Report on science experiments and protocols and the collective creation of knowledge in GROW Missions

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DELIVERABLE 4.3

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Report

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Table of Contents

List of Figures

List of Tables

Glossary of terms, abbreviations and key concepts in GROW

Citizen Observatory (CO) - is a concept that has developed at EU level. It is a community of stakeholders which include citizens, scientists, policymakers and others collaborating on research for environmental monitoring, whose issues have impacts related to land cover and land use.

Citizen Science - scientific work undertaken by members of the general public ("citizens"), often in collaboration with or under the direction of professional scientists and scientific institutions.

Community Champion - An organisation in a GROW Place that coordinates the citizen science in that region and acts as the primary liaison between GROW and the citizens participating in the Changing Climate Mission.

EC – The European Commission (EC) is the executive of the European Union and promotes its general interest.

Edible Plant Database – information about the ecology and cultivation of vegetables, fruits, and herbs that is accessed through the GROW App.

Experiment - a scientific procedure used to gain new knowledge or test a hypothesis e.g. To what extent does adding a 2cm layer of mulch improve soil water retention? In GROW these are valid at household level and also enable a wider scientific understanding from combining data from all growers.

GPS – Global Positioning System - a network of satellites and receiving devices used to determine the location of something on Earth.

GROW – the **GROW Observatory**. A European-wide project engaging thousands of growers, scientists and others passionate about the land. An EC Horizon 2020 funded Citizen Observatory project.

GROW App – a free application for mobile devices (Android and iOS) that provides information about crops and regenerative food-growing practices, and collects information about soils and growing sites in relation to the soil sensors.

GROW Place(s) – specific geographic regions participating in the Changing Climate Mission. There are 19 GROW Places in 15 European countries.

Measurement - simple measure to quantify something e.g. size of growing area, slope angle, number of earthworms in a bucket of soil, weight of food harvested

Mission – a period of coordinated citizen science activity that can involve sampling and sense making. Missions engage citizens, scientists, policymakers and other bodies to collaborate; through contributing to experiments and goals they will amplify innovation and enable better environmental decision-making. Missions are designed to achieve social, policy and innovation outcomes and be sustainable. The two main Missions in GROW with citizens participating in them are the Changing Climate Mission and the Living Soils Mission.

Monoculture – where a single crops is grown in an area.

MOOC – Massive Open Online courses. Free online learning accessible world-wide.

Observation - a subjective measure that may vary depending on the observer or time of observation e.g. Type of vegetation in area, soil cultivation method used, if happy/sad.

NPK – a common abbreviation for three plant macronutrients Nitrogen (N) Phosphorous (P) and Potassium (K).

Participants – members of the public participating in GROW.

Permaculture - Permaculture is a design process. It helps design intelligent systems which meet human needs whilst enhancing biodiversity, reducing our impact on the planet, and creating a fairer world for us all.

pH – a measure of the acidity or alkalinity of a substance e.g. soil. A pH value of 7 is considered neutral, below 7 is acidic and above 7 alkaline.

Polyculture – where more than one crop is grown in the same space at the same time.

Protocol – a method to follow for conducting specific tests, measurements or observations

Regenerative growing practices – practices used by growers and farmers to produce food whilst also regenerating soils and/or restoring ecosystems.

Sensor users - volunteers participating in the GROW Changing Climate Mission who receive and place soil sensor(s)

Shared Planting Calendars – a GROW activity to support the sharing of planting and harvesting dates for vegetable crops across Europe.

Soil Sensor – in GROW, Flower Power sensors were used to measure soil moisture, light and temperature.

STKs – Soil test Kits. In GROW we used Luster Leaf® Rapitest® kits (STKs) to assess soil Nitrogen, Phosphorous, and Potassium and soil pH.

Test - A method used to establish a quantity or value e.g. pH test, soil texture test

GROW Observatory Partner Organisations named in this report

FAO: Food and Agriculture Organization of the United Nations
FE: FutureEverything
IIASA: International Institute for Applied Systems Analysis
JHI: James Hutton Institute
PAB: Permaculture Association (Britain)
TUW: Technische Universität Wien (Technical University of Vienna)
UNIVDUN: University of Dundee
UOM: University of Miskolc

1 Scope

This report is produced by the GROW Observatory Science Team who had the overall remit to provide the underpinning knowledge to facilitate translation of citizen data into usable services, and support participation in collaborative and co-created citizen science.

This report outlines how standard scientific methods can be effectively adopted into protocols that are suitable for participating citizens to use, and considers how data and results from the project were made available for citizens to use themselves and for wider use by other stake holders (including non-governmental organisations (NGOs), scientific institutes and local authorities). For citizen science to be successful, it requires both useful scientific outputs (results) and meaningful engagement of citizens. A key to achieving this is effectively combining robust scientific methods with the contextual requirements of citizens (e.g. their place-based interests, skills, time and available resources). The methods used should therefore be suitable for non-professionals who do not have access to expensive laboratory-grade equipment, and they should be deployed in a relevant and engaging manner.

This report considers individual protocols (specific tests, measurements and observations made by citizens, Table 1.1) and the two main overall citizen science approaches taken in the GROW Observatory (GROW), namely:

> 1 – ***Observation-driven:*** engaging citizens in data collection and sharing, with the primary data analysis and insights done by scientists.
> 2 – ***Hypothesis-driven:*** engaging citizens in direct experimentation and individual discovery and analysis, also shared to scientists for analysis of, and insights from, collective data.

In GROW both approaches were set within a collaborative framework and accompanied by support for citizens to access, understand and use their own data.

Evaluation is made in the context of scientific validity of data produced and the direct knowledge gained (i.e. results). In addition, consideration is given to the supporting tools and information provided to help citizens understand and use their own, and the collective, data. Where applicable, an assessment is made of real-world changes to food growing approaches and soil custodianship after participating in GROW.

Three missions in the GROW Observatory were designed to directly engage citizens in data collection:

- Summer experiment, 2017: A pilot study investigating the effect of mulching on soil, and testing engagement and data capture tools.
- Changing Climate, 2018-2019: Focused on using soil sensors in specific GROW Places to validate satellite data and contribute to the creation of soil moisture maps.
- Living Soils, 2018-2019: Open to all, focused on regenerative food growing practices. This comprised an experiment (in 2018) and sharing planting and harvesting dates (in 2018-2019)

Massive Open Online Courses (MOOCs) were designed to support learners to understand and use the citizen science protocols and to learn from their own results and collective findings. They also served to recruit participants to the Changing Climate and Living Soils missions. This report evaluates the specific tools and protocols used in the three missions.

Wherever practical, the same measurements were used across Missions using the same approaches. Where there were limitations, for example, sensors were only available to the Changing Climate Mission, different protocols to obtain the same measurement information were provided. The observations and measurements for the Missions are summarized in Table 1.1.

Table 1.1 Measurement protocols in GROW's citizen-facing Missions
Inclusions in brackets (y) show protocols that were initially included in a mission but subsequently removed. Those highlighted below with a grey background were scientifically evaluated in GROW.

Protocol	**Summer experiment**	**Changing Climate**	**Living Soils**
Observations (simple criteria/classifications)			
Geolocation	y	y	y
Land – Land cover class		y	
Land – Site management activities		y	
Land - Shading – adjacent structures, time	y		
Land – Shading – canopy cover		y	
Land - Shading – shade category		y	y
Land – Shading – light & temperature (sensor)		y	
Land - Slope position		y	y
Measurements (procedure/quantification)			
Crop - Harvest weight			y
Crop - Harvest quality			y
Land - Site suitability (waterlogging)	y		y
Land - Slope angle and aspect			y
Soil - Aggregate stability	y		
Soil - Decomposition rate (teabags)	y		
Soil - Earthworm abundance	y		
Soil - NPK and pH test kits			(y)
Soil - Stone content		(y)	
Soil - Texture by sediment jar		(y)	
Soil - Texture by touch test			y
Soil - Water by hand	y		
Soil - Water by sensor		y	
Soil – Light (sensor, above ground)		y	
Soil – Temperature (sensor, above ground)		y	

Another GROW report, Deliverable 4.1 "Report on evaluation of tools (crop database, Soil Testing Kit, Land Survey Toolkit) [Confidential]," defines the main observations and measurements used in GROW and describes protocols for measurements and observations (see Appendix 1 for a summary). Initial evaluation of the practical implementation of the protocols is included in that report for the NPK and pH test kits. Subsequent to that report, further evaluation of several individual protocols has been conducted by the GROW consortium, and is included in this report:

- NPK and pH tests
- Soil texture by sediment jar
- Soil texture by touch test

Feedback from Mission participants on the practical implementation of tests is included for all relevant observations/measurements.

2 Introduction

The GROW Observatory is a European-wide project that engages thousands of growers, scientists and others passionate about their land and the soil they grow crops in. Using simple tools, GROW has not only empowered growers to better manage their soil/land, it is also helping growers to contribute to vital scientific environmental monitoring.

Why is there a GROW Observatory?

There are many human and environmental challenges facing us today. Two challenges that GROW focuses on are saving our soils and adapting to climate change. By helping people understand and improve both soil and food growing practices, by contributing soil moisture data over a large geographical scale and by empowering people to work on these topics collaboratively we can aid climate science, impact on policy, and make a difference in our own actions. This means we can help respond to the crucial sustainability challenges the planet faces.

What is GROW doing?

GROW takes action in growing spaces around Europe and provides learning experiences and information services online. Across Europe, thousands of growers are learning together: they try exciting new ways to improve their soil and food production methods. Participants do simple, coordinated soil experiments and measurements to capture and make sense of data on their local environment. This helps validate good local growing practices and international environmental monitoring. GROW citizen science activity is focused into two main Missions.

The Changing Climate Mission

This Mission focused on deploying several thousand soil sensors around Europe, which send soil moisture data back to the GROW Observatory. These data are used to validate soil moisture readings taken by European Space Agency satellites and to inform decisions by food growers and policy makers, helping society adapt to extreme climate events.

Distribution of soil sensors is focused in a limited number of areas, called GROW Places, because a high density of measurements is the most valuable to science and there is a limited supply of the low cost soil sensors that are being used in GROW. There are 19 GROW Places in 15 countries (Sweden, UK, Ireland, Netherlands Luxemburg, Poland, Austria, Hungary, Croatia, Latvia, Italy, Serbia, Portugal, Spain (Canary Islands), and Greece.

Activity in this Mission primarily the following science-related ambitions in GROW:

- Contribute to validation of satellite-retrieved soil moisture products.
- Develop a dataset of in situ land and soil observations exceeding existing national networks in number and density across the continuum of land cover practices from urban to rural- improve smart decision making and the active participation of citizens around land and soil governance
- Smart decision-making and the active participation of citizens around land and soil governance.
- Empowering European growers and farmers to be better able to adapt to a changed climate

The Living Soils Mission

The Living Soils Mission aimed to develop and support an active network of small-scale growers and gardeners who grow food by using, and collaboratively investigating, practices that regenerate soils and create resilient ecosystems. The objectives were to:

1. Help growers to access information and advice tailored to their location and growing conditions.
2. Increase the number of people growing in ways that regenerate soils and support diverse and resilient ecosystems.
3. Investigate regenerative practice(s) at the smaller (i.e. not routinely mechanised) scale of growing and disseminate findings.

We have used the term “regenerative” to recognise the need for action to improve soils and ecosystems over existing conditions, and to indicate approaches that balance production of food with regeneration of soils and enhancement of ecosystems.

The Mission was open to participants from around the world, although the focal region for activity was Europe.

Activity in this Mission supported the following science-related ambitions in GROW:

- Enhance and validate land/soil management practices and production techniques.
- Enable, promote and evidence sustainable micro-farming, diversification and self-sufficiency.
- Smart decision-making and the active participation of citizens around land and soil governance.

3 Observation-driven and hypothesis-driven approaches in citizen science

3.1 Overview

Citizen science is a strong potential mechanism for active citizen participation in environmental monitoring and policy making. The widespread use of technologies such as smart phones and low-cost sensors gives opportunity for unprecedented geographical coverage and high-quality monitoring of the environment. Citizen science, as a method, covers a diverse range of approaches that, with the exception of entirely computer-based projects, can be difficult to classify (Pocock et al. 2017). Some classification systems describe citizen science projects by the level of collaboration between scientists and citizens: *contributory* - established by professionals and inviting citizens to contribute data; *collaborative* - designed by professional scientists but with volunteers doing more than contributing data e.g. guiding questions, analysing and/or disseminating findings; and *co-created* projects - designed by professional scientists and members of the public working together, with at least some volunteers involved in most or all steps of the scientific process (Bonney et al., 2009a).

GROW has adopted an overall framework focused on collaborative working, with the intent to help citizens to learn about the subjects of interest (e.g. soil moisture, soil custodianship and regenerative food-growing practices, satellite science, and climate change), as well as the scientific process from defining questions of interest to collecting, analysing and using data to make real-world change. The collaborative framework balances the resource-demands of true co-creation with the wide-scale engagement that can be achieved with simpler, contributory models.

A genuinely co-created citizen science project requires a significant investment of time and effort to recruit and work with members of the public through each step of the research design process. In GROW, this would have delayed the launch of the wider participation elements of the project and reduced the total longevity of datasets that could be obtained (with 2 years of continuous soil moisture readings as a target aim for satellite validation). Further, the requirements for satellite validation, the soil moisture maps (‘Gridded Product’), and the land cover data had very specific intentions for the use and analysis of data which, in turn, required very specific methods for data collection. These were thus, by necessity, designed by the GROW scientists. Although citizens didn’t set these target questions or contribute to the design of the methods, participants were able to access and use their own data to understand their sites and answer their own questions. Collective findings were made available to participants who collected data and the wider public in such a way as to help them better understand their environments. In other areas of science in GROW, there was more scope for citizen innovation to inform the direction of research. The “Great GROW Experiment” in 2018, for example, was developed in response to areas of interest expressed by citizens.

Within this overall collaborative framework, two different approaches to science have been trialled with citizens. These are distinguished here as “observation-driven” and “hypothesis driven.”

3.2 Observation-driven approaches

In the observation-driven approaches, participants make observations and contribute data to scientists for analysis. This is a common approach in ecological and environmental citizen research (Dickinson et al. 2012) and benefits from relatively limited demands on participants. Thus more people are likely to be involved and a greater geographical coverage of data can be obtained.

In the Changing Climate mission, data collection for the land and soil surveys and the soil sensors was observation-driven. It sought to characterise the soils and landscapes in which sensors were placed, and to collect the data readings from the sensors (specifically; soil moisture, temperature and light). This data collection began with pilots in 2017-2018 and was rolled out more widely in 2018-2019.

In the Living Soils Mission, the collection of crop planting and harvesting times of growers in the final year was observation-driven, seeking to collect and share information on when best to plant crops in the different bioclimatic regions of Europe.

3.3 Hypothesis-driven approaches

In our hypothesis-driven approaches, participants are engaged in experimental testing of hypothesis in their own sites. They take on the role of a researcher and use their own results and observations help them to test the hypothesis for their site and come to a conclusion. Drawing together data from all participants, scientists can analyse and present the collective findings and participants can see how their individual findings relate to those of others. Hypothesis-driven citizen science is more resource-intensive in terms of participant time and resource. It is relatively rare – an analysis by Pocock et al. (2017) found just 15 hypothesis-led examples after assessing 509 citizen science projects, or less than 3% of the studies.

Two hypothesis-driven experiments were designed in GROW, both investigating key regenerative approaches to growing with the primary aim of enhancing and validating land/soil management practices and production techniques, with a secondary aim to increase the uptake of these agricultural practices.

The first was experiment was a pilot Mission called “Summer Experiment.” This focused on soil moisture and compared several parameters of soil with a compost mulch applied to soil without the mulch. This was started in the summer of 2017 but not completed due to low participation (2 participants started this). The second was the Great GROW Experiment, started in spring 2018 and completed in winter 2018. This compared yields of three crops grown in polyculture with the same crops grown in monoculture.

4 Scientific evaluation of protocols

A previous GROW report “Deliverable D4.1 Report on evaluation of tools (crop database, Soil Testing Kit, Land Survey Toolkit)” [Confidential] completed in January 2018 described the selection of measurements and observations to be used in GROW and outlined the protocols. Initial evaluation of the nutrient test kits was also included. Here we extend and update this and describe the scientific evaluation of protocols for nutrient (NPK) and pH testing and for soil texture determination.

4.1 NPK and pH test kits

4.1.1 Overview

Nitrogen (N), phosphorous (P) and potassium (K) are key plant nutrients, often collectively referred to as “NPK”. The availability of reliable soil data, especially on soil nutrients and acidity/alkalinity (measured by pH), is of high importance for land users to make decisions on sustainable soil management and to avoid the overuse of fertilizer resources, which can lead to environmental pollution. Soil acidity in the main root zone, from 0 to 10 cm soil depth, is an important indicator of soil quality. Soil pH is one of the factors controlling root development, microbial activity and the availability of mineral nutrients to plants, as well as the solubility of a number of metal ions; mainly aluminium (Al), iron (Fe) and manganese (Mn). Soil acidification due to the build-up of hydrogen and aluminium ions, leads to the loss of base cations such as calcium (Ca), magnesium (Mg), K and sodium (Na) by leaching (Romeo et al., 2015). As soil pH affects the NPK nutrient balance, it is an essential factor to consider when interpreting data for certain nutrients (Yost and Uchida, 2000).

Low-cost Luster leaf® Rapitest® NPK tests were identified at the start of the GROW project as being of potential value in citizen science campaigns to assess soil nutrients. These give a qualitative assessment of N P and K by category (depleted, deficient, adequate, sufficient, surplus). A leaflet provided in the kits suggests nutrient amendment rates for various garden areas (e.g. lawn, shrubs, leafy vegetables) based on these categorical results. Soil pH is measured on a scale from 4.5 to 7.5 with increments of 0.5 and information on pH ranges for different crops is also included in the kit.

The kits were comparatively evaluated with laboratory analyses of the same samples from two different countries in summer 2017 and results from the analysis were shared in July 2018. At this time, a small number of the test kits had already been purchased and deployed to citizens in the Great GROW Experiment (Living Soils Mission) which began in April 2018.

4.1.2 Summary of the protocol for citizen science participants

A soil sample is taken from a depth of approximately 15 cm[1]. Stones and debris are removed and the soil is left to air dry for two to three days then crumbled into fine particles.

For soil pH, this fine soil is added to the testing vessel (see example in Figure 4.1) to the soil fill line (not shown in figure). The provided capsule of pH powder is added to the test chamber,

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[1] This corresponds to the soil just below the soil sensor’s maximum penetration depth and allows alignment of results on soil texture with those from the Changing Climate mission.

and distilled (or tap) water is added up to the water fill line. The vessel lid is firmly attached and it's shaken well to mix the soil, pH powder and water, then it's left to settle for one minute.

The colour in the test chamber is compared to the pH indicator scale and the best match recorded.

For the NPK tests, 50 g of dried soil is added to a jar and 250ml of water are added. The mixture is shaken for one minute and the jar is left to rest for 24 hours allowing the sediment to settle.

The water from the soil sample jar is added to the test and reference chambers of the testing vessel up to the indicated fill line (Figure 4.1). The relevant capsule of powder is added to the test chamber, and it is shaken then left for 10 minutes to allow the colour to develop.

The solution in the test chamber is compared to the chart on the reference chamber and the best match is recorded.

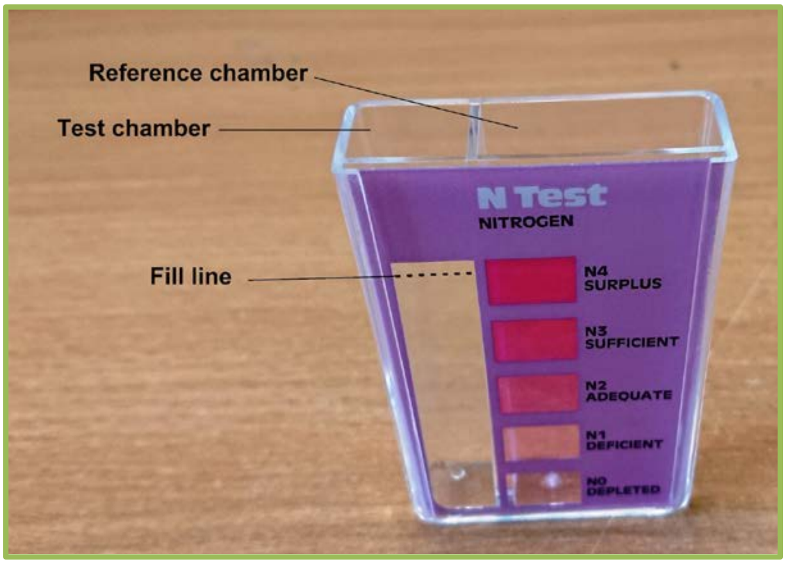

Figure 4.1 Luster leaf testing vessel for nitrogen

4.1.3 NPK Test evaluation method

Results from the Luster leaf® Rapitest® kits (STKs) were compared with those obtained using standard laboratory methods. A total of 731 soil samples were compared. Of these, 447 were provided by the James Hutton Institute (JHI, United Kingdom) with laboratory analysis performed using standard commercial protocols by Lancrop Laboratories (Pocklington, UK). A further 284 were analysed by AGRO DLHÉ (Slovakia). JHI provided additional information on NPK content, soil pH and soil texture. AGRO DLHÉ provided information on P and K content in soil, soil pH, soil type (clay, silt and sand) and land use.

