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Development of a modular IoT system for the agricultural sector.

This document will go into detail what "soil and plant data" is relevant to measure in the agricultural sector and how to design and develop a modular system that is easily configurable which will be used regularly by the professionals in the field.

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Document history

Version	Date	Mutation
0.1	01-02-2019	Setting up the document template and styling
0.12	02-02-2019	Changed Title and Description to be more professional
0.2	09-03-2019	Start on introduction (background, scope, relevance)
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1.0	02-06-2019	Rough version made with pre-existing research (changing it soon)

Glossary.

Term	Definition
Mechanical manual labour	In the context of this document I define this as manual labour with the use of mechanical machines or vehicles which still require a human to operate it.

1: Introduction

In recent years with the adoption of the Internet of Things more and more connected devices are being utilized in our daily lives. This can range from health and fitness to home automation. One aspect of our lives is rarely talked about, this being agriculture. Applying technology like IoT in agriculture could have a great impact in the industry.

The global population is set to touch 9.6 billion by 2050, so ensuring everyone can be fed is no small feat. This means the agriculture industry has to embrace IoT based system to increase the yield of crops and help with challenges like extreme weather, climate change and the result of intensive farming practices. Today methods to increase the yield of crops is to use allot of fertilizers or with a methods like "non-photochemical quenching [1]". Both methods are very promising and are good methods to supply the demand for more food currently but are in no way permanent solutions to the problem. These methods require you to use additional resources, which can become scarce in the future and in reality, only increase production by 20-30 percent. The perfect solution would be to use so called "vertical farms [2]" because the amount of soil that could be used is in theory limitless[1] which in turn means the amount of food that can be produces in also theoretically limitless. Of course, based on the current progression of these vertical farms, this is not a solution that will replace traditional farming anytime soon because of the high costs and maintenance which is required to run such farms at any level that can profitable and cheap. I truly believe this to be the best solution to help with the problem we will be facing in 2050 and the future, but for now this is just a nice concept.

Knowing this you might ask yourself if hope is lost or if there are other alternative which come with the benefits of a bigger crop yield without the downsides of having to replenish or use new resources for the soil. Sadly, this is not entirely possible, but what is possible is to reduce the amount of resources needed for the same amount of crop yield. To do this we need a smart system consisting of many smaller systems which can monitor and regulate the soil constantly whilst being connected to each other in realtime. This sounds awfully much like an IoT system and this is the reason why I think these kinds of systems are perfectly suited for complex problems which can be solved by using many simple parts together. But in most cases the target demographic is limited by the capability of these systems or have to pay a premium to afford systems with a large range of features. But this causes the system to sometimes have features that are not relevant or useful to them. This is where the concept of modularity can play a beneficial role to them.

1.1: Scope

Throughout this document we will be primarily be focussing on the aspect of increasing crop yield in the agriculture sector by using smart devices like an IoT system to decrease the usage of fertilizers, water, nutrients and mechanical manual labour but still giving the target demographic the option to configure the system to a extend that is usable to them. The research will be mainly theoretical but some physical tests will take place in the Dutch area named "Wageningen" at the WUR (Wageningen University & Research) because test appliances are readily available for me here. I am also looking at what solutions are available currently and will skip over anything that will only be feasible in the future. This means the research is primarily focussed on what is currently available and possible to create.

The target demographic for this paper are professionals in the agricultural sector like farmers, consultancy agencies and large corporations making technology for this sector.

[1] Based on the maximum height a construction can be build before it becomes unstable.

1.2: Relevance

In the field of soil science there are already many discoveries made on how to design smart devices to measure and regulate the pH or moisture level. Whilst these being good ways to increase the crop yield, I have yet to see a system that goes into the more detailed and complicated aspects of farming like fungus detection and prevention, purification of filthy water, preventing diseases due to intensive tillage, checking and regulating nutrients in the soil and increasing the fertility of the soil by slowing down nitrification. When looking at existing solutions like the following example for a pH measurement IoT system [3] or other studies online we can clearly see a pattern of systems that only measure and regulate one or more aspects of the soil. And the systems that do measure the remaining aspects are mostly too expensive for everyone to afford. Another issue with current systems, is the fact that they mainly focus on measuring parameters in the soil and not so much on lesser known aspects of plant science, like in the air and others.

This is due the negative effect which occurs when placing many sensitive measurement components in a small space. Doing this can result in sensors or components interfering with each other which in turn decreases the accuracy of the measurements. In a report about the deterioration of measurements due to interference of multiple sensors RGB-D sensors [4] it is briefly mentioned that 95% of depth measurements can be lost when two sensors interfere with each other. Of course, these kinds of sensors are highly sensitive for noise and sensors used for IoT system in agriculture are not nearly this bad. But it can be still noted that even these types sensors have a high percent chance to intervene with each other and can reduce the accuracy. This makes building all in one systems that have multiple sensors more complex which increases prices.

When designing a new alternative which builds up to all the work done by existing research, I understood that a complete package where all the above-mentioned aspects of farming are measured and regulated has yet to be developed or designed in such a way that is affordable for a large range of people of the target demographic[2]. The purpose of this document is to design such a system and research what other functionality can be desired by professionals in the agricultural sector.

Summed up the purpose of this document is to give insight in what professionals in the agricultural want in area of IoT systems for the soil and discover how an IoT system can be created which can measure and regulate multiple aspects of plant science to increase crop yield but allows the target demographic to expand the system to do a wide array of other things.

1.3: Objective

Currently there are three options when buying all in one systems that try to solve the same problem described above:

1. Buy a cheap sensor that measures moisture, pH or another parameter.
2. Buy a more expensive sensor that does the same as option one but allows you to connect it digitally.
3. Pay a premium for a first party to install a complete system or to buy a kit from a company like CropX [5].

The problem with all these options is that they are either too expensive for the large scale, not practical or do not offer any way of expanding the system in the future. Another downfall is that these systems only measure one to three aspects of the soil whilst still being incredibly expensive. Another problem with the first two systems, is the fact that they are not practical in the sense of automation. They only detect and measure the state of the soil or air but do not contribute to regulate this in any shape or form. Ideally you would want a system which can add water, nutrients or regulate the soil and air in other ways to increase the crop yield, without mechanical manual labour.

[2] Based on my personal knowledge and research on the internet.

So you might opt for the third option, as it has all the necessary features built in them. But what about non-standardized features like a data logging system or a soil determination system which can compare different areas with their soil composition? Doing something like this would require you to yet again buy a new system on top of your existing one and pray that the way these system are implemented allows for communication between the two. If this is not the case, you would have to either:

- Buy a new system which can communicate with the soil determination system
- Hire a full time engineer and system architect to make this communication possible.

As you can see having to rely this much on manufacturers of these kind of systems is cumbersome, difficult and dangerous. So this is where modularity comes into place. Why buy an entire new system when you can simply add modules to your existing one which can measure or regulate n amount of things. This ensures you have the freedom to build a system that caters to your needs but at the same time will be much cheaper in the long run because no adjustments will have to be made to the existing system. Another aspect is the increase in innovation and competition that will take place in the agricultural sector on creation of this system. In chapter {xxx} we will go into more detail why this will happen and why this is beneficial to you as a professional.

The big question that will be answered can be summed up as followed: "How do you design and develop an IoT system which can manage plants in multiple aspects of soil and plant science to increase the yield and decrease mechanical manual labour by automation whilst being modular enough to give the user freedom of choice?".

This question can then again be subdivided into the following subsidiary questions:

1. "What are relevant aspects of soil and plant science that can contribute to an increased yield and what additional features does the target demographic want?"
2. "What are direct or indirect pains the target demographic faces in the sector?"
3. "What sensors, encoders, actuators, additional hardware and mechanical components are required to measure and regulate the relevant aspects of soil and plant science which increase the crop yield?"
4. "In what ways does the target demographic want to interact with the system and how can this best be implemented?"

2: Theoretical framework

2.1 Relevant aspects and desired additional features

When reading a magazine which advertises a product called BioFlora [1] I stumbled on the question "What makes crops grow and how can you 'increase' this yield". Although this article is just purely promotion and advertisement which should not be used as legitimate source, it is still made me think about the advantages my system could provide in the end.

So what am I actually trying to find out is the following:

- How do farmers currently do increase their crop yield?
    - Why do they do this in these ways specifically?
        - What downsides are there with these methods?
        - What upsides are there with these methods?
        - What are new opportunities that can deal with any problems they face with these methods?
    - What does the target demographic actually want?
        - Do they want to produce more eco-friendly?
        - Do they care more about profit or are they willing to change if they had the chance?
            - Is this based on region, country, geographic location?
            - If not what causes any large difference in opinion?
                - Are there even different opinion? No, why not?
- What are new upcoming or unknown technologies to increase the crop yield?
    - Which of these technologies can be realistically implemented or utilized currently?
        - If not, what hinders or causes this?
    - In what way, shape or form are these technologies able to be used in the proposed IoT system?
        - Does the target demographic need these features?
            - Do they even know about this?
            - Can they be convinced otherwise?
                - Yes, how and with what motive?
                - No, what causes this?
        - What hinders this and how can this be solved?

2.1.1 Information acquisition and analysation

The information I am looking after is a generalized list of parameters that must be measured and regulated in the soil to ensure each specific aspect of soil that increases crop yield is present in the end system. So, in normal terms: "What does the system need to measure and regulate so that all the requested parameters of the soil that increase the crop yield are handled."

This is easier said than done, due to the scope of the question. So, what I intend to do is split this up into multiple sections of information.

1. I need to understand what the target demographic WANTS to be implemented.
2. I need to know what methods and technologies ARE currently being used by the target demographic.
3. I need to know what new or unknown methods and technologies CAN be added or used.

