Identifying the Requirements of an Agricultural Robot for Sensing and Adjusting Soil Nutrient and pH Levels

by

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ABSTRACT

The nutrient requirements of soils using in agriculture for crop production were examined to determine the needs of a robotic system used to detect and regulate the nutrition levels of the soil. Nitrogen, phosphorus, and potassium levels, along with pH, were chosen as the most important factors for regulation. Based on these four soil qualities, the basic functions the robot needs to be able to perform were determined.

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1. Introduction

When applying fertilizers and lime to fields, typically farmers will send out soil samples for testing to an outside lab and then, based on the lab's recommendations, apply a uniform mixture of nutrients to the entire field. This soil management practice is both time consuming and imprecise. Taking soil samples and sending them for analysis in a lab can take several weeks to complete. The resulting recommendations will not take into account variations that exist in the soils in different parts of the same field, and so can lead to over and under application of nutrients, resulting in damage to crop yield and possibly to the environment. One way to improve accuracy and efficiency in this process is to create an agricultural robot with the ability to diagnose nutritional deficiencies in soil directly in the field and apply the nutrients necessary to correct the deficiency. In this thesis I will describe what such a robot would need to function.

2. Soil Nutrient Needs

In order to successfully grow crops, it is necessary to regulate the levels of several key nutrients in the soil. There are 17 elements which are usually recognized as essential to plant growth. Carbon, hydrogen, and oxygen are supplied by air and water. The remaining 14 elements are plant nutrients which can be retrieved from the soil (Troeh). The primary nutrients needed in order for crops to grow are nitrogen, phosphorus, and potassium. These three nutrients are gotten mainly from organic matter, although potassium also can be gotten from mineral solids. Calcium, magnesium, and sulfur are also needed by plants in relatively large amounts and are gained mostly from mineral solids in the soil (Troeh). Nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur are all needed by plants in large enough quantities to be known as macronutrients. Nutrients needed in smaller quantities, the micronutrients, are iron, manganese, copper, zinc, boron, molybdenum, chlorine, and nickel. Other elements which are beneficial, but not essential, to plants are cobalt, sodium, and silicon (Havlin).

The nutrient level of a soil which has not been altered by humans is determined by the composition of the materials from which the soil was formed, the rate organic matter is mineralized, mineral addition and subtraction by the atmosphere and water, and removal of nutrients by plants which have previously grown in the soil (Troeh). Different combinations of these factors can lead to soils with vastly different characteristics and, as a result, different suitability for agriculture.

Different soil types have different cation exchange capacities. The cation exchange capacity of a soil is the total quantity of negative surface charge on the minerals and organic matter available to attract cations in solution. The cation exchange capacity is one of the soil chemical properties which most influences nutrient availability and retention. The level of the cation exchange capacity of a soil is strongly affected by the nature and amount of clay minerals and organic matter present (Havlin).

Plants absorb nutrients primarily through their roots and root hairs. The rate at which the take up nutrients varies from species to species based on their individual nutritional needs, the rate at which they grow, the distribution of nutrients in the soil around the roots, and the rate that the nutrients in that soil are replenished (Havlin). The size a crop's root network and the proximity of nutrients to the root system are key factors in determining how much of a nutrient a plant will take up.

This paper will be focusing on nitrogen, phosphorus, and potassium as the three main nutrient types which should be managed in an agricultural system. Beyond nitrogen, phosphorus, and potassium, the macronutrients needed by crops are calcium, magnesium, and sulfur. These three elements generally exist abundantly enough in soils naturally to meet the needs of plants (Wild). These elements rarely need to be added to the soil, and so will not be a focus of this paper. The micronutrients are needed in only very small amounts in soil, much less than the macronutrients. Some micronutrients are present in much larger amounts in soil then needed by plants (Troeh). Generally the amounts of micronutrients needed are low enough that testing for their levels in soils needs to occur more infrequently than that of the macronutrients.

