CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Tropical AgriSciences

Influence of rice husk ash on acidic soils in tropical areas

BACHELOR'S THESIS

Prague 2021

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Declaration

I hereby declare that I have done this thesis entitled Influence of rice husk ash on acidic soils in tropical areas independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FTA.

In Prague date 06.08.2021

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Acknowledgements

Abstract

The bachelor's thesis describes the influence of phosphorus addition mixed with rice husk ash and lime to enhance soil pH to obtain increased food productivity on sulphate acidic soils especially in Vietnam and possibly in all the parts of Asia.

Literature review lists important physical and chemical properties of soil along with types of soil. Some of the properties that have been listed are bulk density, pH, erodibility, texture, and structure amongst others.

An experiment conducted by applying rice husk ash, lime, and phosphorus added to pots with *Triticum aestivum.* The regression analysis was used for measurement in the laboratory conditions to determine the amount of lime and rice husk ash required to be added to the pots to reach the optimal pH of the soil. Our results show that the phosphorus addition has no effect on increasing the soil pH and that the rice husk ash has higher influence on pH than lime.

Key words: phosphorus, rice husk ash, soil, pH, liming

Abstract

Téma této bakalářské práce vysvětluje vliv fosforu smíchaného s popelem z rýžových slupek a vápencem na vylepšení půdního pH pro zvýšení výnosu v sulfátových kyselých půdách ve Vietnamu a Asii.

V literární části byly popsány důležité vlastnosti půdy a její typy. Vlastnosti, které byly popsány, byly například objemová hmotnost, pH, erodibilita, textura a struktura a další.

Vytvořili jsme experiment s aplikací popela z rýžových slupek, vápence a fosforu do květináčů s *Triticum aestivum* (Pšenice setá). Před začátkem experiment jsme využili regresní analýzu na zjištění optimálního množství popela a vápence do každého květináče. Zjistili jsme, že přidání fosforu nemělo význam na zvýšení pH půdy, a že popel z rýžových slupek měl vyšší účinek na zvýšení pH než vápenec.

Key words: Phosphorus, Rice husk ash, soil, pH, Liming

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1.1. Soil

1.1.1. Introduction to soil

Soil is a mixture of minerals, gases, liquids, and organic matter that support life all over the world. The soil body of our planet is called pedosphere which has four main functions, namely medium for plant growth; water storage, supply, and purification; modification of the atmosphere and a habitat for all the organisms. All of these functions modify soil and its properties. The term pedosphere is originated from Greek word from ground stone, pedov. Soil is created from solid phase of minerals and organic matter, as well as porous phase that holds gases. It is a product of many factors, including climate, living organisms, soils materials, etc.

Soil Composition

Water 25%

Mineral 45%

Air 25%

Organic Matter 5%
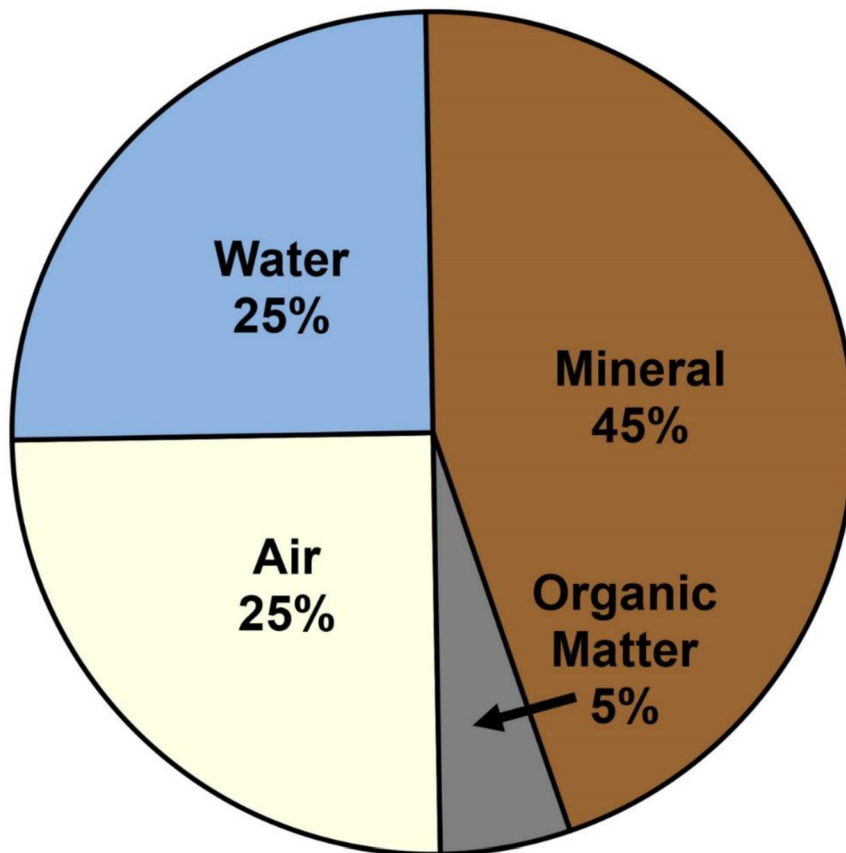
Figure 1 Soil composition (Source: Natural Resources Conservational Centre 2021)

1.2. Soil importance

Soil is one of the three most important components of planet viz., the earth, water and air. Soil also provides fixtures to plant roots. Soil is also responsible for holding water and necessary nutrients for plants to grow and it is necessary for most of the Earth's live organisms. It hosts countless micro-organisms that bind nitrogen. These micro-organisms are responsible for the decomposition of the organic material. Soil is also responsible for filtrating rainwater and preventing flooding through discharge of excess rainwater. Soil is also capable of holding and storing massive amounts of organic carbon. Without soil,

we wouldn't have bricks, that are made from clay; tea or coffee that grows in soil which we drink every day, and the cups, from which we drink liquids are also made from clay. Soil provides food for humankind and records Earths history. We build on soil, we use soil, we need soil. (Mantel 2021)

1.2.1.   Soil physical properties

There are many physical properties of soil that define it, like horizontation that makes up soil profile, from soil colour we can determine at first glance how much of organic matter is present in soil and see some of the elements, that are present, and are further described below. Soil texture is determined by relative proportions of silt, sand, and clay. Other properties to mention are bulk density, that shows us how many pores are there in the soil; soil consistency, which is the ability of soil to stick together; infiltration, erodibility, etc. .(Brady 1990)

1.2.1.1.   Horizontation

Horizons are layers that make soil profile. They are typically in parallel with the ground and in some soils show evidence of soil forming processes. There are 6 types of soil horizons, namely O horizons, that are dominated by organic materials; A horizons which are mineral layers that formed below an O horizons; E horizons which are also mineral layers that show the loss of silicate clay, iron, aluminium, humus or combination of materials; B horizons that typically form below an O, A or E horizons and are dominated by obliteration of all or most of the original rock structure; C horizons which are almost unaffected by paedogenic processes and lack properties of O, A, E and B horizons. And lastly R horizons that are hard bedrocks. Transitional hroizons are always dominated by properties of one master horizon, but have subordinate properties of the other.(Brady 1990)

1.2.1.2.   Soil colour

Soil colour is usually described using some form of colour reference chart, such as the Munsell colour chart. The Munsell system uses hue, value and chroma to describe the colour of the soil. Hue describes, where in the colour spectrum of the soil the colour exists. Value describes lightness of the colour and the chroma describes the strength of

the colour. Soil colour is determined by many soil properties and can be used as indicators of soil conditions. The most prominent property determining soil colour is the content of the soil organic matter. For example, soils with dark brown/black colour generally contains high organic matter content, therefore it is considered the most fertile. Another example that is worth of mentioning is presence of iron, that gives us brown, yellow, and red colour of the soil and found in well aerated soils, oxidized or ferric (Fe^{3+}), iron compounds are the mainly responsiblefor these interesting colours. Of course, when iron is reduced to the ferrous form (Fe^{2+}), it can be removed from some areas of the soil. When the removal process is finished, grey colour remains, or the reduced iron colour can stay in shades of green or blue. Such colour is an indication of anaerobic environment in soil, caused for examples by waterlogging.(Brady 1990)

1.2.1.3.   Soil texture

Soil texture refers to the proportion of the soil „separates "that make up mineral component of soil. They are called sand, silt and clay and make up to the groups described above. Particles that have measurements from 0.05 mm – 2mm are considered to be sand, 0.05mm -0.002 mm are described as silt, and lastly particles measuring less than 0.002 mm are considered to be clay.

The first of the two described are „inactive" part of the soil matrix, because they do not contribute to soils ability to retain soil water or nutrients.

Clay on the other hand, because of its small size and sheet-like structure, has a large amount of surface area per unit mass, and because of its surface charge attracts ions and water. Because of these properties, clay is considered as the „active" portion of the soil matrix.

Based on the percentages of sand, silt and clay, soil is divided into texture „classes", that have been organized into a textural triangle as shown in figure 2 below(Brady 1990).
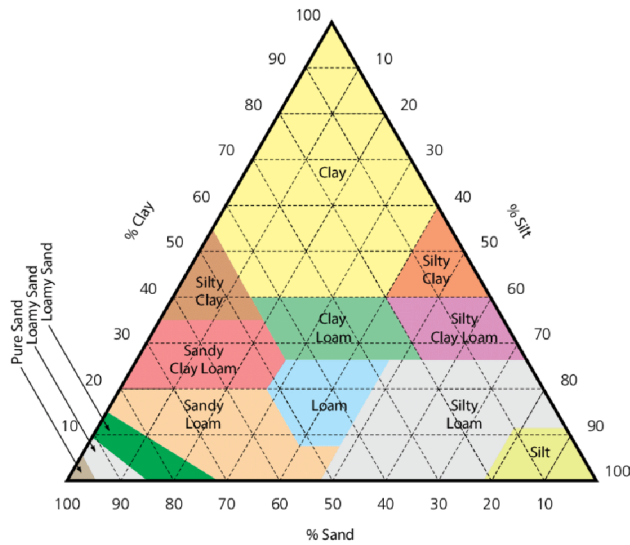
Figure 2 Textural triangle of soil (Source:Jan Meyer 2021)

1.2.1.4. Soil structure

Soil can be divided into structural units called „peds". Peds are organized into a repeating pattern that is referred to as soil structure. Between the peds are pores, through which soil air and water are transferred. Soil structure is most commonly described in terms of the shape of the individual peds that occur within a soil horizon.

Granular is roughly spherical like grape nuts. It is usually about 1-10 mm in diameter. It is most common in A horizon.