Whenever I can give insight or information about these three topics I can than analyse what the corresponding points between these topics are and try to come up with a conclusion.

- For example: "Farmers like to have a system that controls the pH level because they are already using such systems for their farm and from an online rapport it was concluded that the pH level and … are directly responsible for the growth of crops in … way. This means the system needs to implement both a way to regulate the pH and … so that the farmers can have an additional benefit besides only regulating the pH."

2.1.2 Methods and planning

To reliable retrieve information about the three topics, I need to do the following:

- Consult and expert on the second topic.
- Do some desk research to find some background information about the second topic.
- Interview the target demographic on the first topic and map out their needs.
- Do some research online and find some papers about the third topic.
- Ask a personal contact or expert about trends of the third topic.
- Fact check weather my assumptions are real about the third topic.

2.1.3 Results

2.1.3.1 History and opinion

The concept of modern agriculture was laid more than 150 years ago but only since the early 1950's rapid advancements where made in the technologies in this field. Back then it was already known what important role mineral fertilizers had to increase crop production. During the 1950's advancements where made which reduced the production time and manpower needed to sustain these crops. This was also because energy was becoming more affordable and machinery reduces the manpower.

Here these mineral fertilizers, pesticides and cultivars where in a sense where necessary to effectively increase the nutrients levels in the soil which in turn causes in lager yield of the crops. For a long time, this method of production was supported by governments policies which focus more on a reliable source of good quality food for reduced prices. However currently the societal concerns about these methods are worrisome due to the effect it has on the environment, flora, fauna and welfare of domestic animals. Almost ever aspect of these methods are questions and scrutinized by activists, producers' consumers, non-government organization and pollical parties alike. Here current subsidization in the modern agricultural sector is question which causes the demand for more economic and ecological sustainability to increase.

But with the shear dependency of these old methods, it may be very unlikely a complete shift towards new alternative will occur any time soon. The decency mostly in the aspects of cost and production. With an ever-growing population it can get quite dangerous to suddenly rapidly change these methods for the sense of more ecological production of crops. Costs is also a big problem, since food prices can not suddenly rise exponentially to make up for the costs of ecological production, because that would remove the whole purpose of ecological production which is to be benefitable for people.

2.1.3.2 Aspects about soil science

Current crop yield method and dilemma

Raising the yield of crops on existing farm land has stagnated compared to the result from the past 40 years. Here rapid advancement in maintaining the soil and using fertilizers caused the production to increase year over year because currently the soil has reached it maximum yield potential. From the 2000's and onwards there is a bigger focus on so called "green-technology" which currently are about 80% of the maximum yield limit. This means there is a lot of demand for product and methods to close this gap and in many parts of South-East Asia the yield can be significantly increase with the introduction of new technologies.

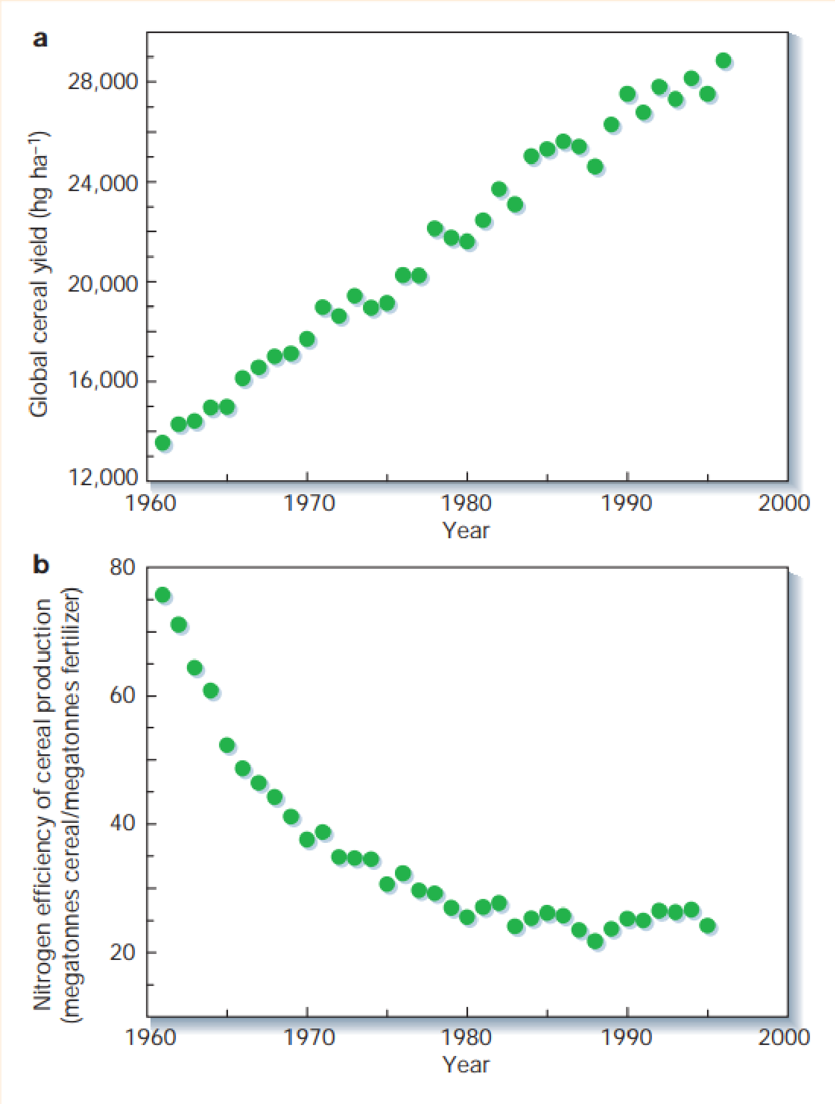


Figure 2 Diminishing returns of fertilizer application imply that further applications may not be as effective at increasing yields. **a**, Trends in average global cereal yields; **b**, trends in the nitrogen-fertilization efficiency of crop production (annual global cereal production divided by annual global application of nitrogen fertilizer)[2].

Currently modern high yielding agricultural system are depended on the following:

- Addition of fertilizers
- Pesticides
- Modern cultivars
- Precision Techniques

Commented [AA1]: I would take away the rhyzobium thing and add modern cultivas and new precision techniques - Jorge Eduardo Leigh Urbina

NITROGEN IN MODERN AGRICULTURE 5

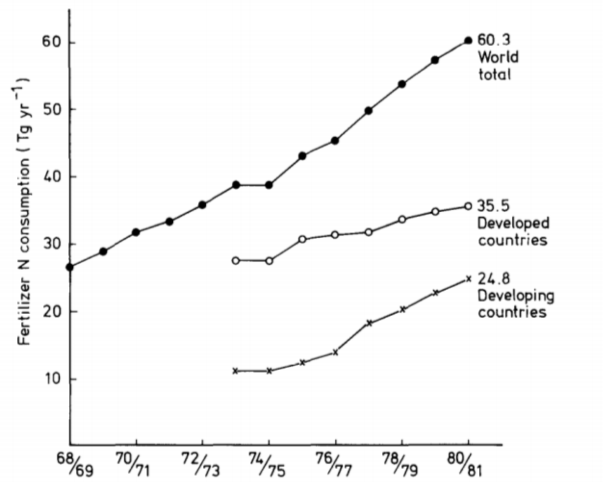


Fig. 2. World use of nitrogen fertilizers (Tg N yr^{-1}) 1968/69–1980/81. For the period 1973/74–1980/81 the use has been separated between developed and developing countries according to FAO[16]. The figures show total fertilizer use in Tg for the year 1980/81.

From the graph above we can see that there was a steady increase in N-fertilizers in the early stages of agriculture.

Precision Farming

The term precision farming [2] is something that recently started to be introduced. Here sensors, mapping tools, robots and data analytics is used to give useful information about the crops. Things like the shape and condition of leaves, the moisture level of the soil to determine the health and stress of crops. In calibrated doses then water, fertilizers and pesticides are added to increase the health and reduce the stress of crops.

All this results in precision farming reducing water and chemical use to provide realtime feedback about the health of crops which can then be used to determine the best time to harvest.

Downsides, benefits and solutions of using pesticides and fertilizers

Pesticides

Pesticides are substances that are meant to control pests and cover a wide range of compound to protect against a wide range of things that can harm plants. The most commonly used once are herbicides which cover about 80% [3] of all pesticides used. But insecticides, fungicides and avicides (used to kill birds) are also used in some cases.

The primary usage of pesticides is to protect crops and plants from weeds, fungi and insects that can harm the them. Pesticides generally applied by directly spraying them over crops with planes or other vehicles. In a study [4] it was noted that not using pesticides can decrease the crop yield (in some cases) by 10%. There are many other benefits of using pesticides but the most important ones being:

- Improving crop yield
- Improving crop quality
- Reducing diseases that can occur lime malaria en saving human / animal lives
    - The use of DDT has saved millions lives alone.

Commented [AA2]: I would rephrase the use of pesticides, fertilizer s,.. to improve crop productivity and not health - Jorge Eduardo Leigh Urbina

The downsides of using pesticides primarily concern the human health and the environment. This can range from simple skin and eye irritation to more severe effects like affecting the nervous system, reproductive problems, cancer en mimicking hormones. There are many scientific papers and research that can prove the correlation between insecticides and neurobehavioral alteration for example.
From a study it was concluded that at least 98% of insecticides and 95% of herbicides 'miss their target' when sprayed like in the water, air and soil. The reason this happens is since spraying pesticides in such a large scale can decrease the accuracy on how its applied. These pesticides particles can be transmitted though the air or water which causes them to be in non-targeted places which in turns causes these areas the be polluted. In a report about the water contamination in the US [5] by pesticides it was recorded that about 1% of all ground water is direct contaminated by pesticides and another 1% had been badly degraded by pesticides. It also reports many lakes and wells that had to be closed temporarily of definitely because of this contamination.