Data analysis was conducted by FAO. STK results for plant-available N, P, and K were categorical variables, whereas the laboratory results were numerical values, hence, a conversion was needed to ensure comparability. Values were converted in advance to conduct the statistical analyses, meaning that laboratory results were categorized using the arbitrary categorical cut-off values as provided by the STK producer Luster leaf®. Conversion values are given in Table 4.1. American units given in parts per million (ppm) were transferred into the International System of Units (SI) using the conversion factor 1. For soil pH, STK results were already numerical providing results in increments of 0.5 on the pH scale. Laboratory results for soil pH were provided in increments of 0.1, requiring values to be rounded to the closest unit class of the STK.

Table 4.1 Parts per million (ppm) equivalency chart for the STK provided by Luster leaf® Values are considered to represent lower boundaries with category means equal to inter-category medians, e.g. "Depleted" P ranges from 5 to 10 ppm with a mean of 7.5 ppm.

Measured nutrient	0 Depleted	1 Deficient	2 Adequate	3 Sufficient	4 Surplus
N (ppm)*	0	10	20	40	80
P (ppm)	5	10	20	50	100
K (ppm)	50	200	400	600	900

*parts per million (ppm) as given by the Luster Leaf Inc. equivalency chart - US to SI unit conversion: 1 ppm = 1 mg kg^{-1}

Statistical analysis was conducted as described in Appendix 2.

4.1.4 Evaluation results

A number of issues with the actual use of the Luster leaf® soil test kits (STK) included poor dispersal of the reagent powder; differences in the soil solution colour between the reference and test chambers making interpretation difficult; difficulty in assigning observed colour to a category, especially for clay soils where high sediment content remained in solution; impact of differential background lighting on observed colour, and colours not corresponding to given reference values. Slight variations in technique between users (e.g. varying settling times, re-dispersion of reagent) was also noted which would suggest further variation in the use and interpretation of the tests between users is likely. That is, different users testing the same soil may record different results.

Nitrate (N)

STK results ranged from 0 to 80 mg kg^{-1} (depleted through to surplus), with 70% of all samples indicating adequate, sufficient or surplus N (> 20 mg kg^{-1}).

Unlike other nutrients, standard agricultural practice determines N fertiliser application rates based on the crop to be grown and soil texture and not on soil N concentration through soil testing. Thus, the soils provided by JHI for the mission and sourced from another project (Innovate UK funded) were not analysed for N as the source project was required to accurately mirror current agricultural practice. Thus, comparisons with laboratory results for N were not possible.

Phosphate (P)

In the upper graph in Figure 4.2, JHI laboratory results (grey dots) are distributed in the five corresponding categories from the STKs. Laboratory mean values and error bars (standard deviations) are indicated in blue in the upper graph. For all classes, the laboratory mean values showed a high similarity, ranging between 22 mg kg^{-1} and 37 mg kg^{-1}, and error bars mostly overlapped for all classes. The STK was found to be not able to measure phosphate accurately. Statistical analysis confirmed these results (Appendix 2).

The lower graph in Figure 4.2 displays the class ranges (red) based on the arbitrary cut-off values provided by the STK producer Luster leaf in the ppm equivalency chart (see Table 4.1). If the test kits were accurate, laboratory results (grey dots) would be expected to fall within this range. However, there is a wide spread of the values within the determined STK class outside of these boxes. Each STK category includes laboratory values across a wide range (approximately 5 to 50 ppm) such that in most cases, any given sample with one STK result (e.g. "deficient") could actually correspond to any other category. All samples that were tested as depleted by the STK actually had higher phosphate levels. The analysis of the dataset from AGRO DLHÉ provided similar results.

The P test did not show higher accuracies for specific soil types, soil textural classes or land use types. The validity was not significantly influenced by any of the other tested nutrients or the soil pH either. Ultimately, the STK showed to be a poor predictor of P compared to standard laboratory analysis. In this regard, the findings are in line with those of Brandenberger *et al*. (2016).

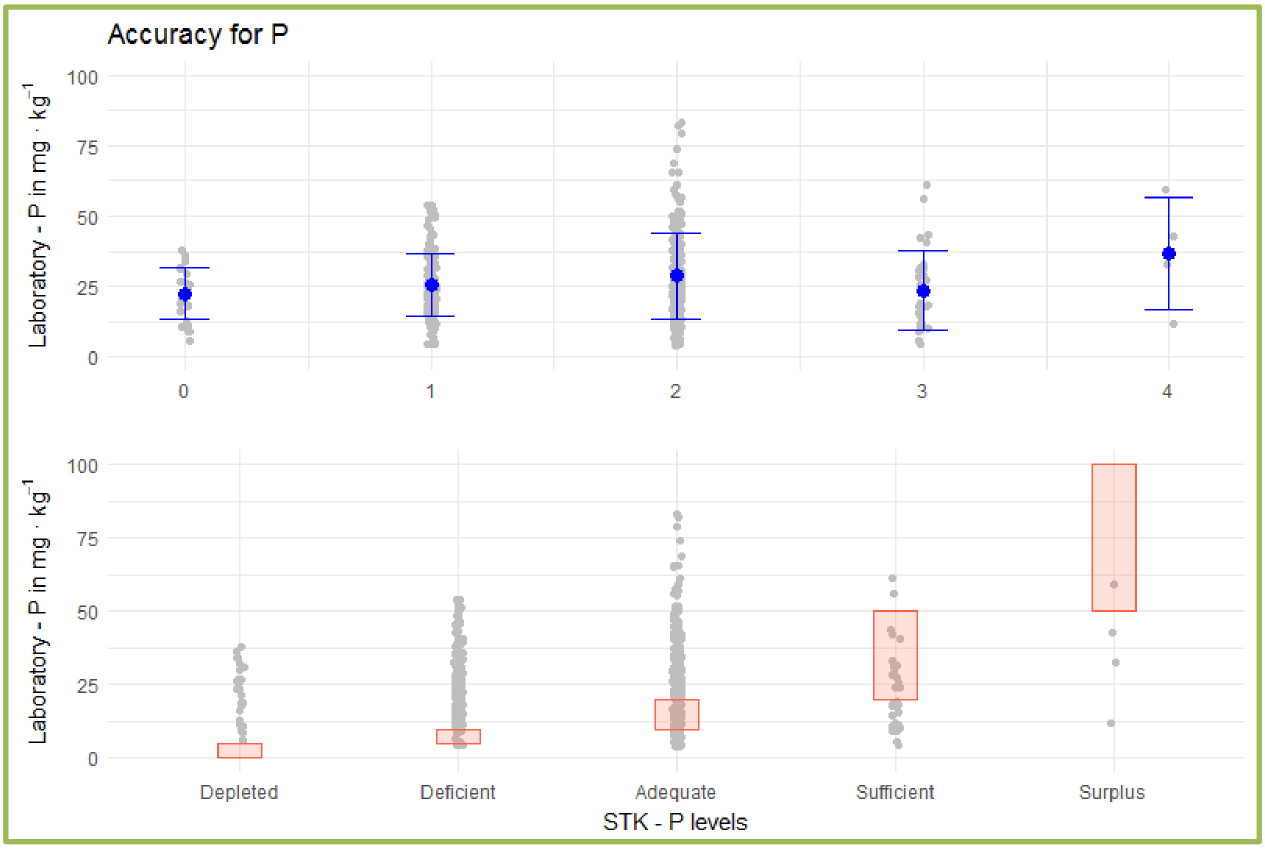

Figure 4.2 Comparison of phosphate levels obtained from the STK and laboratory. The blue error bars in the upper graph indicate laboratory mean values and standard deviations. The red boxes in the lower graph are the equivalency value ranges for the STK (dataset from JHI)

Potassium (K) oxide

Figure 4.3 shows how laboratory values from the JHI data set are distributed in the each of the five classes of the STK scale. Laboratory mean values and error bars (standard deviation) are indicated in blue in the upper graph. Because class mean values are similar ranging between 175 mg kg^{-1} and 233 mg kg^{-1}, and error bars overlap for all classes, the STK was not able to measure potassium oxide accurately. Statistical analysis confirmed these results (Appendix 2).

The lower graph displays the test kit's class ranges (red) based on the arbitrary cut-off values provided by Luster leaf in the ppm equivalency chart (Table 4.1). The graph illustrates the wide spread of the laboratory measurements outside the expected ranges of the STK categories. As for P, all samples that were tested as depleted using the STK actually had higher K levels. In all categories except "surplus," the distribution of the data is again equivalent – all contain values from approximately 50 to 500 ppm. The analysis of the dataset from AGRO DLHÉ provided similar results.

The K test did not show higher accuracies for specific soil types, soil textural classes or land us types. The validity was not significantly influenced by any of the other tested nutrients or the soil pH either.

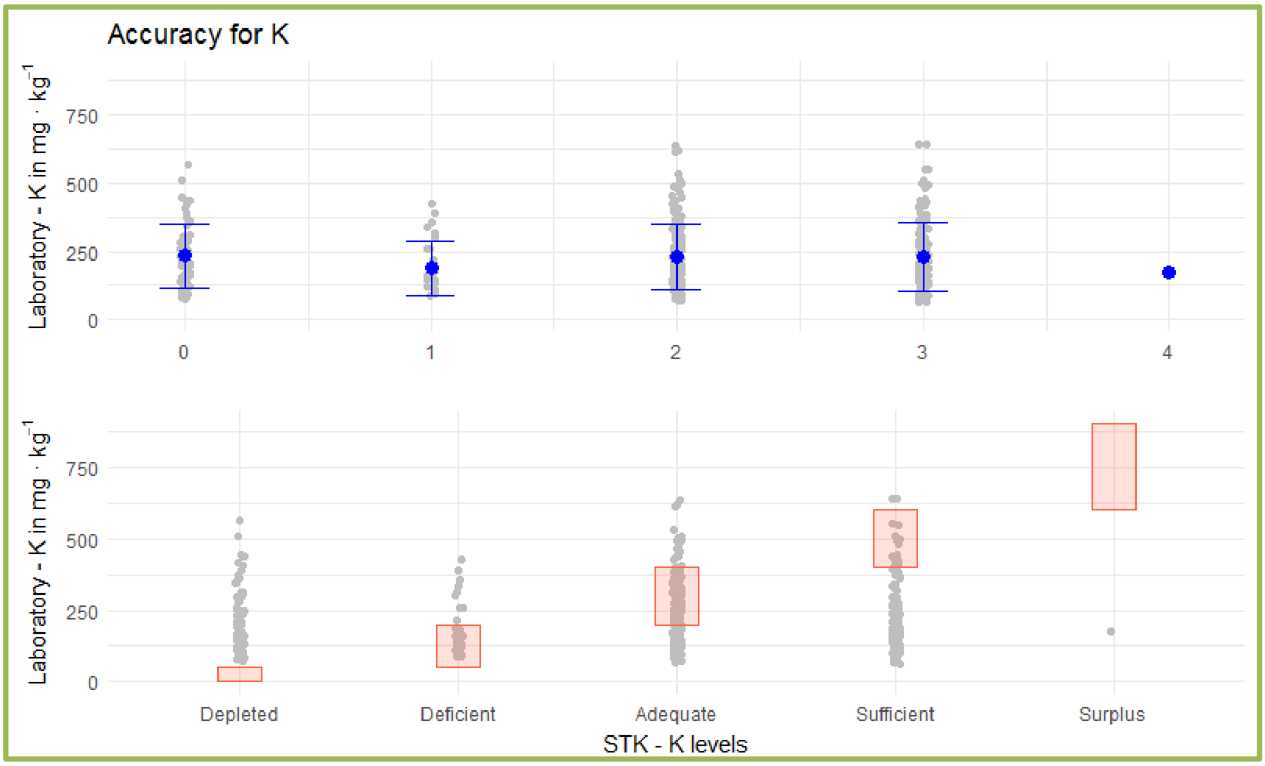

Figure 4.3: Comparison of potassium oxide levels obtained from the STK and laboratory. The blue error bars in the upper graph indicate laboratory mean values and standard deviations. The red boxes in the lower graph are the equivalency value ranges for the STK (dataset from JHI)

pH

The red boxes in Figure 4.4 mark pH value ranges as given for the STK. The majority of laboratory results are located outside the boxes which verifies the low accuracy of the test to measure pH. Although this shows the STK to generally underestimate soil pH in JHI's samples, the opposite trend was observed for samples analysed by AGRO DLHÉ. Statistical analysis (Appendix 2) showed a poor correlation between STK and lab results, a finding that is also in line with that of Brandenberger *et al.* (2016).

Because of the correlation existing between soil nitrate content and soil pH, Figure 4.4 also provides information on observed nitrate levels related to pH measurements. For most of the samples that showed greater acid soil conditions based on laboratory pH values <6.5, the nitrate levels utilizing the STK showed a surplus in N (74% of samples with laboratory pH values <6.5). Ultimately, soil pH can possibly affect the STK test for N assessment. However, no clear conclusion could be drawn on this as it was not possible to determine the accuracy of the N test.

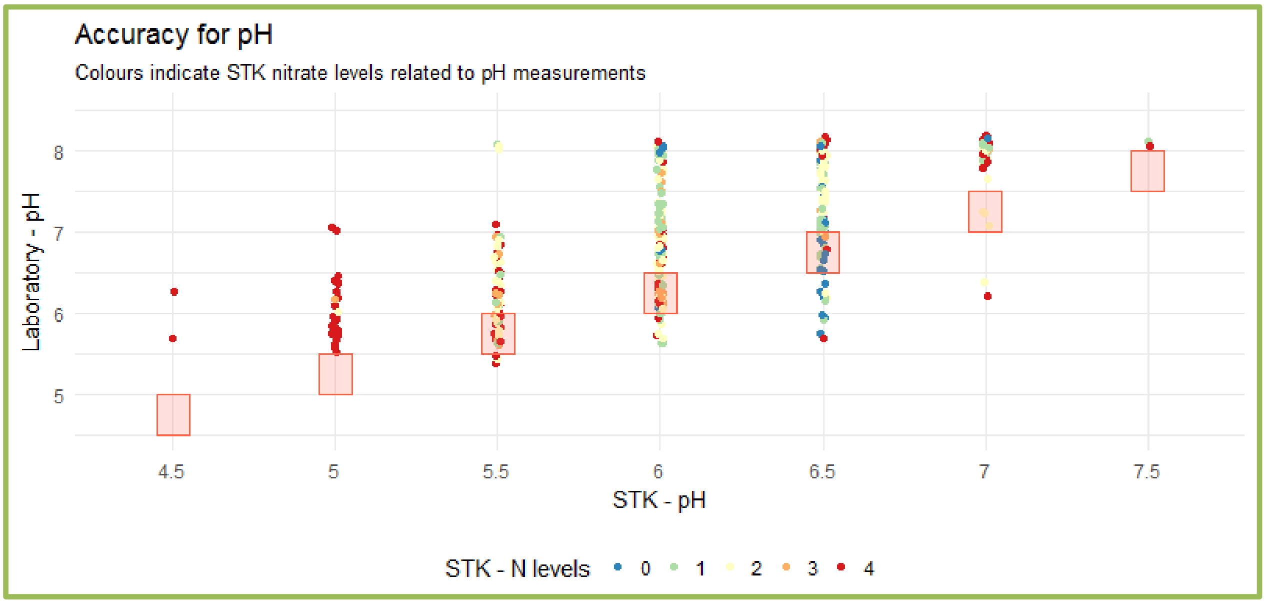

Figure 4.4 Comparison of pH levels obtained from the STK and laboratory. The red boxes represent the equivalency value ranges for the STK. N levels measured with the kit are shown from depleted (blue) to surplus (red) related to pH measurements (dataset from JHI)

Overall, the pH kits showed closer alignment with laboratory results (Figure 4.5) although they tend to overestimate the pH value. However, there is still considerable inaccuracy within each category with laboratory results ranging from pH 5.5 to pH 7 occurring in all STK categories from 4.5 to 6.5.

Although the STK was found to be not reliable for measuring soil pH, it could serve to provide a rough differentiation between slightly alkaline/neutral, slightly/medium acid soil conditions. The STK pH thus only allows two classes to be reliably distinguished:

pH scale: 7.5 to 7.0	Slightly alkaline/neutral
pH scale: 6.5 to 4.5	(slightly to strongly) acid

The pH test did not show higher accuracies for specific soil types, soil textural classes or land use types. The validity was not significantly influenced by any of the other tested nutrients.

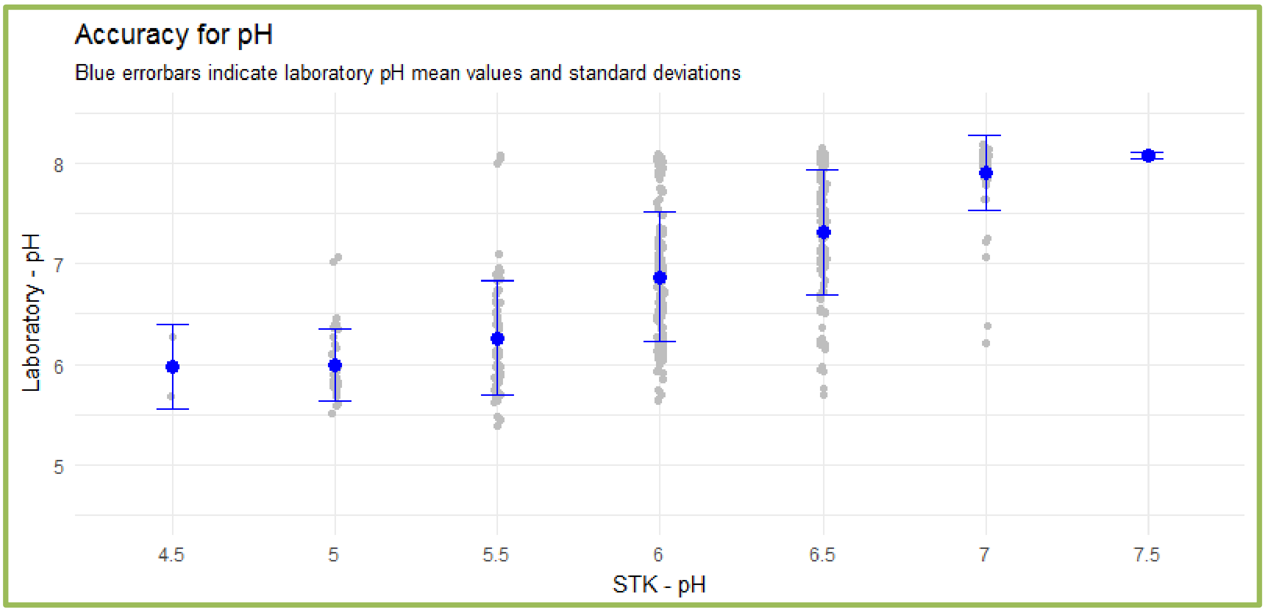

Figure 4.5: Comparison of pH results obtained from the STK and laboratory. The blue error bars indicate laboratory mean values and standard deviations (dataset from JHI)

4.1.5 Conclusion

Overall, the low-cost Luster Leaf® Rapitest® kits were considered not to be fit for citizen science research. The unclear instructions and difficulties in interpreting the colours gave high potential for variations between users. They also fail to provide consistently accurate results that would be required for scientific interpretation or to effectively inform participants about their soil nutrients or pH.

The use of these tests in GROW was discontinued in summer 2018.

4.2 Soil texture by sediment jar test

4.2.1 Overview

Soil texture is the relative proportions of mineral particles (sand, silt, clay) in the soil. It is important for determining soil properties including the capacity to retain water- and nutrients, and the penetration of plant roots and root hairs (Atterberg, 1905). There are a number of low-cost tests available which do not require anything beyond household equipment. However, the efficacy of such tests in unclear.