Platy are flat peds that lie horizontally in soil. It can be found in A, B and C horizons.

Blocky are „cube-shaped" with more or less flat surfaces. Its size commonly ranges from 5-50 mm in diameter and are typical for B horizons, especially in high clay content

Prismatic are largely, vertically long block often with five sides. They can take measures from 10-100 mm across.

Columnar are similar to prisms and are bounded by flat or slightly rounded vertical faces.

Massive is compact soil not separated into peds of any kind. They usually have very small pores, slow permeability, and poor aeration.

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<u>Single grain</u> is common in very sandy soils. It has no binding agent to hold the grains together in peds. Permeability is rapid, but fertility and water holding capacity are low.(Brady 1990)

1.2.1.5. Bulk and particle density

Bulk density is described as the proportion of the weight of a soil relative to its volume. It is expressed as a unit of weight per volume and is mostly measured in units of grams per cubic centimetre (g/cm^3). Bulk density describes the amount of pore space available within individual soil horizons and it is inversely proportional to pore space, and that means that pore space equals 1 – bulk density/particle density.

The difference in bulk density relates to a difference in „particle density" of mineral soil material versus organic soil material. The average particle density of mineral soil material is 2.65 g cm^{-3}, which approximates the density of quartz. Conversely, the average particle density of organic soil material is about 1.25 g cm^{-3}. Organic soil material weighs less than mineral soil material, so it will lower the bulk density of a mineral soil when added, as it reduces the overall weight of the soil.

Bulk density could be described as the proportion of the soil weight compared to its volume. Bulk density describes, how much of the pore space is available within individual soil horizons. Bulk density is described as a unit of weight per volume and is commonly measured as g/cm^3(Brady 1990)

1.2.1.6. Soil erodibility

Soil erodibility is defined by its resistance to two energy sources, which are impact of raindrops on soil surface and the shearing action of runoff between clods in grooves or rills. Henning Filip Hjulström did the first studies on erodibility of materials in canals. Thus, the Hjulström diagram was born, that shows that there are three sectors depending on water velocity and the diameter of soil particles. The most prone particles are the ones that have diameter about 100 μm (fine sand). With finer matter, cohesion develops as the clay particles merge together, while coarser parts become increasingly heavy and therefore harder to transport, as can be seen in the Hjulström diagram below.
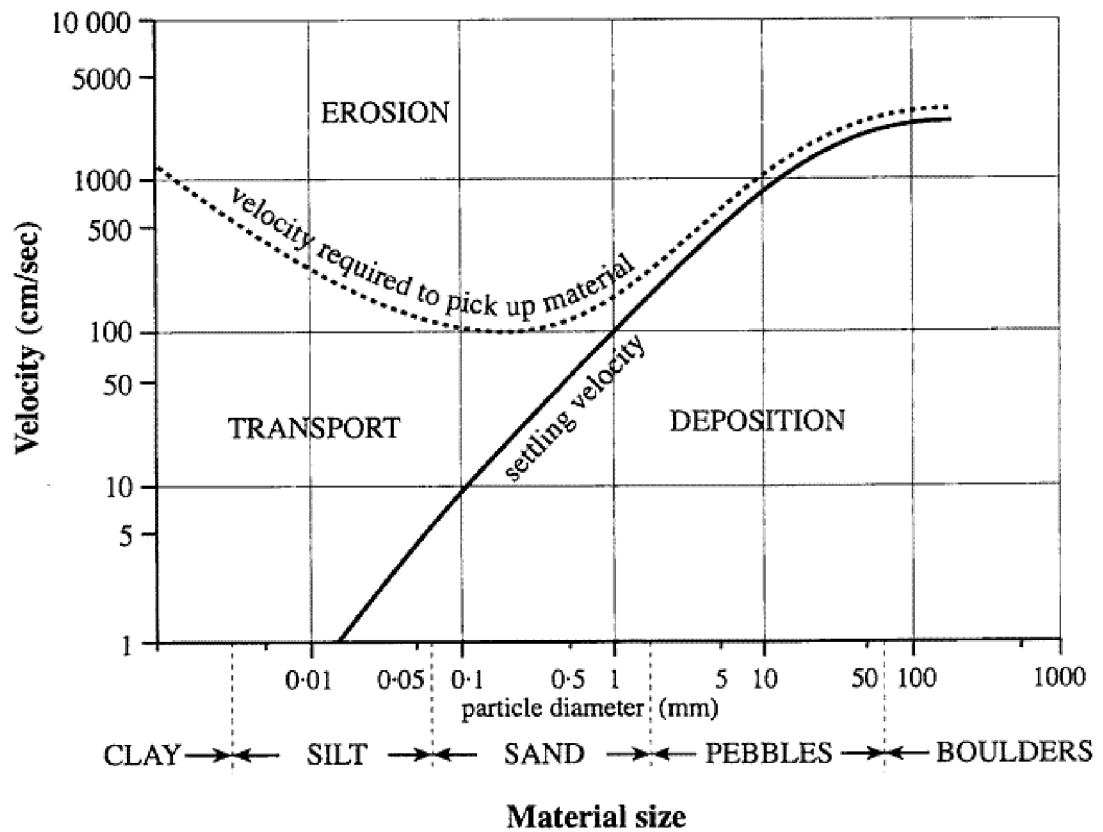
Figure 3 Hjulstorm diagram (Source: Megan de Jager 2021)

This diagram shows, that the soil material is most easily taken by runoff water, when this material is close to fine sand 100 μm. The coarser heavy particles material has, the higher speed of fluid is needed for erosion. When the flow of water is lower than 25cm/sec, no matter the diameter of particle, the soil can not erode. Thus measures have to be taken to spread and slow down the flow in order to prevent linear erosion. Fine clay and loam particles are easily transported even at low speeds, but when the material is coarser than fine sand, it sediments in a short distance from erosion site. This explains, why ditches to channel runoff water either erode if they are too narrow or steep. This is one of the reasons why diversion ditches are unpopular in developing countries, because these ditches and channel terraces have to be regularly cleared and maintained.(FAO 2021)

1.2.1.7.   Soil infiltration

Soil infiltration refers to soils ability to allow water movement into a through the soil profile. It allows the soil to temporarily store water, thus making it available for uptake by plants and soil organisms.

Infiltration rates describe how fast water enters soil and are usually expressed in cm/hour. However, during practical assessments, it is more practical to express infiltration time in the number of minutes it takes soil to absorb each cm of water applied to the soil surface. Water, that enters at slower rates may lead to creation of ponds on level field levels, erosion from surface runoff on sloping fields or inadequate moisture for crop production. Adequate amount of water must be absorbed by soil to reach optimal crop production.

There are many factors that affect soil infiltration, such as soil texture cannot be changed. Soil texture is the major inherent factor affecting infiltration. Water moves more quickly through large pores of sandy soil than it does through small pores of clay soil, especially if clay is clumped together and has little or no structure aggregation. However, depending on the amount and type of clay minerals, some clayey soils develop shrinkage cracks as they dry, thus these cracks serve as conduits for water entering the soil, causing clayey soils to have high infiltration rates under dry conditions.(NRCS 2021)

1.2.2. Chemical properties of soil

1.2.2.1.   Organic matter

Organic matter is part of the soil that is made up of plant and animal tissue in various stages of decomposition. Most productive agricultural soils have between $3-6\%$ of organic matter. Soil organic matter can be divided into three categories, namely plant residues and living microbial biomass; active soil organic matter (also referred to as detritus) and stable soil organic matter, often referred to as humus. Living microbial biomass includes the microorganisms responsible for decomposition of both plant residues and active soil organic matter or detritus. Humus is the stable fraction of the soil organic matter that is formed from decomposed plant and animal tissue. It is the final product of decomposition.

The first two named types contribute to soil fertility because the decomposition of these fractions results in the release of plant nutrients, such as nitrogen, phosphorus, potassium, etc. The third part, humus, has less influence on soil fertility, because it is the final product of breakdown of organic elements. However, it is important for soil fertility management, because it contributes to soil structure, tilth and CEC. It also affects the darkening of soils colour.

There are many benefits of humus and these benefits can be divided into three categories, physical, chemical and biological. It enhances aggregate stability, improves water infiltration and soil aeration. Humus also improves water holding capacity and reduces stickiness of clay soil. It reduces surface crusting and seedbed preparation. There are also many chemical benefits of humus. Humus increases CEC or its ability to hold onto and supply essential nutrients such as Ca, Mg and K over time. It also improves ability of the soil to resist pH change (buffering capacity). It also accelerates decomposition of soil minerals, thus making the nutrients in the minerals available for plant uptake. It also provides food for the living organisms in the soil, enhances microbial diversity which helps in ability of suppressing pests, diseases and other undesirable effects.

The sources of organic materials can vary, but amongst the main sources are crop residues, animal manure, compost, cover crops and perennial grasses and legumes. The quickest increases are obtained via sources that are high in carbon, such as compost or semi solid manure.

The management of organic matter is also a matter at hand and farm practices that help to maintain or increase soil organic matter levels vary. Farms can use conservation tillage practices. Tillage exposes the organic matter to air and will result in lowering of stable organic matter, mainly because of increase in mineralization rates and erosion losses. Another way of managing organic matter can also be rotation of annual row crops with perennial grass, which will reduce erosion and build up organic matter as a result of the decomposition of the root mass. Farmers have to also be vary of avoiding soil compaction, mainly because it increases waterlogging and maintaining proper pH to enhance microbial activity and decomposition of freshly added materials. However, the actual build-up of organic matter depends on many factors such as soil temperature,

precipitation and moisture holding capacity, soil type, existing microbial community, soil fertility status and soil pH.(Fenton et al. 2008)

1.2.2.2.　　　　Cation exchange capacity

Some plant nutrients and metals exist as positively charged ions, or „cations "in the soil environment. Among the most common cations found in soil are hydrogen (H^+), aluminium (Al^{+3}), calcium (Ca^{+2}), magnesium (Mg^{+2}) and potassium (K^+). Most heavy metals also exist as cations in the soil environment. Clay and organic matter particles are predominantly negatively charged (anions) and have the ability to hold cations from being „leached "or washed away. The adsorbed cations are subject to replacement by other cations in a rapid, reversible process called „cation exchange "

Cation Exchange capacity (CEC) is a measurement of the negative charge per unit weight of soil. CEC may vary between different types of soil, while with higher values of clay and organic content, the higher the value of CEC.(Brady 1990)

1.2.2.3.　　　　pH

pH is a measurement of acidity or alkalinity of all the materials in our world. It ranges from 0 to 14, while 0-7 is acidic and 7-14 is alkaline. pH of 7 is considered neutral. The most important that pH has on soil is ion solubility, that affect microbial and plant growth. Crops mostly thrive in pH from 6.0-6.8 and most heavy metals are more soluble at lower pH. pH is very important in controlling movements of heavy metals in soil. In acidic soils, hydrogen and aluminium are the dominant exchangeable cations. Aluminium is soluble under acid conditions and its reaction with water (hydrolysis) produce hydrogen ions. Calcium and magnesium are both basic cations. That means that when the calcium and magnesium are increasing in amount, the relative number of acidic cations will decrease. Factors that affect soil pH include parent material, vegetation and climate. Factors that affect soil pH include parent material, vegetation and climate. Some rocks and sediments produce soils that are more acidic than others: quart-rich sandstone is acidic, while limestone on the other hand is alkaline. Some types of vegetation, particularly conifers produce organic acids, that can contribute to lower soil pH values. In humid areas such as the eastern US, soils tend to become more acidic over time because rainfall washes away basic cations and replaces them with hydrogen. Addition of certain fertilizers to soil

can also produce hydrogen ions. Liming the soil adds calcium, which replaces exchangeable and solution H^+ and raises soil pH.