Commented [AA3]: You could mention the problem.of overuse of pesticides and the development of resistant fungi, weeds and insects to those pesticides, making their management more complicated health - Jorge Eduardo Leigh Urbina

For a reference in the united states alone pesticides cost the government about 9.6 billion in human health and environmental issues annually. But this is reflected by the 40 billion increase of agricultural production.

So the real question that needs to be asked if the downsides to human health and the environment justify the decrease in production knowing that the population will increase steadily each year. Currently however there are no real alternatives besides genetic engineering and interfering with insect breeding to reduce the usage of insecticides. But even this is not enough to justify the ban of all pesticides mainly because insecticides are minority of the pesticides used in agriculture. Other strategies including the Push and pull strategy are promising but sadly require you to give up precious space to so called "trap crops" which will severely limit the potential of crop production in the future.

Unless new technologies or strategies emerge, which can deliver equivalent "performance" to crop yield and reduce the damage to crops, pesticides will not be going anywhere anytime soon. One alternative which is not so much a strategy or material but more of a new way to producing crops is using so called "vertical farm". These are in a sense large closed environment where large "plant boxes" are stacked on top of each other in racks to increase the physical space to grow crops. The advantage is simply the fact that there is more space for the soil in a smaller area of land and any the environment can be controlled to reduce the change of insects, fungi and weeds. Sadly, this technology is still in its early stages and is simply too expensive to be utilized in the large scale or in any scale which is enough to feed the entire population.

Another method is to use biological pesticides which degrade faster in the nature. These pesticides have the benefit of being extremely close to normal pesticides in the aspect of crop yield increase. The issue is that these pesticides are prohibitable expensive to a point that it can become impossible for farmers to make a profit with their current selling price. But of course, there are many farmers who decide to use this alternative but increase the price of their biological produce.

Commented [AA4]: I am not that sure that biological pesticides are not broadly used mainly because of their price. More research should be done on this point. - Jorge Eduardo Leigh Urbina

The usage of biological pesticides seems to be the most promising solution currently that gives farmers the choice what path they want to choose concerning their target consumer and clients. If farmers have a lot of client that demand biological produce than the usage of these pesticide can be very easy and if that's not the case, they can simply chose to use normal pesticides.

Fertilizers

A fertilizer is in a sense plant food for crops which increases the nutrients present in the soil which help the crops grow. Fertilizers do this in two ways:

1. Provide nutrients directly to the soil to increase growth
2. Enhance the effectiveness of soil by modifying its water retention and aeration.
    a. Retention: Water retention ability, also called soil water retention rate, is a measure of how much water a particular type of soil or grow medium can retain.
    b. Aeration: the process of increasing or maintaining the oxygen saturation of water in both natural and artificial environments.

Commented [AA5]: Old description was a bit cluncky, so i changed it. - Jorge Eduardo Leigh Urbina

Fertilized provide the crop with many elements need to grow with the 3 main ones being:

- Nitrogen (N): needed for leaf growth
- Phosphorus (P): development of roots, seeds, fruit
- Potassium (K): stem growth, water movement in plant, increasing fruiting

Generally speaking, there are two types of nutrients in the market that are used:

1. Single nutrient fertilizers: Ammonia or ammonium nitrate based and used to slow down nitrification [6] (process that turns ammonia to nitrate which is needed by plants).
2. Complex fertilizers: More common and exist of two components
    a. Binary fertilizer: provides nitrogen and phosphorus to plants
    b. NPK fertilizers provides nitrogen, phosphorus and potassium

But currently there are even more complex types of fertilizers like micro and Nano fertilizers. More about this in section "Mineral Nutrients"

Commented [AA6]: Now there are even nano fertilizers. Just to mention and advancements in fertilizers - Jorge Eduardo Leigh Urbina

Fertilizers mainly have positives effects on crops but also have some negative environmental effects which can affect water, soil and groundwater. The most comment fertilizers (Complex fertilizers) contain nitrogen and phosphorus which contribute to the eutrophication of fresh water bodies [7] and high concentrations of phosphorus ca cause cyanobacteria and algae to grow. Which is bad because it reduces the oxygen level in water and can produce harmful toxins which can be passed to human via the food chain.

Commented [AA7]: You could aslo mention that:
- Nitrogen and ph depends of the nitrogen source
- If you use ammonia then the pH can decrease
- If you are using nitrate ph will increase

Jorge Eduardo Leigh Urbina

Nitrogen also severely reduces the oxygen content of large oceanic bodies which decrease the chance of live to exist in the water. It can take decades before this process can be reversed and naturally broken down by natural processes.

The nitrogen can also cause soil acidification[8] which increases the pH level reduces the nutrient availability which make be offset by liming.

Currently there are no direct alternatives for fertilizers besides biological fertilizers like compost, but these alternatives do not deliver the same amount of nutrient to crops or increase the crop yield by the same margin. But with careful usage and monitoring of fertilizer usage these problems can be mostly regulated to a degree that is does not become worrisome.

Challenges and methods in increasing crop yield:

- Increasing leaf photosynthetic [9]
  - Diminishing returns
  - No true evidence that this can result in increased yield.
- Nitrogen assimilation [9] [10]
  - Was a crucial feature in the past to increase yield.
  - Nitrogen assimilation is the formation of organic nitrogen compounds like amino acids from inorganic nitrogen compounds present in the environment. Organisms like plants, fungi and certain bacteria that cannot fix nitrogen gas (N_2) depend on the ability to assimilate nitrate or ammonia for their needs
  - Plants absorb nitrogen from the soil in the form of nitrate (NO_3^-) and ammonium (NH_4^+). In aerobic soils where nitrification can occur, nitrate is usually the predominant form of available nitrogen that is absorbed
- Drought stress [9]
  - Inadequate water availability is a crucial limitation to crop yield
  - There has been some success in improving crop water use efficiency, but major increases in yield will require increased water uptake by the crop, which means the crop must access more soil water under water-deficit conditions
  - One approach that has received considerable attention is the possibility that solute accumulation in plants, or osmo-protection, might confer drought tolerance
- Low nutrients reserves [11] [12]
  - The phosphorus, potassium, calcium, magnesium and micronutrients that soils naturally supply to plants come from the dissolution of primary or weatherable minerals.
  - Plants use photosynthesis to assimilate carbon and fuel their metabolism and growth. Atmospheric carbon dioxide is converted into organic compounds, utilizing the energy provided by sunlight. During the night, when photosynthesis is not possible, plants must rely on stored reserves of carbohydrates built up during the previous day. In many plants, this carbohydrate is stored in chloroplastic starch granules which are degraded during the night to produce sugars.
- Aluminium (and Iron) toxicity [13] [14]
  - The most easily recognized symptom of A1 toxicity is the inhibition of root growth, and this has become a widely accepted measure of A1 stress in plants.
  - It is not surprising that an A1-Ca interaction of some kind has been implicated in A1 toxicity. In early studies it was noted that the symptoms of severe A1 toxicity in the field resembled Ca deficiency and that application of Ca as gypsum (Caso,) or lime (CaCO) alleviated A1 stress
  - Excess ferrous Fe also apparently contributes to "freckle leaf' of sugarcane in Hawaii, along with excess Al, Mn, and Zn.
  - Symptoms of Fe toxicity are expressed differently in different plants. It was noted that excess Fe in flax produced dark green foliage and stunted top and root growth. Roots were thickened and showed large accumulations of inorganically bound phosphate.
  - Iron toxicity is frequently difficult to identify by plant symptoms alone and can have different effect based on the type of plant.

- Acidity (not Al-toxic) [15]
  - Direct effects of the H ion on plant growth are difficult to assess because, at soil pH values where it is potentially harmful, Al, Mn, and other mineral elements may be present in toxic concentrations, and the availabilities of essential elements, particularly Ca, Mg, P, Mo, and Si, may be suboptimal. In most acid soils (pH above 4.0), Al and Mn toxicities are probably more important than H ion toxicity in limiting the growth of plants, particularly the non-legumes. However, H ion toxicity may restrict the survival and activity of rhizobia and other soil microorganisms.
  - Because the effects of H ions are confounded with those of other factors in acid soils, investigators have resorted to nutrient solutions or sand cultures to study the effects of low pH. In general, solutions having pH values below 4.0 reduce root growth.
  - Excess H ions compete with other cations for root absorption sites, interfere with ion transport, and cause root membranes to become leaky. Thus, roots can lose previously absorbed cations as well as organic substances (sugars, amino acids), and prolonged exposures to low pH may reduce their capacities for subsequent absorption of nutrients
- Phosphorus fixation [16] [17] [18] [19]
  - Phosphate fixation is defined as the decrease in solubility undergone by phosphates added to soils, but does not necessarily imply that the availability of the fixed phosphate is low.
  - Phosphorus fixation was first recognized in Europe around 1850, when it was reported that soil had the ability to "retain" phosphorus.
  - Phosphorus is one of the least available mineral nutrients to the plants in many cropping environments. Sub-optimal P nutrition can lead to yield losses in the range of 10% to 15% of the maximal yields.
  - Phosphorus (P) fixation happens when it is applied to soil, regardless of the fertilizer brand or chemical composition. Fixation occurs when P reacts with other minerals to form insoluble compounds and becomes unavailable to crops.
  - A good method to spot P-fixation is to look at the pH values. From a test [12] it could be concluded three peek where spotted where phosphorus fixation was highest. Between 3-4pH, between 5.5-6pH and around 8pH.
- Salinity [20] [21]
  - The saltiness of water which is measures in the amount of grams of salt per kg of water.
  - Water moves into plant roots by a process known as osmosis, which is controlled by the level of salts in the soil water and in the water contained in the plant. If the level of salts in the soil water is too high, water may flow from the plant roots back into the soil. This results in dehydration of the plant, causing yield decline or even death of the plant.
  - Crop yield losses may occur even though the effects of salinity may not be obvious. The salt tolerance of a specific crop depends on its ability to extract water from salinized soils. Salinity affects production in crops, pastures and trees by interfering with nitrogen uptake, reducing growth and stopping plant reproduction.
  - Some ions (particularly chloride) are toxic to plants and as the concentration of these ions increases, the plant is poisoned and dies.

