LUT University
School of Energy Systems
Department of Environmental Technology
Sustainability Science and Solutions
Master’s thesis 2019

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IS THERE DEMAND FOR A SHARING ECONOMY OF NUTRIENTS?

- Nutrient balances in Ethiopia, Ivory Coast and Finland

Examiner:	Professor	Helena Kahiluoto
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TIIVISTELMÄ

LUT-yliopisto
School of Energy Systems
Ympäristötekniikan koulutusohjelma
Sustainability Science and Solutions

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Onko ravinteiden jakamistaloudelle tilausta?
- **Etiopian, Norsunluurannikon ja Suomen ravinnetaseet**

Diplomityö

2019

60 sivua, 8 taulukkoa, 7 kuvaajaa ja 2 liitettä

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Hakusanat: maaperän köyhtyminen, ravinnetase, ravinteiden ehtyminen, ravinteiden louhinta, ravinteiden ylijäämä

Sadossa korjattujen ravinteiden riittämätön korvaaminen on johtanut viljelymaan köyhtymiseen Saharan eteläpuolisessa Afrikassa. Työssä tutkitaan Etiopian, Norsunluurannikon ja Suomen peltomaiden ravinnetaseiden kehitystä. Ravinnetaseita koskevat tiedot on kerätty julkisista tietokannoista tuotantovuosille 1961–2016. Ravinnetase-laskelmat tehtiin typelle, fosforille ja kaliumille. Ne koostuivat neljästä maahan tulevasta ravinne-virrasta (mineraalilannoite, lanta, ilmakehän laskeuma ja typensidonta) ja kolmesta maaperästä poistuvasta virrasta (sadonkorjuu, kasvijäte ja kaasuhäviöt). Eroosiota, sedimentaatiota ja huuhtoutumista ei arvioitu puuttuneiden tietojen takia. Tulosten mukaan molemmissa Afrikan maissa, Etiopiassa ja Norsunluurannikolla, ravinteet ovat ehtymässä peltomaassa. Ravinteiden ehtyminen sadonkorjuun ja kasvijätteiden poiston takia on kiihtynyt viimeisen kymmenen vuoden aikana. Tilanne on päinvastainen Euroopassa, jossa ravinteet kerääntyvät maaperään liiallisen lannoitteiden käytön vuoksi. Tämä näkyy Suomen ravinnetase laskelmissa. Afrikan tilanteen muuttamiseksi on tehtävä poliittisia toimenpiteitä ja investointeja.

ABSTRACT

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Degree Programme in Environmental Technology
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Is There Demand For A Sharing Economy Of Nutrients?
- Nutrient balance in Ethiopia, Ivory Coast and Finland

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60 pages, 8 tables, 7 figures and 2 appendices

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Keywords: nutrient accumulation, nutrient balance, nutrient budget, nutrient depletion, nutrient mining, soil degradation,

Insufficient replacement of nutrients in harvest has led to impoverishment of farmland in sub-Saharan Africa. Here I studied agricultural soils in Ethiopia, Ivory Coast and Finland using nutrient balance assessment. Data for the nutrient balance calculation was collected from public data bases for the production years 1961-2016. Nutrient balance calculations were made for nitrogen, phosphorus and potassium for four inflows entering soil (fertilizer, manure, atmospheric deposition and nitrogen fixation) and three outflows leaving soil (harvested product, residue removal and gaseous losses). Erosion, leaching and sedimentation are left out from the calculation because of lack of data. According to the results, in both countries in Africa, Ethiopia and Ivory Coast there appears continuous nutrient depletion in agricultural soils. In both countries nutrient stocks are decreasing. Nutrient depletion has been rapidly increasing for the last ten years. The major reason for nutrient depletion is intensive cultivation. Nutrient balance results should be more utilised than they are at the moment. The situation is very opposite in Europe where nutrient are accumulating in soils because of excessive use of fertilizers. This can be seen in nutrient balance results for Finland. Policy measures and investments are needed to reverse the situation in Africa.