GROW used a sediment jar test method for determining soil texture based on the FAO “bottle test” protocol[2]. This method was chosen for GROW’s Changing Climate Mission because it

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[2] FAO *Soil Texture Training*. Available at: http://www.fao.org/fishery/static/FAO_Training/FAO_Training/General/x6706e/x6706e06.htm

gives a quantification (%) of each of the three soil components which was desirable for accurate determination of soil texture for subsequent satellite data interpretation. The citizen science protocol developed requires some basic tools (trowel, glass jar, water) in its simplest form with possible additional materials (salt, sodium hexametaphosphate). It can take several days to complete.

This test was used by participants in the Changing Climate Mission and shared in the MOOC “Citizen Science: from soil to sky” in 2017.

4.2.2 Summary of the protocol for citizen science participants

Soil samples were taken from a depth of 15 cm corresponding to the soil just below the soil sensor’s maximum penetration depth.

Debris, for example, plant material and stones, was removed and the soil added to a cylindrical jar filling it to 3 cm height from the bottom of the jar. Water is added up to 13 cm, the jar is shaken, and the sediments left to settle (Figure 4.6).

The theory is that the largest sediment particles (sand) settle first and the finest sediment (clay) takes much long to settle out of the water.

The settled layer after 1 minute was marked and measured as the depth of sand. After 5-6 hours, the sediment level is marked. The difference between this new mark and the old indicates the amount of silt in the sample. The final measurement indicates the amount of clay and is done once the water has cleared (24-36 hours).

Figure 4.6 Sediment jar test showing settled layers (sand and silt are marked) and clear water

4.2.3 Soil texture by sediment jar protocol evaluation method

The sediment jar test was conducted and compared to laboratory analyses by the University of Miskolc (UOM). Results from the sediment jar test were compared to laboratory particle size analysis obtained using a hydrometer method (see Michigan State University, 2019) for 3 samples, and Atterberg test for liquid limits for all 103 samples (see Appendix 3 for further details).

Some further analysis for this report was conducted by the Permaculture Association (PAB) by assigning texture classes to the sediment jar test proportions according to the soil texture triangle categories used with citizens in the Mission and MOOCs (Appendix 3)

4.2.4 Evaluation results

Comparison with laboratory quantification by proportional texture class shows that sandy loam and clay are correctly identified but clay loam is estimated to be clay, suggesting an over-estimation of clay in this sample (Table 4.2). It is difficult to draw meaningful conclusions from the limited number of samples.

Table 4.2 Comparison of texture classes (%) from laboratory tests and sediment jar results

Sample	Lab sand[1]	Lab silt[1]	Lab clay[1]	Lab texture (from K_A)	Jar sand[2]	Jar silt[2]	Jar clay[2]	Jar texture (approx.)
1	57.80	37.96	4.27	Sandy loam	64.58	20.83	14.58	Sandy loam
2	31.80	38.42	29.90	Clay loam	10.00	15.56	74.44	Clay
3	36.09	26.70	37.2	Clay	10.44	14.78	74.78	Clay

[1] m/m% [2] percentages (%)

The average content (%) of sand, silt and clay found by the sediment jar test is shown for samples in each laboratory-derived Atterberg texture class (Figure 4.7). The sediment jar tests shows clay as significant fraction (33.5-43.2%) of soil particles in all laboratory-designated texture classes. Unexpectedly, the lowest clay proportions found in the sediment jars are associated with the samples expected to have the highest abundance of clay (heavy clay).

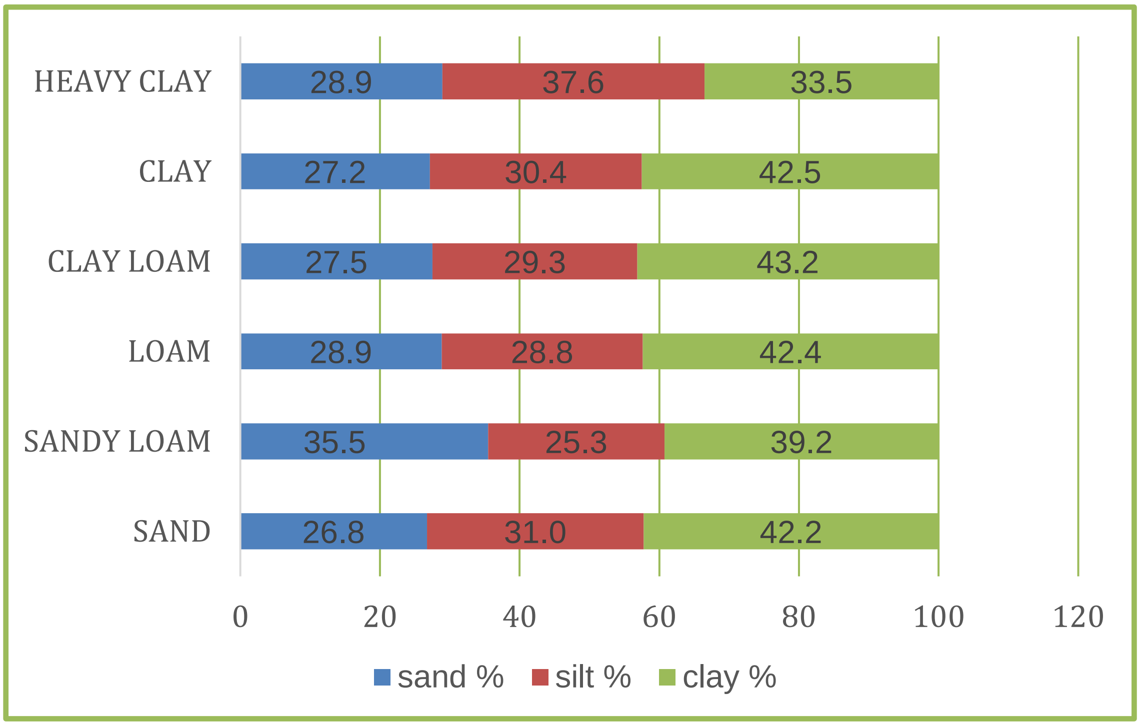

Figure 4.7 Mean values of the jar test by texture class (103 samples)

Comparison of texture class designations from laboratory liquid limits with those assigned to the sediment jar samples shows little correlation with a general over-estimation of clay in all samples (Figure 4.8). Consideration of the proportions of correctly identified texture classes (Table 4.3) shows clay was correctly distinguished in 63.5% of cases, however, this was one of the most frequently identified categories for the sediment jar test (72 samples, 69.9%, were identified as clay). All other categories were very poorly determined by the sediment jar test. Surprisingly, even sand (2 samples) was never correctly identified by the sediment jar test, but was identified as clay or clay loam. These results show that the sediment jar tests show poor correspondence to the laboratory tests.

Descriptive results provided by UOM found several important factors:

- Users found it difficult to distinguish between sediment layers when trying to draw lines on the jar between layers. This may be because there is a continuous range of sediment sizes within the three categories rather than an abrupt difference.
- The overall depth of soil in the jar decreased over time. Sediment layers were sometimes found to further settle into each other, making re-estimation of the levels more difficult.
- The sediment jar test over estimated clay content. For example a result of 25% from the jar test compared to only 2% in the lab test. This could be because the clay particles were not effectively dispersed in solution and/or because they settled into the coarser lower layers over time. The error in this estimate depended on the soil type, but was not possible to quantify consistently for different texture classes i.e. a simple conversion factor(s) could not solve the discrepancy.

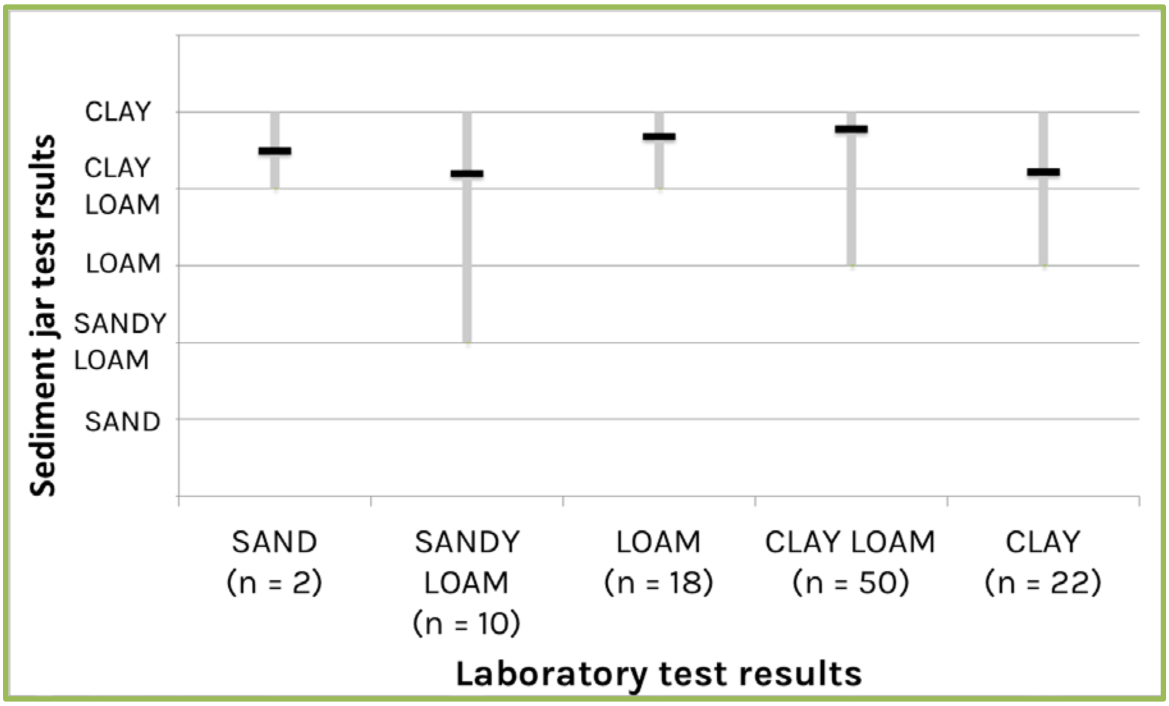

Figure 4.8 Comparison of soil texture results from sediment jar test with laboratory findings

Grey bars represent spread of sediment jar results in each laboratory texture category from maximum to minimum. Black line represents indicative average categorisation (based on Sand = 1 to Clay = 5)

Table 4.3 Summary of sediment jar tests compared to laboratory soil texture class determinations.

Max error shows the proportion of results from the sediment jar test that could have been misattributed to texture classes (the jar test allowed greater discrimination, particularly of silt classes).

Laboratory class	% Matching	% Different	Max error
Sand + Coarse sand	0.0	100.0	0.0
Sandy loam	20.0	80.0	0.0
Loam	0.0	100.0	11.1
Clay loam	12.0	88.0	8.0
Clay + Heavy clay	63.6	36.4	4.5

Salt was added as an intended dispersal agent to help break up the clay particles to reduce this error. This was included in the first set of protocols distributed to the initial GROW Places.

Further discussion between GROW Partners JHI, UOM, IIASA and PAB identified that salt was not an effective dispersal agent and certain salts can cause coagulation in some soils. The use of sodium hexametaphosphate (previously a commonly available reagent sold as Calgon™ for use in dishwashers) was suggested as a more effective dispersal agent that is widely available. This was purchased and distributed to Community Champions along with updated protocols for the soil texture test (1 teaspoon of salt was substituted with 1 teaspoon of sodium hexametaphosphate).

Further laboratory comparisons, however, found that this did not improve the correlation between laboratory sample results and the sediment jar test results.

It is possible that the sediment jar test is adversely affected by organic content of soil taken from the upper soil layer (A-horizon) which can prevent the separation of mineral particles. If true, this could be remedied by taking soil samples from the deeper layers (B-horizon). Further analysis would be required to assess this.

4.2.5 Conclusion

This low-cost sediment jar test is not appropriate for use to determine the percentages of sand, silt and, particularly, clay in soil samples, even with modification. It discriminates texture classes poorly, is time-consuming to conduct, and is difficult for users to interpret.

Hence, GROW discontinued use of this test in autumn 2018.

4.3 Soil texture by hand manipulation

There are a variety of hand manipulation methods that can be used to approximate soil texture category class (see Figure A3.0.1 for texture classes). Two of these were tested in GROW by JHI – 1) the touch test which distinguishes a range of sand to clay categories and 2) the ribbon test which also permits some silt classes to be identified and thus covers the full range of soil texture categories shown in Figure A3.0.1. These are relatively quick methods that require no unusual equipment, and have clear interpretation criteria. The ribbon test is widely used by JHI for field analysis of soil texture.

This test was used by participants in the Living Soils Mission experiment and shared in the MOOC “Citizen Science: from soil to sky” in 2017-2019.

4.3.1 Summary of the protocol for citizen science participants

For both protocols, soil samples were taken from a depth of 15 cm corresponding to the soil just below the maximum penetration depth of the soil sensor used in the Changing Climate Mission. Debris is removed. The soil is slowly moistened until it can be rolled into a ball without sticking to the hands. If a ball cannot be formed, the soil texture is determined to be sand.

The touch test

The touch test was adapted from various existing protocols (including FAO) by PAB and JHI. The soil is manipulated from a ball to a cylinder which is then curved into a circle until it is not possible to proceed and the relevant texture class is determined. The technique can distinguish seven texture types (Figure 3.9). The protocol was provided to citizens in both illustrate text and video formats[3].

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[3] The video for the touch test can be accessed at https://www.youtube.com/watch?v=fv3JCciOhrE&t=2s

The ribbon test

This was based on the protocol originally described by Thien (1979). It can determine twelve texture types on the soil texture triangle. After sand, the other eleven types are defined by a two-step process. Firstly forming a ribbon of soil between your thumb and forefinger until it breaks from its own weight, and secondly by excessively wetting a small pinch of soil and rubbing in the palm of the hand to assess the grittiness (Figure 4.10).

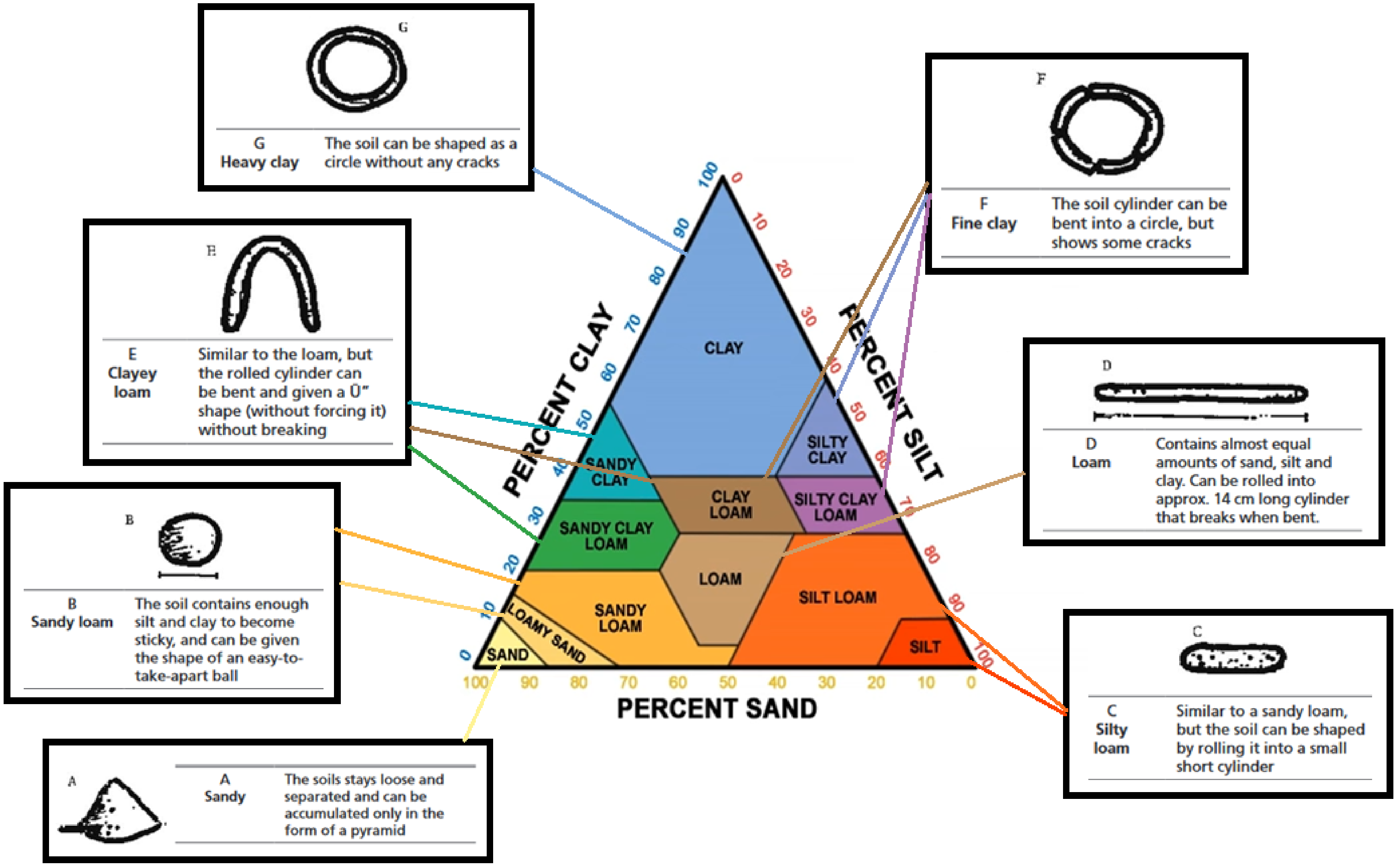
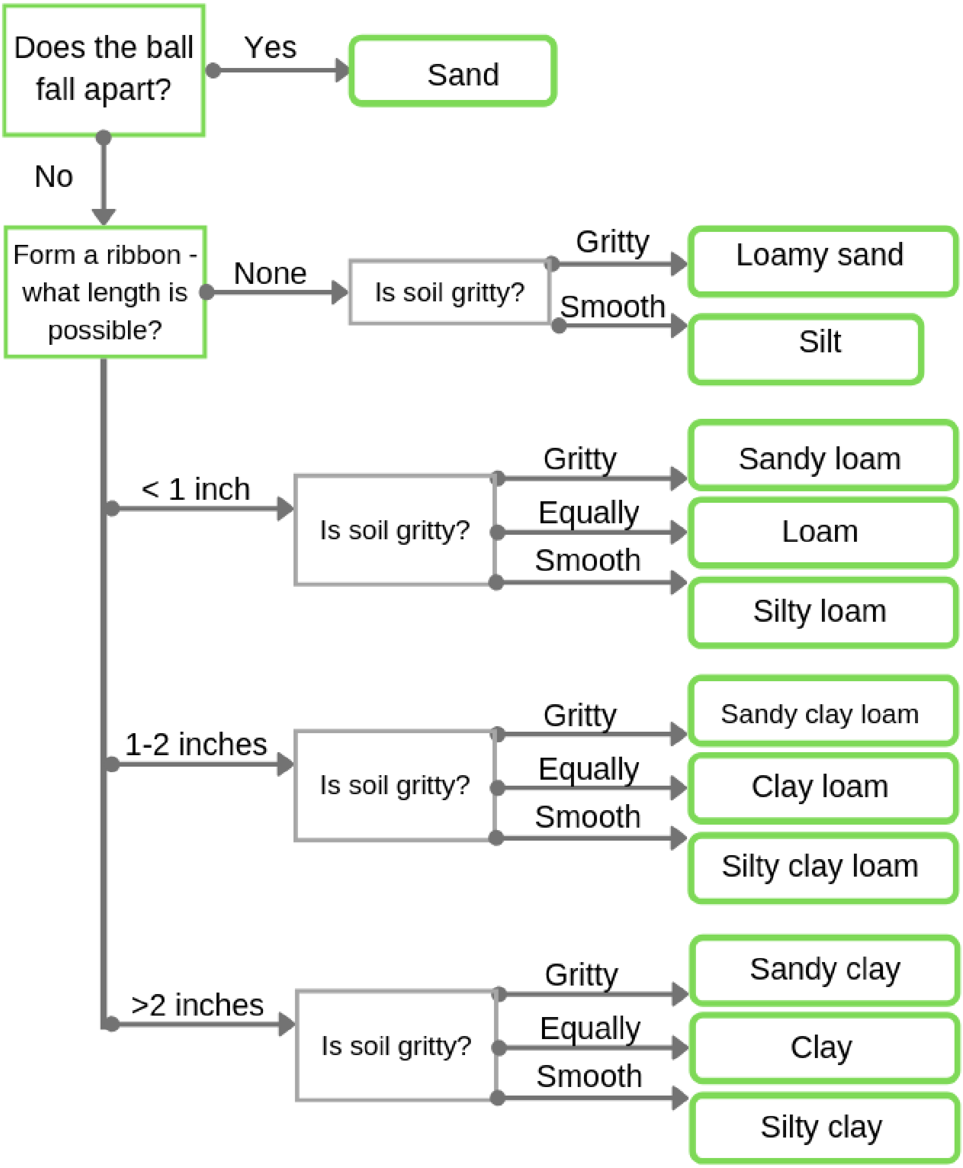


Figure 3.9 Soil texture touch test protocol and texture category designations

Start as for the touch test with a damp ball of soil



To form a ribbon - squeeze the ball of soil between thumb and forefinger to form a ribbon until it breaks under its own weight

To test for gritty soil - wet a pinch of soil well and rub against palm

Figure 4.10 Protocol for ribbon test for soil texture

4.3.2 Soil texture by touch test protocol evaluation method

The touch test was assessed by JHI during the NPK Kit testing (see Section 4.1). Six samples of soil with three replications made in each were assessed by JHI using the ribbon test and compared to analysis of the same samples using the FAO touch test and information from the farmer.