3. Soil Management

A complete soil management plan is based on several factors (Havlin). The type of soil impacts how it is managed. It is important to know where water sources in a field are. Soil testing shows what nutrients are deficient. Knowing what crops were previously planted in a field also gives insight into nutrient deficiencies, especially when the previous crops were legumes. The expected yield of the crop must be estimated fairly accurately in order to determine nutrient needs. The timing and placement method of the nutrients must be appropriate.

In order to manage soil, it is necessary to know the levels of nutrients already in the soil. Testing done on soils can identify its nutritional levels. Nutrient levels found by soil tests are a good indication of how much of a given nutrient will be absorbed by crops, although the numbers are not directly equivalent. These nutrient levels are useful for predicting the probability of obtaining a profitable response in the soil to fertilizer or lime and can be used to provide a basis for fertilizer and lime recommendations (Havlin).

Traditional soil testing involves taking samples from around a field and sending them to a lab for testing. Soil testing labs exist at universities, as parts of state government departments, and as private companies (Oneil). Generally these labs make fertilizer and lime recommendations based on their testing of the soil samples and based on the soil type and conditions of typical soils in their area. Soil testing labs can take up to a month to return soil sample results and take especially long during the busier summer months (UMass).

Interpretations of soil tests are generally based on crop response experiments performed previously. Soil tests are calibrated against crop responses to applied nutrients in field experiments conducted over a wide range of soils (Troeh). Yield responses from various rates of nutrient application are related to the quantity of nutrients which the soil test indicates are available. An accurately calibrated soil test will indicate the degree of nutrient deficiency in a soil and estimate the nutrient rate required to optimize crop productivity (Troeh).

Another important component of managing a soil for a particular crop is knowing the average amount of a given nutrient which is taken up by that crop when it grows. Average nutrient use based on crop type and yield is well documented for the nitrogen, phosphorus, and potassium usage of most crops.

Nutrient deficits can be corrected by fertilizers. Fertilizers come in many forms. They can be single compound or a mix of nutrients. Some are manufactured and some are composed of organic materials like animal manure. Manufactured single compound fertilizers can be either granules or liquids (Havlin). Fertilizers used by the robot in this paper are single compound, to make precision application simpler.

It is possible for fertilizers to improve the quality of many types of soil, but it is important to remember that some soils are not suitable for crop production even with careful management. Some physical properties of soil such as shallow depth and low permeability will always limit a soil's productivity. For that reason, it is important to choose soils with have high potential but low fertility for fertilizer application (Havlin).

Fertilizer placement options are some combination of surface or subsurface application before, at, or after planting. When placing nutrients before or at planting, fertilizers can be either broadcast or banded. Broadcasting fertilizers involves applying nutrients uniformly on the soil surface before soil tilling, allowing for little control in deviating nutrient levels across the field. Band application is generally more accurate (Havlin). Subsurface band application involves placing the nutrients at a depth of 2 to 8 inches below the soil surface (Havlin). In full and reduced tillage systems, a knife applicator is often used to apply nutrients in subsurface bands. Subsurface point or spoke inject of fluid fertilizers can also be effective, especially in applying immobile nutrients (Havlin). Surface band application of fertilizers can be effective in some cases. In certain cropping systems and soils, surface band nitrogen applications can improve nitrogen availability. When applying nutrients in bands at planting, nutrients are generally applied 1 to 2 inches below the seed or 1 to 3 inches to the side and below the seed (Havlin). Fertilizers for crops are generally placed once before its planting. Phosphorus and potassium levels are generally fine for the rest of the growing season, but nitrogen can need reapplication if rain levels are unusually high.

Despite the decrease in reliance on crop rotations for nutrient maintenance purposes due to increasing use of fertilizers, rotating crops between seasons can also be an important part of soil management (Havlin). The use of deep rooted crops such as legumes between other crops can improve soil structure, water infiltration, and nutrient redistribution from subsoil to surface soil. A more continuous vegetative cover, as opposed to leaving land fallow during off seasons, can decrease erosion and water loss. Crop rotation can help with weed and insect control and can reduce diseases by fostering competition between soil organisms. Continuous cropping systems are now viable with the nutrients added by fertilizers, but lack these advantages. Advantages to a continuous cropping system are largely economic in nature (Havlin).

