ease: 91%, Speed: 98%
VES test: Use: 80%, Ease: 83%, Speed: 97%

In addition to the general soil quality rating giving by the VES test, the VSA test assesses soil health according to a number of other factors including, porosity, aeration, organic matter, earthworm count, surface crusting, surface ponding and potential rooting depth.

Soil porosity

A range of pore sizes is essential for maintaining air, water and nutrient movement in the soil and sustaining biological life. Soils are likely to have poor porosity if they are subject to continual traffic, whereas a garden soil cultivated for vegetables is less likely to be subjected to this. It is also likely to receive regular inputs of organic matter through compost, which will help to maintain good porosity and structure.

Table 6 Soil porosity assessment using VSA test

	Good condition VSA2	Moderate condition VSA1	Poor condition VSA0
% of participants	64	33	3

Consistent with this, a majority of 64% classed their soil as having good porosity, with only a small proportion of 3% having poor porosity.
Use: 77%, Ease: 83%, Speed: 98%

Soil aeration

Visual soil aeration test

When a soil is not aerated properly, normal respiration processes cannot occur and anaerobic organisms start to dominate. Many of these rely on reducing iron or other compounds within the soil, to obtain their energy in the absence of oxygen, resulting in characteristic changes in colour. This tends to happen in soils that are waterlogged for a proportion of the year.

Table 7 Soil Aeration assessment using VSA test

	Good condition VSA2 Mottles absent	Moderate condition VSA1 Soil has many (10-20%) fine orange and grey mottles	Poor condition VSA0 Soil has profuse (50%) coarse orange and grey mottles
% of participants	92	5	3

92% of participants classed their soil as having good aeration from the visual test. This is consistent with few participants reporting ponding, surface crusting or smells suggesting anaerobic activity.

Use: 73%, Ease: 88%, Speed: 98%

Surface crusting test

In many soils, particles on the surface adhere together to form a hard cap which is not permeable to moisture and air. This happens more frequently on soils with smaller size particles, such as clay or silt, after heavy rain. Surface crusting decreases the capacity of the soil to absorb small amounts of water, such as dew, under dry conditions. It also means that larger amounts of moisture are more likely to run off the surface and be lost elsewhere.
73% of participants stated that the surface of their soil was in good condition with little crusting, with 24% in moderate condition with only slight surface crusting.

Table 8 Surface crusting assessment using VSA

	Good condition VSA2 Little or no crusting	Moderate condition VSA1 Surface crusting 2 – 3 mm thick with significant cracking	Poor condition VSA0 Crusting is >5 mm thick with few cracks
% of participants	73	24	4

Use: 70%, Ease: 93%, Speed: 97%

Surface ponding

Surface ponding is an indication of soil with extremely poor infiltration. It will result in anaerobic conditions, root death and poor nutrient uptake, leading to yellowing of plant leaves. Luckily, 90% of participants reported their soil did not suffer from surface ponding. Most gardeners are likely to have some choice over where they site their food growing area, so with experience and knowledge of their site, will try and avoid areas that become waterlogged.

Table 9 Assessment of surface ponding using VSA

	Good condition VSA2 No surface ponding after one day following heavy rainfall when soil is saturated	Moderate condition VSA1 Moderate ponding for 2 days following heavy rainfall when soil is saturated	Poor condition VSA0 Significant ponding for 4 days following heavy rainfall when soil is saturated
% of participants	90	9	1

Use: 75%, Ease: 98%, Speed: 99%

Smell test

A healthy soil that sustains good biological life should have an earthy smell similar to compost. If it has no smell, then there are low levels of biological activity. A sour smell or smell of rotten eggs indicates there is anaerobic activity as a result of poor soil aeration. The results of this test was more divided with 60% stating that their soil was in good condition and 38% stating that their soil was in moderate condition. This suggests that many soils had lower than optimum biological activity. Luckily, only very few participants had soil with poor smells, suggesting regular waterlogging and anaerobic conditions.

Table 10 Smell test assessment using VSA test

	Good condition VSA2 Distinct earthy sweet smell	Moderate condition VSA1 Slight earthy smell	Poor condition VSA0 Putrid or unpleasant smell
% of participants	60	38	2

Use: 75%, Ease: 93%, Speed: 98%

Rooting depth

Potential rooting depth

A majority (55%) found their soil to have moderately poor potential rooting depth in the range 20 – 40 cm. A smaller proportion (37%) found their soil to have a moderately good potential rooting depth in the range 60 – 80 cm. The soil provides a significant potential to store water, reducing the need to water plants during dry periods. Plants that root more deeply will have access to much larger reservoir of stored water, so will be more resilient in dry weather.