ACKNOWLEDGEMENTS

I am very thankful to Helena Kahiluoto and Miia Kuisma for the guidance and support to complete this thesis. Special thank for Vilma Sandström who really helped me with the calculation and practical matters. I would like to thank Tuire Tapanen who gave me good tips and advice for writing the thesis.

I would like to thank my friends who supported and helped me during my studies. It would have been very hard years without you. I am also thankful to my family for the support they gave me.

In Lappeenranta 31 October 2019

Miitta Vaittinen

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LIST OF ABBREVIATIONS

B	Boron
BNF	Biological nitrogen fixation
Ca	Calcium
Ca^{2+}	Calcium ion
Cu	Copper
C/N	Carbon to nitrogen ratio
FAO	Food and Agriculture Organization of United Nations
Fe	Iron
$H_2PO_4^-$	Dihydrogen phosphate
HPO_4^-	Hydrogen phosphate
IFA	International Fertilizer Association
IFASTAT	International Fertilizer Association statistical information
IN_1	Mineral fertilizer
IN_2	Manure
IN_3	Atmospheric deposition
IN_4	Nitrogen fixation
K	Potassium
K^+	Potassium ion
K_2O	Potassium oxide
KCl	Potassium chloride
Mg	Magnesium
Mg^{2+}	Magnesium ion
Mn	Manganese
Mo	Molybdenum
MonQI	Monitoring for Quality Improvement (Model)

N	Nitrogen
NPK	Nitrogen, phosphorus and potassium
N_2	Dinitrogen
N_2O	Nitrous oxide
N_r	Reactive Nitrogen
NH_3	Ammonia
NO_x	Nitrogen oxide
NO_3	Nitrate
NUE	Nitrogen Use Efficiency
NUTMON	Nutrient Monitoring Programme (model)
OUT_1	Harvested product
OUT_2	Residues removed
OUT_3	Gaseous losses
P	Phosphorus
P_2O_5	Phosphorus pentoxide
QUEFTS	QUantitative Evaluation of Fertility of Tropical Soils
S	Sulphur
Yp	Yield potential
Yw	Water-limited yield
Zn	Zinc

1 INTRODUCTION

People need food to sustain life and to produce food we need agriculture. At the moment, there are regions where food is not easily obtainable and soil degradation is a great threat. Soil degradation is the lack of actual or potential productivity or utility as an outcome of natural or anthropogenic factors and in other words, it is the decrease in soil quality or downsizing in its productivity and environmental regulatory potential (Lal, 1997).

Nutrient depletion is the main process of soil degradation, with serious economic effects at a global scale, particularly in sub-Sahara Africa (Lal, 1997). According to Haileslassie (2005) many studies have shown that nutrient depletion is one of the main causes for low agricultural productivity and food insecurity. More soil nutrients are taken contrast to anthropogenic and natural inputs in many countries (Hailassie, 2005). Farmers face pressure to use land more intensively and cultivate soils that are low in nutrients in marginal areas because of population growth (Henao and Baanante, 1999a). This is also called nutrient mining. When practising agricultural production in Africa is hindered by the dominance of ecosystems, low natural soil fertility and, low use of external inputs like fertilizer (Julio and Baanante, 1999a). Soil nutrient mining is often connected with low land productivity and agricultural production under serious limitation of poverty in terms of human capital (health and education) and physical capital (infrastructure) (Henao and Baanante ,2006).

Main cause for decreasing per capita food production in sub-Saharan Africa is soil-fertility depletion in smallholder farms (Sanchez et al., 1997). Many Africans rely on agriculture for their livelihoods and the agricultural production directly affects economic growth, social improvement and trade in Africa (Henao and Baanante, 1999b). Food security has not been a global primary concern, but different research like 2020 Vision and the World Food Summit have suggested that food security is one of the main global concerns (Sanchez et al., 1997). Food insecurity covers food scarcity and also the inability to buy food, which is a poverty-related matter. Food insecurity appear throughout developing world, but it is most severe in sub-Sahara Africa, where achieving food security is linked with reversing agricultural stagnation, reducing population growth and safeguarding the natural resource base. Per capita food production resumes decreasing in sub-Sahara Africa, unlike the sustained increases in other parts of developing world. This is happening because the continuing fast population growth is there highest of any region in the world and also due to fast soil depletion. To include this half of sub-Saharan Africa's population, which is classified as absolute poor which means people who get incomes under one U.S. dollar per day and there is also the highest proportion undernourished children. Sub-Sahara Africa needs an annual sustained growth pace in agricultural production of 4% to reverse the situation by the year 2020. (Sanchez et al., 1997.)