Every crop has an optimum pH range for optimal growth and if the pH of the soil drops under critical value, the affected crop will not prosper. However, adaptability to acidic soil varies among plants and can be improved through genetic engineering and crop breeding. Plants have numerous adaptations that can lower the impact of previously stated critical threshold of pH and nutrient deficiencies and toxicity associated with it.

Soil acidification is a process of lowering pH of soil due to many nature factors over the course of many years. It can be accelerated by certain plants and human activities or slowed down by careful management practices. The material and a history of soil´s formation affects the probability of soil acidification. Another variable that has to be taken to account is climate. The atmospheric CO_2 slightly lowers the pH of rainwater and over the course of time it lowers soil pH, thus causing acidification. The removal of base cations such as Ca^{2+} and Mg^{2+} from the root zone either by leaching through the soil or removal along with harvest plant material also contributes to soil acidification. As reported by (Robarge 2008) humid conditions that are present for many years can affect soil acidification quite significantly. Also, industrial farming and mining activities can lead to soil acidification due to acid produced form pyrite oxidation and from acid precipitation caused by the emission of sulphur and nitrogen gases. Acidic soils have unique texture and scarceness of cations that has been lost over the course of millennia through the leaching. The use of nitrogen-based fertilizers such as ammonium or NH_4^+ is reported to accelerate the rate of acidification of agricultural soil. Ammonium in anhydrous ammonia and other nitrogen fertilizers are converted to nitrate by microbes, thus producing acidity in soil. Acidic soil usually develops in reduced tillage systems where fertilizers are banded at a depth of 7,5 centimetres to 12,5 centimetres. However, acidification can be reduced in the short term through tillage and liming.

As described above, liming is an application of Ca rich materials to improve soil quality of acidic soils. The main benefit of liming is the increase of soil pH, thus enhancement of the availability of nutrients that would be otherwise unavailable due to soil acidity. Liming also increases microbial activity, which results in increased rate of decomposition of organic matter. Generally, increasing pH of soil to pH 5.5 and above would be optimal for the development and growth of nitrifers. Higher nitrification values have been

reported when liming agent is applied to strongly acidic soil (Silva-Sánchez et al. 2019)
This increase can be atributed to high microbial activity due to liming agent application
that increased soil pH. Lime also increases availability of phospohorus in highly acidic
soils by decreasing Al^{3+} and Fe^{3+} ions fixation on Al and Fe oxides.
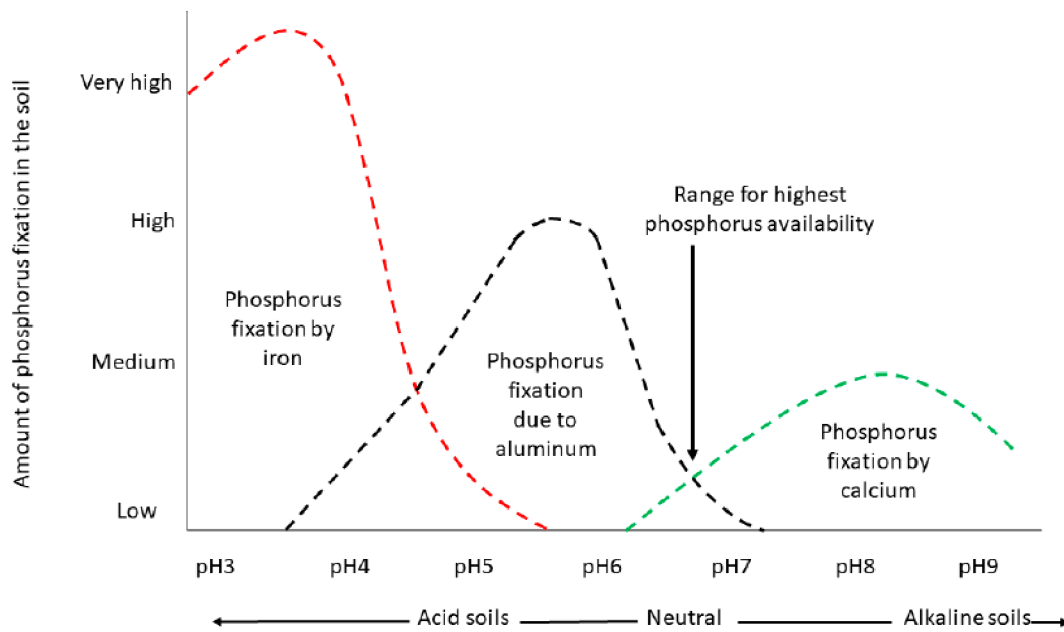
Figure 4 Phosphorus Fixation (Source: Nikola Teutsherova 2021)

The overliming however could increase pH of up to 8.5 thus resulting in precipitation of
$Ca_3(PO_4)_2$. At the moment, the role of Al-organic matter in complexes in fixing P is not
clearly understood, the decomposition of organic matter may release the bound Al into
the soil solution due to liming with possible increase of phosphorus fixation.

From the available liming agents, limestone is currently the most common material. It is
usually mined and then processed into finer particle sizes by grinding. Ground limestone
contains $CaCO_3$ and some impurities, which are in minimal volume compared to $CaCO_3$.
Dolomites, which are also used as a liming agent, however contain instead of $CaCO_3$
$MgCO_3$. Burned lime, also referred to as quicklime is ground limestone that has been
treated by high temperatures to remove CO_2, thus leaving only CaO. CaO has a CCE of
178% and reacts rather quickly. MgO can also be present if it was present in the material
before. It has to be handled carefully as it quickly reacts with water, thus creating hydrated
lime and large amounts of heat. Hydrated lime ($Ca(OH)_2$) is very fast acting and powdery
lime. This material is caustic and has been reported to burn plants that have already been

established. We also have to note marls, which are composed of seashell fragments and contain $CaCO_3$. They are most commonly used around coastal areas, because of lack of material farther from the shore. Marls tend to react similarly to ground limestones.

(Brady 1990; USDA 1999; Mahler 2004; Robarge 2008; Hansen et al. 2017)

1.2.2.4. Nutrients

1.2.2.4.1 Nitrogen

Nitrogen exists in the soil system in many forms and transforms easily from one form to another. The nitrogen cycle is biologically influenced. Biological processes are influenced by climatic conditions along with soils physical and chemical properties.
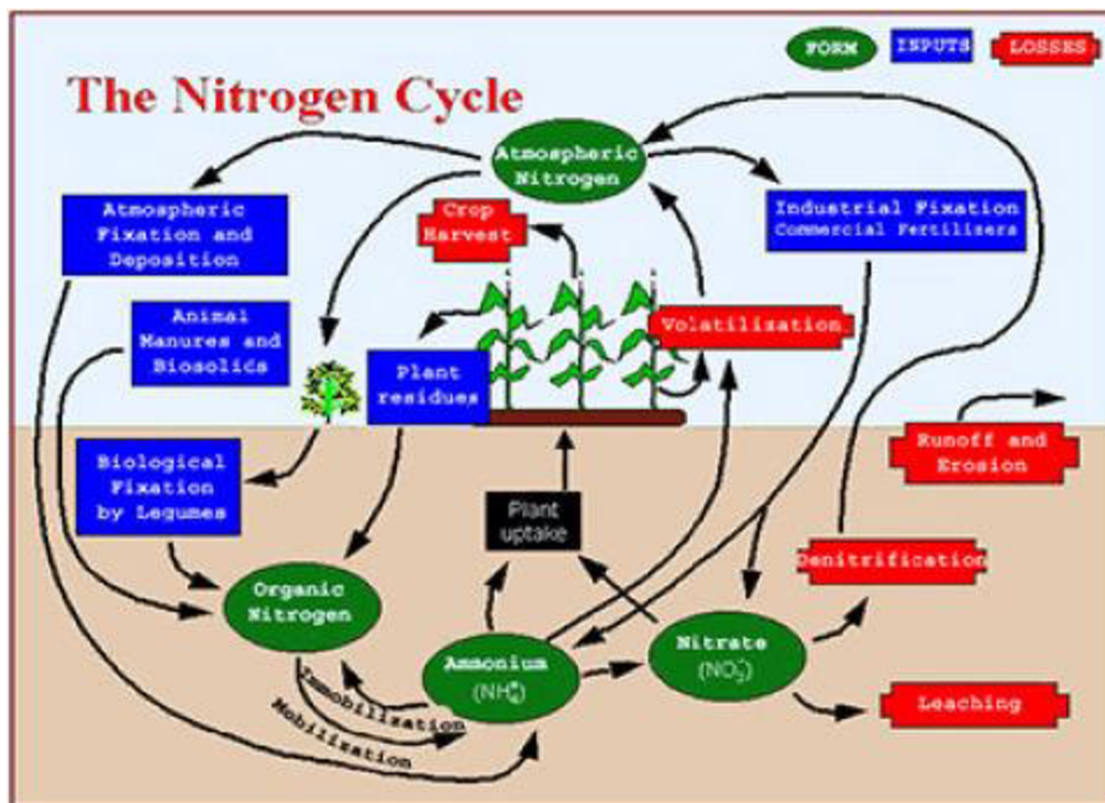
Figure 5 Nitrogen cycle (Tomm n.d. 2021)

Soil nitrogen is be subject to many transformations, which dictate the availability of N to plants and influence potential movement of NO_3 to water supplies.