4. Robot Concept

A device which would unify the testing, diagnosing, and application of nutrients to soil would increase the accuracy of nutrient application and allow for nutrient application that takes into account variations in nutrient levels across a single field. Such a robot would be able to move along a field, taking differences in nutrient levels into account and acting on these levels to fix them for the particular crop to be planted in the field.

The key factors in managing a field are the moisture levels, the nutrient levels, the pH of the soil, and the salinity of the soil. The robot proposed in this paper would monitor nitrogen, phosphorus, and potassium levels in soil as well as the pH. It would decide on the proper rate of and apply nutrient fertilizers and lime. Focus will be on the nutrients nitrogen, phosphorus, and potassium because they are the most important nutrients for management, being the three macronutrients which are least likely to occur in soils naturally in large enough quantities for crop production. The pH is important to manage, as the pH of a soil affects the nutrient absorption rate heavily.

Before the device was put into the field, it would be necessary to input the soil type. The soil type greatly affects the nutrient absorption rate of plants and affects how the nutrients react in the soil. It would also be necessary to input the type of crop that will be planted in the field and the expected yield of that crop.

The device would in theory travel along a field, going over the soil where the seeds will be planted. As it moved, it would sense the nutrient levels and pH of the soil under it and apply the correct fertilizers and lime to fix any deficiencies or soil acidity. The robot would be able to calculate the necessary amounts of nutrients needed based on the inputs telling the soil type, crop, and yield level and based on the sensed nutrient levels in the soil. The robot would have on board sensors which would be able to detect the level of nitrogen, phosphorus, and potassium in the soil, as well as the soil's pH.

The robot should detect soil conditions every 2 to 3 feet. In experiments done using wheat, corn, and Bermuda grass, significant differences in soil nutrient concentrations have been found in areas of soil less than 3 feet apart (Raun). In some instances, significant differences in nutrient need have been found at distances as low as 7 inches (Raun). Concentrations of nitrogen tend to be the most varied of nutrients in soils.

5. Managing Nitrogen

Of the nutrients need by crops to thrive, nitrogen is perhaps the most important one to manage (Troeh). It is both the nutrient which is most vital to improving yields and the most potentially detrimental to the environment. In most developed agricultural systems, productivity is most immediately limited by the availability of mineral nitrogen. Soils rarely contain enough nitrogen to maximize plant growth without management. Nitrogen is crucial to the health of crops and to the nutritional value humans need to derive from them.

Most organic compounds in plants contain nitrogen, including amino acids, nucleic acids, some enzymes, and energy transfer materials like chlorophyll, adenosine di-phosphates, and adenosine tri-phosphates. New cells in growing plants cannot be formed without nitrogen. Photosynthesis cannot be completed without nitrogen. Severe nitrogen deficiencies will stop plant growth and reproduction (Troeh).

Nitrogen in an ecosystem is part of a complex cycle, much of which is mediated by organic matter. Soil gains different forms of nitrogen through a variety of largely microbially mediated transformations (Schjonning). Large pools of organically bound nitrogen exist in agricultural soils, but most of it is unavailable for use by plants. As little as 1-2% of nitrogen in soils may become mineralized and thus available to crop uptake while the crop is growing (Schonning). Most of this mineralized nitrogen comes from labile organic matter and decomposing biomass (Schjonning).

The chemical nature of nitrogen allows it to occur in many very different forms, which vary greatly in their availability to plants and susceptibility to loss to the environment (Havlin). Nitrogen in soils can be renewed through biological or industrial fixation of atmospheric N_2. Still, this is often not enough to offset nitrogen lost to the environment (Havlin). Nitrate is often leached from soils by water moving through.