Many Africans rely on agriculture for their livelihoods and the production of agriculture directly affects economic growth, social improvement and trade in Africa. Population continues to grow and agricultural land is getting more degraded. This lead to intensifying land use to meet food needs by the farmers, without appropriate management practices and external inputs. Nutrient depletion in soils as an outcome has caused crop production to stagnate or decrease in many African countries. There are even cases, especially in the East African highlands, where the pace of depletion is so high that even extreme measures like doubling the fertilizer or manure or decreasing erosion losses, is not enough to compensate nutrient deficits. Weakening agricultural productivity will severely undermine the foundations of sustainable economic growth in Africa, except if African governments, supported by the international community take the lead to confront the problems of nutrient depletion. (Henao and Baanante, 1999b.)

Nutrient balance has been negative every year in all African countries, except Libya, Mauritius and Reunion. There has been soil loss 60-100 kg/ha/year of nitrogen (N), phosphorus (P) and potassium (K) (NPK) in the semiarid, arid and Sudano-Sahelian areas that are densely populated. These areas are cultivated intensively but with low levels of fertilizer and the soils are shallow and highly weathered. Crop diversification and the adoption of good management practices have been restricted by the limited water availability and intensive cultivation. Because growing seasons are short it adds more pressure on the land. There are other significant agriculture areas, like those located in the humid and sub humid regions and in the forest and savannas areas, and among regions losses of nutrient vary greatly. Nutrient depletion rates vary from tolerable (30 to 60 kg of NPK/ha/year) in the humid forests and wetlands in southern Central Africa to high (more than 60 kg) in the East African highlands. There are more countries in Africa that are in the high depletion range than in the medium range. Nutrient depletion is very high in places where fertilizer use is especially low and nutrient loss, mostly due to soil erosion, is high. Naturally low mineral stores in these soils, the low supply in nutrients, and hard climate of interior plains and plateaus worsen the consequences of nutrient depletion. P does not get depleted as much as N and P from African soils- and the primary ways are leaching and soil erosion. These problems in the soils are outcome mostly from constant cropping of cereals without the cycle with legumes, insufficient amounts of fertilizer use and unsuitable soil conservation practices. (Henao and Baanante, 1999b.)

In Africa, it is unwanted to lose nutrients from the topsoil because it reduces productivity and in Western Europe it is unwanted that nutrients leach to the groundwater (Smaling, 1993). According to Antikainen (2008) soil surplus of N and P in Finland is result of increasing total N input almost fourfold between 1910 and 1980-1990 and phosphorus input about eightfold between 1910 and 1970. Also Antikainen (2008) display that during the century, the input and output of nutrients are increased in the agricultural soil and the surplus has increased substantially from 1950s for phosphorus and 1960s for nitrogen. According to Antikainen (2008) the average soil surplus has been reduced since the 1980s, because of the decreased use of fertilization and increasing yield. These nutrient surpluses can cause environmental problems like eutrophication of lakes and Baltic Sea by increase nutrient losses to water and air or their accumulation in soil (Antikainen, 2008). About one tenth of the Baltic Sea's overall load of nitrogen and phosphorus are coming from the Finnish rivers (Environment.fi, 2017). Agriculture is the major sector causing nitrogen and phosphorus load to waters and emissions to air in Finland (Antikainen, 2008). Nutrient balances have decreased in Finland and the biggest reason is reduction in the use of fertilizer (Luke, 2018). Even though nutrients have been reduced from point sources, river-borne nutrients have not changed that much from the 1970 to these days (Environment.fi, 2017).

