UNIVERSITY OF TWENTE.

BSc Thesis Creative Technology

Enhancing soil health measurements for food forest projects

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Abstract

This bachelor thesis presents a prototype of a low-cost soil health monitoring system for food forests. The goal of the system is to provide a cost-effective alternative to current soil health monitoring methods, especially for small-scale food forest owners.

The prototype consists of a website and a set of sensors that e.g., measure pH values and moisture levels in the soil. The collected data is stored in a database and can be visualized on a dashboard. To evaluate the prototype, interviews were conducted with some food forest owners.

The results showed a positive impression of the system and its potential to be a cost-effective alternative to current methods. The users also pointed out some areas for improvement and additional sensor options for future versions.

This thesis demonstrates the feasibility of a low-cost soil health monitoring system for food forests and provides a foundation for further development and testing.

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1 Introduction

Soil quality is critically important for the development of a healthy ecosystem, specifically in agriculture, to ensure high yields. While the agriculture community utilizes artificial enrichment of the soil's minerals using fertilizer, the agroforestry community is convinced that agroforestry practice can improve the soil health naturally, by leaving the soil untouched and keeping most of the plants and soil cover crops after the harvest. As agroforestry projects are getting more popular and gaining more attention, more people are interested in starting their own agroforestry project. In the initial stages of such project, the soil quality needs to be determined to ensure a healthy environmental start. But also in later stages, monitoring and assessing soil health is very relevant to develop a sustainable agroforestry ecosystem. Oftentimes, people that are interested lack the education in what indicates healthy soil, how to measure it, and how to improve soil health with given conditions. Important decisions, such as most effectively choosing planting sites and plant types that fit the soil parameters, need to be grounded in research and knowledge which is oftentimes neglected.

Thus, the main goal of this graduation project is to develop a solution that effectively measures and monitors soil health for food forest projects to help them develop a more sustainable and prolonged ecosystem. Besides that, it can help communities and individuals to gain knowledge about soil health/quality indicators, how they can be measured with technology and non-technology approaches and how the measured conditions can be interpreted and used for justified improvement interventions.

1.1 Research Questions

The following research question was formulated to specify the goal of this research.

"How can a soil health monitoring system be designed for food forest projects to measure and monitor soil health and give suitable planting advises?"

2 Background

To answer the main research question in more detail, the following sub-questions will guide the process of answering, and serve as a preparatory step to design a prototype:

1. What does soil health mean for food forests?
2. What are technological and non-technological approaches for soil health measurement?
3. How can soil health be increased?

2.1 Agroforestry and food forests

Before discussing soil health in more detail, the terms agroforestry and food forests will be introduced.

Agroforestry is a form of traditional land use combining trees and shrubs (and sometimes livestock) with agricultural crop [1]. The Food and Agriculture Organization of the United Nations (FAO) defined Agroforestry as a “dynamic, ecologically based, natural resource management system that, through the integration of trees on farms and in the agricultural landscape, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels” [2]. Agroforestry offers an important opportunity for farmers and communities to improve health, income but also food supply.

Food forests represent a form of agroforestry. Food forests are designed in multiple layers in contrast to monoculture land-use (Figure 1). The first and highest layer is the canopy, mostly nut and fruit trees or nitrogen-fixing trees [3]. The second layer of lower trees is mostly filled with fruit trees. The third and fourth layer are shrubs and herbs, mainly berries, fruits and nuts. Below that, the rhizosphere, the root layer, with e.g., carrots or potatoes can be found. The soil surface layer is the bottom layer, preventing any weeds to grow. It contains the bacteria and fungi with many functions including distribution of minerals and breaking down dead organic matter into reusable energy and minerals for the plants. The fungal layer also connects the roots of the trees and shrubs. The last and seventh layer is the vertical layer, with climbers such as grapes or vines, cutting across multiple layers.

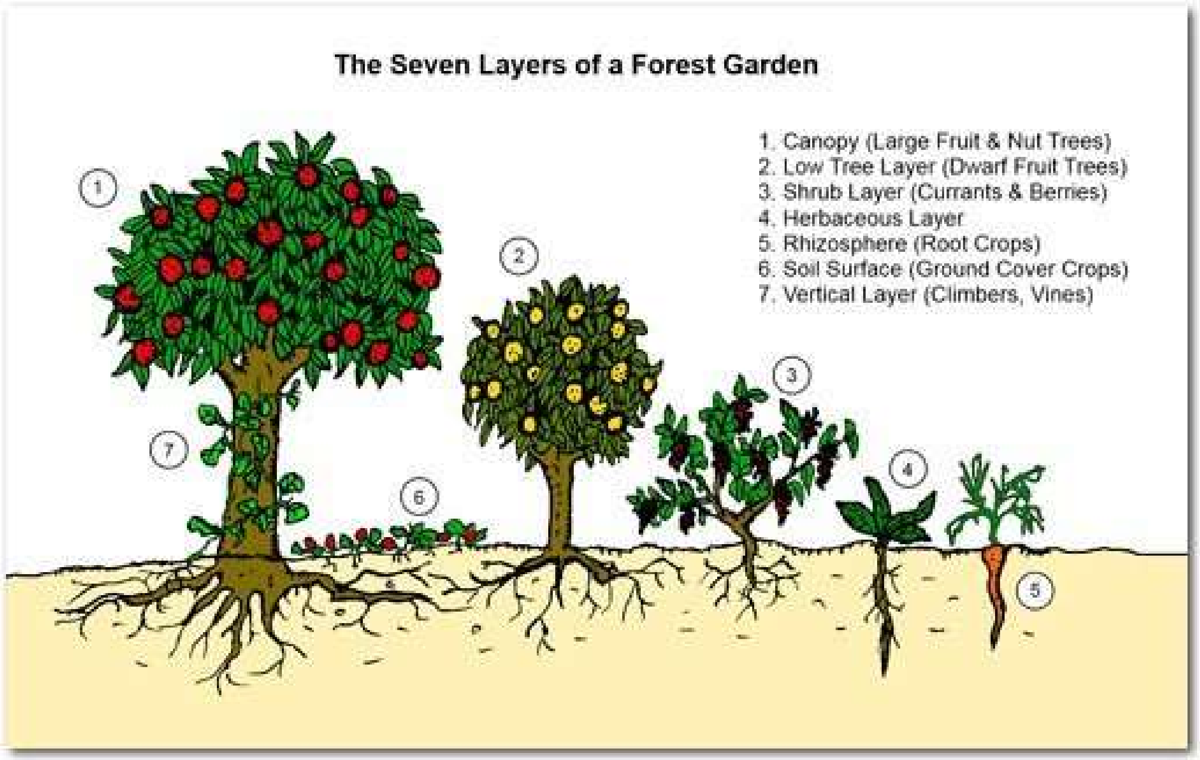

Figure 1 - The seven layers of Forest Gardens [4]

Another key characteristic of food forests is the approach to leave the soil untouched, and not disrupt it every year. This "no dig" approach leads to intact soil ecosystems with worms and other organisms not being disrupted [5]. Apart from that, the plants are not destroyed and keep growing after the harvest, which tends to create bigger yields of vegetables than tillage approaches [5].

In this research, the terms agroforestry and food forests are used synonymously.

2.2 Soil health

Good soil health is critically important for the development of a healthy ecosystem, as it is one of the most critical resources of sustainable ecosystems. Soil health has been defined as "the capacity of soil to function as a vital living system, within ecosystem and land-use boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and promote plant and animal health" [6]. Doran and Parkin [7] defined this as soil quality, and explicitly stated that animal health includes human health.

The terms soil health and soil quality are used synonymously for the purpose of this research paper.

2.3 Indicators for soil health

Soil health is very complex and has many chemical, biological, and physical indicators [8]. Whereas chemical and biological indicators can often only be evaluated in laboratories, physical indicators can easily be observed with visual assessment methods. Biological indicators often relate to soil biodiversity and soil biota [9] [10]. From physical indicators, much information about the arrangement and composition of the soil can be gained.

Bünemann et al. [9] concluded, that the most frequently used biological indicators are soil respiration and microbial biomass. Chemical indicators are more frequently used than biological, with total organic matter/carbon, pH-values, and available phosphorus being the more frequently mentioned indicators. Measurements of these indicators in laboratories can be very cost intensive. Sharma [8] conducted a case study for the chemical soil health, and analyzed samples for various parameters such as pH, electrical conductivity, organic carbon, and many more. Mulyono et al. [11] reported, that 4 chemical indicators can represent 83.6% of their datasets variability. Physical soil health indicators include water-holding capacity and soil depth, but also structural stability and texture. These factors play an important role in the assessment of soil quality [9]. Ball et al. [12] argued that soil structure is a generic indicator independent of soil type, with the exception of soils with high sandy contents due to their poorly developed structure.

Most of the physical indicators can be evaluated through visual assessment methods and low-cost sensor measurements. Most chemical and biological indicators require laboratory equipment and expensive sensors. In the following section, some frameworks and possible assessment methods are discussed.

2.4 Measurement approaches for soil health/quality

Whereas chemical and biological indicators require sensory equipment, physical properties can easily be assessed and measured with visual assessment methods. Increasing the number of considered soil health indicators, results in higher complexity in the assessment. As a consequence, also sensory measurement costs become exorbitant, and thus usually a minimum dataset is used. This dataset typically consists of 6 to 8 soil health indicators, which are derived from a larger indicator set [9]. This minimum dataset is used to evaluate the soil quality index (SQI), a score to classify the soil health in 5 classifications, from very good (SQI score of 1.00) to very low quality (SQI score of 0.00) [11].

Ball et al. [12] concluded that visual soil evaluation can be particularly valuable for detecting compaction and reveal changes in compaction, aeration, and waterlogging status of the soil. The Visual Evaluation of Soil Structure (VESS) and Visual Soil Assessment (VSA) methods are preliminary methods, providing a general understanding of soil health but may not provide a comprehensive analysis of soil fertility and other aspects of soil health. They require manual breakup of soil samples to compare them to photographs for a soil quality score. These methods require additional testing and measurements for a substantial assessment but are useful for initial soil evaluation. Vågen et al. [13] concluded that combining ground measurements with infrared spectroscopy and remote sensing imagery can lead to better soil health monitoring systems. Pádua et al. [14] presented an overview of unmanned aerial vehicles (UAVs) with cost-effective sensors, which can determine the water status and nutritional requirements of plants which can be attributed to the soil quality. A system for carbon storage monitoring, designed by MacDicken [15], utilizes satellite images for land-use changes and a software for calculating the minimum sample size/minimum dataset.