Although 72% of participants found this test useful, only 63% found it easy to do as it involved digging a deep hole.

Table 11 Potential root depth test using VSA

Rating (Potential rooting depth cm)	Good (>80)	Moderately good (60-80)	Moderate (40-60)	Moderately poor (20-40)	Poor (<20)
% of participants	0	37	0	55	8

Use: 72%, Ease: 63%, Speed: 84%

Fork test

This was added as an extra test additional to the VSA tests as a simple and quick method for gardeners to assess a depth at which the majority of roots could be found. 64% found that they could insert the fork to a depth of 30 cm before reaching resistance, whereas 32% found that the fork met some resistance when only pushed into a depth of 15 cm. This will restrict the growth of plants and their ability to tolerate drought. Some people commented that this test was subjective as it depended on strength of person and type of implement. It also requires further development, as it is a subjective guide that hasn't been calibrated with soil physical measurements, unlike the VSA tests.

Table 12 Soil assessment using fork

	Good condition VS = 2 Fork can easily be pushed down to the depth of the prongs in most places	Moderate condition VS = 1 Fork meets resistance when poked in half way in most places	Poor condition VS =0 Fork can't be pushed in more than a few inches in most places
% of participants	64	32	4

Use: 76%, Ease: 95%, Speed: 97%

Biological activity

Soil organic matter

A simple visual soil organic matter test can be performed by assessing the soil colour. Overall, soils that are high in organic matter are darker, than those lower in organic matter. Comparing uncultivated to cultivated areas can give an indication as to the effect of your soil practices on organic matter levels. 74% of participants classified their soil as having good organic levels. This is consistent with many areas that have been cultivated for vegetable production, where generous amounts of compost are applied.

Table 13 Soil Organic Matter assessment using VSA test

	Good condition VSA2 Soil similar colour or darker than uncultivated areas	Moderate condition VSA1 Soil slightly lighter than uncultivated areas	Poor condition VSA0 Soil significantly lighter than uncultivated areas
% of participants	74	23	3

Use: 75%, Ease: 87%, Speed: 97%

Earthworms

It is difficult to assess the biological activity of the soil with a simple visual test, but observing and counting earthworms can provide a good indicator.
Participants sampled a 20 cm cube of soil and counted the earthworms. 65% found that they had less than 20 earthworms in this cube, which was considered poor according to the VSA test. This was cause for concern for many of the participants, but many found this test one of the most interesting, with 51% finding quite useful, and 32% finding it very useful. This test is dependent on the moisture content at the time of sampling, and it is possible that the low rainfall in April 2019, when many would have taken the test, contributed to the low earthworm counts.

Table 14 Earthworm assessment using VSA test

Rating (No. of worms in 20cm cube of soil)	Good (>35)	Moderately good (29-35)	Moderate (22-28)	Moderately poor (15-21)	Poor (<15)
% of participants	7	6	17	5	65

Use: 83%, Ease: 86%, Speed: 82%

Visual weeds test

This test was also added to see what extent weeds could be used as an indicator as to the condition of the soil. Although some weeds commonly appear under certain conditions, such as creeping buttercup in compacted soil, there were too many inconsistencies for this

test to prove useful. This test divided opinions, with 50% saying that it was quite useful or very useful, 33% not very useful and 17% no use at all.

Table 15 Visual weeds test

	Good condition VS = 2 Fertile soil = Chickweed, Nettles	Moderate condition VS = 1 Heavy soil: Perennial Thistles, Dandelions Lighter soils: Corn spurrey	Poor condition VS =0 Creeping buttercup, moss: compacted soil, poor drainage
% of participants	57	33	10

Use: 76%, Ease: 95%, Speed: 97%

Correlations between soil practices and soil visual test scores

We wanted to see if the soil practices carried out by participants influenced their soil assessment score. We attempted to put participants into different groups according to how they treated their soil. In many cases, this was difficult, as being organic gardeners, the vast majority of people treated their soil in a similar way. For example nearly all participants added some form of organic matter to their soil either as home-made compost, green waste or leaf mould.

However, as there was a more diverse mix of people that used green manure plants regularly or never used them, so we were able to demonstrate differences in some visual test results between these groups. Although the effects were not that large and not statistically significant (using chi squared test at 5% probability), there was a consistent trend. Amongst the participants that used green manures every year, more of them (92%) had soil structure in good condition than participants that never used them (76%).