The aim of this thesis was to evaluate plant nutrient status in some African and European countries and to analyse what kind of reasons have led to nutrient depletion or accumulation there and how. To reach this goal nutrient balance method was selected to evaluate nutrients in the soils of these three countries.

The research questions of this thesis were

1. How has the nutrient balances of Ethiopia, Ivory Coast and Finland developed between 1961 and 2016?
2. What has affected the nutrient balances over the years in these countries?
3. How much nutrient losses need to be replaced to return soil fertility in Ethiopia and Ivory Coast?

The theory parts of this thesis consist of the most relevant nutrients to the agriculture which are N, P and K and overall nutrient balances. In the first part of theory is explained these nutrients contribution and effect in agriculture. In the second part of the theory is explained nutrient balance and the origins of it, components of the nutrient balance calculation, possible outcomes of nutrient balance like nutrient depletion and accumulation and other ways to make assessment of the soils nutrient situation. Before the calculation there are introduced materials and methods that are used in this paper and the materials are from difference sources from the literature. Data and material are on country level. There is also discussed about the results and the measures to improvements.

2 PLANT NUTRIENTS IN AGRICULTURE

Nutrients are necessary to plant growth. Nutrients are absorbed by plant roots together with oxygen, water and others from the soil and when crops are harvested, they slowly remove the current nutrients from the soil (Stubbs, 2016). The most common macronutrients for sustaining soil fertility and contribute to plant growth under natural conditions are N, P and K (Yu, 2016). There are also other relevant nutrients like sulphur (S), calcium (Ca) and magnesium (Mg) and plants need small amounts of zinc (Zn), manganese (Mn), iron (Fe), copper (Cu), boron (B) and molybdenum (Mo), these are called trace elements (Department of Primary Industry, 2017).

Each plant species requires different set of nutrients and also they utilize nutrients various ways. The way plants utilize nutrients impacts the overall yield and plant production. It can be valuable to understand a crop’s nutrient needs for farmers to maximize harvest and low the cost of input. The most plentiful elements in plants are carbon, hydrogen and oxygen, which are the basic nutrients. Further, plants utilize other nutrients regularly mention as macronutrient and micronutrients. The center usually is on the three main macronutrients: N, P and K in agricultural production because of the richness in plants. Also micronutrient can have big impact on plant growth as macronutrients when levels are too high (toxic) or too low (deficient). (Stubbs, 2016.)

Ionic form is the way plants use nutrients and they are taken up in three way: the first one is interception by direct contact with the nutrient; the second one is mass flow when nutrients are in water as the plant transpires and the third one is diffusion when nutrients travel from high to low concentration. Nutrient taken up by plants through interception is quite uncommon, unlike mass flow which is most substantial method of nutrient motion toward a plant's roots. This is especially important for more "mobile" nutrients such as N and K and not so important for comparatively "immobile" nutrients such as P. Diffusion is very essential for nutrients which are comparatively immobile, have low solution concentration and are required in huge amounts. Most soils will need supplementary nutrients to preserve or increase crop yield. Nutrients can accumulate when added too much of it and the plants do not have capacity to utilize them and it can cause a risk if nutrients have an access to surrounding environment and makes problems like algal blooms. (Stubbs, 2016.)

2.1 Nitrogen

Nitrogen is an essential nutrient in plant growth, and it can be found in all plant cells, proteins and hormones and also in chlorophyll (Department of Primary Industry, 2017). Living organisms use nitrogen to make many complex organic molecules like proteins, nucleic acids and amino acids (OECD, 2007). Nitrogen appears in selection of form in the soil and it can be taken up in different forms by growing plants, it is transformed by several chemical and biological processes (Reetz, 2016). Nitrogen is obtained from atmosphere to soils by wet and dry deposition of N compounds (OECD, 2007). Also fertiliser factories use nitrogen from the air to produce ammonium sulphate, ammonium nitrate and urea. (Department of Primary Industry, 2017). There are plants like legumes that have certain specialized bacteria that can use part of the energy from photosynthesis to make dinitrogen (N_2) into reactive nitrogen (N_r) compounds, this process is known as biological nitrogen fixation (BNF) (Sutton, 2013). Mineralisation and nitrification decompose organic matter to provide the nitrogen to plants, this kind of nitrogen can be dissolved in soil water or bound to soil colloids and is directly accessible to the plants and it can be leached out of soil by heavy rain which leads to soil acidification (OECD, 2007). Total inputs of N can be compared harvest removal of nitrogen averaged for many years to estimate nitrogen use efficiency (NUE) (Pettygerove, 2009).