The use of new methodologies for biological processes (RNA sequencing or DNA) enhances soil health assessment, but most importantly, an accurate and cost-effective sensor system needs to be developed, to provide reliable estimates for several soil health indicators, as Karlen et al. [16] concluded. Bünemann et al. [9] concluded that future soil quality assessment can benefit from the combination of modern sensors with traditional visual assessment approaches. Through combining more empirical, qualitative indicators that can be easily assessed in the field and deliver immediate results with high-throughput soil analysis sensory equipment, interactive tools can be developed to facilitate communication between farmers and scientists and provide fast and inexpensive ways for farmers to design and cultivate their land more efficiently [16].

2.5 Influence of agroforestry on soil health

It is well known in the agroforestry community that agroforestry systems can improve the quality and health of soil and thus the ecosystem itself, providing sustainable intensification of food production and other benefits to humans and society. A meta-analysis by De Stefano and Jacobson [17] revealed that the soil organic carbon (SOC) stock increased by changing the land-use from less complex systems (agricultural systems) to higher complexity, such as agroforestry/forest. They measured a significant increase by up to 40% with a land-use change from agriculture to agroforestry. The opposite was found for a land-use change from forests to agroforestry. Here, the data revealed a significant decrease in SOC stocks of up to 26%. Similar effects were concluded by Dollinger and Jose [10]. They analyzed 28 relevant papers and concluded that agroforestry can enrich SOC stocks better than monocropping systems, so less complex systems. Furthermore, they discussed an improvement in soil nutrient availability and soil fertility due to the presence of trees, and enhanced soil microbial dynamics, which would positively influence soil health. Trees would also prevent nutrient losses, mostly occurring through erosion, leaching or runoff. Apart from these improvements, Muchane et al. [18] conducted a study in the humid and sub-humid tropics and measured that nitrogen (N) storage increased by 13 %, available N by 46 % and available phosphorus (P) by 11 % while soil pH increased by 2% under agroforestry compared to crop monocultures. Similar to De Stefano and Jacobson [17], and Dollinger and Jose [10], Muchane et al. [18] also found a significant increase of SOC stock by 21%. Sharma [8] agrees with above mentioned improvements, but also mentioned that agroforestry has the potential to reduce erosion and runoff, which are some of the threats introduced by intensive cultivation of crops and input of chemical fertilizers.

Agroforestry as a sustainable land-use practice shows solid evidence of improving soil health. There are some factors that need to be considered: Not every land-use change will improve soil quality, as mentioned by De Stefano and Jacobson [17]. Mulyono et al. [11] concluded that it is also relevant which design and which plants are included in the ecosystem. They found that agroforestry-based coffee with an intercropping system provided the best soil quality of their researched clusters. Conclusively, appropriate land, soil, and vegetation management is crucial for the best soil health improvement.

Some planting decisions and design aspects of food forest projects greatly depend on the soil quality. Different plants have different preferences for soil characteristics, such as moisture levels, compaction, pH, and nitrogen levels. All these factors can be influenced and improved by agroforestry practices. Using the “Plants For A Future” database [19], a farmer can enter his soil quality properties and get a list of suitable plants for his specific soil. The database is specifically designed to store information on plants with both edible and medicinal uses, making it a valuable resource for food forest farmers.

2.6 Interviews with food foresters about practices and motivations

2.6.1 Approach

To expand the background knowledge and gain further insights into the topic of food forests, interviews were conducted with individuals who have a food forest initiative. The aim was to understand motivations, focus, struggles, and challenges related to food forest building. Additionally, the interviews aimed to provide insights into what people are doing in practice and to discover the underlying motivations and methods behind community-oriented food forest initiatives.

For the interviews, I used a certain approach. I prepared and conducted semi-structured interviews. The interview questions covered topics like the interviewee's weekly schedule, their understanding of agroforestry, the crucial design features that shape a food forest, the maintenance of the food forest, the things they wish they had known before starting the project, the unique aspects of their food forest, the feasibility of relying solely on their food forest for food necessities, and indicators of the success of their food forest. The guiding questions can be found in Appendix 1.

The interviews were approved beforehand by the ethics committee of the EEMCS faculty of the University of Twente. I conducted the interviews together with another student doing his bachelor thesis. During or after the interviews, we would walk around the food forest projects to get a feel for the practices and motivations of the foresters. We audio-recorded the interviews for later evaluation and deleted the recordings after the analysis was complete.

In order to evaluate the interviews, I transcribed each interview and recorded the answers and quotes in an Excel spreadsheet. I then labeled each quote and answer with different topic labels. Afterwards, I grouped the various labels into categories. This allowed me to systematically analyze the responses and identify common themes. Through a process of grouping and categorizing the questions and answers, I was able to identify key results and insights. The bottom-up approach in Excel facilitated an organized and structured evaluation of the interviews, ensuring a comprehensive analysis of the data collected. The key results are presented in the next section.

2.6.2 Results

All of the food forest initiatives of the interviewees are based in the Netherlands, in the region around Enschede, Twente. Details of each interviewee can be found in Table 1.

Interviewee ID	Size of food forest	Age of food forest	Background/ Prior knowledge	Motivation
1	2x 0.33 ha	11 and 2 years old	Professional Designer and Educator for food forests	Educating people
2	0.74 ha	2 years (Dec 2020)	Courses in landscaping profession as self-taught	Increase soil health, biodiversity Social aspect, cultural value
3	25 ha	Start end of 2022	Degree in environmental science, Courses and internships	Economic reasons, sell harvest at market, started a nursery as well
4	0.74 ha	2 years (Dec 2020)	Online courses, YouTube videos, self-taught	Education, emotional value, “Gift to nature”
5	0.1 ha	1.5 years	Courses in food forest design	Increase biodiversity, Education

Table 1 - Details about interviewees

The analysis of the interviews revealed 5 main categories, why people and communities started a food forest. The category that was mentioned the most was the social value and aspect to such a project. The interviewees said that the community-oriented practice brought people together and thus the food forest also gave some cultural value. Another aspect was the emotional value and connection to the ecosystem. Some interviewees said that they love to spend time in nature and that their well-being increased tremendously. The third category was education and awareness. The concept of food forests has received increasing attention but there is not enough knowledge about the concept. Increasing education and awareness about food forests was the focus and goal of some of these projects, without targeting a specific group. The fourth category is increasing biodiversity, soil health and the ecosystem in general. In doing so, some projects aim to build a sustainable ecosystem for animals and humans. Interviewee 4 said: “I see this as a gift to nature”. This ideology also shows again the emotional connection with the forest. The last category was the economic perspective.

Especially interviewee 3 pointed this out. The goal of that project is to create a food forest farm and sell the harvest on local markets. This project started in winter 2022 and will also include a nursery for food forest plants, to cover the initial and running costs of the food forest.

Another topic the interview focused on is soil health and related challenges and characteristics. Healthy soil is really important for food forests and ecosystems in general, so measuring the quality is necessary in order to have a good foundation to build on. Whereas the projects with an economic motivation will send multiple samples to the laboratory to get a quantified analysis of the soil health and nutrients, most of the other projects only conducted visual assessment with 2 or 3 indicators. These include counting insects under stone slabs, looking for indicator plants such as stinging nettles, which grow on soils with high nitrogen content, and measuring if the soil is sour (acidic). Sending samples to laboratories is very expensive (200 €-300 € per sample) and oftentimes they measure in agricultural standards, where fertilizers are commonly used. This can affect the usefulness of the analysis of the soil.

Next to measuring and conducting soil health assessments, the improvement and preparation of soil is important. One of the geomorphological characteristics of the soil in the Netherlands is, that it oftentimes has a compaction layer at 30-40 cm depth. This is really important to know, because there is no scientific evidence of whether the roots can grow through this layer. If the compaction layer is too high and dominant, the compaction may need to be removed with a tractor or in other ways. To increase the organic matter and biomass of the soil, the usage of a lot of pioneer species (birch, willows, etc.) was suggested, as organic matter increases by 0.5% per year, and every 1% can hold 18l of water per m^3. Another option to prepare the soil for planting is laying out cardboard with cheap compost as weight, to kill roots and decompose the grass layer. An even better solution would be to use mulch and wood chips, but the price of them has increased too much in the last years.

2.7 State of the art

To improve the practice of soil health assessment, current systems and measurement practices have to be identified and analyzed. Through literature research and the interviews, 4 main measurement categories were identified: manual visual assessment, smartphone applications, laboratory measurements and sensor systems.

The visual assessments are simple and cheap observations on some soil heath indicators. These observations give indications on the general health of the soil and the ecosystem itself, but do not provide quantitative data. Apart from the measurement methods explained above from the interviews, there are also apps available, such as the Soilmentor app from vidacycle [20]. This app lets the user pick a soil test and guides them through the test. They can monitor the progress at every site over time and analyze patterns. This app focusses on biodiversity, so indicators such as earthworm counts and other biological indicators are relevant.

Another option for soil health analysis are laboratories. The food forest farmer has to take 20 samples, equally distributed over 1 ha, and combine them to one sample for that hectare. This sample is analyzed in the laboratory and the farmer gets quantitative data on his soil health. According to interviewee 3, these tests would cost around 400 € and only give an indication over the entire hectare, so the results cannot be interpreted on a smaller scale.

The last option is to use a sensor system to get soil health data. One of the available sensor systems is being developed by teralytic [21], a company that builds NPK (Nitrogen, Phosphorus, Potassium) sensor probes (Figure 2). These probes have 26 sensors separated over 3 depths, generating real-time data about soil moisture, NPK levels, respiration, air temperature, and many more. One probe cost between 1,200 € and 1,500 € depending on a 1 or 3 year subscription plan.

Figure 2 - NPK sensor probe by teralytic [21]

The company Libelium has developed a system called "Smart Agriculture Xtreme Sensor Node" [22]. This system features 19 sensors measuring different parameters related to weather conditions, light and radiation levels, soil morphology and other environmental parameters to improve crop quality production. Apart from that, Libelium offers multiple Plug&Sense IoT products, which have a wide range of use cases, from Air Quality Index calculation, or chemical leakage detection in rivers, to soil monitoring and plants health. Current prices of these systems need to be requested and are not publicly visible.