4.3.3 Evaluation results

Comparative analysis of the ribbon test shows consistent determination of texture class, with the exception of sample 4 which was recorded as silty clay twice and silty clay loam once (Table 4.4). Cross-comparison between the tests does not consistently align because the ribbon method allows finer discrimination by including silt-type classes. The ribbon test protocol requires experience in use, particularly in the subjective comparison of grittiness. Results between users may therefore differ. Both tests differ from farmers' perceptions of their soil type in four of the six cases. There are too few samples and no direct comparison with laboratory methods (e.g. using a hydrometer) to draw further conclusions.

4.3.4 Conclusion

The FAO-based touch test is recommended as a technique to determine soil texture as it provides reliable estimates of soil textural classes for samples either with a high fraction of fine sized particles – clay, clay loam- or samples of predominantly coarse sized particles – sand, loamy sand, sandy loam. They are suited for replication with soils similar to the UK where only a rough assessment of texture category is required i.e. within the range of textures covered in the soil texture triangle (Figure 3.9), which would exclude, for example, chalks.

Table 4.4 Results from ribbon test compared to touch test and farmer's information

Sample	Rep.	Ribbon length	Grittiness	Soil texture (ribbon)	FAO touch test (original)	Farmer's perception
1	1	1-2	gritty	Silty Clay Loam	Clay	Clay Loam
	2	1-2	gritty	Silty Clay Loam		
	3	1-2	gritty	Silty Clay Loam		
2	1	1-2	equal	Clay Loam	Clay	Clay Loam
	2	1-2	equal	Clay Loam		
	3	1-2	equal	Clay Loam		
3	1	1-2	equal	Clay Loam	Light Clay	Sandy
	2	1-2	equal	Clay Loam		
	3	1-2	equal	Clay Loam		
4	1	1-2	smooth	Silty Clay Loam	Clay	Sand Silt Loam
	2	<2	smooth	Silty Clay		
	3	<2	smooth	Silty Clay		
5	1	<2	smooth	Silty Clay	Clay	Sand Silt Loam
	2	<2	smooth	Silty Clay		
	3	<2	smooth	Silty Clay		
6	1	<2	smooth	Silty Clay	Heavy Loam	Clay Loam
	2	<2	smooth	Silty Clay		
	3	<2	smooth	Silty Clay		
	1	<2	smooth	Silty Clay	Clay	Clay Loam
	2	<2	equal	Clay		
	3	<2	equal	Clay		
	1	<2	equal	Clay	Heavy Loam	Sandy clay loam
	2	<2	equal	Clay		
	3	<2	equal	Clay		

4.4 Soil texture tests – comparative evaluation with citizens

Both the sediment jar test and the touch test were introduced to learners on the GROW MOOC “Citizen Science: From Soil to Sky.” in 2017. This allowed for further investigation of the two methods as learners’ results for each test were compared. Learners were also asked how confident they felt about their results for each test. This analysis was conducted by PAB and results were shared during the course’s live webinars[4].

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[4] A recording of the 2017 webinar can be accessed at https://www.youtube.com/watch?v=l693dsSywMs&t=12s
A recording of the 2018 webinar can be accessed at https://www.youtube.com/watch?v=FSy0VfI6-EE&t=8s

Sediment jar test data was submitted as depth of layer (mm) for each sample by 84 participants. These were converted to percentage and then plotted on the soil texture triangle (Figure 4.11). This showed a wide range of results with soils found to be across all possible texture classes.

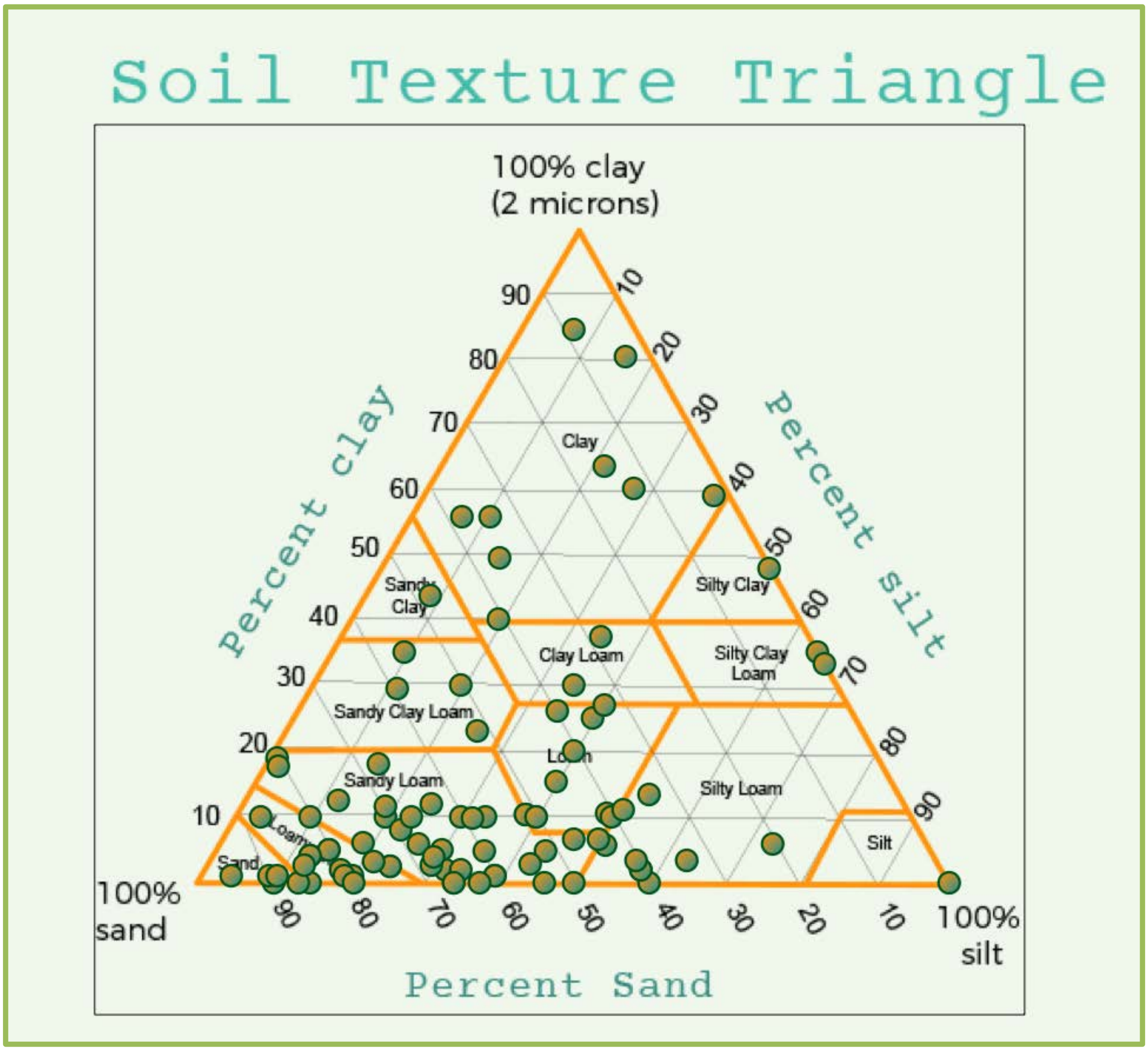


Figure 4.11 MOOC participant data for sediment jar test plotted on soil texture triangle

There was relatively good alignment between results from the two tests (n = 43). The touch test was found to more frequently distinguish all texture classes within scope except for loam, whereas the sediment jar test was able to determine additional categories (Figure 4.12). It is difficult to draw conclusions from these comparisons as to which is more accurate.

Most participants felt confident about the results obtained using the test protocols with the touch test scoring slightly more highly than the sediment jar test (Figure 4.13) confirming that it is felt to be easier to use.

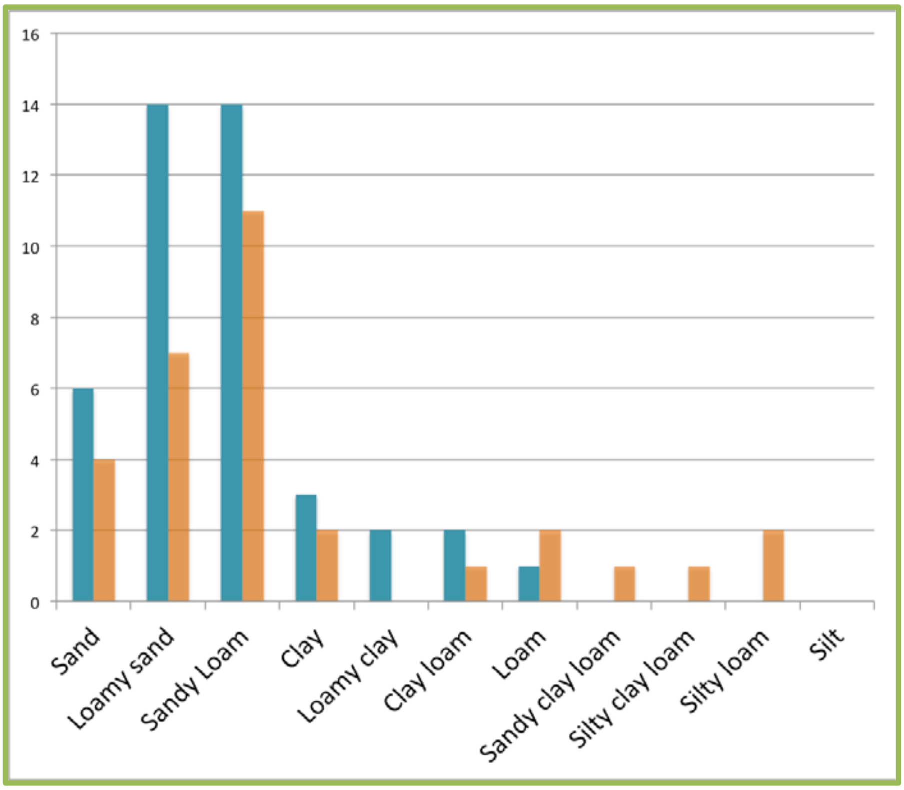


Figure 4.12 Comparison of texture classes determined by touch test (teal) and sediment jar test (orange) as conducted by GROW MOOC participants.
Y-axis shows number of participants

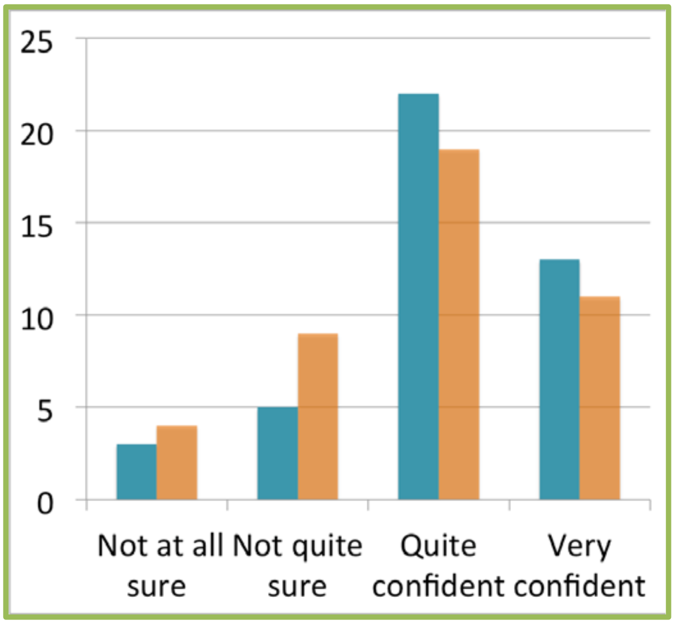
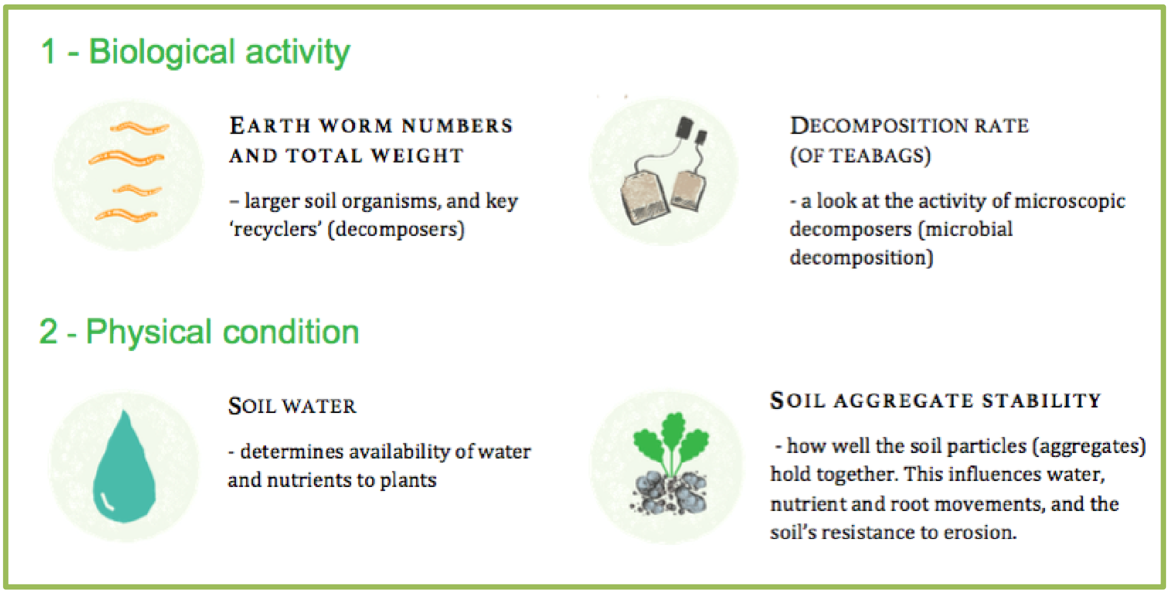


Figure 4.13 Participant confidence levels in soil texture touch test (teal) and sediment jar test (orange)
Y-axis shows number of participants

5 The Summer Experiment Pilot Mission

The 2017 Summer Experiment was designed to enable citizens to individually explore the impacts of applying mulch on soil through the addition of a layer of compost compared to just having bare soil. Combined results were to contribute to the collective understanding of if/how this practice affects soils as part of the exploration of regenerative growing practices. Two plots of one square metre were required – one for growing with a compost mulch and the other without. Four different measures were incorporated to test both physical and biological soil properties; soil water, soil aggregate stability, decomposition, and earthworm counts (Figure 5.1). In addition, participants were asked to assess soil texture using the sediment jar test and to describe their site. This would provide further information aligned across the project on location, soil texture and site description parameters (linked to the land survey).

The physical soil measurements were chosen for their value in understanding soils and to emulate the measurements planned for the Changing Climate mission without the use of soil sensors. The experiment was estimated to take about 13 hours in total with set up and initial measurements in August and final measurements in October.



1 - Biological activity

EARTH WORM NUMBERS AND TOTAL WEIGHT

– larger soil organisms, and key 'recyclers' (decomposers)

DECOMPOSITION RATE (OF TEABAGS)

- a look at the activity of microscopic decomposers (microbial decomposition)

2 - Physical condition

SOIL WATER

- determines availability of water and nutrients to plants

SOIL AGGREGATE STABILITY

- how well the soil particles (aggregates) hold together. This influences water, nutrient and root movements, and the soil's resistance to erosion.

Figure 5.1 The mulching experiment key measurements

Results

14 participants were recruited and two completed the first set of tests. The experiment was not continued or completed.

Lessons learnt for citizen science

Although valuable to science and a more immersive learning opportunity for participants, experiments are a more time-consuming approach to citizen science than some of the more simple observation-based approaches. Key considerations for future experiment design that also fed into the Great GROW Experiment in 2018/2019, were:

1) Keep measurements as simple and quick as possible. Try to avoid too much effort being required at once, particularly at the start.

2) Liaise with potential participants to discover key areas of interest and enthusiasm.
3) Align measurements and investigations with activity that participants are either likely to do anyway (e.g. growing food), and/or clearly show that the rewards are worth the effort.
4) Effective promotion and a sustained recruitment period are essential to gain a critical mass of citizen scientists that can help to motivate others to join and sustain participation.

6 Collective creation of knowledge in the Changing Climate Mission

The Changing Climate Mission took place in a total of 19 GROW Places in 15 countries. 9 GROW Places were involved 2017-2019, with a further 10 Places joining from May 2019. Within each GROW Place, a community champion was recruited to lead the coordination of the citizen science and act as liaison between grow and the participating citizens (sensor users). How this actually happened on the ground varied between GROW Places with some bringing together communities of growers, and others being research institutes or government agencies that conducted the citizen science themselves[5].

The citizen science protocols used in this mission were collated into an info pack comprising technical handbooks for how to conduct observations and tests, guidance on solving commonly reported issues, and resources to understand and use key data. These were made available on the GROW website ("Collaboration Hub")[6] and shared with participants via their respective community champions. Feedback and questions were encouraged both through community champions and directly with the GROW team. Community champion online meet-ups were held monthly with members of the GROW Places team. Further support and interaction between participants (sensor users) the wider GROW team also occurred in the shared online forums on the GROW website ("Collaboration Hub") and in MOOCs, by email and in face to face events and visits.

Section 5 of this report is concerned with the use of citizen science protocols for data collection and with the sharing of results and insights for, and by, participants (citizen scientists). The community champion programme and citizen engagement and participation in GROW are further covered in two GROW reports; Deliverable 2.4 "GROW Community Champions Programme" [Public] and Deliverable 2.5 "Evaluation of Citizen Engagement and Active Participation" [Public] as summarised in Appendix 1.

6.1 Soil sensors

Parrot™ Flower Power™ sensors were used in GROW and have been assessed for suitability and robustness in the Over-winter Pilot Mission in 2017, and for accuracy against a network of professional soil sensors. Results from these tests are included in the GROW Report Deliverable 4.4 "Report on validation and estimation of in situ soil moisture measurements" [Public] due in October 2019 (see Appendix 1). The sensors were found to be reasonably robust (a failure and loss rate of less than 15%) and reliable.

The sensors measure soil moisture, soil temperature, light and also include a proxy for "fertiliser" although the latter was deemed too unreliable for supported use in GROW.

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[5] An overview of each GROW Place can be accessed at https://knowledge.growobservatory.org/article-categories/grow-places/

[6] The Mission info pack is available at https://knowledge.growobservatory.org/article-categories/changing-climate-mission-info-pack/
The Training Manual was available in English, German, Greek, and Hungarian

6.1.1 Deployment strategy

Soil sensors were distributed in pallets of 384 sensors to Community Champions in GROW Places. Champions oversaw the local distribution (either directly or via other sensor users) and installation of sensors in their region.

Following instructions in the training manual[7], sensor users were required to place each sensor in a safely accessible, representative parcel of land of a minimum 30-metre radius of similar land type (e.g. garden, field), in native soil (e.g. not raised beds or greenhouses) that is not prone to waterlogging.

For each sensor site, observations are made as part of the Land Survey covered in Section 6.2.