Nitrogen is present in soil as different molecules. Decaying organic matter causes amine groups from amino acids and sugars to become ammonium (NH_4^+) (Troeh). The ammonium reacts with oxygen in a process called nitrification, producing nitrate (NO_3^-). An intermediate step in this process produces nitrite, but it is oxidized to nitrate very rapidly. As a result soils rarely contain significant amounts of nitrite. High concentrations of nitrite are toxic to plants. Nitrate is the principal form of nitrogen utilized by plants (Troeh).

Plant uptake of NH_4^+ occurs best at a neutral pH and decreases with increasing acidity. NH_4^+ tolerance levels are narrow (Havlin). High levels can retard plant growth and restrict potassium uptake (Havlin). In contrast, it is possible for plants to accumulate and tolerate comparatively high levels of NO_3^-. The form of nitrogen preferred by a plant is determined by its age, type, environment, and other factors. Plant growth is generally improved when both NH_4^+ and NO_3^- are available (Havlin). NH_4^+ and NO_3^- nutrition is a major factor which influences the occurrence and severity of plant diseases. Increasing soil acidity with nitrification generally always happens, but acidification of soil is accelerated with continued application of NH_4^+ containing or forming fertilizers. Because NO_3^- is readily produced, it is very mobile and so more subject to leaching losses (Havlin).

It is possible for plants to have too much nitrogen, as well as too little, so it is important to manage application of nitrogen fertilizers as precisely as possible. If nitrogen levels are too high, plants will grow too rapidly. This can be especially detrimental to plants if other nutrients or water are not present in high enough levels (Havlin). When water leaches nitrogen from the soil, especially when nitrogen levels are very high, eutrophication of bodies of water can occur.

Nitrification and denitrification cause gaseous losses of nitrous oxide, a greenhouse gas. Build up of ammonia can cause acidification of soils (Havlin).

Managing nitrogen content in soils is largely accomplished by using nitrogen fertilizers. The addition of N_2 fixing plants, such as legumes, to a cropping system can also help alleviate the effects of nitrogen removal at harvest. Manure is sometimes used as natural fertilizer. Chemical fertilizers containing nitrogen can be produced.

In all crop systems, there exist significant differences in the year to year crop nitrogen demands. Differences in nitrogen use efficiency can be caused by the weather conditions during the crop's growth period, crop protection intensity and timing, the choice of crop cultivars, and other differences in management (Havlin).

The application of nutrients to fix nutrient deficits is influenced by the mobility of the nutrient. Nitrogen is a very mobile nutrient, and can be dragged down through the soil by water running through. For mobile nutrients, crop yield will be proportional to the total quantity of the nutrient available in the root zone. Mobile nutrients have minimal interactions with other soil constituents. When checking for mobile nutrients, such as nitrogen, it is important to take samples of the soil which profile the depth, for at least 6 in below the surface (Troeh). The robot will need to be able to take samples of soil for analysis at a depth of at least 6 in.

Predicting how much nitrogen fertilizer is needed to help a crop reach its yield goal is very complex and exact methods are beyond the scope of this paper. Of the three main macronutrients, nitrogen is the most difficult to chose fertilizer levels for. Nitrogen recommendation models are developed and redeveloped often, with many theories, formulas, and computer models existing to try and predict necessary nitrogen levels (Jaynes). Nitrogen recommendation models are generally based on experimental data which varies nitrogen input and uses curve fitting to create a response function (Jaynes). The robot must have a viable nitrogen recommendation model for the area it is operating in as part of its software.