Nitrification is a biological process. It is rapidly sped up in warm, moist, well-aerated soils, and slows down at soil temperatures below 10 degrees Celsius. Nitrate-N is negatively charged ion and is not attracted to soil particles or soil organic matter like NH_4^+. Hence, is prone to leaching losses.

In the process called denitrification, bacteria convert NO_3^- to N gases that are lost to the atmosphere. Denitrifying bacteria use NO_3^- instead of oxygen in metabolic processes. The process of denitrification occurs in waterlogged soil and with organic matter to provide energy for bacteria. For these reasons, denitrification process is mostly limited to topsoil. Denitrification can rapidly proceed when soils are warm and become saturated for 2 or 3 days.

Immobilization can temporarily reduce the amount of plant-available N in soil. Bacteria responsible for decomposing high-carbon and low-N residues need more N to process the material that is present in residue. Immobilization takes place when growing microbes use NO_3^- or NH_4^+ present in the soil to build proteins.

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Growing bacteria that is responsible for immobilizing soil N also breaks down soil organic matter to release available N during the growing season.

Nitrogen inputs into the soil are listed below

Atmospheric N is the major source for N in the N cycle and although it is not available to most plants, leguminous plants, such as *Medicago sativa*, *Phaseolus vulgaris* and other legume plants can use large amounts of N_2 that is present in atmosphere via biological N fixation. In this process, Rhizobium family bacteria that are present in the roots of Fabaceae plants can convert atmospheric N_2 to a form that is suitable for plant usage. For example, *Medicago sativa* crop can fix several hundred kilograms of N per acre/year. Basically, any legume crop residue that is left after harvest (roots, nodules) can supply N to the soil system when the residues are decomposed. Some of the nonsymbiotic organisms can also fix N, but N uptake to soil from these organisms is quite low (0,5 – 2,5 kg per acre/year)

Another input of nitrogen into soil is of course via fertilizers. There are many forms of nitrogen fertilizers that can be in the form NO_3^-, commonly known as nitrate. Nitrate is dissolvable in water and moves in the soil with the movement of soil water. However, applied nitrogen can be lost through leaching process, thus causing loss of the potential for nitrate fertilizers. Anhydrous ammonia reacts with the water in the soil and changes its form to ammonium form. However, ammonia is prone to escape into the air and therefore must be applied under the soil surface. Urea is another nitrogen fertilizer that is often applied into the soil.

Nitrogen can of course be lost from the soil via processes listed below.

Leaching is physical event of nitrate loss. It is the loss of soluble NO_3^- as it moves with soil water below the root zone. Nitrate that moves below the root zone has the potential to enter groundwater or surface through tile drainage systems.

Volatilization can be a major source of N loss from surface-applied N sources, such as nitrogen fertilizers. In this process, the N is lost as ammonia (NH_3) gas. Nitrogen loss through volatilization can be enhanced when soil pH is higher than 7.3, air temperature is high, the soil surface is moist and if there is a lot of residue on the soil.

A non-negligible amount of N is lost through crop removal and it accounts for a majority of the N that leaves the soil system

Another type of loss of N from the soil is through soil erosion and runoff. Losses from these events are not usually accounted for a large portion of the soil N supply, however it should be considered for surface water quality issues. (Tomm n.d.; Minesota 2018a)

1.2.2.4.2 *Phosphorus*

One of the main roles of phosphorus in living organisms is to transfer energy in the form of ATP. Adequate P availability for plants stimulates early plant growth and speeds up maturity of plants.

Phosphorus cycle is similar to many of the mineral nutrient cycles, mainly because it exists in soils, minerals, living organisms and water. Phosphorus has an important role in every part of its cycle. Rain and weathering of rocks cause phosphate ions to release, which are then distributed in soils and water. Plants use the P to grow before being eaten by animals and used for maintenance. After the inevitable death of an animal, that ate the plant, the phosphorus returns to soil. Bacteria that are in soil may use phosphorus to grow. P can also end up in waterways, from where it gets incorporated into sediments.
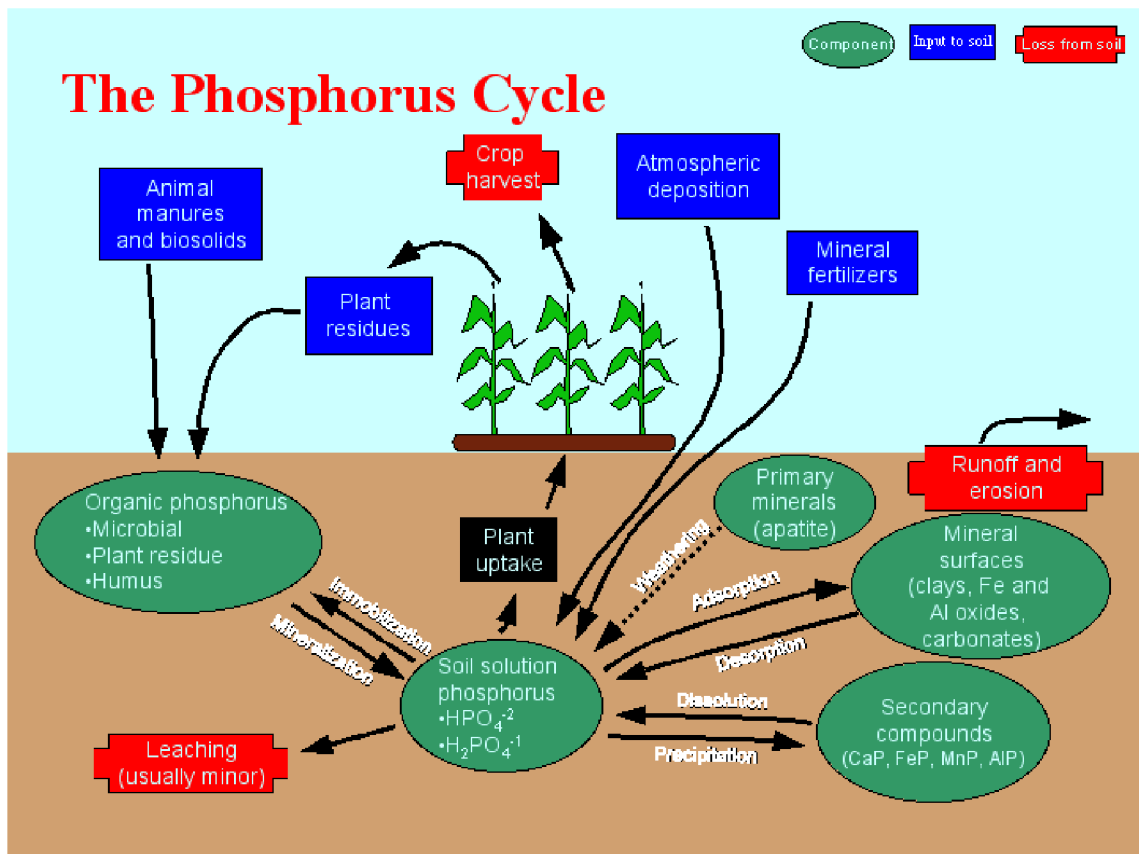
Figure 6 Phosphorus cycle (Source: PGMCapital 2021)

The phosphorus exists in many forms and the chemistry behind phosphorus cycle is very complex. However, in practical terms, the phosphorus can be divided into three pool, namely the solution P pool, the active P pool and fixed P pool.

First named one, solution P pool amounts for a small volume of P/acre and it is mostly inorganic phosphorus. However, solution P is important because it is the pool from which plants get P and it is also the only pool that has measurable mobility.

The active phosphorus pool is made from the solid phase that is more available to be released to the soil solution, which is the water surrounding soil particles. As plants absorb phosphate, the concentration in this pool decreases and some of the active P pool is released. The active phosphorus pool is the main source of P available for crops. It contains inorganic phosphate, that is bound to small particles in soil, P that has made bonds with elements such as Ca or Al to form soluble solids and organic P, that is very easily mineralized.

The last named one, fixed P pool contains inorganic phosphate compounds that are insoluble and also organic compounds. Phosphate in this pool may be stored in soil

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for years, before becoming available to plants and it may have very little impact on soils fertility.

As stated above, P exists in both organic and inorganic forms. Organic forms may be mostly found in humus and other organic materials. When microorganisms break down organic matter, the process called mineralization begins and thus releases the phosphorus in organic materials for plant uptake. However, microorganisms do not directly break down organic phosphorus. Instead, they release phosphatase enzymes that are responsible directly for breaking up organic P into phosphate form, that is ready to be used by plants. The temperature of soil and soil moisture highly influence microorganism activity and the release of enzymes. This process is at its peak when soils are warm and well drained, such as the case with nitrogen.

There are also many factors that affect phosphorus availability for crop growth. Inorganic phosphorus occurs in a variety of combinations with Fe, Al and Ca. When P reacts with these elements, the products that are formed are not very soluble and the P in the insoluble product is considered fixed. The P solubility is highly related to soil pH. Phosphorus that is not fixed can be returned back to plant-available forms, however it depends on the solubility of the phosphate compound formed in soil.
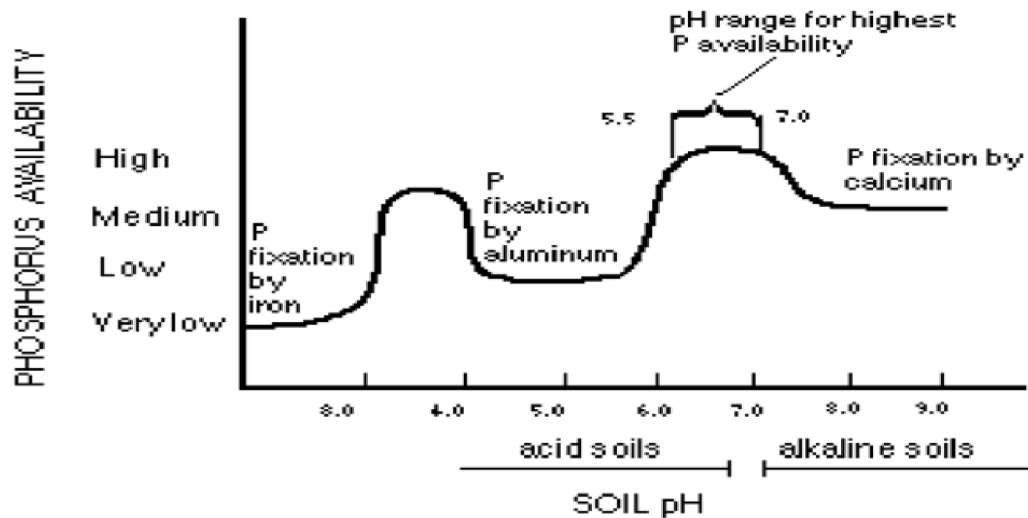

Figure 7 Influence of pH on phosphorus fixation (Source: University of Missouri 2021)

As can be seen in the graph above, the aluminium phosphates are more reactive when pH of the soil is between 4.8-5.5 pH. This form of P is fixed as aluminium phosphates are not available to plants. Liming of the soil can help in increasing of P

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availability from Fe and Al bound forms. Calcium phosphates on the other hand are concern when pH of soil exceed 7.3. However, if soils are not limed for period of time, the availability of pH can change, as soils will become more acidic over time. The acidification of the soil is not recommended and the most effective way of adding P in calcium-bound forms is to change the way P fertilizers are managed, such as through banding.