- Soil erosion [22] [23] [24] [25] [26]
  - Soil erosion can be seen as the displacement of the upper layer of the soil and is form of soil degradation.
  - Soil erosion is a complex process that depends on soil properties, ground slope, vegetation, and rainfall amount and intensity. Changes in land use are widely recognized as capable of greatly accelerating soil erosion and it has long been recognized that erosion in excess of soil production would eventually result in decreased agricultural potential.
  - Although there are many factors that can cause soil erosion like the climate, weather and other envoi mental issues, the biggest contributor is the use of extensive tillage practices. Tillage breaks up the soil into fine particles which increases the risk of water erosion (water transports soil away). Other factors include mono-cropping, farming on steep slopes, pesticide and chemical fertilizer usage (which kill organisms that bind soil together), row-cropping, and the use of surface irrigation.

  - A big negative of soil erosion is that it decreases the phosphorus content in soil. Another issue of soil erosion is that it can decrease crop yield by 12-21% due to loss in fertility and water availability.
  - Reliable and proven soil conversation techniques include ridge-planting, no-till cultivation, crop rotation, strip cropping, grass strips, mulches, agroforestry, contour planting and cover crops.
    - A system manageable conservation technique is crop rotation. This is the practice of growing a series of dissimilar or different types of crops in the same area in sequences seasons. It helps in reducing soil erosion and increases soil fertility and crop yield.
  - As a result of more than 20 years of application, the cacsi urn-137 technique has become established as an important tool for investigating soil erosion and recent work has demonstrated that it can be used in a wide variety of environments.
    - Increased water transfer through soil can reduce fertilizer retention in the soil matrix and fertilizer use efficiency in plants.
  - Disturbance of soil structure through compaction or tillage can result in the rapid recycling of nutrients, crusting, reduced water and air availability to roots.
- Soil structure [27] [28] [29] [30]
  - Soil structure affects plant growth by influencing root distribution and the ability to take up water and nutrients. Soil structure facilitates oxygen and water infiltration and can improve water storage.
  - Some important properties of the soil are:
    - <u>Texture</u>: Soil texture is a classification instrument used both in the field and laboratory to determine soil classes based on their physical texture. Soil texture can be determined using qualitative methods such as texture by feel, and quantitative methods such as the hydrometer method. Soil texture has agricultural applications such as determining crop suitability and to predict the response of the soil to environmental and management conditions such as drought or calcium (lime) requirements. Soil texture affects how well nutrients and water are retained in the soil. Clays and organic soils hold nutrients and water much better than sandy soils. As water drains from sandy soils, it often carries nutrients along with it. This condition is called leaching. When nutrients leach into the soil, they are not available for plants to use.
    - <u>Porosity</u>: Soil porosity, or soil pore space, are the small voids between particles of soil. In heathy soil, these pores are large and plentiful enough to retain the water, oxygen and nutrients that plants need to absorb through their roots. Soil porosity usually falls into one of three categories: micro-pores, macro-pores or bio-pores.
      - These three categories describe the size of the pores and help us understand the soil's permeability and water holding capacity. For example, water and nutrients in macro-pores will be lost to gravity more quickly, while the very small spaces of micro-pores are not as affected by gravity and retain water and nutrients longer.
    - <u>Cation exchange capacity</u>: Cation-exchange capacity is defined as the amount of positive charge that can be exchanged per mass of soil, usually measured in cmolc/kg.
      - This is one of the ways that solid materials in soil alter the chemistry of the soil. CEC affects many aspects of soil chemistry, and is used as a measure of soil fertility, as it indicates the capacity of the soil to retain several nutrients (e.g. K^+, NH_4^+, Ca^{2+}) in plant-available form.
      - Increasing the pH (i.e. decreasing the concentration of H^+ cations) increases this variable charge, and therefore also increases the cation-exchange capacity

- Soil water: Soil water is the term for water found in naturally occurring soil. Soil water is also called rhizic water. Soil acts as a sponge to take up and retain water. Movement of water into soil is called infiltration, and the downward movement of water within the soil is called percolation, permeability or hydraulic conductivity. Pore space in soil is the conduit that allows water to infiltrate and percolate. It also serves as the storage compartment for water.

- Soil moisture stress [31] [32]
  - Moisture stress occurs when the water in a plant's cells is reduced to less than normal levels. This can occur because of a lack of water in the plant's root zone, higher rates of transpiration than the rate of moisture uptake by the roots, for example, because of an inability to absorb water due to a high salt content in the soil water or loss of roots due to transplantation. Moisture stress is more strongly related to water potential than it is to water content.
  - Water stress causes significant reduction in plant productivity. Soil moisture content level must be monitored and maintained at adequate level for optimal productivity.
  - Accuracy of moisture sensors used for monitoring soil moisture content depends on installation technique and proper contact between soil and sensor which is difficult to achieve. Non-contact sensing technique on the other hand, does not have the limitation of contact with soil and can be located in remote location to monitor plant status parameters continuously
- Temperature [33] [34]
  - Root growth: Soil temperature affects both the rate and thoroughness with which a plant root system permeates soil. This can both affect growth and development of the plants root system. It affects the type of root growth. Low temperature encourages white succulent roots with little branching, while high temperatures encourage a browner, finer and much more freely branching root system. However, the soil temperature at which roots grow fastest is usually higher than the temperature which encourages the most extensive root system.
  - Germination of Seeds: The germination of the different seeds is greatly influenced by the variation in soil temperature. If the temperature is too low, the seed fails to germinate or germinate at a slow rate. On the other hand, seeds may be injured if the temperature will be very high.
  - Physical Properties of Soil: Soil structure is greatly influenced by the temperature. The temperature has a great influence on the aggregation of the soil as well as on the binding materials present in it.
  - Microbial Activity: The activity of micro-organisms having thermo-phobic and thermophilic nature is influenced by the variation in soil temperature. A certain amount of heat is necessary, for the proper functioning of various types of soil micro-organisms. Various microbiological processes like mineralization of nitrogen, nitrogen fixation, pesticide degradation etc. are influenced by the temperature. The activity of micro-organisms is lowest when soil temperature is below 5°C and above 54°C. The optimum temperature for the activity of most of the micro-organisms is in the range of 25-35°C.
  - Decomposition of Organic Matter in Soil: Various important functions of organic matter depend on the process of decomposition which is largely influenced by the soil temperature. The decomposed products vary with the rate of decomposition of organic matter. At low temperature the rate of organic matter decomposition is low resulting various toxic organic substances in soil and the high temperature the rate of the same is very fast resulting beneficial products of organic matter decomposition and hence influence the plant growth
  - Absorption of Water: Variation in soil temperature (very low to high temperature) affects the absorption of soil water by the plant roots. The effect of temperature in reducing the rate of water uptake may be important in spring time resulting strong transpiration.

- Availability of Nutrients: Various physico-chemical and chemical reactions are greatly influenced by soil temperature. Temperature influences the solubility reactions of different nutrients and releases larger amount of nutrient elements in the soil solution at higher temperatures. The rate of nutrient uptake, however, is almost different for each crop, but it appears to be known about the relative effect of temperature on the uptake of nutrients.
- Plant Diseases: Development of various diseases is also related to the soil temperature. At low temperatures, the soil contains many weekly parasitic fungi which will grow actively and very rapidly and so those will kill the seedlings. On the other hands, seedlings of the temperate zone cereals, which are adapted to grow actively at the lower temperatures, are relatively resistant to their attack.

Miniral nutrients

The 13 mineral nutrients [35], which come from the soil, are dissolved in water and absorbed through a plant's roots. There are not always enough of these nutrients in the soil for a plant to grow healthy. This is why many farmers and gardeners use fertilizers to add the nutrients to the soil. The mineral nutrients are divided into two groups: macronutrients and micronutrients.

Macro nutrients:

These can be then again separated into primary and secondary nutrients. Primary nutrients are the major nutrients which usually are lacking from the soil first because plants use large amounts for their growth and survival. There are usually enough secondary nutrients in the soil so fertilization is not always needed.

Micro nutrients:

Micronutrients are those elements essential for plant growth which are needed in only very small (micro) quantities. These elements are sometimes called minor elements or trace elements, but use of the term micronutrient is encouraged by the American Society of Agronomy and the Soil Science Society of America.

Soil pH is one of the most important soil properties that affects the availability of nutrients.

- Macronutrients tend to be less available in soils with low pH.
- Micronutrients tend to be less available in soils with high pH.

Lime can be added to the soil to make it less sour (acid) and also supplies calcium and magnesium for plants to use. Lime also raises the pH to the desired range of 6.0 to 6.5.