6.1.2 Data collection

The sensor automatically reads and records each measurement every 15 minutes. Measurements are:

- Moisture
- Light
- Temperature
- Fertility (not used in GROW)

Data upload is via Bluetooth™ to a connected smart device with the Parrot Flower Power™ app installed then uploaded to the Parrot Cloud via Wi-Fi or mobile data. The smart device and app additionally collect information on:

- Location (GPS coordinates of latitude and longitude)
- Sensor ID
- Sensor name (given by user)

Integrated data quality checks:
Data for the sensor measurements are not subject to user error.

6.1.3 Data display

Where users have connected their GROW Observatory and Parrot accounts the data can be retrieved via the GROW Website (“Collaboration Hub”). This lists all the sensors linked to a user, displays the sensor location(s) on a map and interactively displays graphs for the latest recorded month (Figure 6.1).

Further display and use of sensor data is included in Section 6.3.

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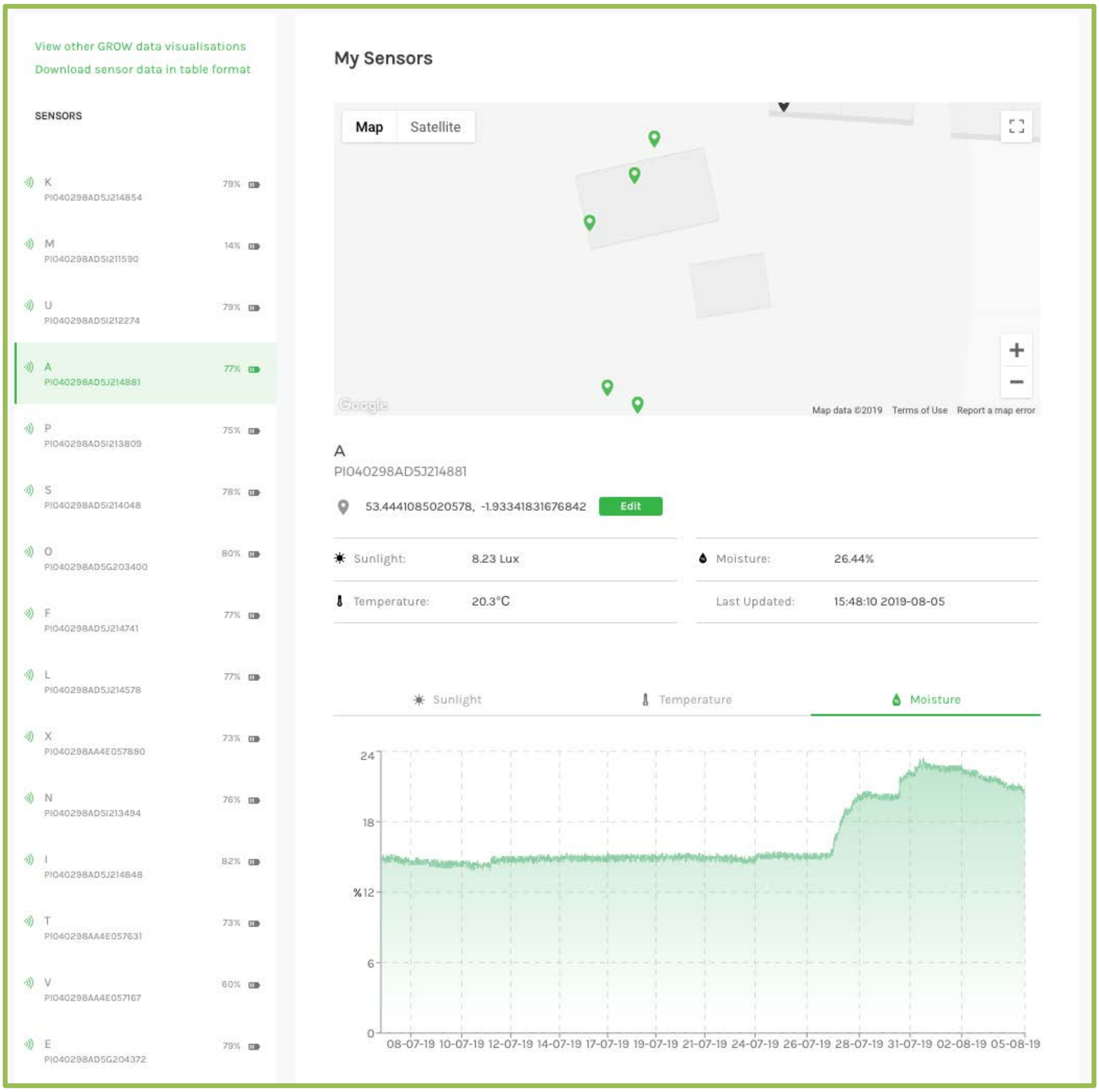
[7] The Training Manual is accessible at https://knowledge.growobservatory.org/wp-content/uploads/2017/10/GROW-Training-Manual-2019.pdf



View other GROW data visualisations
Download sensor data in table format

SENSORS

K	PI040298AD5J214854	79%
M	PI040298AD5I211590	14%
U	PI040298AD5I212274	79%
A	PI040298AD5J214881	77%
P	PI040298AD5I213809	75%
S	PI040298AD5I214048	78%
O	PI040298AD5G203400	80%
F	PI040298AD5J214741	77%
L	PI040298AD5J214578	77%
X	PI040298AA4E057880	73%
N	PI040298AD5I213494	76%
I	PI040298AD5J214848	82%
T	PI040298AA4E057631	73%
V	PI040298AA4E057167	60%
E	PI040298AD5G204372	79%

My Sensors

A
PI040298AD5J214881
53.4441085020578, -1.93341831676842 Edit

Sunlight:	8.23 Lux	Moisture:	26.44%
Temperature:	20.3°C	Last Updated:	15:48:10 2019-08-05

Figure 6.1 GROW Webpage display of list of sensors (left) map of sensors (top right) and interactive graphs of sunlight, temperature and moisture (latter shown, bottom right)

6.2 Land Survey Kit via the GROW App

Many of the protocols used in the Land Survey Kit were introduced during the GROW MOOC “Citizen Science: From Soil to Sky,” with text, images and videos to help facilitate understanding. They are also described as part of the mission info pack in the land survey training pack[7] described in 6.1.

6.2.1 Using the app to make sensor site observations

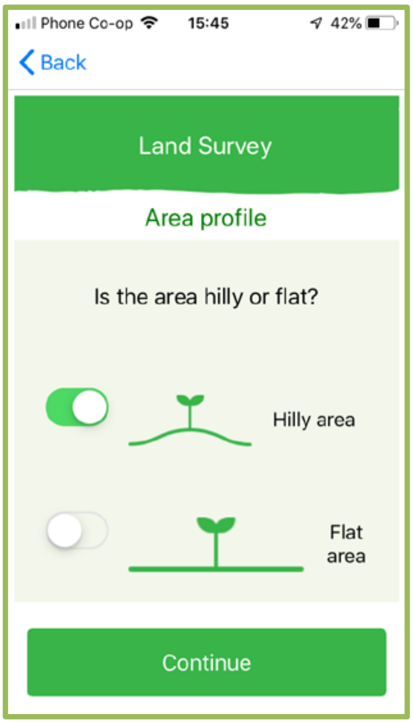
The Land survey is done via the GROW Observatory App for simple and consistent data capture. Sensor users are asked to complete this survey for each sensor, or sensor patch for super users. The survey combines observations and data quality checks.

Protocols accessed by:

- GROW Observatory App (iOS and Android devices). See Figure 5.2.
- Land Survey training pack

Available languages:

- English
- German
- Greek
- Hungarian
- Portuguese
- Spanish



Area profile

Is the area hilly or flat?

● Hilly area

○ Flat area

Figure 5.2 Screen shot from Land Survey part of GROW App

6.2.2 Data collection

Measurements:

- Area size (by category) e.g. <1000 m^2 1000-5000 m^2

Observations:

- Latitude (via device GPS)
- Longitude (via device GPS)
- Photographs (N, E, S, W as aligned by App, down to sensor, plot from a few metres)
- Land use context (by category) e.g. urban, rural, remote
- Land use (by category) e.g. orchard, garden, forest
- Area profile (by category) i.e. hilly or flat
- Slope position (by category) e.g. summit, toeslope
- Slope Aspect (by category) e.g. N, NE, E
- Land cover (by category) e.g. Trees, crops, sealed surfaces
- Canopy cover of a) Trees b) Shrubs (by category) e.g. <5%, 11-25%
- Mulch applied to ground? Y/N
- Intention for area to be managed? Y/N
- Intended management activity type (by category) e.g. fertilise, dig, irrigate
- Actual management activity (by category)
- As above but “other” option enables open text description.
- Dates of activity (start, end).
- Area affected (immediate, within 30 m, whole parcel)

Integrated data quality and interpretation checks:

- Most data entry is categorical with user selecting single category. Participant confirms:

- They are outdoors next to the sensor
- Sensor is placed according to manual.
- If sensor is shaded by trees or shrubs
- If sensor may become overgrown
- Management activity intention and actual activity can be logged separately
- A summary of all information (except photos) is provided to the user prior to data submission. User can go back and edit data if needed.

Approximate time to complete per sensor:

- 5 minutes

Updates following participant feedback:

- Sensor users with many sensors found the activity too time-consuming, especially where the same information applied to multiple sensors. A "super user" category was added to the App in 2019 to enable users to quickly apply the same information to multiple sensors for both the whole land survey and for any management activity.

6.2.3 Data display

Data from the land survey is not displayed.

6.3 Participant data and results

Participants were helped to access, understand, and use their own data in this mission, focusing on the soil sensor data. Most of the activity to help participants access and evaluate their own data has happened since spring 2019 when sufficient data were on the GROW data platform to enable design of these tools. Since April 2019, ten additional GROW Places have joined the mission and are starting to deploy sensors. Participants have received introductory training on understanding and interpreting data during GROW MOOCs in 2018 and 2019. The Community Champions who support sensor users in their GROW Places have received additional support at monthly online meet-ups and at face to face workshops in Austria in 2017 and Scotland in 2018. The results of the scientific evaluation will be presented at a Policy Workshop in Brussels and Insights Workshop in Portugal in September 2019.

6.3.1 Using sensor data (participants)

Two tools have been created to support participants in using their own sensor data. A booklet called "Making sense of sensors" was created to help users better understand what the various measurements were and how to interpret and use the resulting graphs[8], and an Excel worksheet was created to enable users to more interactively graph and explore their own sensor data.

The "making sense of sensors" booklet was available in summer 2019. It was intended both as a useful tool for participants and as an explanation and encouragement to contribute longer term data and complete the site observations (described in Section 6.2 of this report).

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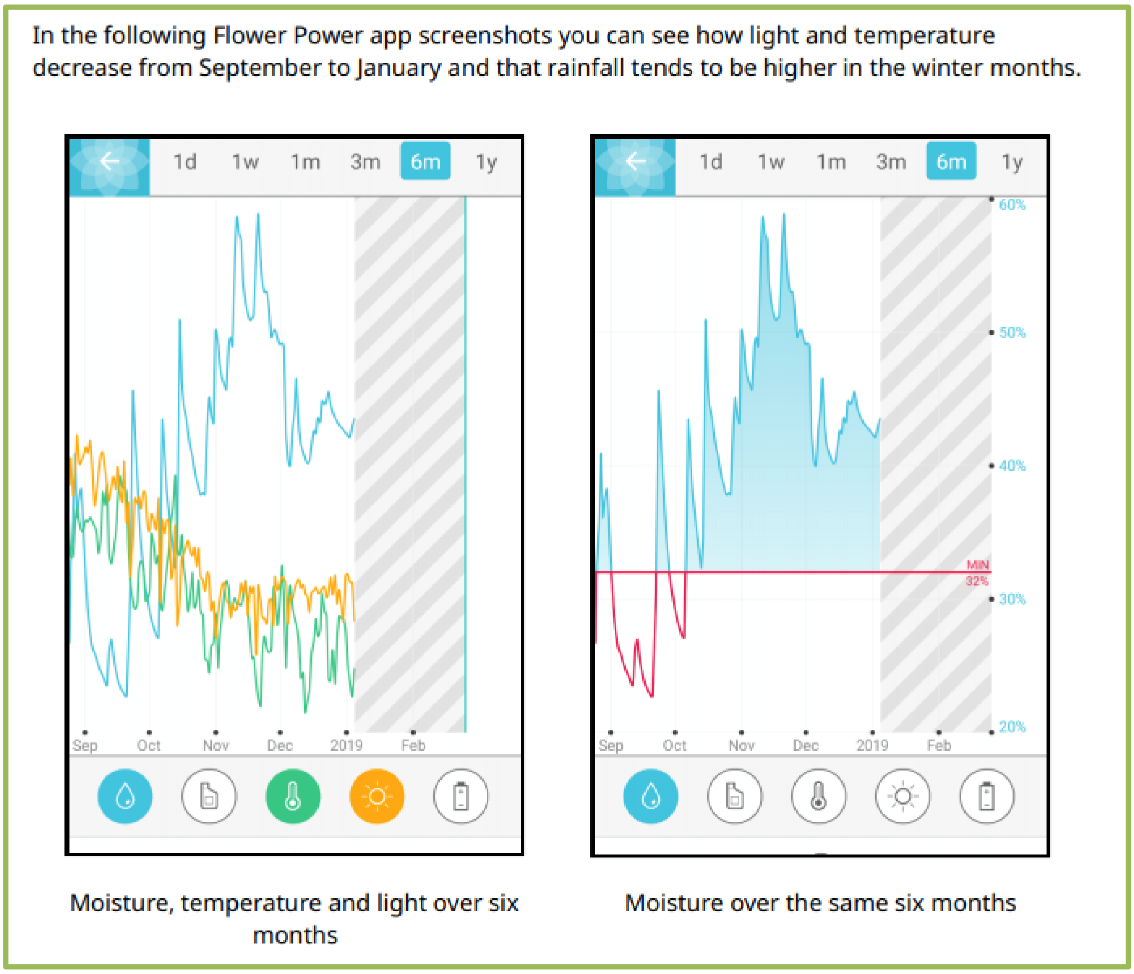
[8] The making sense of sensors booklet can be accessed at https://knowledge.growobservatory.org/wp-content/uploads/2019/07/Understanding-sensor-data.pdf

It starts with a basic overview of the flower power graphs and features and then includes illustrated examples to help users to interpret shorter term (daily, weekly) and longer term patterns (e.g. Figure 6.3). It gives a wider context to the data by including patterns in time and space – using examples from different GROW Places – and considers how the various factors included in the land and soil surveys can influence sensor readings.



In the following Flower Power app screenshots you can see how light and temperature decrease from September to January and that rainfall tends to be higher in the winter months.

Moisture, temperature and light over six months

Moisture over the same six months

Figure 6.3 Example of graphs and interpretation in the GROW booklet

In response to requests from sensor users, the MyData program[9] was written to enable users to access a full table of their own data directly and download in .csv format. Instructions were provided for Windows™ Mac™ and Linux™ users[10]. This enables sensor users to download their own data as .csv files (comma-separated values file format).

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[9] MyData program is accessible at https://knowledge.growobservatory.org/knowledge-base/how-to-download-your-sensor-data-in-table-format/

[10] Instructions to help users access and download their data as .csv files can accessed here: https://knowledge.growobservatory.org/knowledge-base/how-to-download-your-sensor-data-in-table-format/

Further requests were made by sensor users to provide assistance to viewing these data. In response to these, an Excel spread sheet was developed to upload the .csv files and summarise these using Pivot tables and charts, allowing sensor users to interrogate and view all their data. Instructions on how to use this template is available on the GROW observatory website[11]. An example of the detailed data visualisations available in this tool is shown in Figure 5.2. This tool was released in August 2019.

The Excel worksheet tool works with data that users have downloaded in .csv format. It allows citizens to gain a more intuitive access to their data and automatically creates a number of graphs. The data downloaded using the MyData program is accessed by this spreadsheet and summarised in 5 Pivot Tables (Figure 5.4). Using the buttons the data displayed can be filtered, allowing sensor users to view a subset of their data. The instructions manual (need a link once the manual when it goes live) also covers examples of data outliers and how to edit the .CSV files appropriately. Initial feedback from sensor users suggests this tool has been well-received.

6.3.2 Using sensor data (wider audiences)

In addition to individual user data, a summary and interactive data display and maps[12] are available on the GROW website for selected data from the first nine GROW Places (Figure 5.5).

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[11] A spread sheet to help users view and interrogate their data is available here: https://knowledge.growobservatory.org/knowledge-base/visualise-your-sensor-data/

[12] The interactive maps of soil moisture can be accessed at http://soilmoisturemaps.growobservatory.org/#//0/

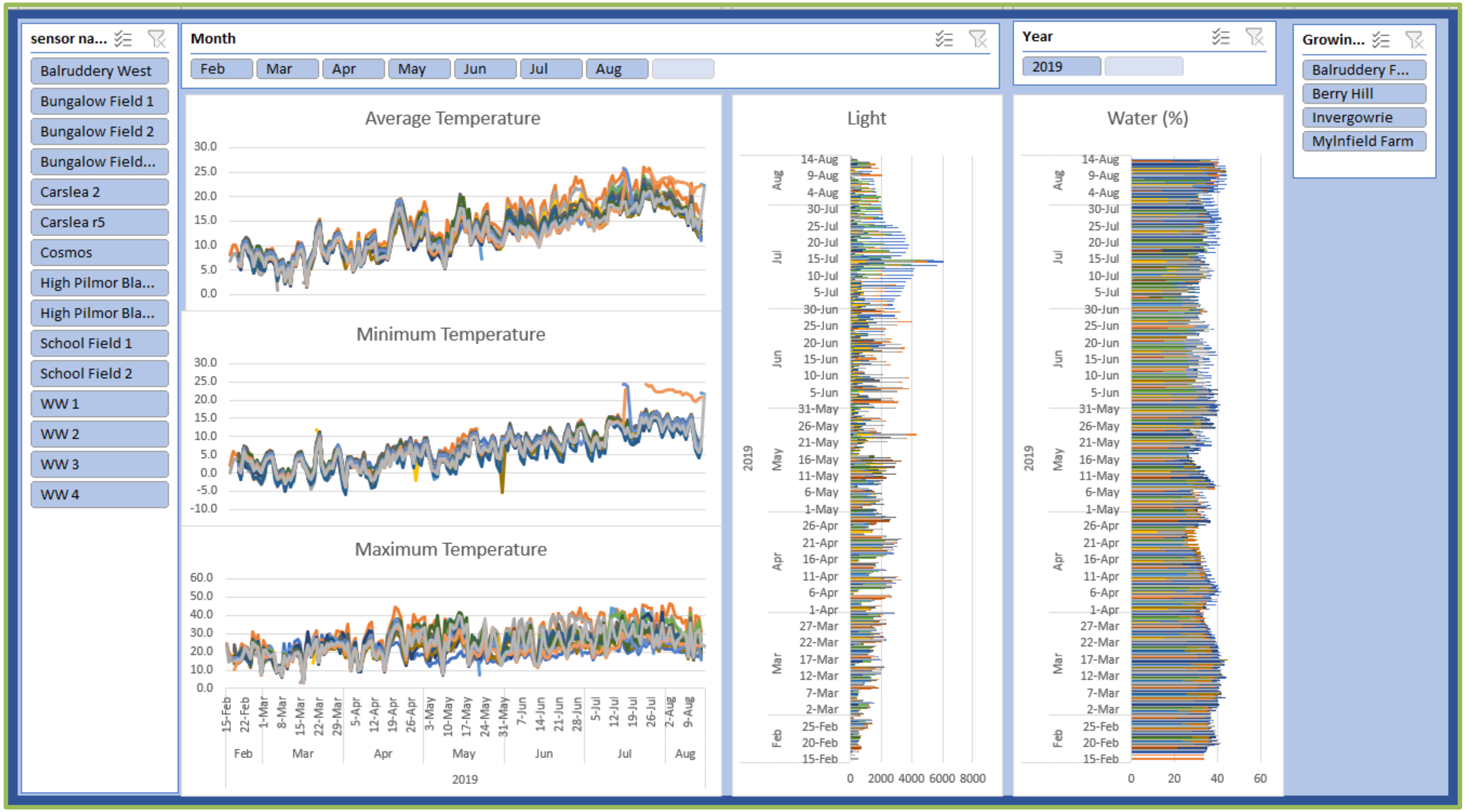

Figure 5.4 Excel “Dashboard” for 15 sensors (left hand buttons) over 7 months in 2019 (top buttons) at 4 field sites (right hand buttons).
The Pivot Charts displaying daily temperature (average, maximum, and minimum), light (daily sum) and water 5 (daily average).