The main loss of P may be accounted to erosion, because P in soils is more associated with fine particles, and soil erosion removes fine particles rather than coarse particles. This process causes the sediment that leaves the soil through erosion to be enriched with P. In instances, when sediment is a source of P to the water system, eutrophication can potentially impair the water system. Thus, responsible P management is recommended to reduction of potentially negative impacts on the environment. (Minesota 2018b; Paulo H. Pagliari; Daniel E. Kaiser; Carl J. Rosen 2018)

1.2.2.4.3   *Other macro and micronutrients*

Another macroelements that we cannot forget are carbon (C), oxygen (O), sulphur (S), magnesium (Mg), calcium (Ca) (Cl)

Sulphur acts as an anion the soil that is receivable by plants in the form of sulphates (xSO^{2-}). It is estimated that soil contain sulphur at volumes that range from 200-600 kg/ha. However, sulphur that is mostly present in soil is in plant unaccesible organic form (xSH) and only small portion of it is converted into sulphate sulphur via funghi bacteria, that is available to plants. Another input of sulphur is through atmospheric contamination and in smaller amounts to oil and gas. Atmospheric sulphur is typically gathered from air via rain and deposited on the land. Another source of sulphur is from the clayey, acidic subsoils, that contain substantial amounts of plant-available sulphate sulphur. It is estimated that subsoils can supply sulphate sulphur at ranges from 10-40 kg/ha. Some sandy soil may require supply of sulphur, because sulphur is very leachable and sandy soils only increase the leaching process of the sulphur.

Potassium acts as a cation in soil and is classified as a macronutrient. Potassium is bound with the movement of water, nutrients and carbohydrates in plants tissue. Potassium is contained in soils in volumes exceeding 20.000 ppm (parts per million). However, small amounts of relatively rich volume of potassium in soil is in to plants unavailable form. Around 90-98% of potassium is present in soil in the form of primary

minerals, that are unavailable to plants. This percentage is of course highly dependant on soil type. However, as time passes, processes break down minerals and release potassium. However, this process is too slow to meet demands made by plants for potassium uptake. Another form of potassium that is present in soil is in form of secondary minerals and compounds. These forms are slowly available, and are thought to be trapped between layers of clay minerals. Therefore they are often described as being fixed. The final form of potassium in soil is solution potassium, that is readily available. This form is dissolved in soil water and is held on clay particle exchange sites. The amount of potassium supplied by soils is highly dependant on soil parent materials. It helps process for regulating the exchange of water vapor, oxygen and carbon dioxide. It increases root growth, aids in photosynthesis, produces grain, that is rich in starch, increases plants protein content, builds cellulose and many more. The plant uptake of potassium has many factors, such as soil moisture, where higher soil moisture usually means greater potassium variability. Another factor is soil temperature, exactly the higher the temperature, the higher the uptake of potassium.

The most notable microelements are chloride, which is received by plants in form of Cl^- iron in the forms of Fe^{2+} and Fe^{3+}, boron in the form of $H_2BO_3^-$, mangan in the form of Mn^{2+}, zinc in the form of Zn^{2+}, copper in the form of Cu^{2+}, molybdenum in the form of MoO_4^{2-} and nickel in the form of Ni^{2+}.

Iron is usually present in soil in relatively small amounts of 20-40 g/kg (60-120 t/ha) and is originated from magmatic rocks. It is mostly present in the forms of Fe^{2+} and Fe^{3+}, while Fe^{3+} is better dissolvable in water. It affects pH, accessibility of air, creation of ferrum oxides and hydroxides, organic matter and of course, microbial activity. Iron is used during creation of chlorophyl, it is a part of cytochrome protein, it functions as a "bridge" between enzymes and substrates and many, many more. Iron is used in fertilizers in chelate form Fe-EDTA (Fe-ethylenediaminetetraacetate) and is used on alkali soils.

Copper is present in soil in amounts from 1-200 mg/kg (3-600 kg/ha). Copper is organically bound, and its dissolvability is affected by pH. Copper is needed by plants in miniscule amounts of 100 g/ha per year. Copper is needed in synthesis of chlorophyl, lipids and saccharides. There are more than 100 proteins containing copper. On the account of fertilizing, copper is part of some fungicides, it is often applied with previously named EDTA and is also a part of some combined fertilizers.

20

Zinc is present in soil in amounts from 10-300 mg/kg (600-900 kg/ha) and is mostly common in form of Zn^{2+}. Its dissolvability is affected by pH of H_2O, sorption potential of soil, availability of phosphorus, presence of organic matter and microbial activity. Zinc is necessary in all types of enzymes, it is contained in structure of phosphatase, RNA and peroxidase and it is responsible for integrity of cellular membranes. Form of zinc used for fertilizing is $ZnSO_4$ in combined fertilizers.

Mangan is present in soil in amounts from 20-3000 mg/kg (60kg-9t/ha) and its most commonly present in the form of Mn^{2+}. Its dissolvability is affected by pH, salinity of the soil, accessibility of air, volume of organic matter and by competition with Fe. In plants, it is present in volumes of 40-200 mg/kg (up to 5 500 mg/kg) and it affects oxidoreduction processes. Mn is also necessary in the creation of chlorophylls, activation of enzymes (at least 35 enzymes), it can also replace Mg in RNA polymerases and affects activity of nitratoreductase. While fertilizing, mangan is mostly contained in combined fertilizers, however, it can be applied separately.

Cobalt is mostly present in soil in volumes of 5-15 mg/kg in the form Fe-Mn in the form of silicones (for example biotite). Its sorption is heavily dependent on pH. Maximum availability of cobalt can be achieved in neutral or medium alkaline soil. Cobalt enhances fixation of nitrogen in air. Fertilization with cobalt is not commonly used, but when it is used, the most common fertilizer is LISTER Co or it can be as a part of combined fertilizers

All of the so far described elements are cations.

Molybdenum is present in soil in volumes from 0,2 mg/kg to 5 mg/kg, while the amount accessible to plants is in amounts from 0,02-0,2 mg/kg. Molybdenum is farcely scarce in sand soils. Molybdenum highest sorption point is in pH of 3,5-4, and in acidic environment, it binds on aluminium and iron. Plants need molybdenum in small amounts of approximately 0,2 mg/kg. Molybdenum is stored in seeds. Molybdenum functions include enzymes responsible for nitrogen changing (reduction of NO_3^-), symbiotic and nonsymbiotic fixation of nitrogen and it also reduces toxicity of mangan, zinc, copper, cobalt and nickel. Molybdenum fertilization is used by treating of seeds in form of $(NH_4)_2MoO_4$ and by spraying 5% solution of $(NH_4)_2MoO_4$

Boron is present in soil in amounts from 5-80 mg/kg (sandy soils 5-20 mg/kg; hume soils 30-80 mg/kg). Its amount corelates with amount of clay. Boron binds on

organic material and clay materials, namely illit, vermiculite, smectite and kaolinite and oxides of iron and aluminium. In plant, boron is present in amounts from 5-100 mg/kg and is gained in form of $H_3BO_3^0$ by passive income. Its function in plant is regulation (metabolism of sugars and creation of ribonucleotide acids). It has also an influence on membrane component activity and integrity. On the matter of fertilizing by boron, it is present in combined fertilizers and fertilizers such as Borax, Borosan and many more.

Chlorine is present in volumes from 2-200 mg/kg, and it is not bonded by strong force. Its main source are fallouts and fertilizers. Physiological need of the plant is about 100 mg/kg and thus it can present as much as 2% of plants dry matter. The form in which plants can achieve chlorine is in form of Cl^- and the income of the chlorine is quite fast. Chlorine in plant is present during the photolysis of water, it affects activity of ATP and it regulates opening of stomata. Chlorine as fertilizer is mostly present in potassium-based fertilizers such as Kamex and Kainit, it is also included in strewing salts. Special based chlorine fertilizers are not common. (Brady 1990; Malmir et al. 2019)
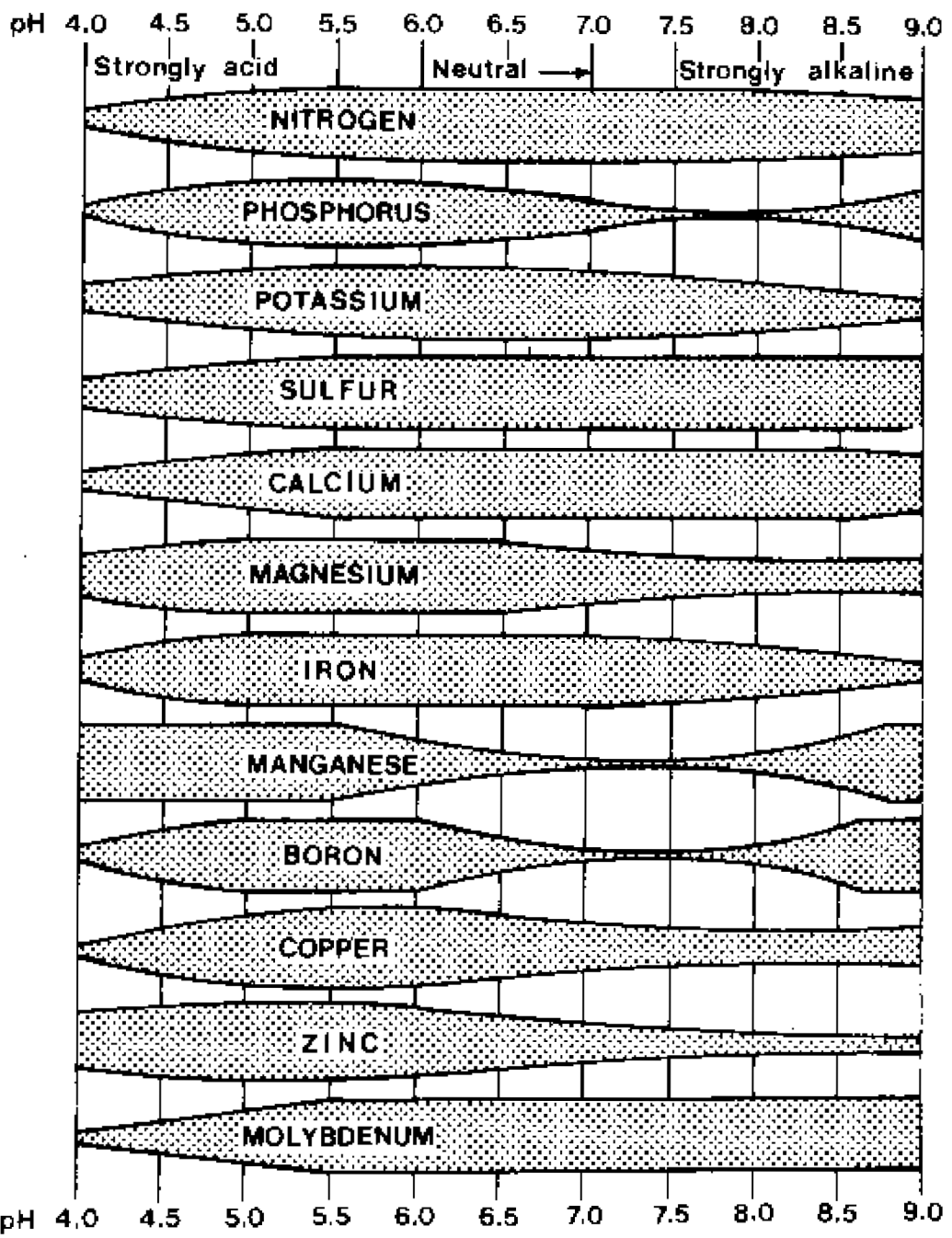
Figure 8 Influence of pH on nutrients availability (Widest parts mean highest availability) (Source: FAO 2021)