Another sensor system was developed by Goswami et al. [23] in their research project. This system focuses on developing a comprehensive soil probe, measuring everything from soil macronutrients (NPK) to soil moisture, pH, and soil humidity. The system includes a DHT11 sensor to get humidity data, a NodeMCU for data processing, an LCD display, pH sensor, and an optical transducer for macronutrient measurement. The data is sent to a database to be visually presented on a website, applying the concept of IoT. This system offers a cheap alternative, giving the user all relevant macro indicators of soil health.

To find suited plants for certain soil properties, there is only one relevant database for food forests, created and maintained by the charitable company Plants For A Future [19]. Their database consists of over 8000 plants for edible and medicinal uses. It is also possible to filter and search for plants for specific soil types, including soil type, pH-value, moisture levels, wind, and shade placements and much more.

2.8 Conclusion

Research and studies have shown that soil health is really important for healthy and vital ecosystems. Whereas some projects consider the assessment of soil quality, most smaller community-oriented projects have limited knowledge about the health of their soil. This finding through the interviews reconfirms the importance of soil health assessments discussed in the literature.

Current technologies and solutions are either too expensive and thus not practical, or they are designed to fit standard agricultural farming methods. Similarly, there are limited possibilities to find suitable plants for specific soil types. For improvement interventions, food forest farmers currently have to rely on multiple sources, like user forums or websites, to gain sufficient knowledge. This can be very time consuming.

Thus, it may be worthwhile to develop a more cost-effective system, that helps food foresters to get insight into soil health data, how it develops over time and across the space of the forest. Apart from that, more accurate planting and design decisions can be made using the gathered data. The following sections elaborate on possible methods and systems and show the finalizing and realizing processes of the most prominent system idea.

3 Ideation

In order to find solutions for the problems mentioned above, some ideas were developed and limitations and possibilities will be formulated. After this ideation phase, the most promising idea will be further refined and specified. After the interviews and background research, the following preliminary requirements were identified: easy to use, cost-effective, quantified soil health data and justified improvement interventions such as plants and other methods to improve soil health.

The first idea is a smartphone application that lets the user input data about the soil properties. This input only relies on visual assessment methods, so no sensory equipment is used. The advantage of this is that food forest farmers, who want to get quick and not as accurate results and improvement suggestions would not have to spend any money on sensor systems but can use VSA as low-cost evaluation method for soil health. The app could also use build-in sensors from the smartphone, such as GPS sensors, to get a spatial overview of the forest soil health and provide better and more useful information to the farmers. This idea also presents some challenges and limitations. Farmers need to have sufficient hardware in their smartphone, which nowadays is not a big problem, but still needs to be addressed. Furthermore, the data gathered can be inaccurate and thus leading to wrong interventions.

To tackle these challenges, the second idea consists of a website, which lets the user manually input data, similarly to idea 1. On top of the manually inputted data, the user will use a compact sensors system with some sensors to measure pH-values, moisture, and other relevant parameters of the soil quality more accurately. This would give the system a higher accuracy and also lead to better suggestions. This sensor is not placed in the soil for a longer time, but only during the assessment method, thus only one sensor system is needed. The challenge with this idea is, that the system might not be low-cost but rather cost-effective. The website gives the user room to see the data and planting suggestions.

The third idea is connected with the second idea, where a sensor system is connected with a website, so the farmer can manually input data about soil heath but will also receive accurate data from sensors. The key characteristic of this idea is, that the sensors stay in the soil and are not only used once the farmer wants soil data. The challenge here is that the farmer would need multiple sensors systems, thus being more expensive. Furthermore, soil health improves relatively slowly, making the placement of a permanent sensor only in a few projects suitable.

The second idea was the most promising idea due to its scalability and ability to address all requirements set before. The further refinement of this idea is presented in the following chapter.

4 Specification

This chapter will provide an in-depth look at the specifications of the system being developed for food foresters. The system is designed to measure soil health by using sensors to collect data on moisture levels and pH values, as well as allowing users to input visual assessments of soil health, based on the guidelines from the visual assessment techniques from the Visual Soil Assessment (VSA) guide published by the Food and Agriculture Organization of the United Nations (FAO) [24] and described by Ball et al. [12]. The system will then use this data to identify the best planting locations for different tree species. The chapter will cover the sensor specifications, visual assessment specifications, data collection and storage, data analysis and interpretation, user interface and user experience, and will conclude with a summary of how the specifications contribute to achieving the system's goals.

4.1 System Requirements

During the background research and initial interviews, some methods for soil health measurements and monitoring were identified. Although all these methods and systems are helpful in their own way, they are not really applicable for food forest projects. They are either too expensive for smaller community-oriented food forests, to not measure quantitative data, or are not representative on a small scale.

Thus, the system I am developing has to be:

- Cost-effective
- Applicable on a small scale
- Measure quantifiable soil health properties, such as pH levels and moisture

All of these system requirements will be assessed and analyzed during the user evaluation of the prototype.

4.2 Sensors

The system uses an ESP32 microcontroller with a connected GPS module to collect geolocation specific sensor data. This microcontroller was chosen because of its cost-effectiveness, due to already build-in Bluetooth and Wi-Fi modules. The ESP32 is paired with a pH sensor and a moisture sensor to measure the soil's acidity and water content. These sensors have a measurement range of pH 0-14 and 0-100% respectively, and an accuracy of +/- 0.1 pH and +/- 2% respectively. The sensor data is transmitted to a MongoDB database for storage and further analysis.

4.3 Visual Assessment

Visual assessments of soil health will be conducted using guidelines from the Visual Soil Assessment (VSA) of soil quality under cropping, by Graham Shepherd and the UN [24]. The assessment criteria include soil structure, color, porosity, earthworm count, tillage pan, the degree of soil erosion and clod development and the number and color of soil mottles. All these parameters will be assessed with a number between 0 and 2, representing a poor to good condition, respectively. The final soil score is calculated by multiplying the parameters with weighting between 1 and 3 and adding them for the final score (see the score card in Appendix 2). Users will input their visual assessments through a web interface, which was programmed using HTML, CSS, and JavaScript. These assessments will be sent to a Node.js backend server and stored in the MongoDB database along with the sensor data.

4.4 Data collection and storage

The sensor and visual assessment data will be collected by the ESP32 microcontroller and the user input on the web interface. The data will be transmitted to a Node.js backend server, where it will be processed and then stored in a MongoDB database. The data will be stored in JSON format, with the ability to handle large amounts of data. Security measures will be implemented to ensure that the data is protected and accessible only to authorized users.

4.5 Data analysis and interpretation

The data collected by the sensors and visual assessments will be analyzed and interpreted to identify suitable planting locations for different tree species. A dashboard on the web interface will allow users to choose specific parameters to view and display them on a map using the Google Maps API. Users can click on an image of an apple tree to see the suitability of planting that tree in a specific location. Information windows on the map will provide an overview of all parameters for a given data location.

4.6 User interface and experience (UI & UX)

The system's user interface is designed to be easy to use, have a modern and clean design, and provides a clear visualization of the data using rectangles on the Google Maps API. The web interface has a dashboard page where users can view the sensor and visual assessment data on a map. Users can interact with the map by clicking on different locations to see the data for that specific location.

The design of the interface is optimized for data visualization to make it easy for users to understand the information.

4.7 System architecture and layout

To better understand the system architecture and dataflow, Figure 3 shows a schematic representation of all the components in the system. The user interacts with both the sensors and the web interface, to enter the gathered data. This data will be transmitted to either the backend server and to the database or, in case of the sensors, directly post the data to the database. To display the data to the user the backend server fetches all existing data points and sends them to the web interface, where the user can access his gathered soil health data.

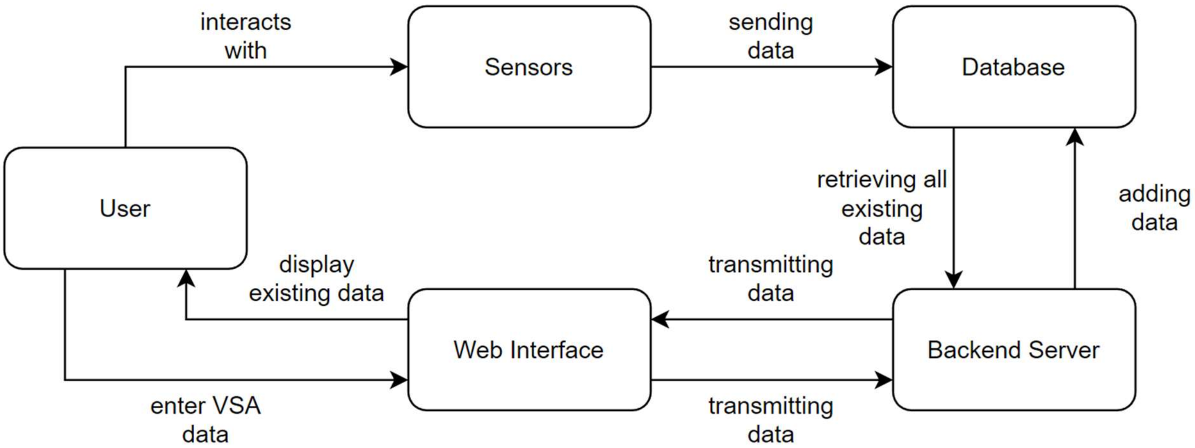

Figure 3 - Schematic of the system architecture

4.8 Conclusion

The system's specifications include the use of an ESP32 microcontroller with a GPS sensor, a pH sensor, a moisture sensor, and a web interface for visual assessments. The sensor and visual assessment data is collected, transmitted, stored, and analyzed to identify suitable planting locations for different tree species. The user interface is designed to be easy to use and provides a clear visualization of the data, with a dashboard that allows users to interact with the data on a map. The system's specifications are designed to achieve the goal of providing accurate and reliable soil health information to food foresters to help them determine the best planting locations for different tree species.

5 Realization / Implementation

This chapter covers the process of implementing the system developed for food foresters. The chapter will detail the hardware and software components used, the design and implementation of the MongoDB database, the creation and implementation of the web interface, the design and implementation of the data visualization, and testing and debugging of the system.

5.1 Hardware implementation

The hardware implementation of the system includes an ESP32 microcontroller with an integrated GPS module, a pH sensor, a moisture sensor, and a display to show the data and the system's status. A button and a green and red LED are implemented to start the measurement and give the user feedback about the process of the system. The schematics can be seen in Figure 4.