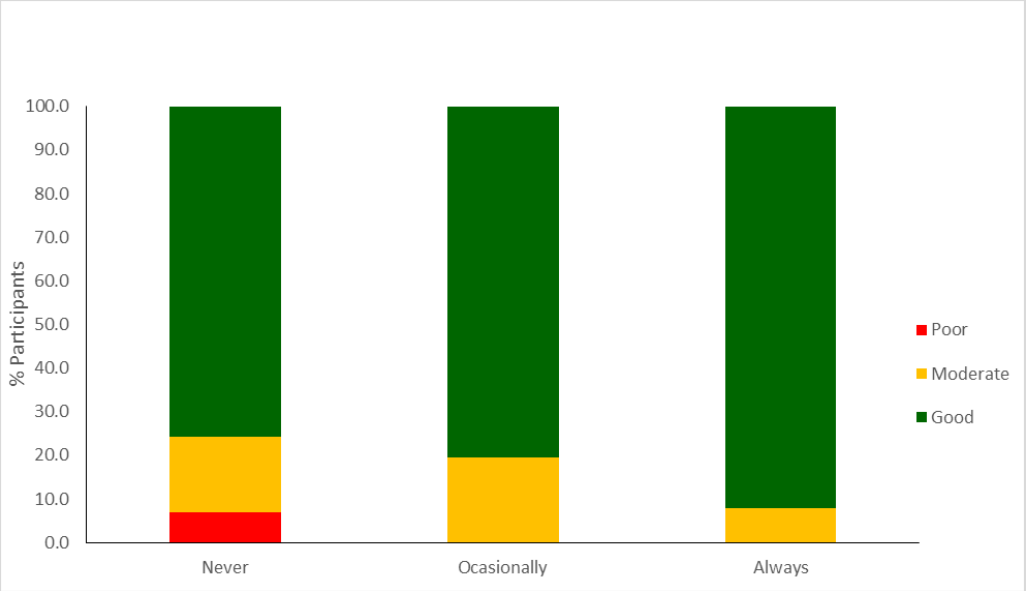

Figure 4 Effects of green manures on soil structure

Growing green manures also improved soil porosity, with more participants who regularly grew green manures (78%), having soils with good porosity, compared to those who never use them (56%)

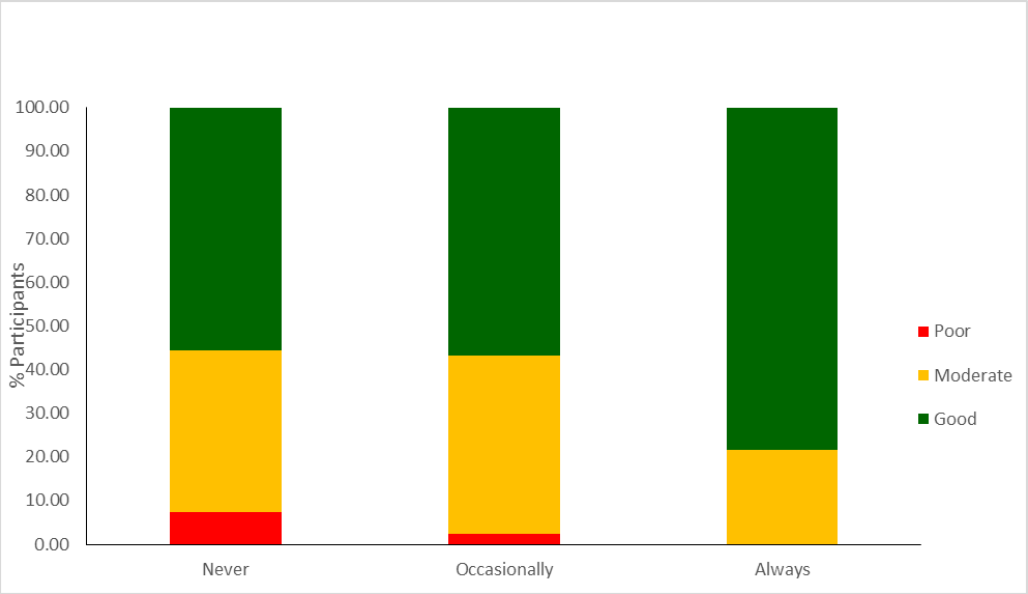

Figure 5 Effects of green manures on soil porosity

Other practices had small effects on soil conditions. For instance, no dig slightly improved soil structure and increased the worm count, but these effects were only small and could be due to natural variation.
This survey was carried out on organic gardeners who, more than likely, all pay good attention to their soil health already. It would be interesting to carry it out on a group with a wider range of soil practices.

Recommendations from soil tests

The results from the tests were divided into 4 categories: structure, aeration, rooting depth and biological life.