In this pH range, nutrients are more readily available to plants, and microbial populations in the soil increase. Microbes convert Nitrogen and Sulphur to forms that plants can use. Lime also enhances the physical properties of the soil that promote water and air movement

Mineral nutrients can be summed up te following diagram:

<table>
<tr><td colspan="2">Macro nutrients</td></tr>
<tr><td>Primary</td><td>Secondary</td></tr>
<tr><td>Nitrogen (N)
Nitrogen is a part of all living cells and is a necessary part of all proteins, enzymes and metabolic processes involved in the synthesis and transfer of energy.
Part of chlorophyll responsible for photosynthesis.
Helps plants with rapid growth, increasing seed and fruit production and improving the quality of leaf and forage crops.
Nitrogen often comes from fertilizer application and from the air.</td><td>Calcium (Ca)
Calcium, an essential part of plant cell wall structure, provides for normal transport and retention of other elements as well as strength in the plant. It is also thought to counteract the effect of alkali salts and organic acids within a plant.
Sources of calcium are dolomitic lime, gypsum, and superphosphate.</td></tr>
<tr><td>Phosphorus (P)
Like nitrogen, phosphorus (P) is an essential part of the process of photosynthesis.
Involved in the formation of all oils, sugars, starches, etc.
Helps with the transformation of solar energy into chemical energy; proper plant maturation; withstanding stress.
Effects rapid growth.
Encourages blooming and root growth.
Phosphorus often comes from fertilizer, bone meal, and superphosphate.</td><td>Magnesium (Mg)
Magnesium is part of the chlorophyll in all green plants and essential for photosynthesis. It also helps activate many plant enzymes needed for growth.
Soil minerals, organic material, fertilizers, and dolomitic limestone are sources of magnesium for plants.
Sulphur (S)
Essential plant food for production of protein.
Promotes activity and development of enzymes and vitamins.
Improves root growth and seed production.
Helps with vigorous plant growth and resistance to cold.
Sulphur may be supplied to the soil from rainwater. It is also added in some fertilizers as an impurity, especially the lower grade fertilizers. The use of gypsum also increases soil sulphur levels.</td></tr>
<tr><td>Potassium (K)
Potassium is absorbed by plants in larger amounts than any other mineral element except nitrogen and, in some cases, calcium.
Helps in the building of protein, photosynthesis, fruit quality and reduction of diseases.
Potassium is supplied to plants by soil minerals, organic materials, and fertilizer.</td><td></td></tr>
</table>

Micro nutrients
Nutrient
Boron (B) • **Helps in the use of nutrients and regulates other nutrients.** • **Aids production of sugar and carbohydrates.** • **Essential for seed and fruit development.** • **Sources of boron are organic matter and borax**
Copper (Cu) • **Important for reproductive growth.** • **Aids in root metabolism and helps in the utilization of proteins.**
Chloride (Cl) • **Aids plant metabolism.** • **Chloride is found in the soil.**
Iron (Fe) • **Essential for formation of chlorophyll.** • **Sources of iron are the soil, iron sulfate, iron chelate.**
Manganese (Mn) • **Functions with enzyme systems involved in breakdown of carbohydrates, and nitrogen metabolism.** • **Soil is a source of manganese.**
Molybdenum (Mo) • **Helps in the use of nitrogen** • **Soil is a source of molybdenum.**
Zinc (Zn) • **Essential for the transformation of carbohydrates.** • **Regulates consumption of sugars.** • **Part of the enzyme systems which regulate plant growth.** • **Sources of zinc are soil, zinc oxide, zinc sulfate, zinc chelate.**

Legend

	Non metal
	Alkali metals
	Alkaline earth
	Semi metal
	Transition metal
	Halogen

2.1.3.3 Aspects about plant science

The most determining factors of plant growth (which in turn increases yield) are based on soil science, but there are also some other factors in plant science, which can affect plant growth or increase the yield. These are mainly focused on things around or about the plant like the quality of the air, the environment, the amount of sunlight and physical detectable attributes about the plant that can indicate diseases. In the following sections I will go into more detailed about these factors.

Effects of air pollution

In most urban areas the term air pollution mainly refers to substances emitted into the atmosphere by vehicles, factories and other heavy pollution devices. There are many different substances ranging from SOx to C02 which can have a negative impact on human health. Not all of these substances are present in rural areas like farms, due to the fact that there any not any heavy polluting devices or vehicles. The only significant polluting factor would be the old combustion engines used by agricultural vehicles, but this is steadily improving recently. Although it should be noted that trying to get exact measurement is almost impossible since there is little monitoring information available in these agricultural areas [36]. The most common substances which have the highest damaging effects to plant growth are [37]:

- Sulphor dioxide (SO2)
- Nitrogen oxides (NOx)
- Carbon monoxide (CO)
- Suspended particulate matter
- Ozon (O3)
- Carbon dioxide (CO2)[3]

These pollutants (besides C02) when absorbed by the leaves cause a reduction in the concentration of photosynthetic pigments viz., chlorophyll and carotenoids, which directly affect to the plant productivity. Chlorophyll is the principal photoreceptor in photosynthesis, the light-driven process in which carbon dioxide is "fixed" to yield carbohydrates and oxygen. Carotenoids are a class of natural fat-soluble pigments found principally in plants, algae and photosynthetic bacteria, where they play a critical role in the photosynthetic process (Ong and Tee, 1992; Britton, 1995) and also protect chlorophyll from photo-oxidative destruction (Siefermann-Harms, 1987). When plants are exposed to the environmental pollution above the normal physiologically acceptable range, photosynthesis gets inactivated (Mizalski and Mydlarz, 1990). [37]

Vehicular emissions have a profound impact on the concentration of different photosynthetic pigments. The shading effects due to deposition of suspended particulate matter on the leaf surface might be responsible for this decrease in the concentration of chlorophyll in polluted area. It might clog the stomata thus interfering with the gaseous exchange, which leads to increase in leaf temperature which may consequently retard chlorophyll synthesis. Dusted or encrusted leaf surface is also responsible for reduced photosynthesis and thereby causing reduction in chlorophyll content (Mishra and Gupta, 1993). [37]

Ozon in particular has negative effects to the plant cells it selves which reduces it photosynthesis and stomatal conductance in the leaves. This in turn leads to a reduces biomass production and reproductive output of the crops. However, the specific effects of elevated [O3] on reproductive development, a critical stage in the plant's lifecycle, have not been quantitatively reviewed. [38]

[3] It is still unclear if these substances really the fit to be classified as "true pollutants" due to the fact that there are many positive side effects of having regulated amounts of CO2. I will talk more about those in the next chapter

Positive and negative effects of C02

- Positive [39]
  - Studies have shown that higher concentrations of atmospheric carbon dioxide affect crops in two important ways: they boost crop yields by increasing the rate of photosynthesis, which spurs growth, and they reduce the amount of water crops lose through transpiration.
    - Plants transpire through their leaves, which contain tiny pores called stomata that open and collect carbon dioxide molecules for photosynthesis. During that process they release water vapor. As carbon dioxide concentrations increase, the pores don't open as wide, resulting in lower levels of transpiration by plants and thus increased water-use efficiency.
  - But in the same studies results also show that yields of carbon dioxide remaining at 2000 levels would experience severe declines in yield due to higher temperatures and drier conditions. But when grown at doubled carbon dioxide levels, crops fare better due to increased photosynthesis and crop water productivity, partially offsetting the impacts from those adverse climate changes.
    - But this varies majorly between the types of crops and the area used to farm
      - Results show that doubled carbon dioxide levels increase yield by 8 percent, an increase that's driven by improved crop water productivity of up to 50 percent. As in arid climates, without the carbon dioxide boost, crops do not cope as well because of the greater water stress imposed on them, resulting in a 29 percent reduction in yield.
- Negative [40]
  - Although an increased amount of CO2 can increase the rate of photosynthesis, there are also a couple of drawbacks to increasing CO2 levels drastically. When CO2 is added irregularly in high doses it can increase the overall temperature of the area which can cause drought, cause a soil moisture deficit and interfere with the plants reproductive process. (Frances Moore, an assistant professor of environmental science and policy at the University of California)
  - Another factor is the fact that is can cause harm on human health. When crops are grown at elevated CO2 levels in the field it becomes less nutritious. This is because the crops will lose significant amounts of iron (Fe), zinc (Zn) and grains and will cause a protein deficit. Researchers do not yet know why higher atmospheric CO2 alters crops' nutritional content.

Summed up it is true that elevated C02 levels can have a positive outcome to plants, but irregular and uncontrolled levels of it can also be very bad for the quality of the crops. If CO2 is added in a controlled area (such as a glass house) than this can be drastically reduced, but for large open areas this becomes almost impossible. So many advise to don't add inflated amounts of CO2 to the area, because it ca become unclear when its too much.