Nitrogen is frequently the most limiting nutrient for plant growth even with its richness in the atmosphere (OECD, 2007). Even though over 78% of the atmosphere is constituted of nitrogen, it is chemically and biologically unusable form (Erisman, 2008). Before humans, N_r from N_2 creation took place mostly through two processes, lighting and BNF (Galloway, 2003). Now nitrogen is manufactured to fertilizer through many different formulations, with individual properties and uses for crop production method (Reetz, 2016). Nitrogen fertilizer making starter from Haber-Bosch process, reaction of ammonia, which could be synthesized by reacting atmospheric dinitrogen with hydrogen in the presence of iron at high temperatures and pressures and it is discovered by Haber (Erisman, 2008). It made attainable to mass produce low-cost nitrogenous fertilizers (Smil, 2011). Because of this discovery, has been possible to feed billions of people but, it was the cascade of environmental changes (Erisman, 2008). Global agriculture is more dependent on synthetic nitrogenous compounds without there would not be produced about half of today's world food (Smil, 2011).

The biggest stock of nitrogen is discovered in the atmosphere where it is in the form of an inert gas (mainly N_2) and the atmospheric storage is around million times bigger than total nitrogen included in living organisms (OECD, 2007). There are also other nitrogen gaseous compounds in the atmosphere like ammonia (NH_3), nitrogen oxide (NO) and nitrous oxide (N_2O) which is a strong and relatively long-lived greenhouse gas (Ghaly, 2015). Nitrogen is stored also in a reactive form in the oceans and organic matter, but the most common way nitrogen is stored, is in living and dead organic matter in most ecosystems (OECD, 2007). Nitrogen is returned back to the soil in a form available to plants after these organisms die through activities of soil microorganisms and to a lesser extent is lost to the atmosphere (Ghaly, 2015). In crop rotations, when residue is left on the field, organic matter is provided to the soil including nitrogen in a form that is not immediately available to plants. Soil microorganisms like fungi and bacteria convert it to the form of nitrogen that plants can use. (Shober, 2015.)

Nitrogen can be lost from production systems in various ways like into the atmosphere from the soil or plants as N_2 gas, NH_3, N_2O or NO_x gases and it can be lost as nitrate (NO_3^-

) or ammonium (NH_4^+) in soil water by leaching or runoff from soil surface (Reetz, 2016). Spreading inorganic fertilisers and livestock manure is the most common method to supply supplementary nitrogen to replace the losses, but also some of this supplementary nitrogen volatilises from manure in the form of ammonia during and soon after spreading, and rainfall may cause leaching and run off of highly soluble nitrate before plants can absorb it (OECD, 2007). The direct impacts of NH_3 are mostly of close distant to N_r sources like manure storage tank (Erisman, 2013). Nitrogen has impact on air, water quality and human health (Erisman, 2013). The impacts nitrogen has on environment are through eutrophicating surface water bodies feeding algal growth and aquatic plants, and can tie up oxygen in the waters as they die and in the soils when nitrogen is released into the atmosphere as N_2O (Reetz, 2016). Main emission of oxidized nitrogen is via the formation of nitrogen oxides (NO and NO_2) and nitrous oxide (N_2O) and other compounds are formed in the atmosphere (Erisman, 2011). NO_x can increase tropospheric formation, smog, particulate matter and aerosols when it is released into the lower atmosphere (Erisman, 2013). Leakages from agriculture, industry and transport result in cascade of N through the global environment leading to numerous of different environmental effects like eutrophication of water and soils, greenhouse gas emissions, loss of biodiversity, acidification, drinking water pollution human health risks and destruction of the ozone layer (Erisman, 2011).