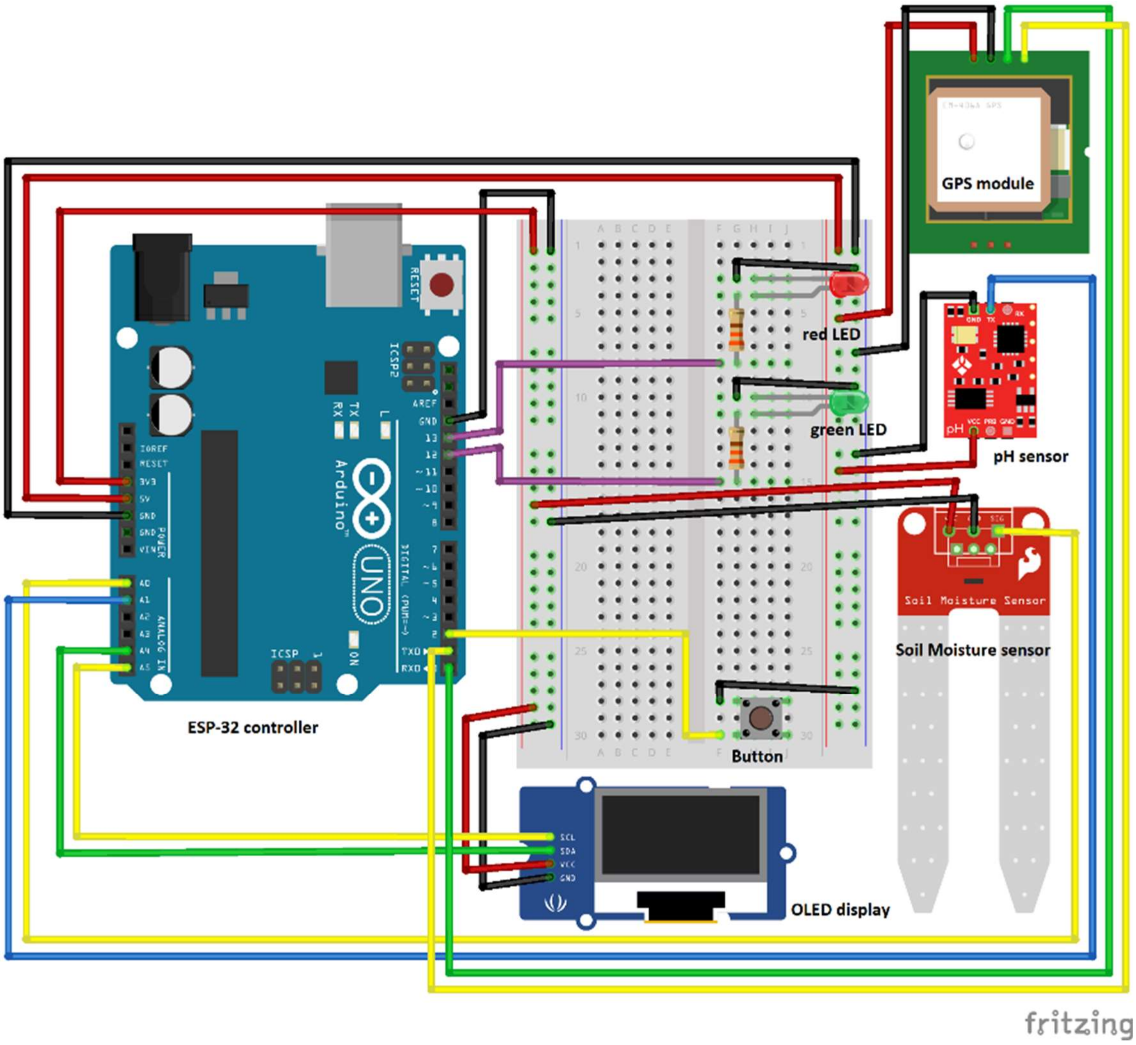

Figure 4 - Schematics of the hardware connections (made with Fritzing)

In Figure 5, the hardware components can be seen, which are connected on a breadboard. The power supply for the ESP32 is a powerbank with a 5V / 2.1A output.

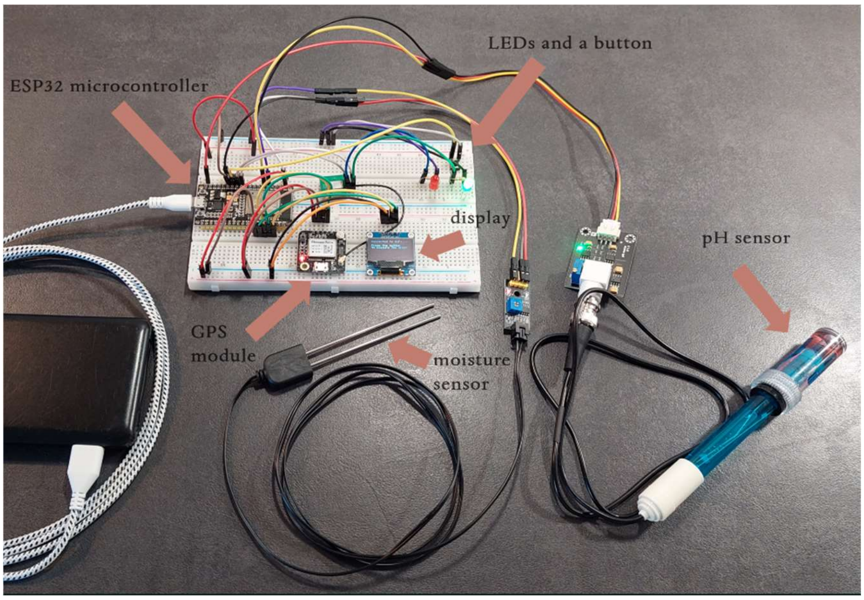

Figure 5 - Sensor connections on a breadboard

5.1.1 ESP32 microcontroller

The ESP32 microcontroller has a build in Bluetooth chip and Wi-Fi module, and thus there is no need for extra connection modules in the prototype. These controllers costs approximately 10 € (as of 01/2023) and this prototype used one from AZDelivery.

The integrated Wi-Fi module was used to send the measured data to the MongoDB database. The data was sent as a JSON document using a HTTP POST statement. Apart from the sensor values and GPS location, the date was also transmitted for monitoring.

5.1.2 GPS Sensor

The GPS sensor is a GT-U7 GPS Module from Seamuing. It costs approximately 15 € (as of 01/2023). The module outputs multiple NMEA sentences, but for this system I only decoded the GPRMC and GPGGA messages. This is what a GPRMC message looks like (near Orlando, USA / 28.536390°N, 81.017560°W):

$GPRMC,001225,A,2832.1834,N,08101.0536,W,12,25,251211,1.2,E,A*03

To encode these messages, the TinyGPSPlus library was used and a SoftwareSerial on the Tx and Rx pins to read the data from the sensor.

5.1.3 OLED Display

The display is the 0.96 inch OLED SSD1306 Display from AZDelivery. This display has 128 x 64 pixels and costs approximately 7-8 € (as of 01/2023). To use the display, the libraries Adafruit_GFX and Adafruit_SSD1306 have to be included in the project.

The aim of the display is to give the user feedback of what the system is currently doing and to display instructions for the user.

5.1.4 Moisture Sensor

The moisture sensor is from AZDelivery and costs approximately 6 € (as of 01/2023). The sensor simply works by inserting it into the soil and measuring the output voltage of the sensor. The voltage is translated to a bit representation between 0 and 1023. For the calibration, two known reference values have to be selected. For this prototype, The dry value was determined by holding the senor in the air, thus having no moisture reading. The output averaged out at 780.72. For the wet value, I put the sensor in water, thus having 100% moisture. Here, the output was 0. Using the map function, the measured value can be mapped in the range between 0 and 100%. After the mapping, the minimum and maximum must be filtered using two if statements. A code snippet can be seen in Figure 6.

```
// calculate the moisture percentage using the calibration curve
moisturePercentage = map(moisture, wetValue, dryValue, 0, 100);
// limit the moisture percentage to a maximum of 100
if (moisturePercentage > 100.00) {
  moisturePercentage = 100.00;
}
// limit the moisture percentage to a minimum of 0
if (moisturePercentage < 0.00) {
  moisturePercentage = 0.00;
}
```

Figure 6 - Code snippet from the moisture sensor calibration

5.1.5 pH Sensor

The pH sensor is from VBESTLIFE and costs approximately 46€ (as of 01/2023). This module is a combination of a pH electrode with a BNC socket to connect to the ESP32.

To calibrate the sensor, two calibration liquids were used with a pH of 4.01 and 7.01. Then the output voltage was analyzed for both liquids and a linear function was determined, which can be seen in Figure 7:

```
float calibrated_ph_value(float voltage)
{
  // calculate the pH value from the voltage
  return (7 + (voltage - 1) * 3);
}
```

Figure 7 - Calibration of the pH sensor

Similarly, to the moisture sensor, the calculated pH value was filtered to be in the range of pH 0-14.