Structure (Structure test, porosity test)

The structure is one of the key indicators of soil physical health. An ideal structure should have aggregates that resemble small crumbs, and have a range of pore sizes to allow the flow of water, gases and nutrients, and allow spaces to support biological life. The soil biology is integral in maintaining a good soil structure, as many organisms are responsible for maintaining the pore structure within the soil. Fungi and bacteria play a part in stabilising the aggregates too. (Oades, J. M, 1993; Jacot, 1936).

The visual tests for structure and porosity are good indicators for this. Most gardeners reported that they had good or moderately good soil structure and porosity with few reporting serious structural problems. Crops grown in beds in a garden setting, are perhaps less likely to suffer from structural problems, as they are free from traffic or mechanical cultivations. The main dangers are treading on the soil, which can be negated by having

raised beds or well-defined, small manageable growing areas. Cultivating under less than ideal conditions can also damage soil structure, but a large majority of this group stated that they practised minimal soil cultivations. Only a small proportion practised no dig

Tips for improving structure:

- Addition of organic matter which will reduce the tendency of particles to stick together as large aggregates. It will also support biological life, which will contribute to maintaining a range of pore sizes and stabilise aggregates.
- Reducing cultivations to a minimum to avoid damaging soil structure, and the biological life that maintains it.
- Having well-defined growing areas that are small enough to be reached without treading on.
- Growing green manures such as grazing rye which have an extensive fine root structure and are very good at breaking up larger aggregates into a fine crumb structure.
- Lucerne or alfalfa have a strong taproot which is very good for breaking through harder layers lower down in the soil.

Aeration (Visual aeration test, surface crusting, surface ponding, smell test)

Soil aeration is essential for maintaining healthy roots and biological life in the soil. Some of the soil tests were designed to provide an indicator as to the degree of aeration. This includes observing the colour. In a soil that is regularly under anaerobic conditions, compounds commonly containing copper or iron, tend to develop greenish or orange mottles (Evans & Franzmeier, 1988). The smell test can also detect whether soils have turned anaerobic. Hydrogen sulphide gas can accumulate in anaerobic soils, as it diffuses a lot more slowly through water than air, generating a smell of rotten eggs (Setter, T., & Belford, 1990). The surface ponding and surface crust tests show whether a soil is likely to suffer from aeration problems. Luckily, only a small proportion of participants suffered from these problems. Also very few people observed the tell-tale signs of anaerobic conditions such as unpleasant odours and grey or orange mottling in the soil.

It is also important to retain a permeable soil surface so that the soil is able to absorb moisture. This increases the resilience of the soil to water stress as it will allow it to absorb small amounts of moisture such as dew, and prevent run off in heavy rain.

Tips for improving aeration of the soil:

- Adding organic matter to loosen soil particles and reduce aggregate size.
- Applying a mulch to the surface to prevent it from drying out and forming a crust.
- Avoiding leaving the soil bare. A green manure will protect the surface against heavy rainfall which tends to damage smaller aggregates, causing them to glue together. Green manures can be sown any time between April and September. Vetch and grazing rye are good for a late summer or autumn sowing, phacelia or buckwheat is good for sowing any time in the spring or summer.

Rooting depth (Potential rooting depth, fork test)
The soil is a huge potential reservoir of water and nutrients. The deeper the plant can root, the better access it has to this reserve, and the less often it needs irrigating during dry periods (FAO, 1998). Hard, more compacted layers of soil will greatly restrict rooting depth, resulting in less resilient plants (Taylor & Brar 1991).

Tips for improving rooting depth:

- Watering with larger doses less frequently to encourage roots to search for water at greater depths.
- Growing alfalfa / lucerne as green manures to break through compacted layers.
- Growing perennial crops where possible rather than annuals, to allow them to establish a larger root system.

Biological life (organic matter, earthworm test, smell test)
Although biological life is a vital component of soil health, it can be difficult to assess using visual tests. Some of the tests can be used to give an indication. Soils with high levels of organic matter are more likely to sustain high levels of biological activity. The colour of the soil can give a good indication as to its organic matter content (Aitkenhead *et al*., 2013). The smell test will also give an indication, as soils rich in biological life, often have an earthy sweet smell resembling compost (Sullivan, 2004). Around 60% of people reported that the smell test indicated that there were good levels of biological activity, so there was room for improvement in 40% of cases.
Earthworms are widely accepted amongst growers as a good indicator for soil biological health (Stroud, 2019). A soil rich in earthworms will also have better structure, as earthworms improve porosity, structure and the capacity of water to infiltrate into the soil. Many people discovered that they had below optimum levels of earthworms in the soil. This test is dependent on soil moisture levels, so may have been influenced by a drier than normal early spring months. This test was rated as the most useful, perhaps because many people discovered something that they hadn't previously realised, and also because it generates a numerical result which can feel more authoritative than a subjective judgement.