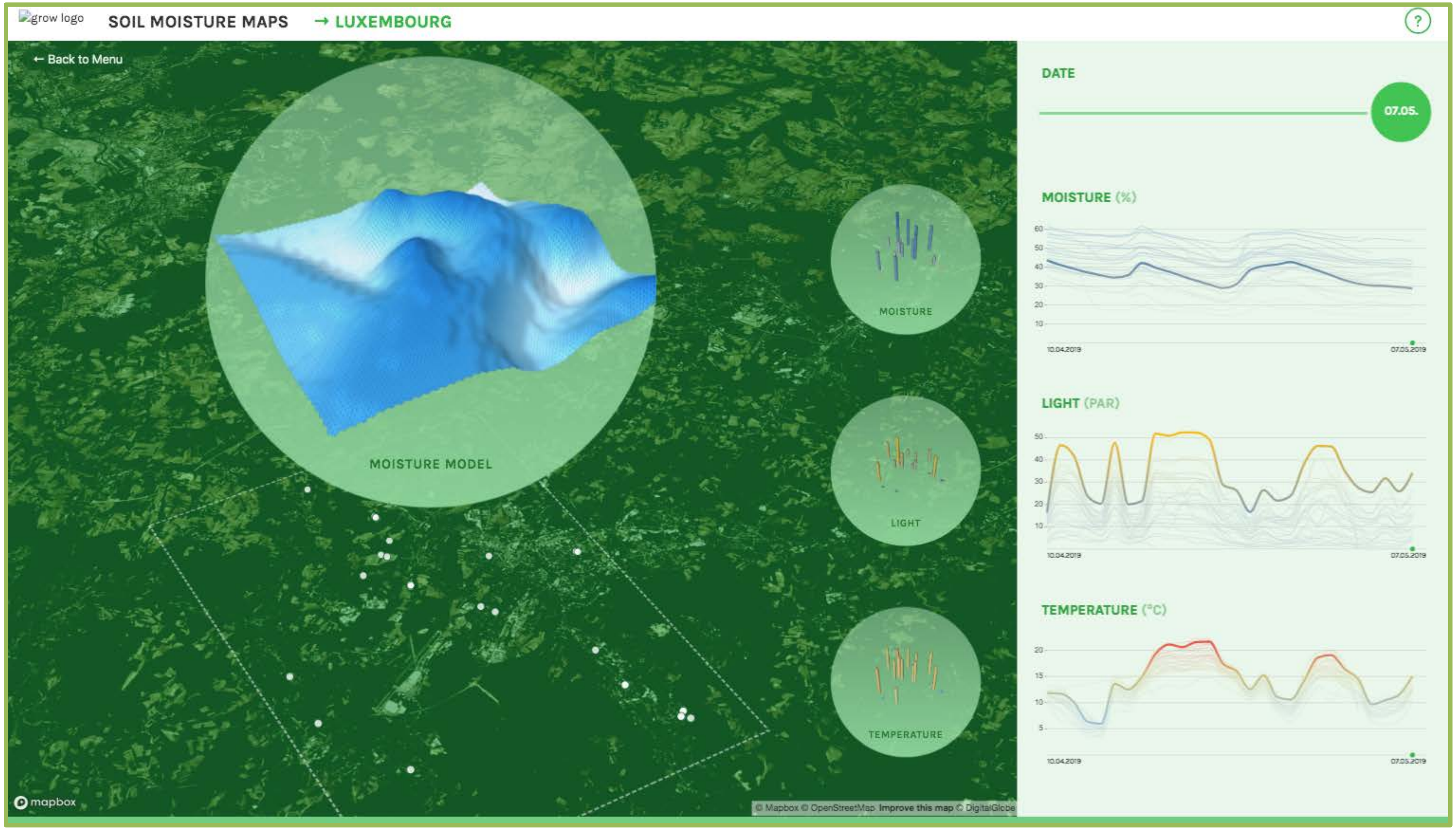

Figure 5.5 Soil moisture maps and graphs.

6.4 Scientific data and results

Scientific analysis of the soil moisture data is underway and will be reported in GROW reports Deliverable 4.4 “Validation and estimation of *in situ* soil moisture measurements derived from all sources” [Public] and Deliverable 4.5 “Validation of remotely sensed soil moisture products” [Public] both due in October 2019.

6.5 Conclusions

There has been a high level of interest and enthusiasm from the participants collecting data in this Mission from community champions to sensors users. They are inspired by the idea of contributing to the greater scientific knowledge and by learning about their own growing spaces and landscapes. A number of “super-users” have emerged who have placed, and recorded data from, multiple sensors. Some of these are actively creating their own dynamic maps to assess patterns and changes in soil moisture across their landscapes to help understand how they can improve their areas.

7 Collective creation of knowledge in the Living Soils Mission

There were two main data-focused activities within this mission; the Great GROW Experiment and the Shared Planting Calendars. The Great GROW Experiment was hypothesis-driven and the Shared Planting Calendars work was observation-driven and linked to the Edible Plant Database that sits behind the GROW Observatory App and informs which crops people can plant in their location and when.

The Great GROW Experiment, hereafter “the Experiment” was the main hypothesis-driven citizen science in GROW. It was open to participants around the world, but used crops best suited to temperature climates. It aimed to investigate the productivity of three crops grown together in a polyculture with those same three crops grown separately in monocultures with the research hypothesis that the polycultures would be more productive per land area.

The Shared Planting Calendars activity was derived from an existing JHI project and adopted and modified for GROW to align with the Edible Plant Database (EPD) accessible via the GROW Observatory app. During the collation of data for the 145 crops included in the EPD, it was noticed that many of the planting and harvesting dates found were unrealistic; they suggested crops that were unlikely to be able to grow in the locations suggested, or timings that did not correspond to known planting times for a region. This activity provided an opportunity to collaborate with citizens, improve the location-specific information available to growers, and facilitate knowledge-exchange through a crowd-sourced approach.

7.1 The Great GROW Experiment

The Great GROW Experiment, hereafter “the experiment”, ran from April to November 2018. It required intensive investment of both time (across the growing season) and growing space (6 m^2) from citizen scientists so recruitment was targeted to not only to reach high numbers of potential participants but those who had the capacity for committed participation.

The experiment was launched via the free Massive Open Online Course (MOOC) called “Citizen Science: Living Soils, Growing Food” during its first iteration from April until May 2018. The course aimed to support learners to understand some of the issues and challenges in our food production systems and involve them in investigating solutions through experimenting in their own growing space. Participants were encouraged to identify issues, develop research questions, and plan how they would conduct an investigation or an experiment of their own to answer their own question(s). They also learned how to take standardised site observations. They were invited to participate in a collective experiment to add to our wider knowledge and to increase their own understanding of both the scientific process of discovery and the outcomes for their own growing plot.

The experiment compared productivity from a polyculture planting to a monoculture planting of the same three crops. This topic was chosen as citizen feedback from surveys conducted in the first MOOC (Citizen Science: From Soil to Sky) in spring 2017 showed that this was an area of high interest but also high uncertainty amongst growers, and because literature reviews[13] revealed little scientific knowledge, particularly at this scale of food-growing, yet high potential benefits to soils, ecosystems and growers.

7.1.1 Method for citizen science

Several experiment protocols were introduced in the MOOC "Citizen Science: Living Soils, Growing Food" supported by illustrated text and videos. A full experiment handbook was available on the GROW website both as a sequence of linked webpages with multimedia content and as a downloadable file (in .pdf format). Recording sheets for use on the plots were available to download and print. Participants entered their results on the GROW website after logging in and were able to view a summary of their harvest data.

During the experiment (from May until November 2018) monthly online meet-ups open to all were held. Additional communications were by email and on the GROW Discussion Forums.

Participants were supported to analyse their own results In November 2018 in the fourth GROW MOOC "Citizen Science: From Data to Action." This included sections to help experiment participants explore, describe and use their own results. An example dataset was provided and illustrated text and video showed participants how to use free online software to manipulate and graph their results.

A final survey was conducted in January 2019 to explore participant engagement in, and learning from, the process.

7.1.2 Summary of the protocol for citizen science participants

The experiment was set up in a suitable location (where soil is good for growing and the site is not heavily shaded by adjacent structures or vegetation) with a total area of approximately 2 x 3 metres or 1 x 5 metres free from weeds.

Site observations matching those in the Changing Climate Mission were made:

- Latitude (via GPS or online maps)
- Longitude (via GPS or online maps)
- Area profile (by category) i.e. hilly or flat
- Slope position (by category) e.g. summit, toeslope
- Slope Aspect (by category) e.g. N, NE, E
- Land cover (by category) e.g. Trees, crops, sealed surfaces
- Canopy cover of a) Trees b) Shrubs (by category) e.g. <5%, 11-25%

Additional observations and measurements specific to this experiment include

- Light/shade by category e.g. full sun, 1-25% shaded. 26-50% shaded
- Slope angle (degrees)

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[13] Review of available academic and technical literature was conducted for twelve regenerative growing practices: mulching; using compost; using cover crops; planting legumes; growing polycultures; establishing flower cover; creating flower strips; promoting wild areas; contour methods; no-till farming and no-dig gardening; growing perennials; agroforestry. These are being compiled into an academic review (van der Velden *et al*., *in prep*) and public-facing summaries are being made available on the Permaculture Knowledgebase. https://knowledgebase.permaculture.org.uk/

- Photographs of the plot at the start, during growing, and at the end were encouraged and participants shared these by email, Facebook and/or Instagram.
- Soil texture by touch-test (see Section 4.3).
- Soil nutrients and pH in each plot were assessed using the STKs described in Section 4.1 at the start and end of the experiment.
- Harvest weight (in grams or ounces)
- Harvest quality (by categorical scale) e.g. 0 – none is good to eat, 1 less than a quarter is good to eat, 2 - a quarter to a half is good.

Within the site, four experiment plots were required:
- 1 metre by 1 metre square (for the polyculture)
- 1 metre by 60 cm (for the beans)
- 1 metre by 40 cm (for the spinach)
- 1 metre by 30 cm (for the radish)

Each was separated from the others and any adjacent crops by 50 cm (Figure 7.1).

Seeds or seedlings for the following crops were needed:
- 18 seeds - Climbing green beans “cobra” variety - *Phaseolus vulgaris* "cobra"
- 72 seeds - Spinach “matador” variety - *Spinacia oleacea* "matador"
- 160 seeds - Radish “cherry belle” variety - *Raphanus sativus* "cherry belle"

In addition, participants needed garden canes and tools to prepare the site and scales to weight their harvests.

Directions were given on the spacing and arrangement of crops and guidance offered on when and how to plant the seeds.

Guidance was also given on when to harvest crops. Weights of each harvest of each crop were recorded and entered on the GROW website. Crop quality was also assessed and recorded.

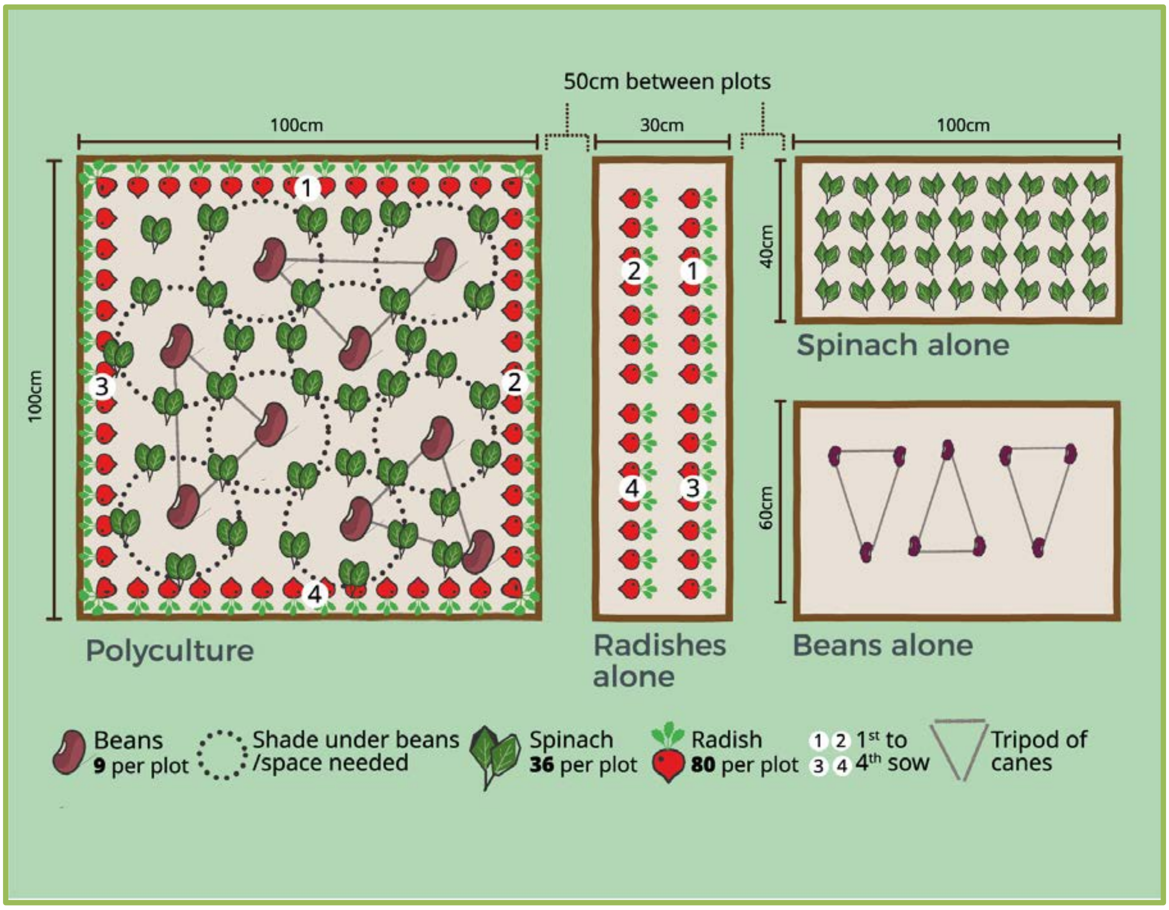


Figure 7.1 Layout of crops within the four experiment plots

7.1.3 Results

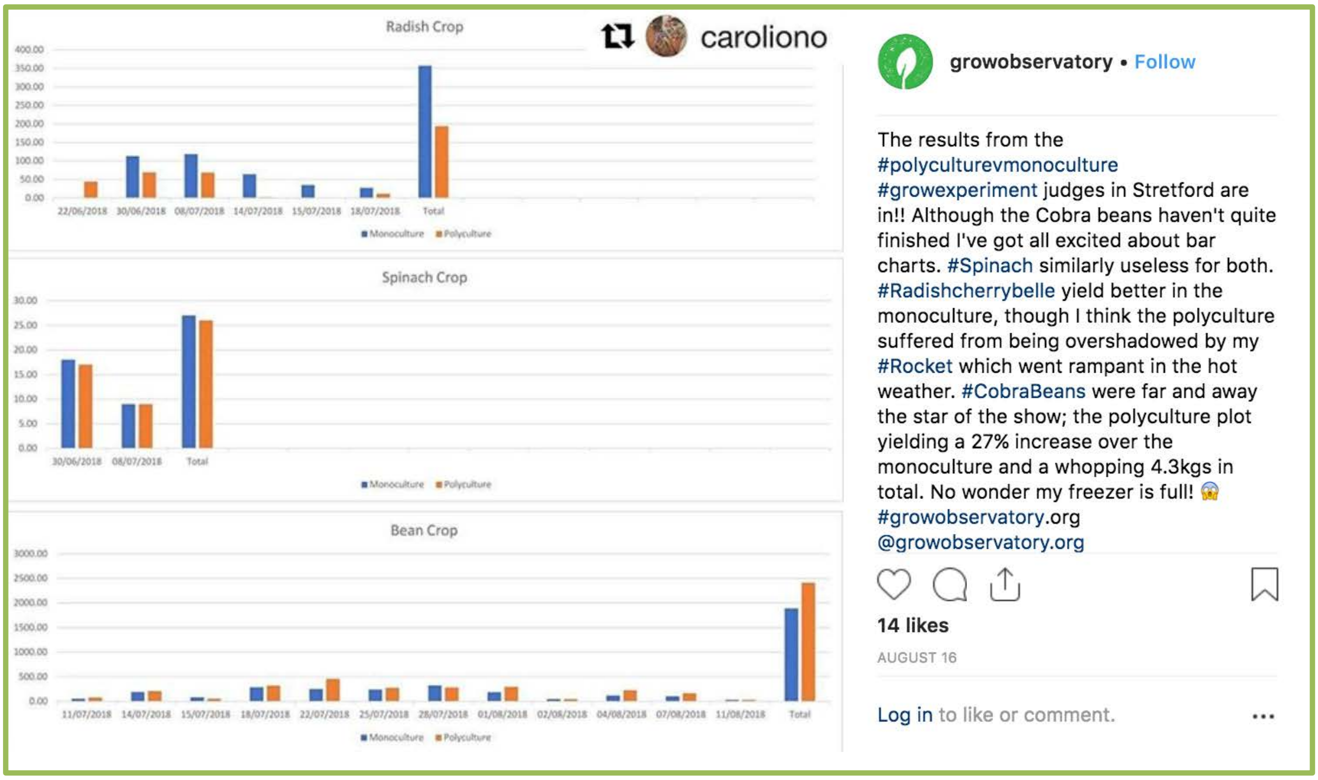
A total of 161 people registered for the Great GROW Experiment, of these 68 reported they had set up the experiment and 34 completed the experiment (defined as submitting at least one harvest, Figures 2 and 3). Initial participants were from across Europe (with strong UK representation) and even one from the USA (Figure 7.2). Of those who did not start the experiment reasons given included insufficient space, lack of time, and difficulty sourcing the seeds needed. Of those who did not complete the experiment reasons included loss of crops to pests and poor weather.

Individual participants' results

Experiment participants took initiative in exploring and sharing their own results and experiences, most often as photographs (e.g. Figure 7.3) with short comments. Many posted to social media accounts (Facebook, Twitter and Instagram). Others wrote blog articles about their experiences. Some analysed and presented their results and insights in graphical form (e.g. Figure 7.4). One was even interviewed on local BBC radio.

Figure 7.2 Locations of initial participants in the experiment

Figure 7.3 Results shared as a photo by experiment participant
(Copyright Adela Nistora, under licence)



The results from the #polyculturevmonoculture #growexperiment judges in Stretford are in!! Although the Cobra beans haven't quite finished I've got all excited about bar charts. #Spinach similarly useless for both. #Radishcherrybelle yield better in the monoculture, though I think the polyculture suffered from being overshadowed by my #Rocket which went rampant in the hot weather. #CobraBeans were far and away the star of the show; the polyculture plot yielding a 27% increase over the monoculture and a whopping 4.3kgs in total. No wonder my freezer is full! 😱 #growobservatory.org @growobservatory.org

Figure 7.4 Results and insights shared by an experiment participant (reproduced with kind permission)

Collective results

Collective experiment results were regularly shared with participants from the first month of harvesting onwards as a reward and motivation. Interim results were shared more widely at events in September 2018 (at the Permaculture Convergence, Manchester UK) and December 2018 (in a GROW webinar[14]).

The overall findings showed that the polycultures were significantly[15] more productive (Figure 7.5) and this was the case for 67.7% of individual participants. The higher productivity of the beans accounted for much of this (Figure 7.6).

Experiment results have been, or are being, presented at academic conferences[16] and are further explored in two papers currently in preparation one focusing on the citizen science context (Burton *et al., in prep*) and one describing the method and results (van der Velden *et al., in prep*).

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[14] The GROW world soils day webinar is available at: https://www.youtube.com/watch?v=mqPMqoB8oG4

[15] Statistical test results: Wilcoxon Signed Rank test (V = 333, p = 0.002, n = 34)

[16] *Place-Based Citizen-Science for Wellbeing*, London August 2019. *Agroecology Forum, Crete*, September 2019.