Nitrogen loss mechanisms have to be considered when deciding on the timing of nitrogen fertilizer application. Nitrogen leaching in soils is affected by the rate of nitrification, the amount of rainfall, the permeability and water-holding capacity of the soil, and the crop being grown (Troeh). Nitrogen should be applied as close to peak crop nitrogen demand as possible (Havlin). Because nitrogen is a mobile nutrient, the amount and distribution of rainfall must be taken into account when deciding when to apply nitrogen fertilizer. As annual rainfall increase, so does the potential for nitrogen leaching, especially on land that is not protected by plant cover (Havlin). Experiments have shown that rain can move nitrates from the soil surface to as deep as 2 ft below over the course of a single day (Troeh). Sandy soils are especially subject to leaching after rain, and rainfall greater than 4 inches that infiltrates a sandy soil can cause significant leaching of soil nitrate below the root zone (Camberato). Heavier soils would experience similar nitrate losses after heavy flooding. Particularly heavy rains can necessitate extra soil testing and nitrogen fertilizer application (Camberato). Denitrification becomes more likely in waterlogged soils. In warmer climates, conditions conducive to nitrification occur during a greater part of the year and so soils are more subject to nitrification and leaching. Cooler climates are generally recommended to apply NH^{4+} fertilizer during the fall after soil temperatures drop below 50° F. Course textured soils respond better to NH^{4+} application in the spring.

Generally, it is undesirable to apply large amounts of nitrogen near to seed rows at planting because of possible injury to the crop, especially on sandy soils (Havlin). Most nitrogen is applied either before planting or as an in season top or sidedressing. Under conditions conducive to nitrification, also using a nitrification inhibitor with the nitrogen fertilizer can help improve crop response. Nitrogen immobilization and denitrification can be minimized by subsurface placement of nitrogen fertilizers. This keeps the nitrogen fertilizer from interacting with surface residues and increases nitrogen recovery by the crop (Havlin). Banding nitrogen below the surface can also help prevent weeds from using nutrients to grow (Jones). The exact depth of placement needed will vary based on soil type, weather patterns, seed planting depth, and crop root depth, but it will generally range between 3 to 6 inches below the soil surface (Hairston) (Jones). Based on these facts, the robot will need to be able to band apply nitrogen fertilizer below the surface of the soil it is working.

6. Managing Phosphorus

Phosphorus is another important nutrient to regulate in soils. It is second only to nitrogen in the frequency of its use in fertilizers. In certain environments, it is even more important to manage than nitrogen (Troeh). Phosphorus is used with other elements to form complex organic molecules necessary for a plant's life, and it is an essential component of the genetic material of the cell nucleus. It is also heavily involved in the storage, transfer, and release of energy in a plant. Phosphorus is also especially important for plants' reproductive parts (Troeh).

Phosphorus forms complex ions with oxygen, like many other nutrients in plants, but phosphates are largely insoluble, leading to a sever limitation on phosphorus availability in soils. This low solubility also leads to low leaching loses of phosphorus (Troeh).

At any given time, the amount of dissolved phosphorus in a soil is very low (Havlin). The quantity of total phosphorus in soils has little relationship to the amount of phosphorus available to plants. Phosphorus absorbed by plants generally takes the form of $H_2PO_4^-$ and HPO_4^{2-}. Whether plants absorb more $H_2PO_4^-$ or HPO_4^{2-} depends on soil pH (Havlin). Plants also absorb some soluble low molecular weight organic phosphorus compounds which are the product of soil organic matter decomposition. Plant uptake of HPO_4^{2-} tends to be much slower than that of $H_2PO_4^-$. Average soils have only 1lb/acre of dissolved phosphorus, and the rates can be as low as 0.1 lbs/acre (Troeh). Most crops will utilize phosphorus at a rate of between 10 and 30 lbs/ac a year (Troeh). Phosphorus removed from the soil by plants is replaced by either mineralized organic matter or equilibrium reactions with adsorbed phosphate ions and solid phosphorus compounds (Troeh).

Phosphorus fixation in soils can be affected by many factors. These include the minerals present in the soil, the soil pH, the concentration of other cations and anions in the soil, the amount of organic matter present in the soil, temperature, time of year, and any previous flooding (Troeh).