1.2.3. Acid soils in Vietnam

In recent years, food security has become a major concern in the less developed parts of the world. The supply of rice, the main source of nourishment in Asia, is sometimes interrupted by environmental conditions. However, in recent years, there is a decrease of food supply in Asia because of ever-growing population and the lower yields of rice fields. Thus, rice production increase is needed and it can be achieved either by increasing the crop yield or increasing the area where rice is grown. As such, the farmers have resorted to grow rice on marginal or degraded lands, and one of the areas, that they are using for growing rice are sulphate acid soils, which are abundant in Southeast Asia, occurring almost exclusively in its coastal plains.

Acid sulphate soils are common in many parts of the world. It has been said that they occupy about 12-14 million ha over the world, while 7.5 million ha are found in tropic areas, mainly Southeast Asia. Vietnam has about 500,000 ha of sulphate acid soils on its land, mainly around the Mekong Delta. They are characterized by their low pH and the presence of the sulphuric horizon, overlying sulfidic materials, mostly pyrite (FeS_2). The pyrite oxidizes when exposed to the air, either by digging up the soil containing the sulfidic material or by other means, it transforms into jarosite and eventually high acidity and toxic aluminium are released into the environment, thus affecting crop growth. Acid sulphate soils are difficult to manage for crop production because of their low fertility. These soils have been intensively studied throughout the world in the last 50 years and they are usually occupied by mangrove swamps. Pyrite formations occur when mineral or organic soil materials have pH lower than 3.5 and if the develop under moist aerobic conditions at room temperature, they can even result in a lowering of pH by 0.5 units or more to a value of 4.0 pH or less within 16 weeks.

They can be classified at soil series using many variations of criteria. In the region of Peninsular Malaysia, they are classified into soil series based on the depth of sulfidic materials or sulfuric horizon, profile development, soil colour and structure. The soils used for crop production in the regions of Indonesia, Myanmar, Malaysia, Philippines, Thailand and Vietnam are classified as Sulfaquepts.

However, one of the agronomic problems common in acid sulfate soil it its Al^{3+} and Fe^{2+} toxicity, which is one of the main constraints for rice farming on acid sulfate soils. Acid sulphate soils also have deficiency of Ca and Mg and liming is therefore necessary. (Goverment 2019)

2.   Objective

Literature review suggests that crops have difficulty growing in acidic soils, because of lack of phosphorus and other crucial macro and micro elements. Thus, we need to improve soil pH by liming it with liming materials, such as lime or rice husk ash that we plan to use in our experiments. The lime is commonly used so far, but unfortunately it is finite resource, that we will eventually run out and therefore its price is steadily increasing. Thus, alternatives to lime have to be found. Although lime improves soil pH quite significantly, it does not provide additional improvements to soil, such as improving texture, bulk density, water holding capacity, etc.

Rice husk ash is known to be potential alternative to commonly used lime. Rice husk ash has many positive effects on improving the quality of soil, apart from pH improvement. Rice husk ash improves soil texture, water holding capacity, bulk density and many more. However, as reported by(Singh 2018)rice husk ash contains some of the heavy metals, that could potentially with long-term application of rice husk ash store themselves in soil thus contaminating it. However, study by (Qin et al. 2017) proved that the heavy metals contained in rice husk ash did not actually contaminate the soil with long-term application of rice husk ash as a liming agent.

The usage of biomass ashes as soil additive has not been yet thoroughly studied, and authorities are reluctant on using it on wider scale.

3.   Materials and methods

3.1.   Soil description

The soil that was used was collected from the edge of forest growth. In the forestry typology, the type of the forest is 4M1, which means beech forest vegetation degree, ecology series „acidic ", edaphic category „poor ", forest type „modal ". Soil sample has been collected, as stated above from the edge of forest growth under the *Pinus sylvestris* that has been growing there for approximately 140 years with the degree of rooting at scale 8. Soil type and subtype is dystric cambisol from the medium depth up to 60 cm. The parent rock for this soil is granite. The initial pH of the soil was 4.63. The soil was dried under sunlight and covered and sieved as to not be contaminated by biomass outside, such as leaves and sticks. After drying, the soil was sieved through 2mm sieve.

3.2.   Rice husk ash

The 10 kg of rice husk ash we have used in our experiment was prepared in specialized boilers for biomass made by company PONAST spol. s r. o. We have measured the pH of rice husk ash at values of 10.01 The rice husk is the main by-product in rice mills and is currently being produced in more than 100 countries around the world (FAO 2021)). The annual world output of rice husk is approximately around 200 million tons (FAO 2021) Rice husk is usually used as a furnace fuel for producing electricity, while producing enormous quantities of rice husk ash (rice husk ash), that can range from 16 to 23% of yield (32 to 46 million tuns of ash). This agro waste causes environmental problems as stated by (Kapur 1985)

Rice husk is the main by-product of rice mills and is produced in over 100 countries all over the world (FAO 2018). According to the research by (Singh 2018) rice husks contain

30%-50% of organic carbon. The rice husk ash is the result of combusting rice husks. As reported by study by(Singh 2018), the husk contains 30%-50% of organic carbon and it makes up to 20% of rice weight. Rice husk is most commonly used as a fuel, either for parboiling paddy in rice mills or it is burnt as a local fuel. The characteristics of the ash are dependant on composition of rice husks, burning temperature and burning time, and after the husk has been burnt, the residue that is left are mostly silicates. "The ash obtained from uncontrolled combustion (as in open-field burning or in industrial furnaces at temperatures greater than 700 C − 800 C will contain significant amounts of cristobalite and tridymite which are nonreactive silica minerals."(Singh 2018). rice husk ash however has many advantages, either in required energy for production, rice husk ash requires only 12 kJ/kg of produced material to lime, that requires 173 kJ/kg of material. As we can see, the lime requires on average more than 10 times amount of required energy to generate. rice husk ash can be used in many ways, either as addition to cement, as fertilizer or as a liming agent. Also, as stated by (Kapur 1985) the rice husk ash is practically speaking a waste that is dangerous for environment and ecosystems. There is plenty of rice husk ash that could be used. Since rice husk ash is a biomaterial, it is a renewable resource that could be used as a liming agent instead of lime used today. The lime is a non-renewable resource that humanity will eventually dig out and run off. Disposal of previously stated wastes has become a serious problem because large quantities of these ashes are regularly thrown into rivers, ponds and open space, thus further damaging fragile ecosystems presented in the area and slowly, but surely, devastating our planet and decreasing the fauna and flora variability and survivability in said areas. After burning of organic biomass, nitrogen and sulphur are dissolved in the atmosphere, whereas other nutrients essential for plants are preserved to a non-negligible degree in bio ash. Rice husk ash contains significant amounts of phosphorus, potassium, sulphur, iron, calcium and magnesium among with sodium(Kapur 1985; Thind et al. 2012) This liming agent is cheap, easily produced and available and can be used in agriculture to further improve soil quality, crop yield and soil fertility. Whether it would not be used, this material would continue to pollute said ecosystems and further damage the environment, therefore proper usage is essential for sustainable crop yield and the saving of the planet Earth.

3.3. Calibration of pH neutralization

In order to increase the soil pH to a desire value (pH 5.5), I determined the required amount of rice husk ash and lime in a laboratory incubation. rice husk ash. Based on the measured pH values, I determined how much limestone or rice husk ash should be added to one kilogram of soil using the regression analysis. The values were 3.70 g of lime per pot that was supposed to be treated by lime and 70.77 g of rice husk ash per pot that was supposed to be treated by rice husk ash.