Computer vision and AI in plant science
Crops are being affected by uneven climatic conditions leading to decreased agricultural yield. This affects global agricultural economy. Moreover, condition becomes even worst when the crops are infected by any disease. Also, increasing population burdens farmers to increase yield. This is where modern agricultural techniques and systems are needed to detect and prevent the crops from being affected by different diseases [41]. This is where the realm of many Computer Vision and Artificial Intelligence solutions could be a great benefit.
Currently these technologies are being utilized for things like [42]:

- Agriculture parameter estimation and retrieval
    - (e.g. carotenoid, chlorophyll, and anthocyanin content, nitrogen status, water content, biomass and leaf area index)
- Yield prediction with the help of Deep Learning.
- Crop classification and crop/material detection
- Early disease detection and monitoring
    - (e.g. disease due to bacteria and fungi or caused by insect infestation); iv)
- Machinery guidance in pre/post crop tasks

Generally, there are 8 kinds of camera's used for computer vision related application [43][44]:

- Thermal cameras
- Multi-spectral cameras
- Modified traditional cameras (wider spectrum)
- NDVI cameras
- RGB cameras
- NIR and UV cameras
- Stereo cameras
- Hyperspectral cameras

2.1.3.4 Trends in agriculture and usability

In a couple document which go through new trend and challenges in agricultural productivity and innovation a couple of new methods and technologies are discussed. These being:

- Resource-conserving practices to increase agricultural productivity [45]: The key to sustainable agriculture is to grow crops more efficiently which decreases the stress of farm land and increase the amount of resources that can be used. This also mean long-term investments in buying more land, can result in direct benefits because the production increases yearly, but the resource usage does not change (from what previously was needed). This can be done by reducing the usage of mechanical tillage and using organic materials.
    - This trend really suits the system as it describes the building blocks and the vision of what the system is trying to achieve which is reducing mechanical manual labour by autonomous systems.
    - The only negative part about this trend is that is reduces the sense of choice by the farmers as he can no longer decide which kind of pesticides and fertilizers he wants to use.
- Climate-smart agriculture aims at sustainably increasing [45]: This is basically switching the role of land to be used for tillage or live stock periodically. By first growing crops on land, harvesting a certain amount and then letting livestock feed of the remainder which in turn produces natural compost that in the next turn can be used for tillage.
    - This is interesting trend that can reduce the usage of resources and is more efficient, but sadly shares no direct correlation with the system that can be implemented
- Satellite-based remote sensing technologies [46]: With the advantages of macroscopic, fast, accurate, dynamic and abundant information, satellite-based RS technologies are widely used to provide guidance in global agricultural production for things like analysing crop diseases.
- UAV-based remote sensing technologies [46]: The accurate acquisition of agricultural information is critical to precision agricultural production management and decision-making supporting the need for continued development and application of crop information monitoring technologies
- Aerial spraying technologies [46]: Agricultural aerial spraying, which falls into both manned and unmanned platforms, is a critical agricultural aviation service providing efficient and effective application for crop pest control allowing for rapid response to sudden pest outbreaks of pests and the ability to apply crop production and protection products in terrain difficult for ground based systems, such as rice. Additionally
- Real time image processing [46]: Real time image processing is needed to bridge the gap between remote sensing and variable-rate aerial application. Data analysis and interpretation is one of the most important parts of precision aerial application.
- Multisensor data fusion technology [46]: A key step in successful precision system development is creation of accurate prescription maps for aerial application. Creation of these maps can be assisted by multisensor, multispectral, multitemporal and even multi-resolution data fusion utilizing GIS techniques.
- Big data analytics in agriculture applications [47]: This provide a new insight to give advance weather decisions, improve yield productivity and avoid unnecessary cost related to harvesting, use of pesticide and fertilizers.

2.1.3.5 Interview results:
Based on the answers given from the interviews [b2] I can conclude:

- All of the people I interviewed where biological farmers because the of the following reasons:
    - Less paper work and requirements of inspection agencies.
    - Wanted to help the environment (People and Planet)
    - Demand for biological crops grew which allowed to afford it.
- The amount of biological farmers are steadily growing but some can be considered "hybrids"
    - Hybrids are biological farmers who in majority produce ecological, but if times are bad or some issue pops up they will temporary resort to pesticides to supply the demand.
- Their opinion about solar power is sceptical, some believe it is a true asset other don't see potential in it. One thing they can agree on is that solar energy is only useful in sunny climates in agriculture. In other climates new technologies will have to be made to produce green energy.
- The concept of IoT and Smart Devices is already very known, but the knowledge about it differs for each person. Some already have fully automated systems which can satisfy their needs, but lack the ability to be further expanded. Others just don't know what can be done with it or are not heavily invested.
- All of the people interviewed would not mind large level of automation but three points where important to them:
    - Integrity of the system.
    - Accuracy of the system.
    - Feasibility and advantage in cost for a sustainable income.
- All of the people liked the idea of modularity because it can save them money and gives them freedom. Some are willing to invest or help me with it if there is a clear direction a proper research done. People are mainly interested in adding their own functionality and modules with the system that can-do specific tasks which are not widely available.

2.1.4 Conclusion

From the research and interviews we can conclude the following:

- Farmers are constantly pushing forwards to automate processes in their company but sometimes financially or technically are unable to implement specific desired functionality. This means the system needs to give them the ability to easily change certain aspects of the system or expand on it without too much trouble.
- Due to the low competition between suppliers and companies the innovation in the agricultural sector has decreased (according to the target demographic). This means the system should give them freedom of choice by allowing third parties to make their own submodules which in turn increases the competition between companies.
- Knowledge on new or existing technology in the agricultural sector depends drastically on the company or farmer, but majority are not informed well enough how these technologies can solve certain problems in their company. This means the system should help the target demographic to find out these technologies and learn if it can help solve problems, is feasible and how this can be done.
- There are many different aspects that contribute to the reduction of plant growth in the soil. Naming all of them would be almost and impossible task, but from their occurrences in research papers you could say the following aspect are the most important:
  - Drought stress of the plant and its ability to retain or access clean water.
  - The temperature of the soil and plant
  - The amount of nutrients used in the soil like (N), (K), (P), (Ca), (Mg), (S)
  - The pH value of the soil to prevent acidification, but in same time ensure that its not to base.
  - Metal toxicity and the diseases it brings forward.
  - The amount of C02 around the plants and how much can be adsorbed.
  - The physical properties of the soil like texture, porosity, how much water is can contain, the CeC, the available minerals in it, etc.
  - The salinity of the soil and the soil water.
- The effects of air quality on plant growth is rarely discussed, but the following can be said:
  - The most common pollutants in the air in rural areas are SO2, NOx, CO, O3, CO2 and suspended particulate matter.
  - It is still not clear is CO2 is a true pollutant, because it has positive and negative effects of crop growth. Increased amount of CO2 increase photosynthesis and reduces water transpiration, but at the same unregulated amounts of CO2 can affect the crop quality and be a hazard to human health.
  - All other pollutants (besides CO2) cause a reduction in the concentration of photosynthetic pigments viz., chlorophyll and carotenoids, which directly affect to the plant productivity.
  - Suspended particulate matter also clogs the lead stomate which increases the lead temperature, which is bas for the plant.
  - Unlike other pollutants, Ozon also reduces the plant reproductive output.
- Computer vision and AI are very recent additions to soil and plant science and are currently used for things like estimating plant disease, predicting crop yield, crop classification and detecting, estimating agricultural parameters. Important types of cameras used: Thermal, Multi-spectral, NDVI, RGB, NIR/UV, hyperspectral cameras.

2.2 Pains and gains target demographic

The target demographic which mainly consists of farmers currently are using mechanical manual labour in the form of larger vehicles which distribute water, nutrients and other materials which contribute to crop growth. This made me think about the following question in my head: "Are farmers satisfied with the current way of maintaining crops or are there ways to help with any frustration and problems they might have?"

2.2.1 Information acquisition and analysation

I am looking for a way to answer this question in couple of sentences. This can best be expressed as one sentences based from a value proposition canvas.
Using this diagram I could ask the two following questions:

1. What are they pains and gains of the customer?
2. What does my system provide to help with these pains and gains?

Upon being able to answer the two question I could formulate the answer by describing the "Fit" of the value proposition canvas and looking how far this corresponds with the question.

- For example: "Based on the value proposition canvas I can conclude that the customer does not like mechanical manual labour so in order to help him with that I could ensure that my system removes this as much as possible by doing … "

2.2.2 Methods and planning

This is primarily personal research based on answers users give so I need to make an interview where I try to ask as many people from the target demographic to participate to get a well rounded answer.

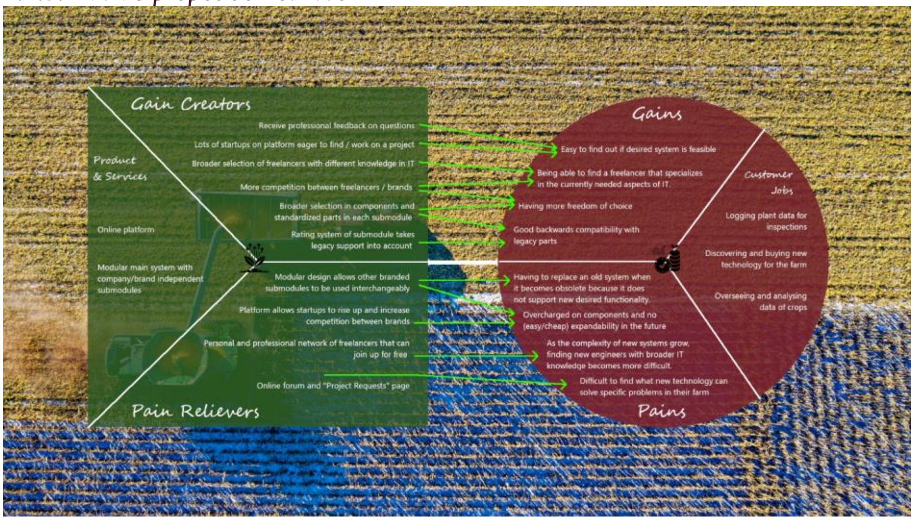
2.2.3 Results

2.2.3.1 Interview results

Based on the answers given from the interviews[b2] I can conclude:

- Based from the interview the target demographic does not have any major pains and gains regarding the quality of their existing systems. What they do have however is a problem with the expendability of their system and their knowledge of what systems can help them solve new problems they face. So a good pain relievers would be:
    - Designing a system that can help them find new technology that can solve their new problems
    - Integrating this new or existing technology into one main system by the use of submodules.
    - Have freedom of choice because of the many new competition of smaller start-ups that will jump on the platform to advertise their products.

2.2.3.2 Value proposition canvas



2.2.4 Conclusion

Based on value proposition canvas and field research the following value proposition can be formulated: "Soilar is the go-to solution which allows professionals and consumers in the agricultural field to buy backwards compatible, modular and interchangeable components from different brands to get a fair and competitive price which is highly expandable with new unique features throughout the future. With the online platform you can also easily connect to professionals and freelancers in the field, get advice and guidance on new or existing technologies that can help your company grow or sell and advertise your new upcoming product to potential clients in the agricultural sector."