Tips for improving biological life in the soil:

- Avoid use of chemical fertilizers, pesticides, fungicides and herbicides
- Minimise cultivations, especially those that turn the soil over to a depth
- Add organic matter, especially home compost and leaf mould
- Grow green manures whenever possible to avoid bare soil

Overall utility of the tests

Visual soil tests have been around for a long time. The VSA tests have widespread adoption by growers internationally, and published as FAO guides. Likewise the VES tests are used by a number of UK agricultural advisory agencies. An evaluation of the many soil testing methods was made by farmers and growers at a number of workshops as part of the GREAT soils project funded by the Agricultural and Horticultural Development board

(https://ahdb.org.uk/knowledge-library/greatsoils-soil-assessment-methods). The visual soil tests were thought to be a useful tool for providing a general picture and could be complimented by other more specific tests such as nutrient or micronutrient testing.

However, although many of these tests can be adapted by gardeners with not many changes, much of the advice and context given is aimed towards a more agricultural setting rather than a garden setting. This exercise aimed to tailor the VSA tests and the VES tests towards providing more appropriate recommendations to a garden setting.

In addition to the quantitative evaluations, participants provided useful qualitative written feedback. Here is a summary of participants' written comments to the tests. followed by our suggestions

Table 16 Summary of participants' comments on soil tests

Summary of participants' comments	**Our suggestions**
Some found that the tests provided a useful framework, and reassured them that their soils were healthy and that their current practice was working well.	These tests aim to provide a framework for people wishing to assess their soils both for existing gardeners at a site and to people taking on a new site and to provide recommendations.
Some stated that it was a useful way for a community group to assess their plot together.	The tests would provide a method for community groups who are perhaps less familiar with gardening to assess their soils, and encourage them to consider the importance of their soil.
The tests were easy to do but not always easy to interpret. The quality of the print in the protocols didn't help.	This can be rectified, and would be made easier by supplying electronic copies of the photos.
The tests might provide a useful way of assessing a new site, but if you had already been working with the soil, they didn't tell you anything that you didn't know already.	Many gardeners have made many of these observations in the tests already whilst working with their soils. The tests provide a way of formalising some of these observations. It also encourages people to think about their soil more carefully and place greater emphasis on soil health as an essential component of growing healthy plants.
Their soil was very variable in their garden, so it depended on where they took the samples from.	This is a problem faced with any soil test. It is important to consider what you what you are trying to achieve and then take representative samples. Gardens will have a higher degree of variability over a small area than an agricultural field. It is

	necessary to take separate tests on areas that have been treated differently and used for different purposes (eg wild areas and areas cultivated for food).
Three categories wasn't always enough, some people found the VES tests a bit more helpful for assessing structure as they provided a bit more 'resolution'.	This might be the case, but the VSA tests are designed to provide simple categories for assessing soil. They are then built up together to provide an overall picture of soil health.
The visual weeds test provided inconsistent results, many people had all of the weeds listed. Others said that the list of weeds was too restrictive.	Certain weeds show correlations with soil conditions, but there are often outliers. Many weeds thrive under a range of conditions, so it can be difficult to draw conclusions.
Some found that they scored well in some categories but poorly in others, so found it hard to draw conclusions from the tests.	The VSA tests have an accompanying score card which adds up scores, weighted to give more emphasis to some tests. The structure and the earthworm tests are weighted to give more emphasis to these tests. This gives an overall score for the health of your soil. It might also be useful to give scores for broad categories such as structure, biological life, aeration and rooting depth with accompanying recommendations.
Some found the recommendations for soil practice helpful, but many commented that the many of the suggestions were repetitive.	There is no getting away from the fact that many of the recommendations for achieving a healthy soil will be similar: adding plentiful organic matter, growing green manures, mulching and minimising cultivations. Splitting the recommendations into broader categories as mentioned above (structure, biological life, aeration, rooting depth) could lead to more targeted and less repetitive advice.
The worm tests provided an interesting insight into the biological activity but many were concerned at the low numbers in what they otherwise considered to be a healthy soil.	The worm tests may have been popular because they involved counting, so generated a number rather involving a subjective test. Although worm activity is a very good indicator of soil biological health, care needs to be taken, interpreting the absolute numbers as they do vary with moisture content.

Next steps

The next steps will be to take the some of the tests used here, and put them together with some recommendations for gardeners to provide a soil testing guide for gardeners. Putting the tests together to make separate scores in the categories: Texture, Structure, Aeration, Rooting depth and Biological will allow targeted recommendations to be made for each category.

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