As long as the concentration of dissolved phosphorus in a soil is kept fairly steady, plants can grow reasonably well even if the concentration is low (Havlin). The problem plants generally have is reaching the phosphate ions. Some phosphorus is intercepted by growing roots or carried to the roots with water that is absorbed. The majority, however, is taken in via ion diffusion. As a result, it is important for phosphorus to be placed very near the plant roots. Fertilizers are most effective when place in concentrated bands, instead of being mixed evenly throughout the soil (Havlin). As with the nitrogen fertilizer, the robot will need to be able to place the phosphorus fertilizer under the ground, at a depth that will be nearest the maximum amount of the crop's root system. A depth of 6-8 inches is common for row crops (Troeh).

Excess amounts of phosphorus can contribute to water pollution through eutrophication, although to a lesser degree than nitrogen due to its low mobility in soils (Havlin).

Immobile nutrients are generally simpler to make application recommendations for than mobile nutrients. Soil tests for immobile nutrients, like phosphorus and potassium, provide an index of nutrient availability that is generally independent of its environment (Havlin). Some recommendations are based solely the soil test level and yield potential of the crop. Immobile nutrient level should be tested at least annually.

Immobile nutrients affect the yield of a crop proportional to the concentration of the nutrient near the root surface because these nutrients strongly interact with or are buffered by soil constituents (Havlin).

When soil tests show nutrients at or slightly above the critical level, the soil can be maintained by phosphorus or potassium fertilizer rates that replace phosphorus or potassium made unavailable by crop removal, erosion, and fixation (Havlin). The robot will need to know how much phosphorus and potassium a crop generally absorbs during a growing season, and make sure the nutrients present are sufficient.

7. Managing Potassium

The third most important mineral to regulate in soils is potassium (Troeh). Plants absorb large amounts of potassium. Potassium is absorbed by plants is in the form of K^+ ions. Plants need relatively high amounts of potassium and can generally benefit from more potassium than the soil can supply naturally. Exchangeable potassium occurs as hydrated potassium ions (Troeh).

Potassium aids in the uptake and movement of other nutrients in plants. Ions like K^+ help maintain the osmotic concentration needed to keep plant cells turgid. Potassium is also important in the formation and transport of carbohydrates and proteins. Potassium is necessary for photosynthesis to take place (Troeh).

Because most potassium compounds are highly soluble in water, the soil solution is probably never saturated with potassium ions. Potassium ions are withdrawn from solution by adsorption to cation exchange sites before saturation can occur, but potassium in solution is still the kind most readily available to plants. Exchangeable potassium is available to a plant only if the plant's roots reaches it, and it will not move to the root unless an exchange occurs. Inorganic potassium is the principal factor in the overall distribution of potassium in a soil, but organic materials also have an effect as a source of cation exchange sites which can attract the available inorganic potassium ions (Troeh).

Potassium levels in soils do not change much over time. An average growing soil contains 30,000 lbs/ac of total potassium (Troeh). Exchangeable potassium generally exists in soils at a rate of between 100 and 400 lbs/ac. Dissolved potassium is generally less than 5 lbs/ac. Nonexchangable potassium makes up about 99% of the total potassium in the average soil (Troeh).

When potassium is changed from a nonexchangeable to an exchangeable form, it is called being released (Troeh). Release occurs when minerals containing potassium are weathered enough to break their structure. Release is affected by environmental factors like temperature and moisture levels. Potassium fixation and cation exchange capacity are effective storage mechanisms and as such, potassium leaching from soils is rare. Potassium availability is affected by the pH of the soil. Available potassium is more likely to be deficient in soils which are acidic (Troeh).

Potassium, like phosphorus, is an immobile nutrient. Potassium is often applied and incorporated into the soil before or at planting (Havlin). Fewer loss mechanisms exist for potassium than for both phosphorus and nitrogen, so applying the potassium early will have few ill effects (Havlin). Fall incorporation of potassium is generally made before planting potassium responsive crops. Fall applications of potassium are desirable, as it gives the potassium time to move down into the root zone (Havlin).