5.1.6 Testing

After every sensor was calibrated and implemented in the prototype, the system flow had to be tested. This was done by following the steps below from Figure 8 - Figure 11:

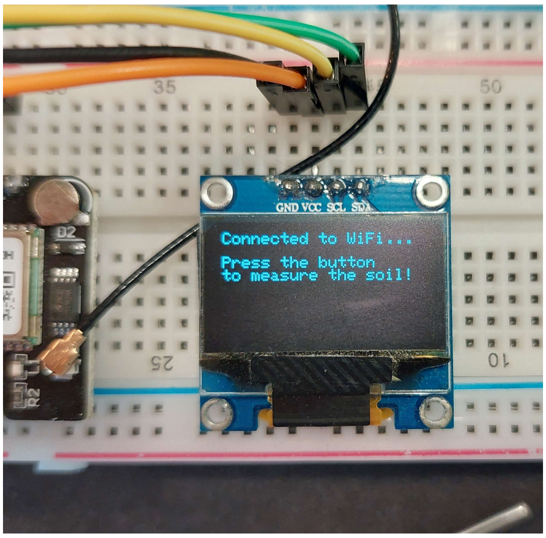

Figure 8 - Testing process part 1

1. Connecting the system to Wi-Fi and prepare sensors using provided guide

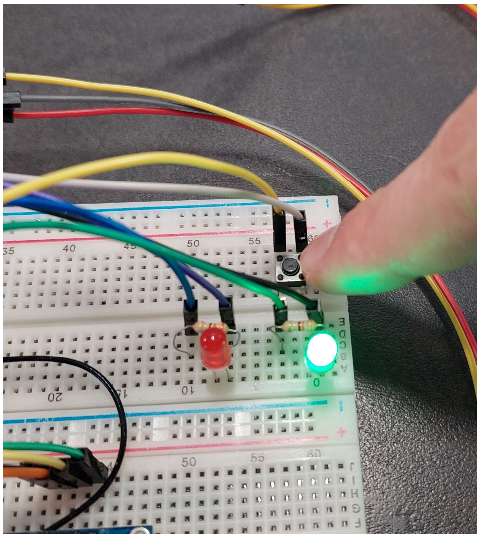

Figure 9 - Testing process part 2

2. Press button to start measuring

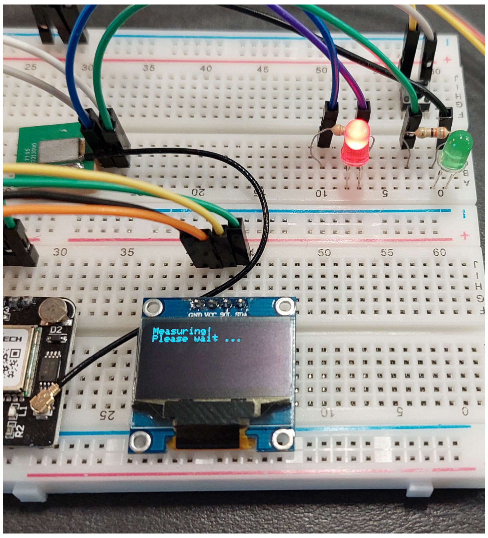

Figure 10 - Testing process part 3

3. LED turns red and the system measures for 15 seconds

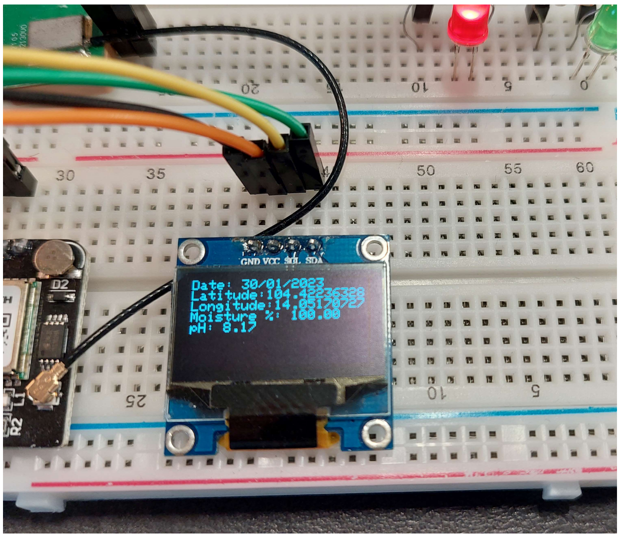

Figure 11 - Testing process part 4

4. Display will show the measured data to the user and sends it to the database

5.1.7 Costs

As one of the system requirements was to develop a cost-effective monitoring system, the cost of the sensors have to be analyzed.

For this prototype setup, the combined sensor and microcontroller cost was around 85 €. This price does not include the wires and breadboard, which can be estimated to cost a maximum of 10 €.

For a final system, the cost for a robust and waterproof casing and additional software costs must be considered. Due to these irregular and individual costs, a total cost for this system is difficult to predict, but the hardware components of this prototype can be estimated at around 100 €. This is significantly lower that the prices for some methods presented in section 2.7, which amounted to 400 € to 1500 €.

These steps conclude the hardware side of the prototype. The sensors were calibrated and used to measure quantifiable soil health parameters. After sending the data to the database, the user can focus on the visual soil assessment.

5.2 Software implementation

Apart from the hardware and sensor-side, the system also required a user interface to let the user input data and monitor the soil health. A website was built as the user interface. To send the data to a database and get the existing data, a backend server was developed to process the data and communication between frontend and database.

5.2.1 Frontend - Web interface implementation

The frontend implementation of the system was built using HTML, CSS, and JavaScript. The visual interface was designed to be user-friendly and visually appealing, incorporating design elements such as color palettes and typography to improve the overall user experience. The frontend also communicates with the backend to retrieve and display data, and it allows the user to input visual assessments and view the data on a map.

A detailed schematic of the data communication structure and connections between parts can be seen in Figure 12. The web interface is split into three subsections, one for the data input of the visual assessments, and another subsection operates as a dashboard where, apart from the collected data, also the planting advise is generated and displayed. The web interface connects though the backend server to the database.

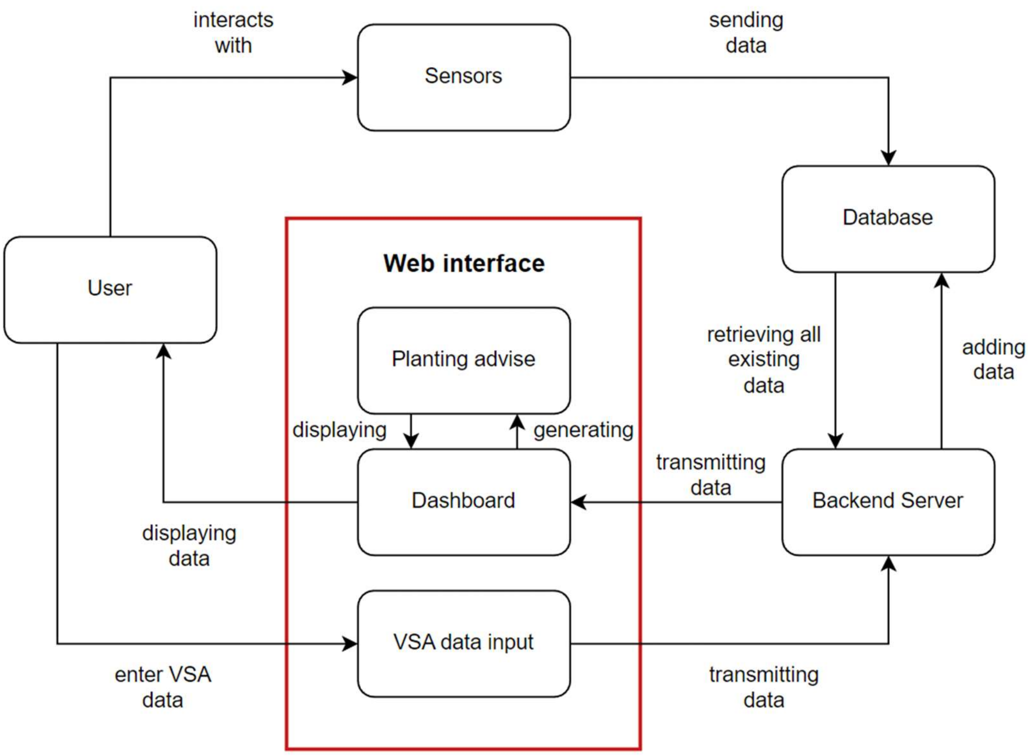

Figure 12 - Schematic of the flow of data between each component

The color palette of the website can be seen in Figure 13. This color palette was chosen to fit the systems background in agroforestry, and food forest projects.

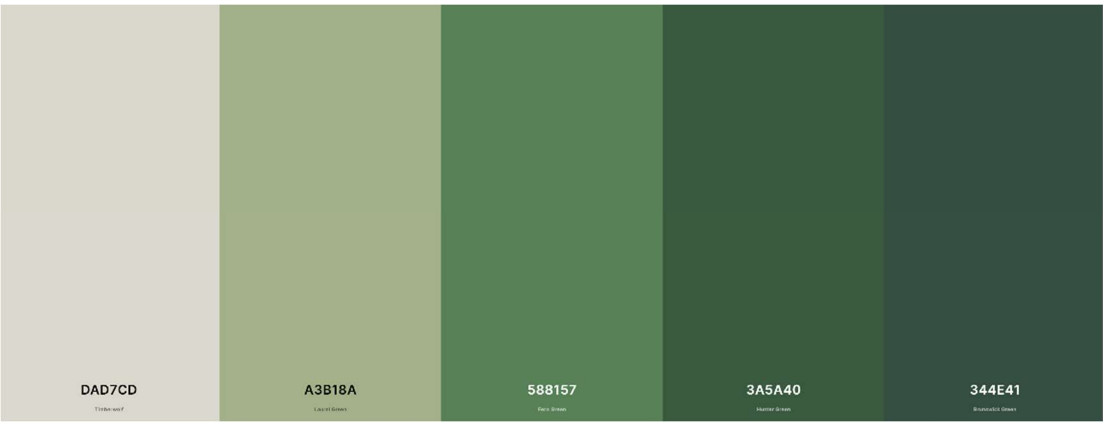

Figure 13 - Color palette of the system with the respective hex code

For the typography, the popular Arial, Helvetica, sans-serif font family was chosen due to its wide availability and its clean and modern appearance.

The website consists of multiple pages and features provide a seamless and intuitive experience for the user, making it easy to access the information they need.

The first page the user will see when loading the website is the login page. It provides secure access to the website, allowing the user to access their personal data and assessments. The login page can be seen in Figure 14.