2.3 Sensors, encoders, actuators, additional hardware and mechanical components

In the previous chapter I mentioned some aspects of soil science that influence the plant growth in the soil and air. I also went through some new and existing ways to increase the yield. This was purely scientifically to get a better overview of "how it all works". In this chapter I want to expand on this research and address the more technical part of this field (mainly the hardware and software side)to find what "parts" you exactly would need to build a system to measure or regulate these aspects.

2.3.1 Information acquisition and analysation

I want to know the following:

- What hardware, software, mechanical parts do I need to all the different aspects of soil and plant science?
- What other hardware, software, mechanical part do I need for the system in general?
- What communication protocol, connectors or other depending factors do I need to support to ensure all the different hardware, software, mechanical parts can work.

2.3.2 Methods and planning

For this research to be usable in the technical field of agriculture, it would be wise to list all the different important aspects of soil and plant science that can be measured and what components, hardware software you would need for them.

It would be also useful to know what other hardware, software, mechanical parts would be needed to create the system in general.

2.3.3 Results

2.3.3.1 General soil measurements

Aspect	How to measure	Needed	About
Nitrogen assimilation	What is important is that there is a good pH and Ionic balance. This means for every NO3- uptake, there must be a cation uptake or anion excretion. [48]	- Ammonium and nitrate sensor. - pH sensor - ion and anion sensor	- Measuring Ammonium and Nitrate in the soul is bascily impossible because the NH4+ and NO3- are constantly changing, it can volatize, transform or leach. But you could use an ammonium biosensor [49] but this would not be very reliable. - The best way would be to measure the Nitrogen nutrients in the soil (see 3.2 Nitrogen) - pH sensors are very easy to find and connect.
Drought stress	To detect if a plant has drought stress, you would need a series of sensors which collect digital data which in turn has to be filtered with DWT (Discrete Wavelet Tranform). This can be done by [50]: 1. Thermography 2. Hyperspectral vision 3. Gas exchange principles	1. Infrared thermometer sensors OR thermal cameras 2. Hyperspectral camera 3. Infrared Gas Analyzer (IRGA)-based carbon dioxide (CO2) sensors [51] OR NDIR sensor [52][53]	- Thermography measurement have a resolution that is too low and is easy susceptible to noise. - Hyperspectral vision only works in dark controlled rooms - Gas exchange principles are the best overall option. The sensors used here require a supply of air with the containing CO2. They can work with UART, UCHAR, analogue or be digital
Low nutrients reserves	To measure if a plant has a low nutrient reserve, you should measure the amount of starch present in the plant at night. Doing this from the soil is not possible unless you take a leaf sample directly.	-	-

Aluminium (and Iron) toxicity	Measuring aluminium and iron toxicity can be difficult because the symptoms can differ for each type of plant. 1. Some plant will get white spots or other distinctions on the lead it self 2. Others will have larger expanded root with increased phosphate accumulation. 3. Another way this toxicity can be detected in the soil by looking at the pH, the total Al en Fe present in the soil. [54]	1. High resolution Camera 2. Night vision camera or phosphate sensor 3. pH sensor and electrochemical sensors [55]	- To reduce Al and Fe toxicity, you need to add Ca in the form of gypsum or lime. - Electrochemical sensors are relatively expensive to other kinds of sensors. [56]
Acidity (not Al-toxic)	Just like the name suggestes, measuring soil acidity can be done with a pH sensor	- pH sensor	Most pH sensors are analogue, but some can be digital. Most common ph sensors use a BNC connector so an adapter is needed. Other also use an US, DIN or S7 [56] connector. These require onboard PWM modulators.
Phosphorus fixation	1. Phospurus fication can be spotted by looking at the pH values. 2. Another way is to look at the amount of phosphorus in the soil	1. pH sensor 2. NPK-sensor or electrochemical sensor.	-
Soil Salinity	Soil salinity is difficult to exactly measure, but can be astimated by [57]: 1. Measuring the electrical conductivity (EC) of a water and soil mix 2. Using an electromagnetic induction device (EM) to measure the apparent EC. 3. A chemical analysis of total dissolved TDS to measure ion concentration	1. EC sensor 2. EM device / sensor 3. TDS sensor	- EC and EM sensors are analogue and are connected by a BNC or similar connector - TDS sensors can be analogue or digital and be connected with a BNC (or similar) or smaller 3 pin fan header connector.

Soil erosion	Soil erosion is a complex process that happens because of many different factors so it is almost impossible to accurately prevent or measure it. What you can do how ever is detect it by looking at the soil properties. For example looking at wet patches (puddles), cracks, gullies, group of plant falling. This can be done with the help of computer vision [58]	- High resolution camera or hyperspectral camera (anisotropy) - UPV (Ultrasonic Pulse Velocity) sensors - Echo sensors [59]	Detecting cracks with an UAV (Unmanned Arial Vehicle) is the most accurate, fastest and can be done over a large area.
Soil moisture stress	Measuring the soil moisture stress is very straight forward and can be done with a moisture sensor	- Moisture sensor	-
Soil Temperature	Measuring the soil temperature is very straight forward and can be done with a temperature sensor	- Temperature sensor	-

2.3.3.2 Measuring minerals in the soil

Miniral	**How to measure**	**Needed**	**About**
Nitrogen (N)	You can measure nitrogen content with an optical transducer and a photodiode. he optical transducer is implemented as a detection sensor which consists of three LEDs as light source and a photodiode as a light detector. The wavelength of LEDs is chosen to fit the absorption band of each nutrient. The nutrient absorbs the light from LED and the photodiode convert the remaining light that is reflected by reflector to current. [60]	- Optical transducer made from 3 LEDs. - Photodiode as light detector.	These kind of optic sensors can be analogue or digital.

2.3.4 Conclusion

Based on the list I can see that most aspects of soil and plant science can be measured with a couple of sensors these being:

- EC sensor
- pH sensor
- EM sensor
- TDS sensor
- NPK sensor
- NIR/NDVR camera's
- Electrochemical sensors
- Normal camera
- Hyperspectral camera

2.4. User interaction and implementation

When reading in a page of the book “Translating systems thinking into practice”[b1] in section “2.5.5.2 Principle2: interaction and relationships” I got really inspired and the information written there made me really think about the usability of systems in general.
Here is was note that the interaction between components of a system is more important than the behaviour of these components themselves. This due to the fact that the quality of the interaction is the first and probably only thing the user can use to judge the overall system.
For example if the logic behind a student grading system is very complex and accurate but the way teachers can access the system is too difficult or confusing than the overall quality will degrade because it is simply not usable or will underperform due to incorrect parameters given to the system.

This is the reason I think it is important to ask the following questions:

- In what ways does the target demographic currently interact with tools or devices that help with maintaining crops?
    - Why do they use these system like this?
    - What do they think is frustrating or bad about the interaction?
    - What are the positives about this interaction?
- To what extend is the target demographic willing to change their current way of interaction with systems that help with maintaining crops?
    - What do they absolutely do not want to change?
    - What are things they can get behind or would like to see?
- How should the interaction physically or visually with the system happen?
    - What information about the soil are they interested in seeing?
        - In what way should this be represented?
    - How do they like to interact with he system?
        - By touch, speech or some other way?
- How do you translate the desired method of interaction into physical devices which can be used?
    - What hardware, software and other parts are required?
    - How do you link all these components to work with each other?
    - What are the requirement and constraints of each part?

2.4.1 Information acquisition and analysation

I am looking on way to describe the system context in a global matter. This includes all the devices, tools and other materials that are needed to interact with the system. I also would like to know how to these parts will interact and what their use cases are (what does each part do and with what purpose?).
To be able to do this I need to know the following specifically:

1. How does the target demographic LIKE to interact with the system?
2. How CAN these desires be translated into components?
3. In what way MUST these components interact with each other in order to satisfy the desires?

Answering these three questions ensures that I can make a traceability diagram where I will link the use cases with requirements to components of the system.

2.4.2 Methods and planning

To be able to answer this question realistically I need to the following:

- Do some minor desk research on “system thinking” based on interaction on the system.
- Interview of personally ask the target demographic to get their point of view with requirements.
- Make a system context to describe the communication between components.

2.4.3 Results

2.4.3.1 Interview results

Based on the answers given from the interviews[b2] I can conclude:

- Majority of the target demographic already has completely automated systems that can handle their basic needs (these being related to the farm) and the way they interact with these system is through an application of a integrated display.
- The majority really does not want to use manual labour to simply check on the plants and they are more focused on overseeing the plant digitally than actually doing this the old way by hiring people.
- Currently there lays an issue with the expendability of these system which causes many people to still have to use manual labour for things like documentation and keeping up backlogs of the plants. They would really appreciate if this could be automated but are open to the idea to make this a separated module that can be purchased beside the main system.
- The way data is represent varies extremely what the data represents but the majority believed they want to see at least the following representation methods for all type of data:
  - Bar chart, line chart, circle chart (percentage based).
  - Map with zones, difference levels or hotspots.
  - Physical image or video with date, time and location.
- They find the integrity and accuracy of the data the two most important parts of the system.
- They would apricate some structure and categories of the data.
  - For example: Water -> (Moisture Plant -> (… , …) , Moisture Soil -> (…, …))
- Some people would like the idea that the system can be moved easily and would like it to be energy efficient enough to work on solar energy. Other don't care much about it. But what both parties agree on is that every aspect that can be done wirelessly should be wireless.