Potassium fertilizer can be placed in the ground in a band below and to the side of the seed (Havlin). This keeps the salt toxicity of potassium fertilizers, which generally have a much higher salt index than other nutrients, from affecting plant growth (Havlin). More salt tolerant crops can have potassium placed directly with the seed. The robot will need to know where seed planting will occur, in order to make sure that the potassium fertilizer, which like nitrogen and phosphorus will be band applied below the surface of the soil, will not be applied directly where the seeds will be placed and is instead put towards the side of that area by about 2 inches (Troeh). Because potassium is immobile, it must be placed where plant roots will be able to reach it (Troeh), causing the depth of potassium placement to be dependent on the crop. In general for row crops, a depth of 6-8 inches below the surface is standard (Troeh).

8. Managing pH

As mentioned in the previous sections, the pH of a soil can affect the nutrient absorption rate of nearly all nutrients required by plants, including nitrogen, phosphorus, and potassium. Acidity in soil can be caused by the leaching of bases by percolating water. Acidic soil is generally treated with lime. In addition to reducing soil acidity, treating soil with lime can help control certain plant pathogens (Havlin). The concentration of Al^{3+} ions increases as pH decreases (Havlin). This can lead to Al^{3+} toxicity in soil, which is the major growth limiting factor in acidic soils. Acidic soils can also lead to Mn^{2+} toxicity.

In arid and semiarid regions, calcareous surface soils can also become a problem, although this is less common of a problem than acidic soils (Havlin). The soils become too basic, generally due to a buildup of $CaCO_3$. This is generally corrected by the addition of acids to the soil.

In order to adjust soil pH to become more basic, lime is added. Limes are generally magnesium or calcium based (Havlin). Lime takes time to react with the soil, and the rate of reaction changes over time, starting fast then decreasing (Havlin). Nutrient fertilizers vary in their affect on the soil pH. Some fertilizers, like those containing or forming NH^{4+}, exhibit a great effect on soil pH (Havlin). Others, like potassium fertilizers, affect the soil pH very little. When applying very high rates of lime, it is better to apply it in two parts, applying half and plowing it under and them applying the other half. Lime recommendations are usually made for a 6 inch soil depth and so must be adjusted for different tillages, with deeper tillages needing more lime (Havlin). Lime should not be applied too close to planting, or it will not have enough time to react.

Lime application would likely occur several months before nutrient application, to give lime time to react with the soil and improve the soil's pH. The robot would need to sense current nutrient levels in order to predict the amount of fertilizers likely to be applied near planting time in order to offset the change in pH that the fertilizers will cause. The robot would need to know the tilling depth in order to adjust the lime application rate. The robot would need to know the acceptable range of pH of the soil for particular crops.

9. Sensors

An important component of the proposed robot which will require further research is agricultural sensor technology. The robot would need to be able to sense the nitrogen, phosphorus, and potassium levels of the soil, along with its pH. Currently, there is a significant amount of research being devoted to finding new ways to sense soil conditions.

Nutrient detection in soil is being examined. Methods of sensing the atomic composition of soils are being developed using a wide range of technologies, including atomic absorption spectrometry, flame emission spectrometry (Cresser), inductively coupled plasma, mass spectrometry (Hill, Fischer, Cave), automated colorimetry, ion chromatography (Tabatabai), and x-ray fluorescence analysis (Potts).

In order to start making physical specification of this robot, it will be necessary to find sensor technologies for soil component analysis that can be made portable. Portable sensors for agriculture are still a work in progress.

10. Conclusion

Current common agricultural methods can be improved by on site soil testing technologies and automated fertilizer and lime application. A robot which senses soil nutrient levels, determines the needed nutrient levels for the appropriate crop and soil type, and makes the appropriate nutrient adjustments by adding fertilizer and lime would improve agricultural efficient and yield. The robot would be able to sample soils from below the surface and place the fertilizers in the location most beneficial to the plants. The sensors needed for such a robot are still in development. Further research is required to determine the exact specifications of such an agricultural robot.

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