2.2 Phosphorus

Phosphorus is a vital element for life and cannot be replaced because it is part of biological processes like reproduction, energy supply and body structure (van Dijk, 2016). Phosphorus is one of the main structural elements of membranes that surround plant cells and it is associated with the synthesis of proteins and vitamins and takes place in key enzymes (Johnston, 2000). Also phosphorus has important part in photosynthesis, functioning in the capture and transfer of energy into chemical bonds (Reetz, 2016). Produced carbohydrate molecules in photosynthesis are transferred to the plants' stock organs like the roots or the grains and sugars are converted to starch (Johnston, 2000).

Phosphorus is obtained from phosphate rocks being a non-renewable resource (Cordell, 2007). Before mining of phosphate rock for fertilizer manufacture, phosphorus was spread to agricultural soils by recycling animal manure, human and bird excreta, ash, crushed animal bones and city waste (Van Vuuren, 2010). There are three main uses of phosphorus at the moment: first, to make fertilizer for use in agriculture for food production (in Western Europe about 79% of total use), second, to make feed grade additives for animal feeding stuff (around 11%), third, to make detergents (about 7%) and the rest of it is used in speciality products as diverse as additives for human food and metal surface processing to delay corrosion (Johnston, 2000).

Phosphorus is absorbed from the soil by plant roots as orthophosphate ions, mostly dihydrogen phosphate ($H_2PO_4^-$), and less as hydrogen phosphate (HPO_4^{2-}) (Svers, 2008). Phosphorus is as an element very bondable, which means it easily combines with various other elements, which is reason it appear in phosphate form (EcoSanRes, 2005). There are many factors that affect both the rate and amount of phosphorus absorbed by plant and the recovery of single application of phosphorus fertilizer, and the same factors impact the recovery of phosphorus stocks accumulated in the soil from past use of phosphorus as fertilizer or manure (Svers, 2008). The low availability of phosphorus is because of slow diffusion and high fixation in soils and the main impact factors of soil phsophorus availability are soil parent material, fertilizer practices and soil chemical, physical and biological properties (Yu, 2016). Examples of the biological properties are mycorrhizal fungal functioning, P-solubilizing bacteria, decomposing microbes and so on. Phosphorus availability is measured by solubility determining extractants which are, among others, water (easily available), citric acid (moderately available) and formic acid (very slowly available) as an indication of the pace of chemical phosphorus transformation in these different soil conditions (Reetz, 2016). Phosphorus buffer capacity controls the rate of the replenishment of phosphorus in the soil solution. The size of the root system, extent of it and the efficiency of phosphorus take up are also important (Svers, 2008).

Most of the soils which are not manured do not contain enough readily available phosphorus to meet the huge demand of crops, especially during certain periods of the growing cycle and the lack of phosphorus influences not only plant growth and development and crop yield, it also has impact on the quality of fruits and the formation of seeds (Johnston, 2000). This lack of available phosphorus in soils creates need of it and phosphorus is added to soils as a mineral fertilizer, which has led to positive agronomic P balance in some places like in United States, Europe and Asia where there is surplus of phosphorus, unlike in Russia, Africa and South-America where it is in deficit (ITPS, 2015). Overusing P fertilizers, P nutrients coming from other sources and P detergents may result in large flows of P to water creating eutrophication of freshwater and marine ecosystems and it has many effects like toxic algal bloom, algal scum, enhanced benthic algal growth and huge growth of submersed and floating macrophytes and also secondary issues comprise fish death and oxygen depletion in water (Van Vuuren, 2010). There can be surplus of P in nature too, that is causing eutrophication, decreasing water quality and biodiversity. There are potential solutions for the P challenges like stewardship formed of efficient and effective use of phosphorus in society containing more and better recycling. (van Dijk, 2016.)