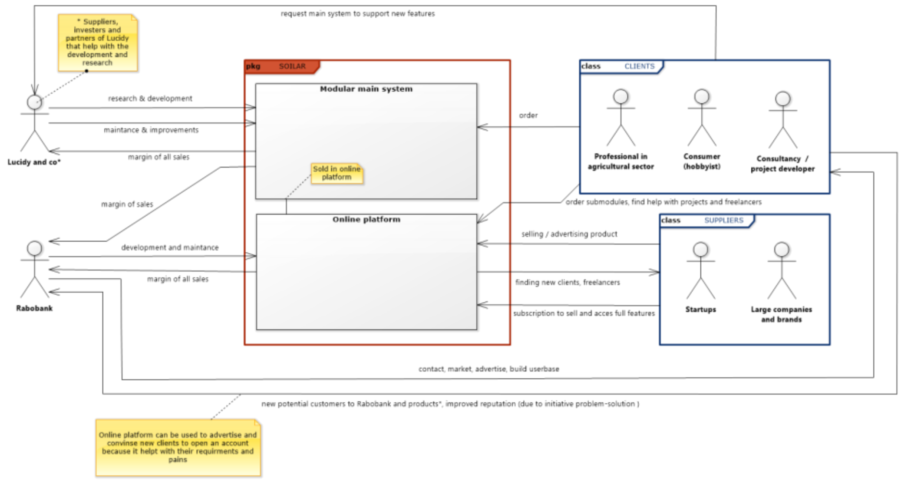
2.4.3.2 System thinking

Systems thinking is a method to analyse the relationships between the system's parts to understand the potential for better decision-making. The system isn't just a collection of things, it consists of elements, interconnections and a purpose.

A football team is a system, with elements such as players, a coach, field and a ball. Interconnections are game rules, strategies and players' communications. The purpose is to win games, have fun, or have exercise. We are all members of numerous systems and subsystems.

Systems thinking has typically some of the following characteristics: the issue is important; the problem faced is not a one-off event; the problem is familiar and has a well-known history and people have unsuccessfully tried to solve the problem before. For these reasons, systems thinking is more a strategic than operational tool.

2.4.3.3 System context diagram



3: Conclusion and discussion

An Architecture document has been made to further explain the inner workings of the proposed system.

References

You list all sources that you have used in the reference list. Your educational program will often specify which style you must use for the acknowledgement of sources. The most prevalent style is APA style.

[s1]: https://modernfarmer.com/2016/11/scientists-may-found-way-increase-crop-yield-bonkers-20/

[s2] https://www.wur.nl/en/Dossiers/file/Vertical-farming.htm

[s3] https://ieeexplore.ieee.org/document/8273717

[s4] http://www.robotics.tu-berlin.de/fileadmin/fg170/Publikationen_pdf/martinmartin_14_ki_iros.pdf

[s5] https://www.cropx.com/

[b1]
https://books.google.nl/books?id=fDduDwAAQBAJ&pg=PT52&lpg=PT52&dq=why+good+interaction+with+a+system+is+more+important+than+the+system+itself&source=bl&ots=x1MmuvhoxJ&sig=ACfU3U1b9ND22_7NUACmNeJBV85povmELw&hl=nl&sa=X&ved=2ahUKEwjHu9mj-PzgAhUNMewKHZ-gC0wQ6AEwAHoECAMQAQ#v=onepage&q=why%20good%20interaction%20with%20a%20system%20is%20more%20important%20than%20the%20system%20itself&f=false

[b2] Interview data.docx, interview raw data.docx

[1] https://www.bioflora.com/

[2] https://www.scientificamerican.com/article/precision-farming/

[3] https://en.wikipedia.org/wiki/Pesticide

[4] https://www.jstage.jst.go.jp/article/jcs1927/70/4/70_4_530/_article/-char/ja/

[5] https://pdfs.semanticscholar.org/6064/d56fb0d8f15c3f6016f725ae693fb7091369.pdf

[6] https://en.wikipedia.org/wiki/Nitrification

[7] https://regimeshifts.org/item/55-freshwater-eutrophication

[8] https://en.wikipedia.org/wiki/Soil_acidification

[9] Crop transformation and the challenge.pdf

[10] https://en.wikipedia.org/wiki/Nitrogen_assimilation

[11]
https://books.google.nl/books?id=YKh7DwAAQBAJ&pg=PA123&lpg=PA123&dq=%22The+phosphorus,+potassium,+calcium,+magnesium+and+micronutrients+that+soils+naturally+supply+to+plants+come+from+the+dissolution+of+primary+or+weatherable+minerals%22&source=bl&ots=2KEsug7DXk&sig=ACfU3U1NLbk775ThvR06hP-96py9_d-asA&hl=nl&sa=X&ved=2ahUKEwijsoLEl7bhAhWFr6QKHXdAA9MQ6AEwAHoECAEQAQ#v=onepage&q=%22The%20phosphorus%2C%20potassium%2C%20calcium%2C%20magnesium%20and%20micronutrients%20that%20soils%20naturally%20supply%20to%20plants%20come%20from%20the%20dissolution%20of%20primary%20or%20weatherable%20minerals%22&f=false

[12] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4379750/

[13] Aluminium Toxicity and Tolerance.pdf

[14] The physiology of metal toxicity in plants.pdf

[15] https://link.springer.com/chapter/10.1007/978-1-4612-2894-3_5

[16] https://www.slideshare.net/StanleySamuel1/phosphate-fixation

[17] https://www.cabdirect.org/cabdirect/abstract/19511900032

[18] https://www.sciencedirect.com/science/article/pii/S0065211308601108

[19] https://www.canr.msu.edu/news/the_peaks_and_valleys_of_phosphorus_fixation

[20] https://en.wikipedia.org/wiki/Salinity

[21] https://www.qld.gov.au/environment/land/management/soil/salinity/impacts

[22] https://www.pnas.org/content/104/33/13268

[23] https://en.wikipedia.org/wiki/Soil_erosion

[24] Environmental_and_Economic_Costs_of_Soil_Erosi.pdf

[25] https://en.wikipedia.org/wiki/Crop_rotation

[26] The use of caesium-137 measurements in soil erosion surveys.pdf

[27] Soil structure and management.pdf

[28] https://en.wikipedia.org/wiki/Soil_texture

[29] https://www.gardeningknowhow.com/garden-how-to/soil-fertilizers/soil-porosity-information.htm

[30] https://en.wikipedia.org/wiki/Cation-exchange_capacity

[31] https://en.wikipedia.org/wiki/Moisture_stress

[32] https://www.researchgate.net/publication/271421733_Hyperspectral_Imaging_for_Detecting_Water_Stress_in_Potatoes

[33] Soil_Temperature_and_Root_Growth.pdf

[34] http://www.soilmanagementindia.com/soil-temperature/influence-of-soil-temperature-on-plant-growth-and-nutrition/1748

[35] https://www.ncagr.gov/CYBER/kidswrld/plant/nutrient.htm

[36] https://books.google.nl/books?hl=nl&lr=&id=e7jYBAAAQBAJ&oi=fnd&pg=PP1&dq=air+pollution+in+agriculture&ots=ZAZbfr2rRz&sig=GCgnk7_Gi5bpwMsv69TkxGW9Ko4#v=onepage&q=air%20pollution%20in%20agriculture&f=false

[37] Air pollution induced changes in the photosynthetic pigments of selected plant species.pdf

[38] Quantifying the effects of ozone on plant reproductive growth and development.pdf

[39] https://www.sciencedaily.com/releases/2016/05/160504092936.htm

[40] https://www.scientificamerican.com/article/ask-the-experts-does-rising-co2-benefit-plants1/?redirect=1

[41] Pomegranate Disease Detection Using Image Processing.pdf

[42] Opportunities, Challenges and Technology Enablers.pdf

[43] https://support.pix4d.com/hc/en-us/articles/202559059-Which-cameras-can-be-used-for-precision-agriculture

[44] Devices, Systems, and Methods for Automated Monitoring enabling Precision Agriculture.pdf

[45] http://www.fao.org/3/a-i6583e.pdf

[46] Current status and future trends of precision agricultural aviation technologies.pdf

[47] https://ieeexplore.ieee.org/abstract/document/7375220

[48] https://en.wikipedia.org/wiki/Nitrogen_assimilation

[49] https://www.sciencedirect.com/science/article/pii/S0925400504004691

[50] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4239877/

[51] http://researchguides.library.vanderbilt.edu/c.php?g=69346&p=809921

[52] https://www.analog.com/en/analog-dialogue/articles/complete-gas-sensor-circuit-using-nondispersive-infrared.html

[53] https://www.banggood.com/nl/NDIR-CO2-Sensor-MH-Z14A-PWM-NDIR-Infrared-Carbon-Dioxide-Sensor-Module-Serial-Port-0-5000PPM-p-1248270.html?gmcCountry=NL&currency=EUR&createTmp=1&utm_source=googleshopping&utm_medium=cpc_union&utm_content=2zou&utm_campaign=ssc-nl-css-all-0423&ad_id=344756946906&gclid=Cj0KCQjwz6PnBRCPARIsANOtCw3jJAOJUJj5AKWVvHkqE5XTPha0qPGFmMcFECw9cb7z1ZjA7s_QfQgaAkGeEALw_wcB&cur_warehouse=CN

[54] https://www.researchgate.net/post/What_are_reliable_criteria_for_identification_of_Al_toxicity_in_an_acid_soil

[55] Electrochemical sensors for soil.pdf

[56] https://camblab.info/wp/index.php/what-connector-do-i-need-for-my-ph-electrode/

[57] https://www.agric.wa.gov.au/soil-salinity/measuring-soil-salinity

[58] https://link.springer.com/article/10.1007/s40808-015-0036-z

[59] https://www.fprimec.com/3-methods-crack-depth-measurement-in-concrete/

[60] https://ieeexplore.ieee.org/document/8312001