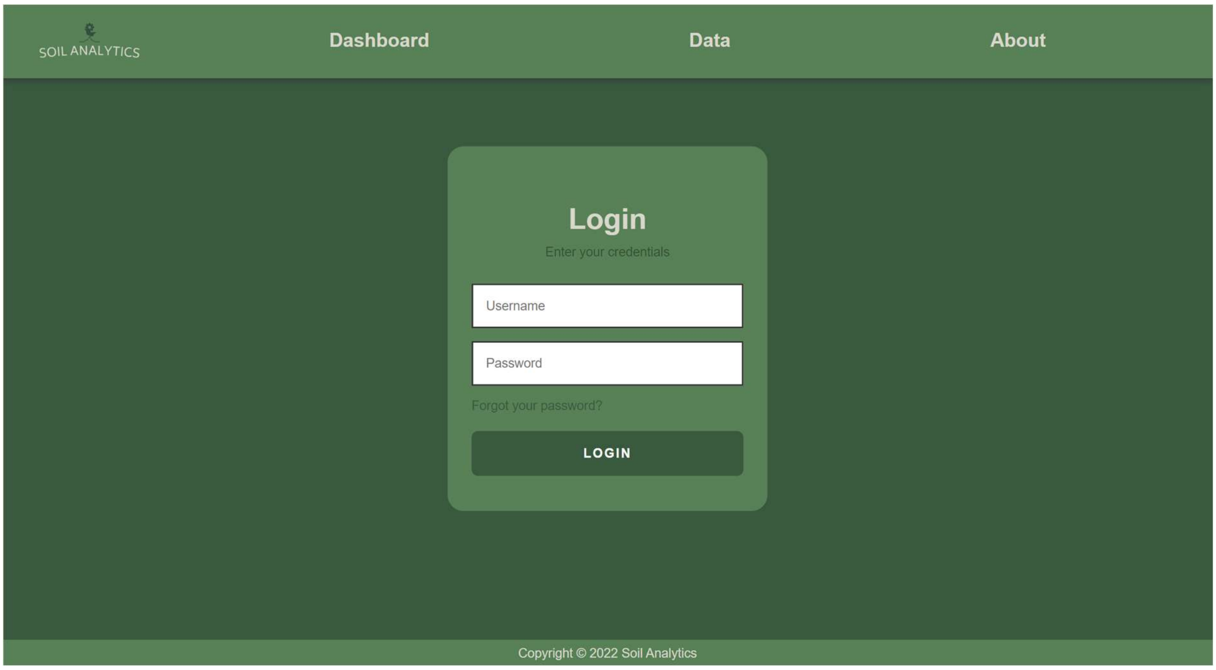

Figure 14 - Login page of the website

When the login was successful, the user can go to his dashboard or the data input page for the visual assessments. An overview of the data page is shown in Figure 15. To provide a simple and understandable interface, some instructions are displayed at the top of the page. The user is asked to select the location where he took the sample for the visual assessment by clicking on the map and creating a marker. For simplicity, the user can also click the "Get Location" button. This will create a marker on the map for him based on the location of the device he is using. If this is not available, the system will ask the user to manually input the location.

Next, the user must fill out the form on the right side of the page. Each measured indicator has a dropdown menu, from which the user can select "Good, Moderate, or Poor", based on the assessment he did in the food forest. For earthworm counts, the user must type in the number he counted.

After the data has been selected and inserted, the user clicks submit. This will create a JSON document which is sent to the backend server. Apart from the latitude and longitude and the selected data, also the date is inserted in the JSON document. Using JavaScript, the website sends a POST request to the backend server API with the route .../api/submit.

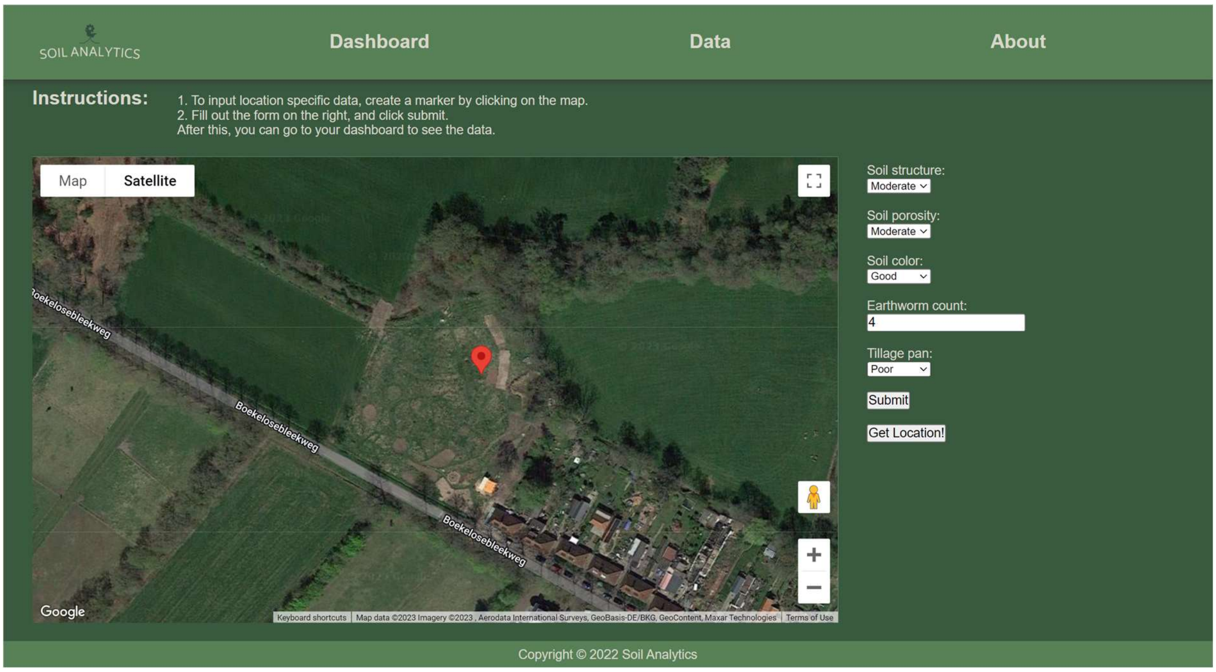

Figure 15 - Data input page of the website

When the user inserted all his visual assessment data, he can click on the dashboard button in the header menu. This will load the dashboard page as it can be seen in Figure 16.

At the initial loading of the page, the website fetches every data entry from the backend server using a HTTP GET request on the API route …/api/data. On this dashboard page, the user can select a parameter to be visualized, such as “Moisture %”, “pH Value”, or “Earthworm Count”. This will create a square for each location where data is available for the selected parameter.

Next, the user can use the date slider under the parameter list. This slider uses the oldest and most recent dates in the database to set the minimum and maximum dates, respectively. When the user interacts with the slider, the website checks if there is data available for this date and the selected parameter and draws squares for each possible data location.

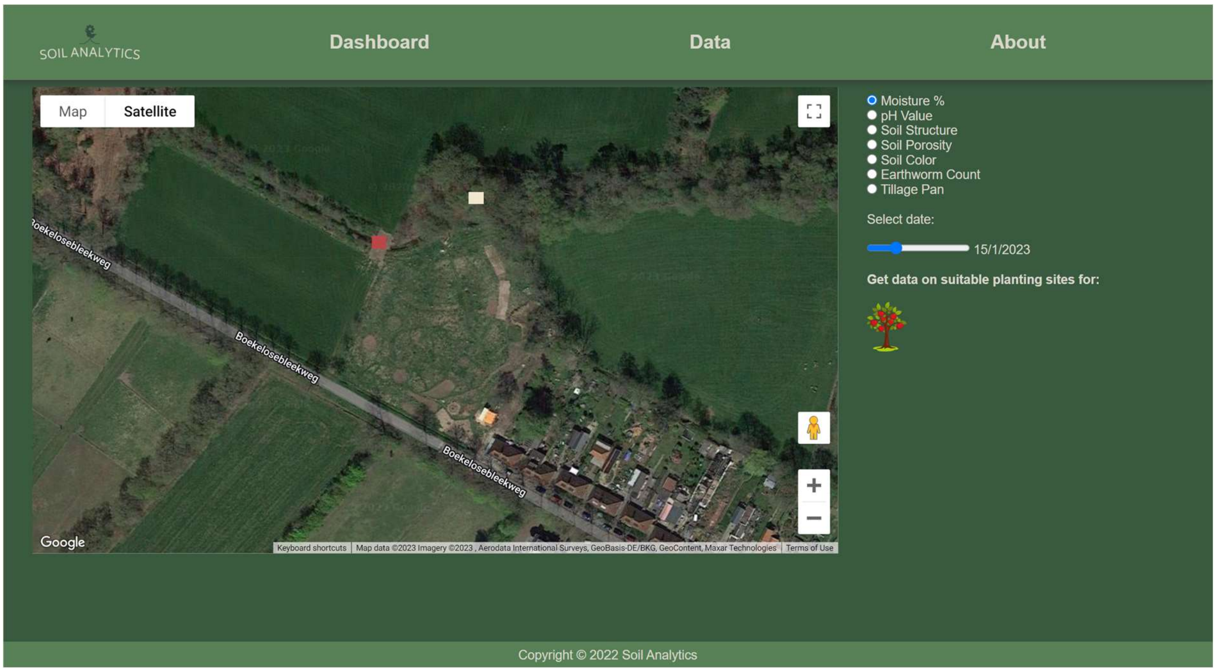

Figure 16 - Dashboard page of the website

To give the user a good and insightful data representation, the system is using choropleth maps. Choropleth maps are a type of geographic data visualization that use shading or color coding to represent the quantity of data being displayed on a particular region. It draws equal squares using the google.maps.Rectangle function. The squares are color-coded to show the data value for that location, with different colors representing different ranges of values. To view more detailed information about a specific data location, the user can click on the square, which will open an info window displaying the data values for that location (Figure 17). The user can also interact with the map by panning and zooming to view different areas, as well as switching between different data locations to compare values across different sample points.

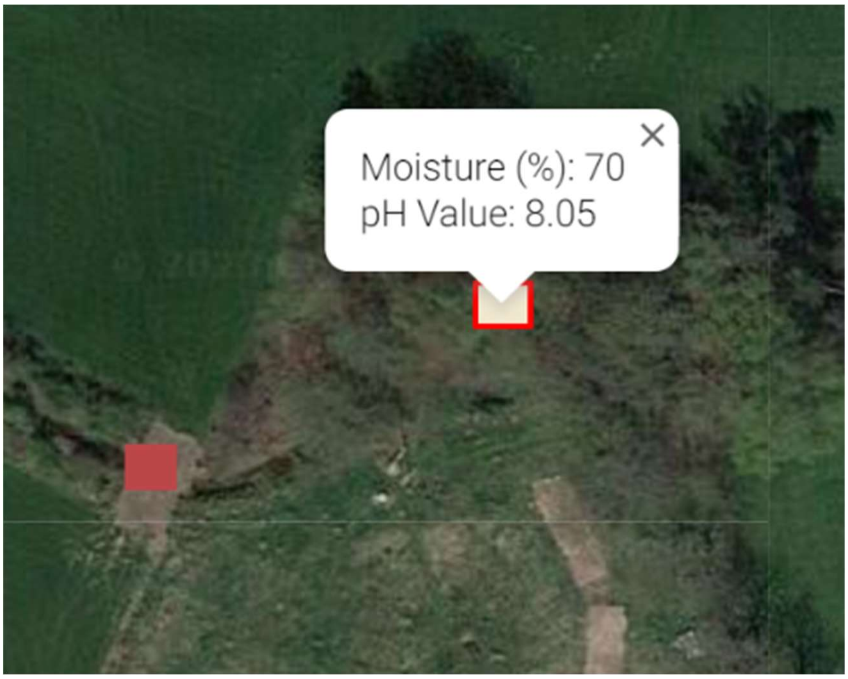

Figure 17 - Detailed data for each data location

Another feature of the system is to give suitable planting advises to the user. For this, the user can select a plant from a list of typical plants for food forests. For this prototype only advise for apple trees was implemented.