Table 1 Adjustment of pH substrates via regression analysis to achieve desired value of 5.5

	Code	dry soil weight	amendment weight	amendment	amendment %	added water to reach 80% of water retention capacity	water added to measure pH (ml)	measured ph
Rice husk Ash	A1	10	0,0251	0,0025	0,25	2	25	4,67
		10	0,0251	0,005	0,25	2	25	4,61
	A2	10	0,0503	0,005	0,5	2	25	4,9
		10	0,0503	0,005	0,5	2	25	4,82
	A3	10	0,101	0,01	1	2	25	4,9
		10	0,101	0,01	1	2	25	4,84
	A4	10	0,1523	0,015	1,5	2	25	4,91
		10	0,1523	0,015	1,5	2	25	4,97
	A5	10	0,2041	0,02	2	2	25	5,05
		10	0,2041	0,02	2	2	25	5,02
lime	L1	10	0,005	0,0005	0,05	2	25	5,46
		10	0,005	0,0005	0,05	2	25	5,62
	L2	10	0,01	0,001	0,1	2	25	5,06
		10	0,01	0,001	0,1	2	25	4,97
	L3	10	0,0251	0,0025	0,25	2	25	5,63
		10	0,0251	0,0025	0,25	2	25	5,74
	L4	10	0,0503	0,005	0,5	2	25	6,75
		10	0,0503	0,005	0,5	2	25	6,81
	L5	10	0,0756	0,0075	0,75	2	25	7,12
		10	0,0756	0,0075	0,75	2	25	6,89

Table 2 Addition of lime/rice husk ash from regression analysis of samples

Treatment	Addition of P+/ without P-	Number of pots (repetitions)	Addition of lime/rice husk ash (g/pot)
Lime CaMg(CO$_3$)$_2$	+ P	6	3,70
	- P	6	3,70
Rice husk ash	+ P	6	70,77
	- P	6	70,77
Control	+ P	6	
	- P	6	
Total		36	

3.4.   Greenhouse experiment

3.4.1.   Pot preparations

I have used tubes (10 cm diameter) cut to 25 cm length as growing pots. The bottom part of the pot was sealed with 2mm sieve and 150g (fraction under 10 mm) of bedrock was added inside of each tune to allow for water percolation but prevent of the losses of solid materials. The sieve was held in place with duct tape, as to not allow any damage to the pots during the experiment. The pots were then placed on top of the funnels used for the collection of leachate into the bottles prepared under the funnels. The pots and the funnels held in place with a custom made metal rack.

Figure 9 Pots in metal rack
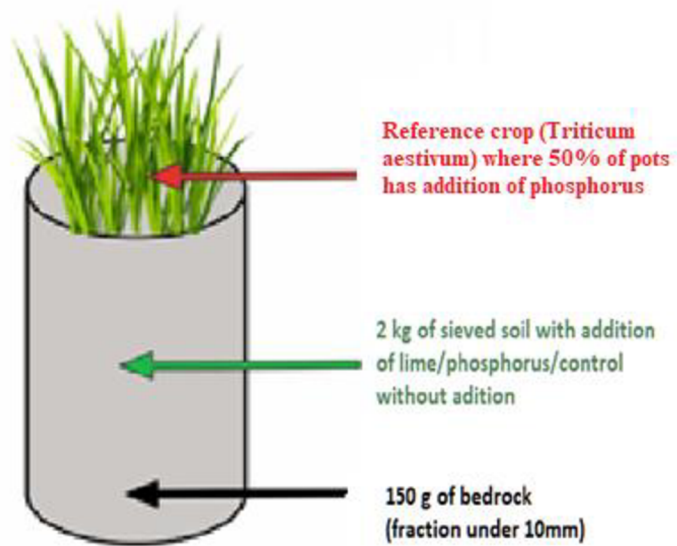

Reference crop (Triticum aestivum) where 50% of pots has addition of phosphorus

2 kg of sieved soil with addition of lime/phosphorus/control without adition

150 g of bedrock (fraction under 10mm)
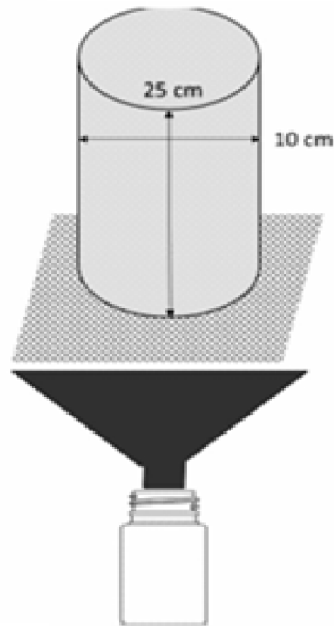
Figure 10 Design of the pots 1/2

Figure 11 Design of pots 2/2

3.4.2. Experimental design

The experiment was established in full factorial design with two factors: liming agent (control without liming, lime and rice husk ash), and phosphorus application (0 and 2.5 mg P kg^{-1} soil), with six repetitions. Twelve pots were filled with 2 kg of homogenized sieved soil (control), twelve pots with 70.77 g of rice husk ash treatment and twelve pots with 3.70 g of lime (Lime treatment). Consequently, P was applied to six pots of each treatment.

After the pot preparation was finished, we have prepared approximately 1000 grams of *Triticum aestivum* to sow. The volume was measured by weighting 50 seeds and measuring their weight. The 50 seeds that were weighted had 19.84 g and we have determined that approximately 20 grams were measurement for 50 seeds. We have sowed aproximately 20 grams of *Triticum aestivum* into each pot, to the depth between 2-4 cm. The pots were then watered to reach 60% of water holding capacity. On the 20th DAS, ½ of the pots were fertilized with 2.5 mg P kg^{-1} soil as KH_2PO_4. KH_2PO_4 contains 22.8 % of P and to achieve applying 2.5 mg P per kg^{-1}, total amount of 10.96 mg of KH_2PO_4 was

applied to 1 kg of soil, meaning 21.92 mg of KH_2PO_4 was applied to each pot. This solution was prepared by dissolving 1.09 g of KH_2PO_4 in 100 ml of water and then adding 2 ml of this solution to each pot with a pipette with distribution more or less homogenously on the surface of the pot.

Figure 12 Aplication of phosphorus solution into the pots

Figure 13 Observable difference between treatments on 11th day after sowing (1st and 2nd row lime treatment, 3rd and 4th row rice husk ash treatment, 5th and 6th pot control)

3.4.3. Leachate collection and analysis

The leachate was collected three times during the experiment. We have collected 50ml of leachate from each pot by slow application of water until the desired volume was collected. In case of higher leachate volume, the percolate was re-applied to the pots again. The collected leachate was then stored in a freezer at temperatures of -20 °C The samples of leachate were collected 27th DAS, 42nd DAS and 48th DAS after which we have ended the experiment due to non-existent growth of aboveground biomass.

The plants were harvested on 48th DAS. The aboveground biomass was clipped at the soil surface level, washed if necessary, stored in paper bags and dried at 70°C until constant weight (36 hours). Roots were hand-picked from the soil with tweezers and hands. Afterwards they have been washed carefully with tap water and dried as described above for the aboveground biomass.

Soil was sieved in the fresh state and air-dried before the measurement of soil pH. Soil aliquot (10 g) was added to 25 ml of distilled water, stirred with agitator on 300 rpm for 30 minutes. Afterward, we have measured pH by using pH meter, washing the electrode between samples with distilled water.

3.4.4. Canopeo measurements

The Canopeo is an application to Android and iOS mobile operating systems that is used to determine the quantity of canopy cover for live vegetation of any crop. The application is very simple to use and it is useful for farmers and researchers. Canopeo can assist farmers to track plants growth process, which can lead to better decision making. Each image is tagged and labelled, so farmer is aware exactly when and where the image was captured. The Canopeo application uses the analytical software to determine the amount of green colour in the picture. Therefore, it can be used by farmers to analyse the growth improvement of their crops. We have used Canopeo to determine the growth of the crops ourselves, and the pictures with Canopeo on 29th of October 2020, 13th of November 2020 and 20th of November 2020. The measurement with Canopeo in this experiment were taken at same distance at a fixed distance (0.5 meters) and from the same

angle to allow for comparisons between samples and sampling dates, as to provide most proving results.(Patrignani & Ochsner 2015)

Figure 14 Photograph of control with added phosphorus on 42nd day after sowing

Figure 15 Photograph of control with added phosphorus on 42nd day after sowing in Canopeo (Source: Canopeo 2021)

3.5. Hypothesis

1) Increase the soil pH will improve plant growth
2) At same pH, ash will have a better effect on plant growth due to large amounts of other nutrients (including phosphorus)
3) P application will have stronger effect on plants in lime treatments when compared to ash treatments

4. Results & discussion

In this pot study, that applied various combinations of lime, P and rice husk ash to grow *Triticum aestivum* samples for analysis are collected at several end points. Results are expressed as average pH. As depicted in the figure 19, the average pH raised to 4.8 – 6.2.

4.1. pH

The pH of all the samples measured using by SevenCompact^{TM} S220 Basic by Metler-Toledo are presented in the figure 19 while standard deviation is depicted in figure 20.
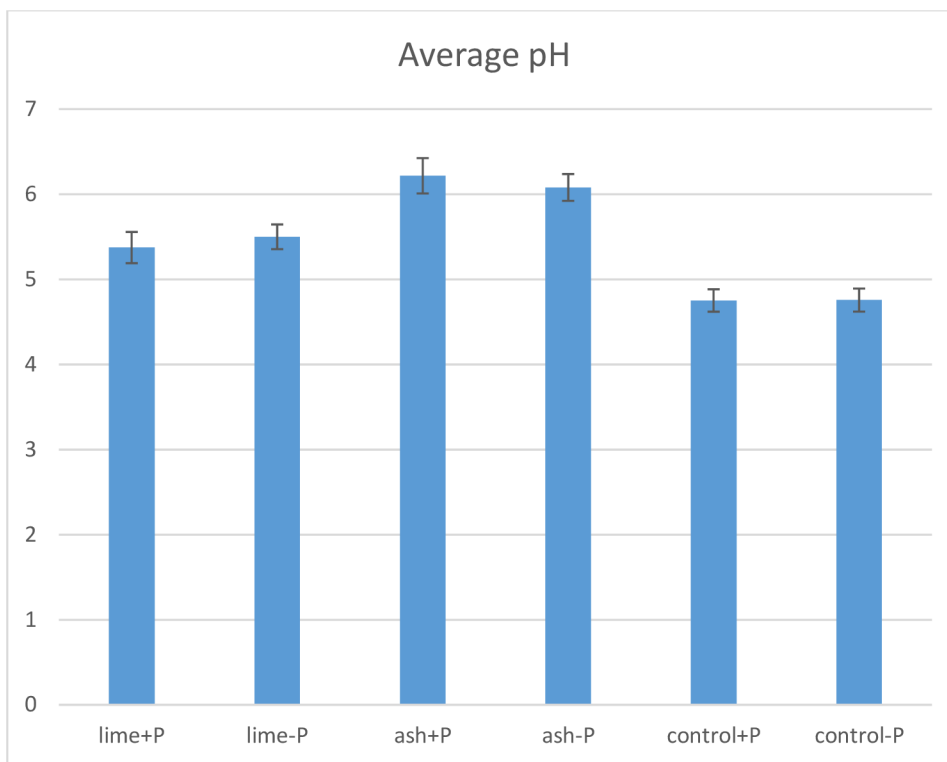
Figure 16 Average pH at the end of the experiment