Phosphorus fertilizers are needed to maintain and increase food production, but because it is produced using non-renewable resources, there is a concern that current extraction rates could lead to depletion of these resources (Van Vuuren, 2010). Reserves known at the moment are evaluated to be exhausted within 50-400 years depending on the demand and supply (Dijk, 2016). Two big opportunities for increasing the life expectancy of the world's phosphorus supplies lie in recycling by recovery from municipal and other waste products and how efficiently both phosphatic mineral fertilizer and animal manure are used in agriculture (Johnston, 2000). Main phosphorus resources are spatially concentrated as 77 % of the known global phosphorus rock stocks are located in Morocco and Western Sahara. Europe has only few phosphorus rock stocks, most of them locate in Finland. (Dijk, 2016.) Because of this phosphorus is under the influence of international politics (Cordell, 2009).

2.3 Potassium

Potassium is important factor to many plant processes; it determines fruit size, stem strength and leaf thickness. It is taken by plants from the water in the soil when growing (Johnston, 2003). Potassium appears in relatively small amounts in soil solutions as the positively-charged cation and it is absorbed by plants in that form in the soil (Reetz, 2016). Potassium is needed for multiple plant growth processes: transport of sugar, water and nutrient transport, enzyme activation, photosynthesis, protein synthesis, starch synthesis and stomatal activity (water use) (Agriculture solutions inc, 2019). Potassium helps plants tackle the unwanted effects of drought and frost damage, insect and disease attack by maintaining the salt concentration in the cell sap (Johnston, 2003).It can reduce water loss and wilting, produce grain rich in starch, build cellulose, reduces lodging, maintain turgor for strong structure, aid in photosynthesis and food formation, reduce respiration, preventing energy losses and increase protein content of plants (Agriculture solutions inc, 2019).

Potassium is about seventh in sequence of abundance in the earth's crust, so it is very common element, but its concentration in rocks is small (Johnston, 2003). Potassium form about 2.1-2.3 % of the earth's crust and stocks in soil is quite high (Hasanuzzaman, 2018) But still there are reported large agricultural areas to be insufficient in K availability (Zörb, 2014.). The number of potassium depend on the parent material, weathering, potassium supply from manure and fertilizers and losses from the removal erosion and leaching (Lalitha, 2014). Sandy, waterlogged, saline and acidic soils are often naturally low in potassium (Zörb, 2014). Potassium fertilizers are mostly obtained from geological deposit (Reetz, 2016). These salt deposits are usually complex mixtures of salts, including potassium, sodium and magnesium (Johnston, 2003). Potassium has become a limiting element especially in intensive agricultural production systems in singular in coarse-textured or organic soils (Zörb, 2014). Potassium is easily leached from crop residue, after the plant dies, it can also leach from living plant tissue during heavy rainfall (Reetz, 2016). Lowering fertilizer K application when fertilization is unbalanced may result significant depletion of available soil potassium reserves (Zörb, 2014). Most of the potassium reserve have accumulated from past applications of fertilizers and manures and needed to preserve by putting fertilizers or manures that haves potassium (Johnston, 2003).

Physicochemical properties of the soil effects on the content of potassium (Lalitha, 2014). It is classified into four groups depending on its availability to plants: water-soluble, exchangeable, non-exchangeable and structural forms (Zörb, 2014). Water soluble K is readily uptake by plants and comparatively unbound by cation exchange forces and easily leaching (Lalitha, 2014). Exchangeable potassium is bounded to surface of clay mineral and humic substance by electrostatically bound (Zörb, 2014).The water available and exchangeable potassium are considered to be easily available to plants (Lalitha, 2014). Non-exchangeable and structural forms are reviewed as slowly- or non-available potassium sources for plants, but pools can provide remarkably to the plant supply in the long term. (Zörb, 2014.)

3 NUTRIENT BALANCE

A soil nutrient balance is an often used indicator to estimate amends in soil fertility. Nutrient balance is about calculating five nutrient in- and outflows by Stoorvogel and Smailing (1990) (Lesschen, 2007). The fertility of the soil is determined based on, which nutrient exports are balanced by nutrient imports. The nutrient exports or outflows are uptake by crop, leaching, erosion, runoff, volatilization and denitrification. The nutrient imports or inflows are fertilization, BNF and atmosphere deposition. Internal flows of different nutrients are considered to be more or less in balance. The nutrient balance can determine quantification and valuation of nutrient depletion, the ranking of the different nutrient output channels and, the modelling and identification of management options influencing them, here by analysing and preventing nutrient mismanagement. Nutrient balance calculations has been developed into decision support models that allow monitoring of the effects of changing land use and proposition of interventions to make better the nutrient balance. NUTMON model is very well known and is very adaptable instrument. (Drechsel, 1999)