When the user selected a plant and clicks on the image, the website will categorize the suitability of this plant for each available data location. For this prototype only the pH values were used as parameter for the advice. Based on the evaluated suitability, the website displays squares with different colors, indicating the pH value and suitability of the plant. An example output of this feature can be seen in Figure 18.

Figure 18 - Planting advise for apple trees

Similarly, to the previous information window, the user can again click on each square and a more detailed description will be displayed. The yellow squares represent a too acidic soil with a pH lower than 6, green is perfect for apple trees with a pH between 6 and 7 [25], light blue is slightly too alkaline for apple trees and dark blue is too alkaline for apple trees. An example of a too acidic location can be seen in Figure 19.

Figure 19 - Detailed description of each data location

The "About" page, shown in the header of the website, would contain details about the project and background of this website. Since the project was not deployed and made publicly available, this page was not implemented.

5.2.2 Backend

The backend implementation of the system was built using Node.js, a server-side JavaScript platform, and the Express framework. The implementation consists of a REST API that communicates with a MongoDB database using the MongoDB Node.js driver.

The Express framework provides a set of features for building web applications and the Node.js environment provides a runtime for executing JavaScript code on the server side. The backend code is responsible for receiving HTTP requests and handling the communication with the database.

The REST API has two main endpoints, one for submitting data to the database and another for retrieving data from the database. The data is sent and received in the form of JSON objects.

The communication with the MongoDB database is handled using the MongoDB Node.js driver. The driver allows connecting to a MongoDB database using the MongoDB Atlas cluster URL, which consists of a username and password for authentication and the cluster name.

The application uses the environment variables for storing the configuration values, to ensure data protection and security for vulnerable data. The submit endpoint receives a POST request with a JSON object in the request body, which is then inserted into the MongoDB collection. The get endpoint retrieves all the documents from the MongoDB collection and sends them back in the response. The methods can be seen in Figure 20.

```
app.post('/api/submit', (req, res) => {
    mongodb.MongoClient.connect(uri, (error, client) => {···
    });
});

app.get('/api/data', (req, res) => {
    mongodb.MongoClient.connect(uri, (error, client) => {···
    });
});
```

Figure 20 - Code snippet from backend with post and get methods with endpoint /api/...

5.3 Database implementation

The database is a crucial component of the system and plays an important role in storing and managing the data collected by the sensors and the visual assessments. For this system, the MongoDB database was chosen due to its scalability, flexibility, and ability to handle large amounts of data. The data collected is transmitted to a Node.js backend server, which then posts the data to the MongoDB database. The data is stored in a structured format, allowing for easy retrieval and analysis of the data. An example of the stored data can be seen in Figure 21. The MongoDB database also provides robust security features to ensure the data is protected and can only be accessed by authorized users. Additionally, the database was designed to support future expansion and the addition of new features to the system, making it a flexible and scalable solution for the system's data storage.

```
_id: ObjectId('63c74dafa68ed2b87e0ccfa0')
latitude: 52.21205950579433
longitude: 6.797298000210807
moisturePercentage: 70
pHValue: 8.05
date: "15/01/2023"
```

```
_id: ObjectId('63c79b115eb039f7b8cbb2e5')
soilStructure: 1
soilPorosity: 2
soilColor: 2
soilMottles: 0
earthwormCount: 5
tillagePan: 0
date: "18/01/2023"
latitude: 52.211862914470686
longitude: 6.797649496063016
```


Figure 21 - Data stored in the MongoDB database

5.4 Conclusion

The implementation of the system was a complex process that involved integrating hardware and software components and connecting multiple different programming languages into one working prototype.

The system was calibrated and can provide reliable information to food foresters about soil moisture and pH values. For the visual assessments, the user can use the website interface to input measurement data and monitor and analyze the soil health.

For the planting advise, the system has a feature to categorize the suitability of a selected plant on each available data location. This is currently only determined on the pH value and must be further developed to be more accurate.

6 Evaluation

This evaluation chapter will present the approach and results of the user evaluation. The goal of this evaluation was to gather feedback from the users on the feasibility and usability of the prototype, as well as to identify any potential improvements or modifications that could be made.

6.1 Approach

For the evaluation, I used a certain approach. I prepared and conducted semi structured interviews in combination with observations during prototype testing. The guiding questions were related to general impression, usability, accuracy, improvements, challenges, and the overall value. The evaluations were planned to happen in the forest and to observe the interviewee using the prototype. Due to scheduling, season and other reasons, the evaluations were more theoretical in practice. Instead of going in the forest and conducting some visual assessments and testing the prototype, the interviewees only interacted with the web interface and sensors, without measuring real data about soil health.

The questionnaire and procedure plan of the evaluation can be found in Appendix 3. The interviews were approved beforehand by the ethics committee of the EEMCS faculty of the University of Twente. I audio-recorded the interviews for later evaluation and deleted the recordings after the analysis was complete.

In order to evaluate the interviews, I used the same bottom-up analysis as for the initial interviews. I transcribed the interviews, labeled the quotes and answers of the interviewees, grouped the labels for topics and themes. The detailed description of the analysis approach can be seen in section 2.6.1. The key results are presented in the next section.

6.2 Results

All user evaluation were conducted with the same food forest farmers I interviewed at the start of this project. Details of each interviewee can be found in Table 2.

Interviewee ID	Size of food forest	Age of food forest	Background/ Prior knowledge	Motivation
1	2x 0.33 ha	11 and 2 years old	Professional Designer and Educator for food forests	Educating people
2	0.74 ha	2 years (Dec 2020)	Courses in landscaping self-taught	Increase soil health, biodiversity Social aspect, cultural value
3	25 ha	Start end of 2022	Degree in environmental science, Courses and internships	Economic reasons, sell harvest at market, started a nursery as well
4	0.74 ha	2 years (Dec 2020)	Online courses, YouTube videos, self-taught	Education, emotional value,

Table 2 - Details of interviewees for the evaluation

The general impression from the interviews was positive, with everyone expressing their appreciation for the prototype and the website.

Regarding the accuracy of the system, interviewee 3 mentioned that the prototype does not allow to input a depth in which the sample was taken, and that the layers below the topsoil, so below 20-40cm are more important when working with food forests and trees in general. Interviewee 1 disagreed with this statement, saying that in the lower layers are only anaerobic microbes, and you need the aerobic soil like from the top layer, because it indicates much more about the soil health then the lower layers. But apart from this discussion, interviewee 1 pointed out that the system currently cannot give accurate planting advice, when only considering the pH values. There are many more factors and parameters to be evaluated before giving such advice.

The interviewees also mentioned some challenges and limitations the prototype might have. The challenge every interviewee mentioned was that there is currently no casing for the hardware components and that it needs to be a very robust and waterproof casing, as it can fall into water, mud, or get damaged by some other farming equipment. Another challenge was that the Google Maps images in the web interface might be outdated in some areas, so that the user might have a difficult time to identify the location where he took a sample. interviewee 2 and 3 also mentioned that this system required a lot of discipline from the user, as taking the samples in multiple locations can be exhausting and annoying for the user. Since there is no reminder system integrated, the user might also forget to take regular measurements, so a reminder system was suggested by the interviewees to keep the user engaged.

During the interview, the users were also asked to mention additional parameters and sensors they would want in such a system. Interviewee 1 pointed out that in his opinion, most relevant parameters are already included and that too much data and parameters will scare the users off. So, simplicity is key. The other interviewees were interested on some other parameters, e.g., a groundwater level sensor, which determines the depth of the ground water during the year. If the water is too high in winter, the roots of the trees can start rotting and for some trees this is less of a problem, but for nut trees e.g., this can be very difficult. Other sensors mentioned were an NPK-sensor, measuring nitrogen, phosphorus, and potassium in the soil, an EC (electrical conductivity) sensor, measuring the electrical conductivity of the soil, and is often used to measure the nutrient content in a solution, and a temperature sensor.

The interviewees also mentioned some features they would like to see in a next version of this prototype. A comment box was mentioned, to let the user input additional information and observations for each data location. The mentioned reminder system or a scheduling assistant was also a requested feature, to remind the user to take regular measurements and keep them engaged. Interviewee 3 also pointed out that some additional visualizations would increase the value of the prototype. An example of the visualization type mentioned can be seen in Figure 22, where instead of individual squares, a map is dynamically filled out with the appropriate color of one or more parameters.

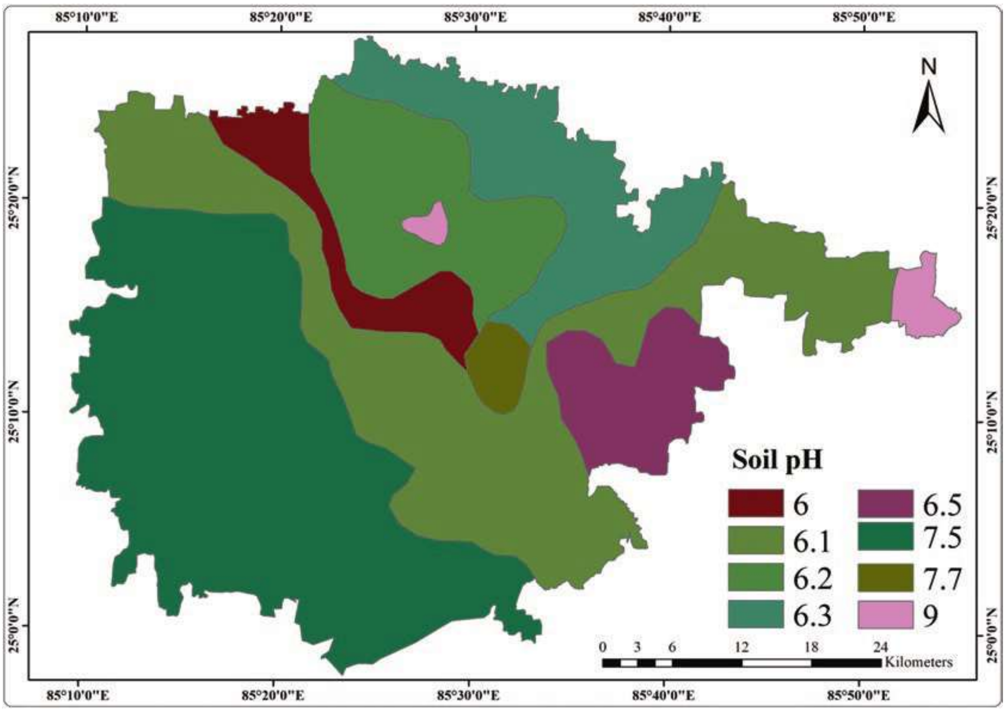

Figure 22 - Soil pH map visualization [26]

Apart from all these topics, the system requirements set in the specification were also analyzed. For this, three quotes were particularly interesting, and they showed that the set requirements of the system were met.