The average pH of the samples obtained from pots of lime supplement with and without the addition of P showed no significant difference (pH between 5.3 – 5.5). Similarly, pot samples of ash with and without supplementation of P showed almost no pH variation (pH between 6.0 – 6.2). Samples from control pots supplemented with and without P had no difference. Therefore, the addition of P has no impact on soil pH. Results also show that rice husk ash reduced the soil acidity to a greater extend compared to lime and control. Overall, based on the obtained results, we can conclude that rice husk ash may be substituted to lime. However, because of the limitations of this experiment, further larger set of experiments and field trials are needed to verify these findings.
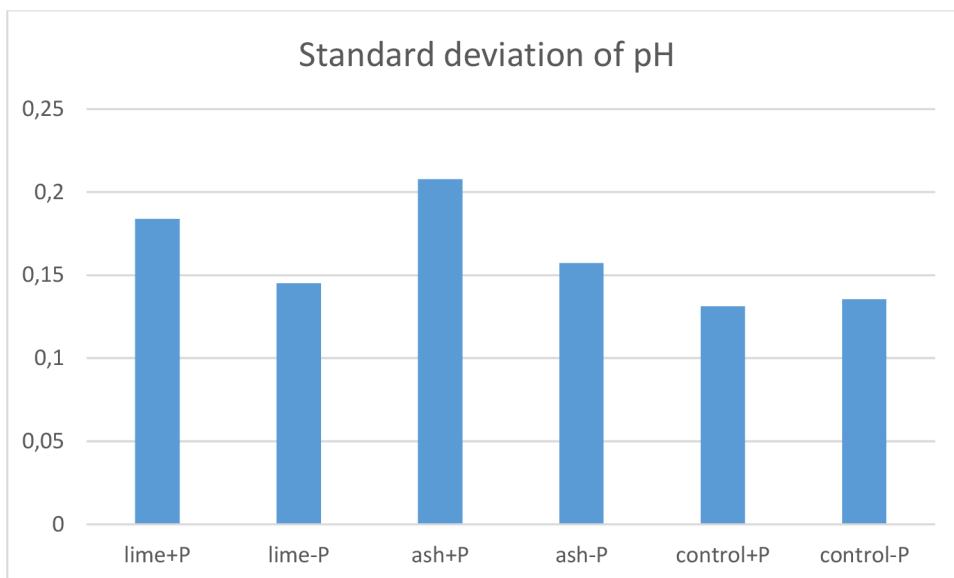
Figure 17 Standard deviation of pH at the end of the experiment

As we can see from this graph, the phosphorus addition on the 7th DAS had non-existent effect on the soil pH. We can conclude from this graph, that there are other variables in rice husk ash that had this effect. The lime treatment with phosphorus addition average values were 5.37333 with standard deviation of 0.18381. The lime treatment without phosphorus had average values of 5.5 with standard deviation of 0.14519. The ash treatment with added phosphorus average value was 6.21667 with standard deviation of 0.20772 and ash treatment without phosphorus had average value of 6.08 with standard deviation of 0.15735. The control that was treated with phophorus had average pH of 4.75167 with standard deviation of 0.13121 and control that was not treated with phosphorus had average pH of 4.75667 with standard deviation of 0.13545.

4.2.   Canopeo measurements

We have used regresion analysis to compare the measurements of the plants shoots biomass and compared it to the Canopeo measurement taken on the 48th day after sowing.
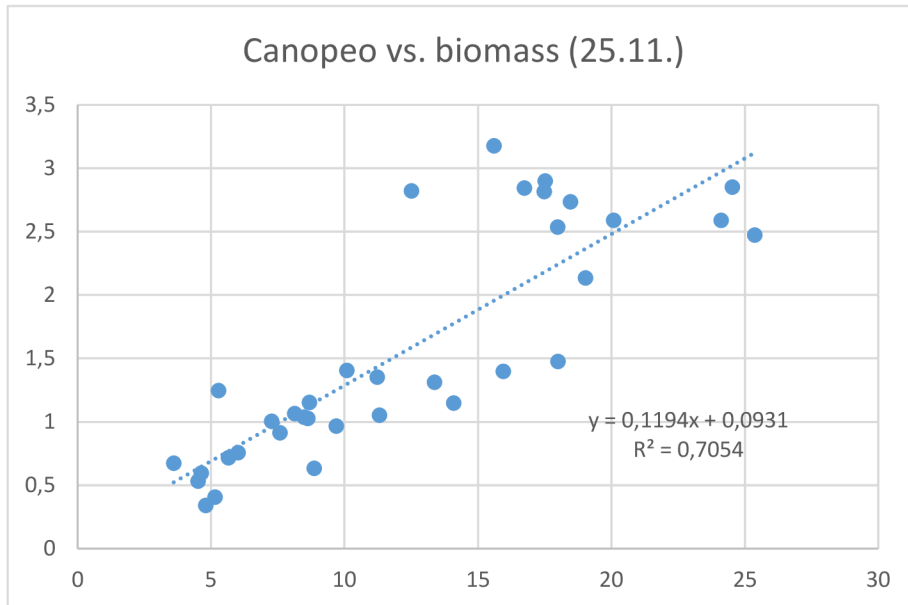

Figure 18 Canopeo vs biomass on 48th day after sowing

This graph represents the measurements from taken from Canopeo described above on the 1st measurement on 29 of October 2020, 13th of November 2020 and 20th of November 2020. As we can see from these results, there is a massive improvement between 2nd and 3rd measurement. However, as we can see now, the phosphorus addition has not made major changes in plants growth and there is different factor that is in play here, that is yet to be discovered by further testing.
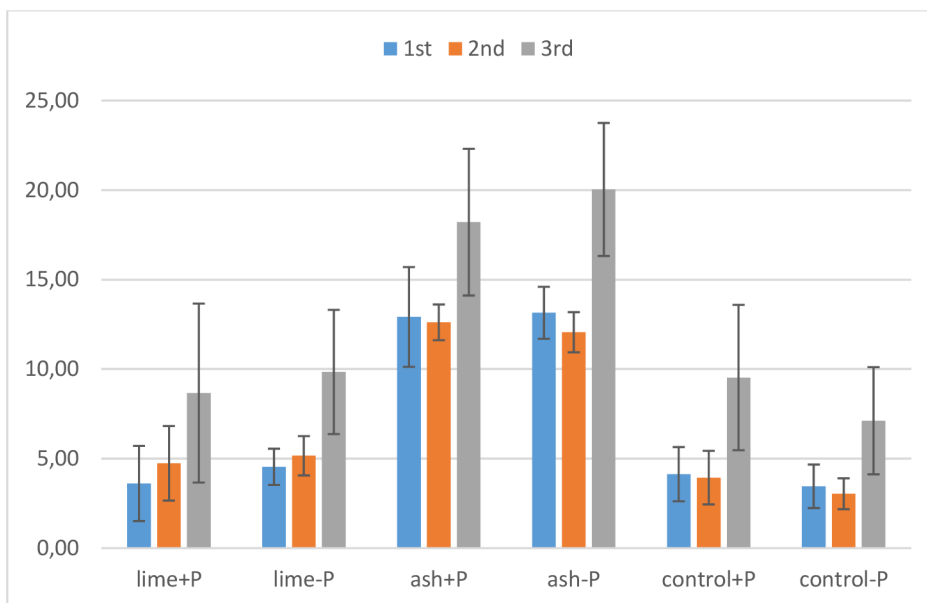
Figure 19 Canopeo improvements

The results of this experiment show that the rice husk ash and lime raised the pH to the optimal level of 5.5 with standard deviation, that is needed for cultivation of most vegetables and arable crops. Rice husk ash has therefore significant liming effect due to its possession of cations, as stated by (Okon et al. n.d.). The results also show that the application of phosphorus made non-existent difference in the pH of the measured samples. Rice husk ash also improved the growth of the *Triticum aestivum* by significant level and therefore the pH of the soil was not the main factor of lower yield of crops, as opposed to the lime that was used in other group of pots. Another factor that was not the reason of lower growth of crops was phosphorus, as we could have seen from the results, as opposed to the research by (Okon et al. n.d.). The rice husk ash has potential as a viable liming agent and could be used as a liming alternative to the more expensive and commonly used lime. The higher yield of crops in pots treated by rice husk ash was caused due to yet unknown reasons that are expected to be revealed in the further tests in the experiment. However, the rice husk ash has also improved the texture of the soil, as we could have seen during the last stage of the experiment, namely the harvesting period, which could be another reason of improvement of growth of the crops. Another non-negligible value that is added to rice husk ash is that it is abundant and needs little energy to produce. However, unfortunately this part of the experiment was insubstantial and as

of now, we can only determine from these results that the phosphorus addition had non-existent effect on growth of the crops and pH of the soil. We could also assume that the merged effect of addition of nitrogen and phosphorus solutions along with the addition of rice husk ash had effect on the growth of the crops. It could be possible that the addition of nitrogen solution had supplied the crops with necessary nitrogen, which rice husk ash lacks, as stated by (Okon et al. n.d.). We will be performing further testing of collected samples in upcoming year to determine, what caused the difference of growth of crops. However, at this time we can determine that the difference in results was not caused by other factors, such as weather or difference in temperature, as this experiment was conducted in greenhouse, as to exclude these factors. The pots were watered by same water, so the nutrients in water are also not the reason of the increased growth of plants grown in pots that were treated with rice husk ash. As stated above, only further tests of the biomass and soil will prove to us, what caused the increase of biomass growth in pots treated with rice husk ash

5.   Conclusions

In conclusion, rice husk ash has improved the pH of the soil significantly, and has a potential as a liming agent. However, the results of the experiment were inconclusive as the low pH of the soil was not the main reason of the decreased crop yield. We can also state, that the addition of phosphorus had non-existent effect on the crop yield, as could be seen in the results. Rice husk ash is cheap liming material that could be used as an alternative to commonly used lime to increase the pH of the acid sulphate soils in tropical areas. Addition of 70.77 g of rice husk ash has proven to increase the pH of the soil to the optimal pH of 5.5 that is necessary for the good growth and yield of the crops, also because of the availability of micro and macronutrients. We will have to study other samples that we have got from this experiment to determine, what caused the increased growth of crops in soil treated with rice husk ash. As stated, we could assume that the mixed effect of addition of nitrogen, phosphorus and rice husk soil could have created improved environment for plants growth. However, until further results from the harvested samples are not available, we cannot be sure what caused the increase of yield of biomass.

6. References

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Appendices

List of the Appendices:

Appendix 1: Appendix title