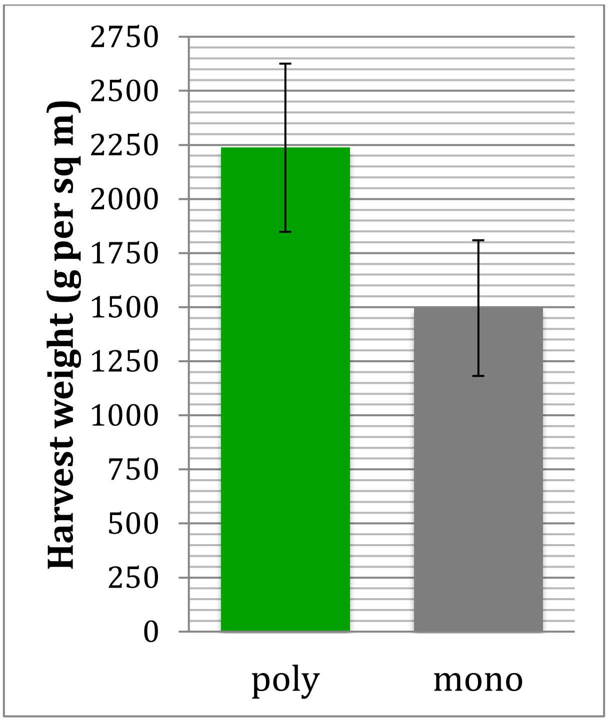

Figure 7.5 Collective experiment overall results
Columns show average yields with standard error shown by lines

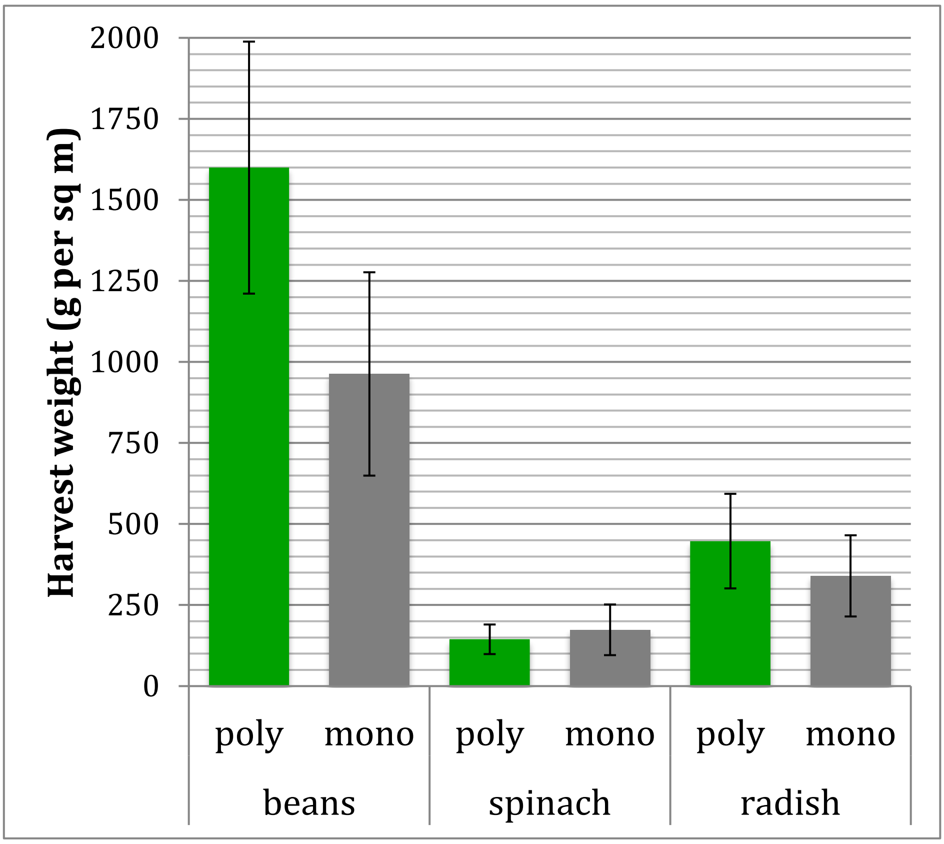

Figure 7.6 Collective experiment results by crop
Columns show average yields with standard error shown by lines

Based on the survey results in January 2019, the main motivations for joining were to learn (82.4%) and to contribute to science (70.6%) with "for fun" also seen as very important by 58.8% of respondents (Table 7.1). These are also reflected in comments about what people most enjoyed, examples include: *"The GROW experiment was the highlight of 2018 for me. I learned something meaningful" "I enjoyed being part of a bigger project, and learning from other growers. It was also very valuable to get to know scientific methods." "Good to take a new look at how I cultivate and to feel part of a community of growers."*

Table 7.1 Motivations for participating in the experiment

Other reasons were: To grow food to eat; To help future generations care for the earth and the Earth; I want to grow polycultures, as intuitively they seem the best idea to me. So I wanted evidence to back that up; I often grow polycultures but not always sure how well they work, so it's interesting to see lots of people doing the same thing. It feels nice to have connected with a like-minded community.

Figures show % of respondents	**Not at all important**	**Not very important**	**Slightly important**	**Very important**
Contribute to scientific research	0.0	0.0	41.2	70.6
Learn something new	0.0	0.0	29.4	82.4
Develop new skills	0.0	11.8	47.1	52.9
Share knowledge and experience	0.0	11.8	58.8	41.2
For fun	0.0	17.6	35.3	58.8
Other (tell us what)	23.5	23.5	0.0	35.3

The challenges encountered were often in the scientific requirements "*following the exact specifications*" "*taking pH and nutrient samples*" and in outside influences "*The pests eating my crops and the weather challenge"*

7.1.4 Conclusion

The in-depth nature of this citizen science approach does seem to have limited the number of completing participants. Recruitment and completion were significantly higher than for the 2017 experiment, however, and may reflect the learning points from that around improving the focus to what the citizens are most motivated by and/or to better advertising and awareness-raising prior to the experiment start.

Those who did participate were highly motivated and engaged. They found the experience rewarding; 93.6% said they would definitely participate in future experiments. Their enthusiasm was also rewarding to science team members who found that interacting with the participants was one of the highlights of the project.

In terms of impact on growing practices, 36.8% of the survey respondents said they had previously grown polycultures. The majority were therefore growing this way for the first time. Of those, 50.0% had already incorporated this new technique into their growing within 4 months of completing the experiment and a further 33.3% planned to do so. Many also commented to say they were planning their own experiments.

Experiments that are tailored towards the interests and activities of citizens can promote truly in-depth engagement in both science and the subject. The challenge remains in balancing recruitment numbers with the level of commitment needed to complete it.

7.2 Shared Planting Calendars

To support new and existing growers to make the most of their growing space, time and effort, accurate localised information on which crops will grow and when they can be planted and harvested is essential. GROW compiled planting calendars as part of the information in the Edible Plant Database (EPD) that gives the crop information in the GROW Observatory App. Information was compiled from seed catalogues (Dobbies and Suttons) and web pages of Grow Veg[17] and the Royal Horticultural Society (RHS)[18] in the UK. Planting and harvesting dates for each of the 145 crop were determined, where possible, for each of the thirteen environmental zones of Europe described by Jongman *et al.* (2011).

UK examples have shown that the planting and harvesting dates obtained are often generalised and inaccurate. For example, our calendars wrongly indicate that sweet potato, *Ipomoea batatas,* can be grown the North Atlantic climate zone (ATN) (planting through June and harvesting in September and October), whereas local, knowledgeable growers have indicated that although the plants will grow, this area does not have the long hot summer weather required to produce a crop. Similarly, it is suggested that lemon trees, *Citrus x limon,* will also grow in this region, and although growers have successfully produced lemons, these trees are not grown outdoors.

To address this lack of accurate data, a crowd sourcing approach was taken to gather planting and harvesting dates for a variety of crops using social media (predominantly Facebook).

7.2.1 Method

Several methods were used to collect planting and harvesting dates from growers. Dates were recorded as approximate two-week intervals with two in each month (e.g. 1-15th May, 16-31st May). When three or more entries from one bioclimatic zone agreed on the same date, entries in the EPD were updated (confirmed as accurate or changed to new dates).

A crop survey (created using Bristol Online Surveys) was sent to GROW members, and advertised through GROW online courses and social media. The survey asked if, and when, respondents sowed and harvested 10 of the most commonly grown vegetables in the UK (Broad beans, cabbage, carrots, onions, potatoes, radish, runner beans, spinach, peas, and courgettes). There were 44 respondents in total, but due to the nature of the survey and the limitations of the platform, many of the responses were unusable. For example, there were many general statements in response to planting and harvesting questions, such as “in the autumn”, or “in the spring 7 days after the last frost”, despite clear instructions on answer formatting. To validate the calendars 2-week windows or dates were needed.

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[17] The Grow Veg website is www.growveg.co.uk

[18] The RHS website is www.rhs.org.uk

Calendars were also distributed at events, meet-ups (Permaculture Convergence), and via email, asking growers to indicate if their planting and harvesting dates aligned with our calendars, again, resulting in very few responses. These methods yielded little data that could be used in our crowd sourced data set, with no values validated by 3 or more growers within the same region, responding with the same dates. Our conclusion is that these methods are not suitable for crowd sourcing accurate data.

A Facebook group "Share my planting calendars"[19] was set up. There is a strong presence of people growing food on Facebook and many Facebook groups dedicated to vegetable growing and allotment growers. These groups provide a space for both new and experienced growers, allowing for knowledge to be shared. Thus, Facebook was identified as a strong platform to engage with growers.

The first posts in the Share my planting calendars group asked members to share when they planted and harvested specific crops, with information about the crop (Figure 7.7). Of the four crops posted, 42 comments were collected, leading to only 7 data points. These posts required members to remember when they planted, and when they would normally harvest, this yielded little data, but did stimulate discussions, and sharing information within the group. This engagement with the page members hinted at the potential of the page if a method suitable to generate real data was used. Our second method was to post polls (Figure 7.8) at the beginning, and the middle of each month, asking members what they were planting or harvesting in the next 2 weeks. These 2-week windows aligned with the dates in our calendars, and required little input from members. This method did not require members to remember anything, as they were simply asking, "What are you doing now?" The resulting data from this strategy, over a period of 5 months, yielded over 500 usable data points for harvesting, and over 1100 data points for planting. This was the most successful method (by far) implemented to collect grower's information.

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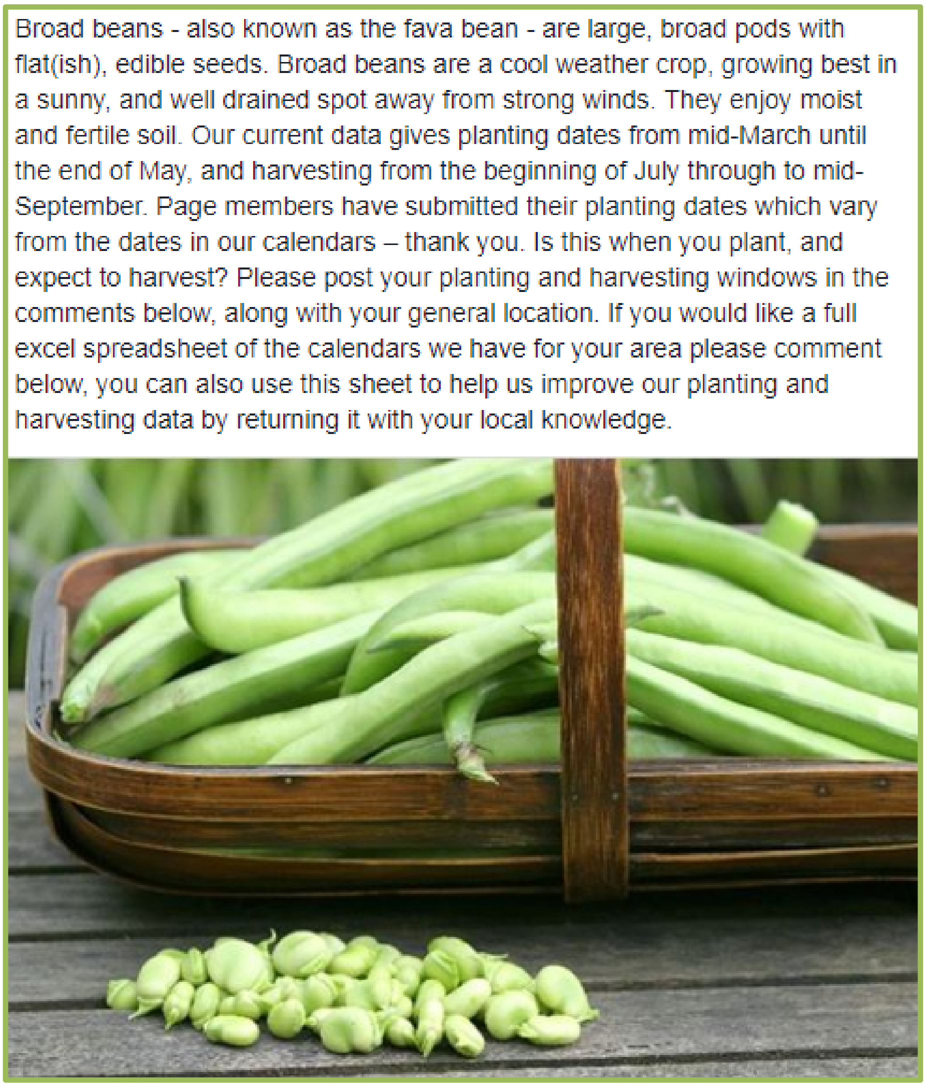
[19] The Facebook group "Share my planting calendars" can be accessed at: https://www.facebook.com/groups/sharemyplantingcalendars/



Broad beans - also known as the fava bean - are large, broad pods with flat(ish), edible seeds. Broad beans are a cool weather crop, growing best in a sunny, and well drained spot away from strong winds. They enjoy moist and fertile soil. Our current data gives planting dates from mid-March until the end of May, and harvesting from the beginning of July through to mid-September. Page members have submitted their planting dates which vary from the dates in our calendars – thank you. Is this when you plant, and expect to harvest? Please post your planting and harvesting windows in the comments below, along with your general location. If you would like a full excel spreadsheet of the calendars we have for your area please comment below, you can also use this sheet to help us improve our planting and harvesting data by returning it with your local knowledge.

Figure 7.7 **Original style of Facebook posts asking for planting and harvesting dates**

Data collection was done by manually filling in an excel table, consisting of crop, poll date, poll type (planting or harvesting), user name, location (where available), European climatic zone, and European climatic sub-zone. The data was summarised using the Excel add-on “Power Query”. This connects to the data table and exports the requested information for validation. Figure 7.9 shows the query results for planting carrots in the Atlantic central (ATC) region.

Hi everyone! Harvest season is definitely upon us in the UK, what about everywhere else in Europe? Are you **harvesting** anything over the next few weeks (first few weeks in August)? You can add crops to the poll if you have harvested different crops to the ones listed. Please post your general location in the comments below, with pictures if you have any 📷😀! Happy harvesting!

☐ Courgettes
Added by
+17

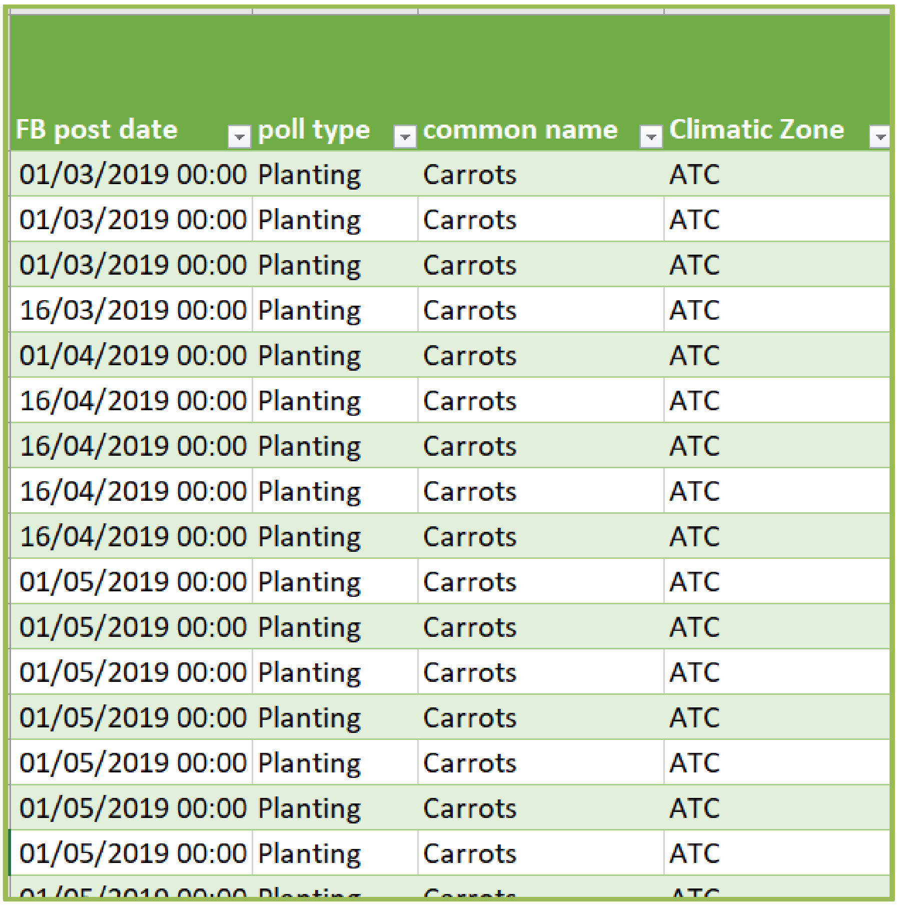
☐ Onions
Added by
+14

☐ Potatoes
Added by
+10

☐ Lettuce
Added by
+10

☐ Tomatoes
Added by
+10

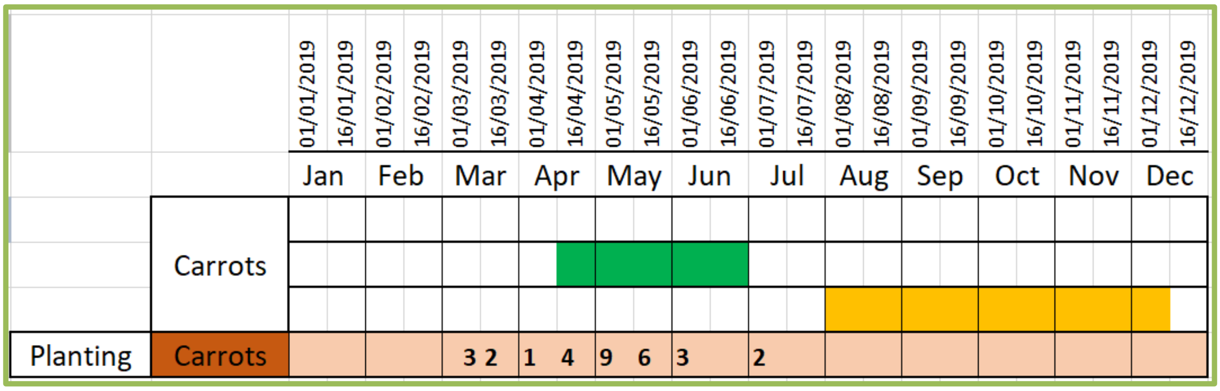
Figure 7.8 **Harvest poll showing votes for the top 5 crops of 46 listed.**



FB post date	poll type	common name	Climatic Zone
01/03/2019 00:00	Planting	Carrots	ATC
01/03/2019 00:00	Planting	Carrots	ATC
01/03/2019 00:00	Planting	Carrots	ATC
16/03/2019 00:00	Planting	Carrots	ATC
01/04/2019 00:00	Planting	Carrots	ATC
16/04/2019 00:00	Planting	Carrots	ATC
16/04/2019 00:00	Planting	Carrots	ATC
16/04/2019 00:00	Planting	Carrots	ATC
16/04/2019 00:00	Planting	Carrots	ATC
01/05/2019 00:00	Planting	Carrots	ATC
01/05/2019 00:00	Planting	Carrots	ATC
01/05/2019 00:00	Planting	Carrots	ATC
01/05/2019 00:00	Planting	Carrots	ATC
01/05/2019 00:00	Planting	Carrots	ATC
01/05/2019 00:00	Planting	Carrots	ATC
01/05/2019 00:00	Planting	Carrots	ATC
01/05/2019 00:00	Planting	Carrots	ATC

Figure 7.9 **Results from power query with filtered data from the master table.**

The results from the power query are totalled into 24 'bins' representing the start and end of each month. Any bin with three or more votes is considered validated, and the first validated entry is used as the crowd sourced date. In figure 4 the validated date is the 1st of March, whereas the suggested dates in our calendars is from mid-April (example zone Atlantic Central ATC).