"Decision-maker, money-saver and motivation-saver" [Interviewee 4]

This interviewee highlighted that the prototype was seen as a good and cost-effective alternative to current methods.

"The price of sending 1 sample of 1 ha to the lab costs 400€, and only gives

an indication over the entire ha, so this device would be good and cheaper" [Interviewee 3]

With this, the interviewee pointed out that the prototype could be used on a small scale, unlike laboratory measurements which give an indication over 1 hectare.

"Very valuable for newer projects in the first 10 years" [Interviewee 2]

This quote is not directly related to the system requirements but is still important to mention. The user indicated that in older food forests, the soil health has improved so much that the system would not detect any major changes in soil health, and thus the need for such system would be negligible.

6.3 Conclusion

In conclusion, the evaluation of the prototype and the website showed that the system met the set requirements and received positive feedback from the food forest farmers. The interviews also provided insights into areas for improvement and additional features that could be added in future versions to enhance the user experience.

Some additional sensors were mentioned, which could be added to a next version of this system after evaluating if the cost-effectiveness is still achievable.

7 Discussion & Future Work

This chapter aims to reflect on the results and limitations of the study, and to propose ideas for future development.

The evaluation of the prototype through interviews with the food forest farmers showed that the prototype met the set requirements, including the classification of the prototype as a cost-effective alternative to current methods and the ability to use the prototype on a small scale. The users also mentioned some improvements and wishes such as a comment box for additional information and observations, a reminder system to remind the user to take regular measurements, and additional sensors. However, some limitations of the prototype were also pointed out, such as a missing casing and the actuality of the satellite imagery. This highlights the need for further development and research into these key limitations.

The results of this study suggest that the prototype has the potential to be a useful tool for food forest farmers to monitor the soil health of their food forests. However, there is also room for further improvement and development, including the integration of additional sensors, improvement of the user interface, and considering the informative value of different measurement depth on the soil health in food forests.

Future work on this prototype could include the integration of additional sensors, such as an EC sensor, temperature sensor, and groundwater level sensor, to provide a more comprehensive assessment of soil health. Additionally, the development of a mobile application for the prototype could make it easier for the farmers to access the data and analysis. Another area of improvement could be the implementation of machine learning algorithms to analyze the data and provide more in-depth analysis and recommendations.

In order to give the user valuable suggestions for suitable planting locations on a selected plant, a database could be used to get all the needed information about the soil health parameters for the specific plant. One of the largest available databases is “Plants For A Future” [19], the largest free database for suitable plants for every soil type. This database has over 8000 plants and specific information about possible hazards, edible and medicinal uses, but also cultivation details.

In conclusion, this project provides a solid foundation for further development and improvement of a cost-effective soil health monitoring system for food forests. The future work will aim to address the limitations of the prototype, to make it a more useful, valuable, and accessible tool for food forest farmers.

7.1 Limitations

One of the major limitations faced during the research was the technical constraints of the sensors and software used in the prototypes. The accuracy of the sensors and the precision of the data collected were also limited by the cost of the sensors and the complexity of the software. The limited budget for the project also meant that additional features, such as the integration of additional sensors, were not feasible. Additionally, I am not an expert in the various programming languages used, which may have impacted the efficiency and functionality of the developed prototype. For data security reasons, the code for the prototype is also not available for deployment. This hinders the practical implementation of the solution and limits its potential impact.

Another limitation faced during the research was the limited sample size of the interviews used to evaluate the prototype. The small sample size of the interviews may not fully represent the views of the food forest farmers, which could have affected the results. All interviewees came from the same region in the Netherlands, which also may indicate that the results are location-specific and may not hold true for other regions with different climate and soil conditions.

8 Conclusion

In conclusion, this bachelor thesis project aimed to develop a cost-effective tool for measuring and monitoring soil health in food forests and answer the research question:

"How can a soil health monitoring system be designed for food forest projects to measure and monitor soil health and give suitable planting advises?"

Background research and user interviews indicated that such a system should be cost-effective, applicable on a small scale, and measure quantifiable soil health properties, such as pH levels and moisture.

The developed prototype was a combination of quantitative sensory measurements and visual assessment using the guidelines of the Visual Soil Assessment published by the UN [24]. The website interface of the prototype was developed using MongoDB, Express, React, and Node.js stack technology, and it was evaluated through interviews with food forest farmers. The results showed that the prototype was well received by the users, who identified it as a good alternative to current methods and appreciated its cost-effectiveness. The interviews also revealed some suggestions for improvement, such as the addition of a comment box, a reminder system, additional sensors, and a robust and waterproof casing.

The prototype successfully achieved its goal of being a cost-efficient and user-friendly tool for monitoring soil health in food forests. The future work will involve incorporating the suggestions for improvement and exploring the potential for integrating additional sensors. This project can provide a foundation for further development of the tool and contribute to the overall efforts of sustainable agriculture and food production.

In conclusion, this bachelor thesis project has demonstrated the potential for using modern web technologies to develop cost efficient tools for monitoring soil health in food forests. It has provided a valuable contribution to the field of sustainable agriculture and has opened up avenues for future research and development.

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10 Appendix 1 – First interview guiding Questions

1. How does your week look like?

    a. Describe a regular/irregular weekly schedule.

    b. Tell us about a week when everything went wrong.

2. What does agroforestry mean to you?

    a. Why did you start a food forest? (Ideology)

    b. How is the current food forest going?

    c. What are your dreams for the future?

3. What are the crucial design features that shape a food forest?

    a. How and why did you design the layout of your food forest? (Wind and sun directions, and water management)

    b. Why did you decide to use / not use animals?

    c. Which types of plants do you have? (Cloned trees, a mixture of types of plants)

        i. Are there ones you find that are necessary?

    d. How do you use the edges of the forest?

    e. Who helped you get the knowledge about agroforestry?

4. How do you maintain your food forest?

    a. What could be helpful in making it easier to maintain your food forest?

    b. Did you get help from anyone or anything like machines?

    c. How much time does it take?

5. What do you wish you had known before starting the project?

6. Anything that makes your food forest special in some way?

    a. Think about: Design, types of plants, end goals like education, etc.

7. Do you think you can get most of your food necessities from your food forest?

8. How do you know if your food forest is going well / in the right direction?

a. What are indicators of healthy forests, and how do we measure them?

9. What are the limitations and complications of a food forest

11 Appendix 2 – Score Card of the VSA

SCORE CARD

Visual indicators for assessing soil quality under cropping

SOIL INDICATORS

Land use:

Site location/Paddock name:

Date:

Soil type:

Textural qualifier: ☐ Sandy ☐ Loamy ☐ Clayey

Moisture condition: ☐ Dry ☐ Slightly moist ☐ Moist ☐ Wet

Seasonal weather conditions: ☐ Dry ☐ Wet ☐ Cold ☐ Warm ☐ Average

Visual Indicator of Soil Quality	Visual Score (VS) 0 = Poor condition 1 = Moderate condition 2 = Good condition	Weighting	VS Ranking
Soil structure & consistence (Fig. 1, p.17)		× 3	
Soil porosity (Fig. 2, p.19)		× 3	
Soil colour (Fig. 3, p.21)		× 2	
Number and colour of soil mottles (Fig. 4, p.23)		× 2	
Earthworm counts (Fig. 5, p. 25)		× 2	
Tillage pan (Fig. 6, p. 27)		× 2	
Degree of clod development (Fig. 7, p. 29)		× 1	
Degree of soil erosion (wind/water) (Fig. 8, p. 31)		× 2	
RANKING SCORE (Sum of VS rankings)			

Soil Quality Assessment	Ranking Score
Poor	< 10
Moderate	10 – 25
Good	> 25

If your soil quality assessment is moderate or poor, guidelines for sustainable management are given in Volume 2, Part One.

Figure 23 - Score Card of the VSA [24]

12 Appendix 3 – Evaluation Plan

Procedure:

1. Ask for consent to audio-record it. Ask again at the start of the recording
2. Explain the graduation project and its goal
3. Introduce the prototype and its features (sensors, website)
4. Elaborate on the necessities of the prototype:
    a. 2 glasses of water, one for the dissolved soil and one for cleaning the sensor
    b. Shovel
    c. Smartphone (for Wi-Fi connection to the ESP32)
5. Explain how to use it and let them test it at min. 5 sample locations (more if they want)
6. Ask remaining questions
7. Thank the user for his time and efforts to help me evaluate my graduation project

Questions:

1. What is your general impression of the prototype?
2. How easy was it for you to use the prototype to measure soil health parameters?
3. How helpful was the visual assessment feature of the prototype in assessing soil health?
4. How accurate do you believe the soil health data collected by the prototype to be compared to traditional methods?
5. Can you explain how you would use the data and analysis provided by the prototype in your agroforestry project?
6. How do you think the prototype could be improved to better suit your needs in monitoring and assessing soil health?
7. Can you discuss any challenges you encountered while using the prototype in your food forest?
8. Is it easy for you to go around the field and taking measurements or is it a hassle after some samples?
9. How do you think the prototype could be adapted to be more user-friendly for those with limited technical expertise?
10. Overall, how valuable do you believe the prototype will be in monitoring and assessing soil health in agroforestry projects?
11. Are there any suggestions on how to improve it?
12. Can you explain the impact of using the prototype on your food forest?
13. How does the prototype compare to other tools you have used for soil health assessment?
14. How do you think the prototype could be used in other agroforestry projects?
15. Are there any additional comments or feedback you would like to mention regarding the prototype?