		01/01/2019	16/01/2019	01/02/2019	16/02/2019	01/03/2019	16/03/2019	01/04/2019	16/04/2019	01/05/2019	16/05/2019	01/06/2019	16/06/2019	01/07/2019	16/07/2019	01/08/2019	16/08/2019	01/09/2019	16/09/2019	01/10/2019	16/10/2019	01/11/2019	16/11/2019	01/12/2019	16/12/2019
		Jan		Feb		Mar		Apr		May		Jun		Jul		Aug		Sep		Oct		Nov		Dec	
	Carrots																								
									🟩	🟩	🟩	🟩	🟩												
																🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟨	
Planting	Carrots					**3**	**2**	**1**	**4**	**9**	**6**	**3**		**2**											

Figure 7.10 Example of data validation for the EPD planting dates.
Shown are the number of votes for planting carrots in one region.

Updating the app with the information shown in Figure 7.10 informs the users in the zone validated that growers in their region are planting from the 1st of March, which is earlier than the original calendars suggest.

7.2.2 Results

Using social media several approaches where used to engage citizens to share their planting and harvesting dates for their regions. Asking the questions “when will you”, or “when did you” yielded few responses, however asking “What are you planting now?” or “What are you harvesting now?” provided over 1500 responses.

The number of participants that contributed to the calendars crowd sourcing mission is 113, with 1781 data points covering 8 of the 12 European climate zones for 92 different crops. These data have provided validated data for 43 crops in the Atlantic North region of which 25 planting and harvesting dates agree with ours and 18 have new crowd sourced dates. In the Atlantic Central zone, there are 36 crops with validated data, of which 19 agree, and 17 crowd sourced dates.

Without exception all 35 crowd sourced dates indicate that growers are planting and harvesting earlier than indicated by the planting calendars.

These data are being used to update the GROW Observatory App to indicate where and how this crowd-sourced data has improved the information. The next update is due for release in September 2019.

7.2.3 Conclusions

Of the methods used, social media was the best method by a long way; Facebook was the ideal platform. Out of the two methods implemented on Facebook, the polling method was the best, yielding significantly more data points than any other method used. This was likely to do with the lack of effort this requires for participation; simply clicking on the crops being planted over the next two weeks, as opposed to remembering planting and harvesting dates. Figure 7.11 shows member activity on the Facebook page. Our first poll started at the beginning of February 2019 where the graph clearly shows a significant rise in member activity, and this increase in quantifiable engagement has been maintained in the following months.

Social media not only allows citizens to provide information to the EPD, it also facilitates valuable information exchange between participants through an online community.

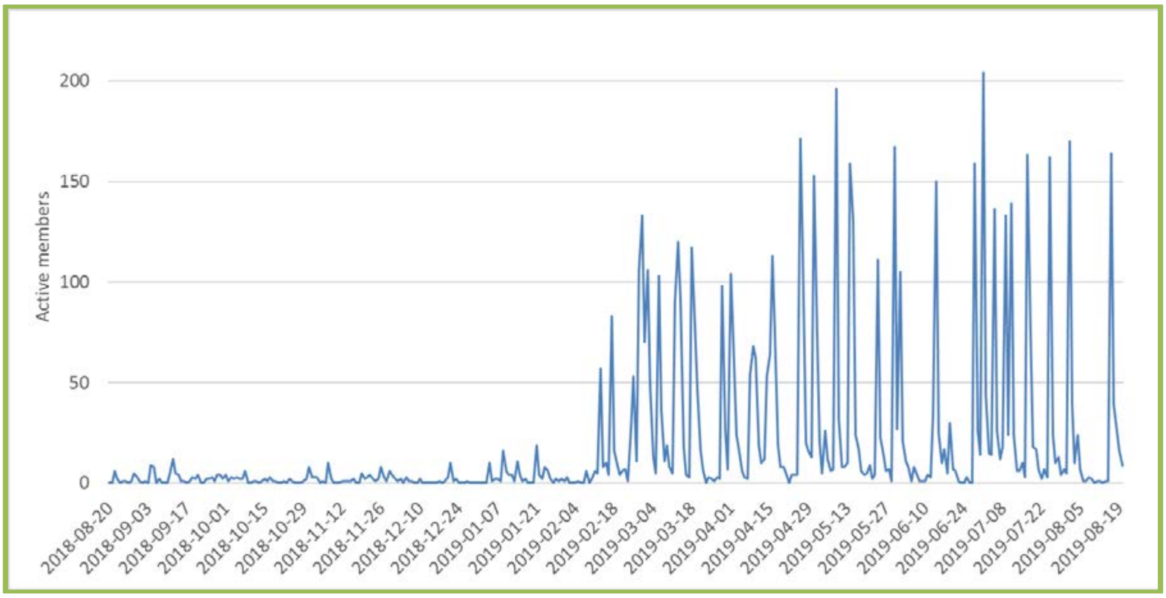


Figure 7.11 Active members of the "share my planting calendars" Facebook page

8 Conclusions - citizen science protocols and approaches in the GROW Observatory

This report has shown the importance of the scientific evaluation of citizen science protocols to ensure robust results for science and a meaningful and enjoyable experience for citizen science participants. The NPK and pH test kits were somewhat difficult to use but this was overshadowed by the significant lack of accurate results obtained. The sediment jar test was highly time-consuming for participants and difficult to interpret. The results obtained were not comparable to laboratory analysis. Quicker, easier tests like the soil manipulation tests for texture give less precise but more consistent and reliable results. Future citizen science initiatives should endeavour to keep equipment and protocols as simple as possible to maximise enjoyment and engagement.

GROW combined both observation-driven and hypothesis-driven approaches and found advantages and limitations to each. Both were well-supported by a range of educational materials in a variety of formats, and by high levels of interaction with participants in a combination of synchronous and asynchronous modes (including live meet-ups, forum discussions, blogs, emails, webinars, and social media). This contact not only motivated citizens and participants but was also rewarding to the GROW partners. Good communications with participants also enabled more rapid identification of issues and meant that solutions could be found and shared more effectively.

In summary, we find that it is good practice to:

- Evaluate citizen science protocols against proven scientific methods.
- Seek simple tests that are easy for participants to interpret and need minimal time investment.
- Consider MOOCs, or similar set-ups with specific cohorts of learners and good interaction from educators, to help citizens to learn scientific methods and approaches as well as understand the context of investigations and measurements and the meaning of results.
- Actively encourage citizen feedback at all stages and respond rapidly to issues.
- Share results and insights regularly to sustain participation.

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Appendix 1 – Summary of reports (deliverables) produced in GROW and referenced in this document

Deliverable	Deliverable description	Status
D2.4 GROW Community Champions Programme	This deliverable will outline the approach and outcomes in the Community Champions programme. This will detail 1) the principals and approach 2) delivery methods i.e. the commissioning process 3) provisions for community and resource management across cultural and social contexts 4) success criteria and evaluation techniques 5) key results and insights	Public
D2.5 Evaluation of Citizen Engagement and Active Participation	This deliverable will document the outcomes of the communication and engagement activities and evaluate the delivery of targets for active and passive participation. The report will delineate modes of engagement based on specific qualities and criteria such as contribution of soil data or other user-generated content, event based engagement of light-touch digital interaction. The report will detail the methods used for capture and analysis of data on engagement and participation.	Public
D4.1 Evaluation of tools - crop database, Soil Testing Kit, Land Survey Toolkit	This deliverable describes three main components for collecting soil, landscape and crop data focusing on rationale, logic and semantic background including definitions and classifications of the soil, landscape and crop elements. It also describes the steps for technical implementation towards the physical data storage during the citizen observatories. An evaluation part will, in simple terms, describe the performance of the tools as implemented in COs, both from a semantic and technical perspective.	Confidential (only for members of the GROW Consortium and the European Commission Services)
D4.3 [THIS REPORT] Report on science experiment(s) and protocol(s) and the collective creation of knowledge in GROW Missions	This deliverable will describe the approach(es) used and the outcomes in both direct knowledge gained (e.g. results from experiment) and in the use and interpretation of this collective knowledge (e.g. benefits to participants of own and shared data). It will offer insights into the use of crowd-sourced data and existing auxiliary data and expert knowledge to answer questions and provide information relevant to growers and researchers. It will discuss the value of supporting citizens to understand, contextualise and use their own data as part of a citizen observatory.	Public
D4.4 Validation and estimation of in situ soil moisture measurements derived from all sources	This deliverable describes the exercises done to render the utilization of crowd-sourced in situ soil-moisture data from sensors for Sentinel 1 satellite data validation (e.g. Sentinel-1) with advanced statistical methods such as triple collocation and	Public

	its interpretation towards practically useful gridded soil moisture information at regional and continental scales.	
D 4.5 Validation of remotely sensed soil moisture products	Report on validation of remotely sensed soil moisture products (e.g. Sentinel-1). This deliverable will describe the exercises done to render the utilization of crowd-sourced in situ soil-moisture data from sensors for Sentinel 1 satellite data validation (e.g. Sentinel-1) with advanced statistical methods such as triple collocation and its interpretation towards practically useful gridded soil moisture information at regional and continental scales. It will also describe the examples of how crowdsourced soil data can be effectively integrated within existing soil gridded products and how it can provide important soil-landscape covariates for validation exercises.	Public
D6.4 Operational GROW Platform	This deliverable includes an operational GROW platform and a document containing the design specifications. Time series data are avail-able via the Thingful API. This includes data access to Flower Power sensors hosted (PA), citizen sourced database of soil (IIASA) and High Quality sensor data (SL). Gridded data are available via the HydroNET API. This includes an authentication module to access the 3 gridded data sources: processed Sentinel soil moisture (SL), crowdsourced soil data processed into spatial grids (IIASA), and one possible other gridded data source (to be decided). The GROW platform API consists of a metadata catalogue, a data proxy service and management tools.	Confidential (only for members of the GROW Consortium and the European Commission Services)
D6.7 Development of the GROW App	This deliverable reports on the development of the GROW Observatory mobile app (GROW app). The GROW app is a multi-functional app for smartphones that can serve different purposes within the GROW project. It is deliberately developed based on user surveys and detailed user requirements with the aim that the design and functionality of the app serve the needs of the GROW user community. It helps growers make better choices in managing their plants (e.g. soil management, how to attract pollinators etc.) and give recommendations on how to improve soil (incl. soil moisture), consider irrigation needs of plants or how to try growing practices that benefit the wider ecosystem. Other recommendations on, for example, choice of plants and timing of planting at a specific location are added according to the requirements of the growers. At the same time, the GROW app serves as an important data recording tool for land and soil data.	Confidential (only for members of the GROW Consortium and the European Commission Services)

Appendix 2 – Supplementary information for STKs (assessing NPK and pH)

Statistical analysis

To evaluate the accuracy of the STK relative to standard laboratory methods, a set of statistical metrics and measures was used (see Box 0.1). Descriptive/summary statistics provided an overview of the data characteristics.

Validation was obtained through statistical analyses, testing the goodness of fit of the STK data with laboratory data, and providing a standard error measure (see Box 0.1). Contingency tables were produced to check if the data meets the statistical assumptions of the Pearson's Chi-Squared test. Root-mean-square error (RMSE) estimation was done with standard laboratory test being the estimator and STK results being the estimate. For simple linear regression and calculation of the Pearson correlation coefficient, laboratory results were utilized as the independent variable and the STK results as the dependent variable in regard to the four soil properties in question. Plotting of the results in scatter diagrams enabled a visualization of the sample correlation. Accuracy of the STK was assumed for a Pearson correlation significantly different from zero (no linear correlation).

Box 0.1 Used statistical metrics and measures

Summary statistics Used to summarize the results. Summary statistics included mean, median, standard deviations, ranges, distributions, observed frequencies within each combination (two-way/contingency table).
Pearson's Chi-Squared test The Pearson's Chi-Squared test was applied to determine the association between two (categorical) variables by testing the hypothesis that there is no relationship between two variables. Reported level of significance (p-value): 0.05.
Fisher's exact test In case the assumptions of the Pearson's Chi-Squared test were not met, the Fisher's exact test was applied. It is a statistical significance test used to analyse contingency tables. The test uses pure probability calculations based on every combination of category frequencies given in the variable totals. No test statistic is provided. Reported level of significance (p-value): 0.05.
RMSE Standard statistic metric in model evaluation for measuring differences between sample values predicted by an estimator and the values actually observed.
Pearson correlation Measure of the linear correlation between two variables, with a value ranging between +1 and -1, where +1 explains a total positive correlation.

Results for phosphate (P)

In the JHI data set, laboratory results for phosphate (P) ranged from 4 to 83 mg kg^{-1}, and STK results from the same soil samples ranged across all categories (equivalent to 0 to 100 mg kg^{-1}). Laboratory results from AGRO DLHÉ ranged from 0 to 346 mg kg^{-1}, with the corresponding STK results ranging across all categories (equivalent to 0 to 100 mg kg^{-1}).

For accuracy assessment, the association between P results from the laboratory and P results obtained with the STK was tested. Both the Pearson's Chi-Squared test and a Fisher's exact test showed no significant association (tests results were negative with p-values > 0.05). However, test results for AGRO DLHÉ (Pearson's Chi-Squared test p-value = 0.4; Fisher's exact test p-value = 0.2) differed from JHI test results (Pearson's Chi-Squared test = 0.1; Fisher's exact test p-value = 0.04), with much lower p-values indicating a better goodness of fit for the JHI dataset. This may be due to the large sample size from JHI, but may also reflect the use of different laboratory protocols for soil testing.

Results for potassium (K)

In the JHI data set, laboratory results obtained for potassium (K) oxide ranged from 65 to 640 mg kg^{-1}, whereas STK results from the same soil samples ranged across all possible categories (equivalent to from 0 to 900 mg kg^{-1}). In the AGRO DLHÉ data set, the range of laboratory values was even larger from 39 to 1932 mg kg^{-1}, whereas STK results from the same soil samples ranged from deficient to sufficient (equivalent to 0 to 600 mg kg^{-1}). The STK did not measure a surplus for any of the samples.

For the statistical analysis, the same testing scheme as described for P was applied. Results of the summary statistics for the AGRO DLHÉ data set indicated that assumptions have not been met to apply the Pearson's Chi-Squared test and Fisher's exact test. Statistical testing results for the JHI data set showed that there was no significant association as tests results were negative with p-values > 0.05 (Pearson's Chi-Squared test p-value = 0.9; Fisher's exact test p-value = 0.9). These findings are also in accord with Brandenberger *et al*. (2016), who reported no sensitivity of the STK to soil K and a similar lack of correlation with laboratory results.

Results for soil pH

In the JHI data set, soil pH laboratory results ranged from 5.4 to 8.2 and from 4.5 to 7.5 using the STK. The AGRO DLHÉ data set laboratory results ranged from 4.2 to 7.5, whereas test kit results from the same soil samples ranged from 5.5 to 7.0.

For the soil pH accuracy assessment, the same testing scheme as previously described was applied. Results of the summary statistics for both data sets indicated that they did not meet the assumptions to apply the Pearson's Chi-Squared test and Fisher's exact test. A simple linear regression was conducted alternatively, utilizing standard laboratory results as independent variable and STK data as the dependent variable. The results (JHI: trend-line slope = 0.49, R^2 = 0.48, RMSE = 1; AGRO DLHÉ: trend-line slope = 0.1, R^2 = 0.11, RMSE = 0.98) indicated that the kit did not provide a reliable test for soil pH.

Regarding the accuracy of the measurement, laboratory mean standard deviations were especially high for pH values from 4.5 to 6.5 and lower errors were observed for pH 7.0 and 7.5 in both data sets. This could be interpreted as a higher accuracy of the STK when measuring neutral and slightly alkaline soil pH values, but it is more likely that smaller errors occurred due to smaller sample sizes for pH values 7.0 and 7.5 (13% of all samples for JHI; 3% of all samples for AGRO DLHÉ).

Appendix 3 – Supplementary information for sediment jar evaluation

The sediment jar test was conducted and compared to laboratory analyses by the University of Miskolc (UOM). Volunteers (students and growers) were recruited to collect the soil samples and conduct the sediment jar test. Forty-eight samples followed the citizen science sediment jar test with measurements at 2 minutes, 5 hours and 24 hours for sand, silt and clay respectively. Those and a further 54 were left to settle and the sediment layers (re-)assessed after 116 days.

Results were compared to laboratory particle size analysis obtained using a hydrometer method (see Michigan State University, 2019) for 3 samples, and Atterberg test for liquid limits (103 samples). The liquid limit measure is a simple approximation of soil texture, suitable and cost-effective for large number of samples. The air-dry soil sample is milled and sieved and then saturated with distilled water drop by drop until reaching full saturation. The result in millilitre of water saturating 100 grams of soil is then converted to soil texture class using a simple scale (Table A3.1, first two columns). Comparison was conducted by UOM and a summary of key findings shared.

Table A3.0.1 Conversion of liquid limit measures to soil texture classes. *Atterberg values correspond to those assigned to the laboratory tests by UOM, "Triangle" values correspond to equivalent sediment jar test assignations by PAB.*

Liquid limit [K_A]	Texture class (Atterberg)	Texture class (triangle)
< 25	Coarse sand	Sand
25–30	Sand	Sand
31–38	Sandy loam	Sandy loam
39–42	Loam	Loam/Silt loam
43-50	Clay loam	Clay loam
51–60	Clay	Clay
> 60	Heavy clay	Clay

Some further analysis for this report was conducted by the Permaculture Association (PAB) by assigning texture classes to the sediment jar test proportions according to the FAO soil texture triangle (Figure A3.0.1) and comparing the resultant texture classes obtained by the two approaches according to the categories in Table A3.1

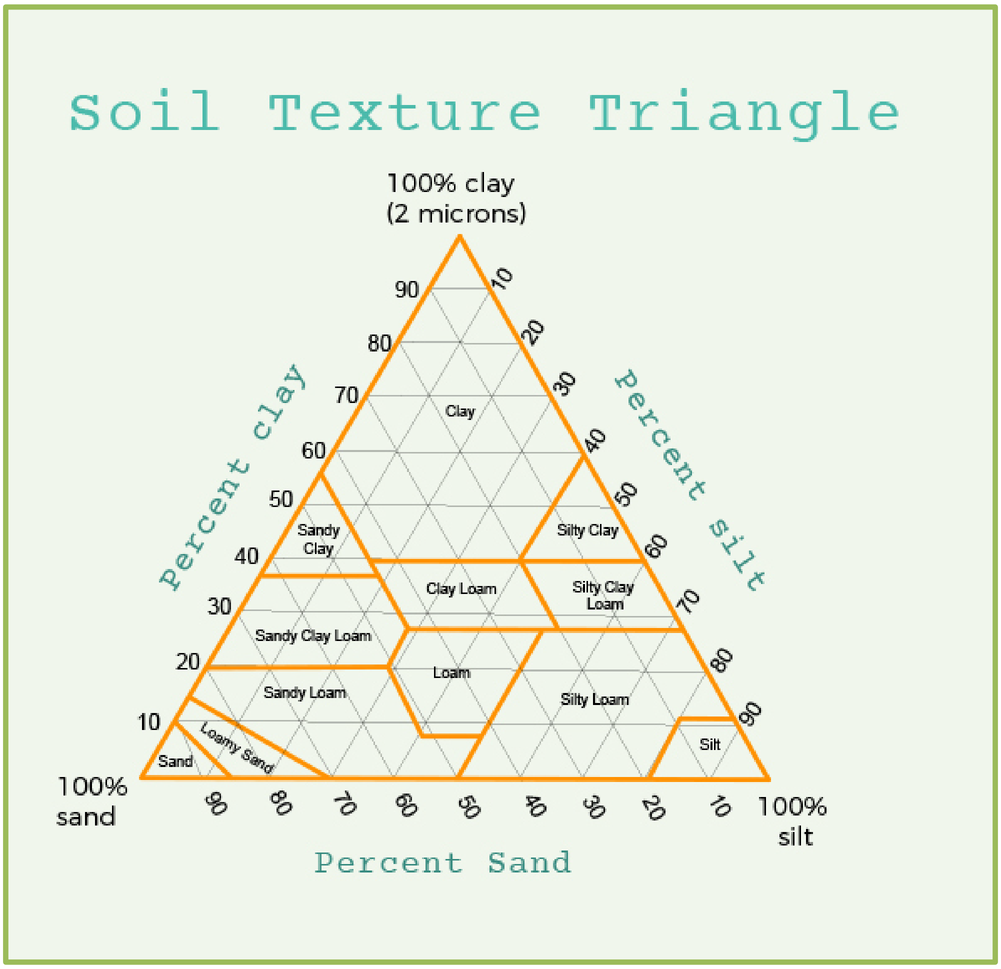

Figure A3.0.1 Soil texture triangle showing how the relative quantitative proportions of sand, silt and clay relate to texture classes that can be determined by the sediment jar test (after FAO, n.d.).

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