Nutrient balances have been used over the years to improve natural resource management and/or for policy recommendations, but with this approach there are many methodological complexities and uncertainties, so caution should be taken because of the uncritical interpretation of the results. There has been showed that scaling-up nutrient balances in the spatial hierarchy can display bias and big errors in the results if flows are not well enough extrapolated. This is partly because of the detailed data required for the calculations are usually based on small-scale experiments or monitoring at plot level. (Cobo, 2010.) Now there are available new geographic data sets and remote sensing images that make it possible to calculate soil nutrient balances in spatially distinct way. Because of these regional differences due the soil and climate variability can be taken consideration and national soil fertility policies can be better addressed towards the lower levels for ensample district or cooperation region. (Lesschen, 2007.)

3.1 Assessment

There are many methods to assess nutrients in the soil. The widely known approach nutrient balance was in Africa firstly used in the study of Stoorvogel and Smailing (1990). Also NUTMON is very well known and very adaptable tool (Drechsel, 1999). Data can be gathered up by soil samples from the study area, which can be more precise for the specific area and give more realistic results. This kind of method has been used in Hengl (2017) article and also in that article they used Mehlich 3 method and/or equivalent. When using this method the time period can also be much more precise. There has been used the yield gap method and QUEFTS (QUantitative Evaluation of Fertility of Tropical Soils) model.

NUTMON is nutrient monitoring for tropical farming that has two phases: the diagnostic and the development phase (Roy, 2003). NUTMON use primary data, assumptions and estimates and determinants are mainly scale-neutral and are usable to monitor nutrient balance at different levels like regional and farm level (Drechsel, 1999). There have been made modification models from the NUTMON. One is Farm-NUTMON which has been used in studies by Van den Bosch (1998). MonQI (Monitoring for Quality Improvement) is also a modification from the NUTMON (MonQI, 2015). There have been case studies that show the integration of spatial scales in models like NUTMON is potential, but restricted by limited data availability and by scale-specific variability (Drechsel, 1999).

Yield gaps are evaluated by the difference between average farmers' yields and yield potential at a particular desired spatial and temporal scale (Lobell, 2009). Spatial scale chosen for benchmarking should depend on the essences of the problem and also time scale needs to be considered and it should be long enough to get as much fluctuation in seasonal conditions as possible, and also needs to be short enough to fulfil the presumption of constant technology, if the goal is to benchmark crops by current technology (Sadras, 2015). Yield potential (Yp) is crop grown with non-limiting nutrients and water and biotic stress effectively managed (Van Ittersum, 2013). There are three factors that determine yield potential: solar radiation, temperature and water supply (lobell, 2009). Regions without significant soil limitation Yield potential is very relevant benchmark for irrigated systems, but for rainfed crops, water-limited yield (Yw), where crop growth is also limited by water supply, is comparable to water-limited potential yield, is very relevant benchmark and for partially irrigated crops both can work as benchmark (Van Ittersum, 2013).

Analysis of yield gap assist recognizes opportunities to better crop yield and estimates food security scenarios (Guilpart, 2017). The exploitable yield gap consider for both unrealistic alignment of all factors needed for achievement of potential or water restricted yield and the economic, management and environmental limitation (Sadras, 2015).

QUEFTS delivers an evaluation of potential yields of the region and it takes into account the availability of nitrogen, phosphorus and potassium and there are two versions of QUEFTS the original version and the modified version. It is reliable under specific boundary conditions for these soil properties (Mulder, 2000). It is a method to evaluate the site specific marketable yield and the impact of fertilizer application on the yield for a crop based on soil characteristics and it is designed in 1990 by Bert Janssen and co-workers of the Wageningen University & Research centre (Fertile Ground Initiative, 2015). The core of QUEFTS is the ratio between the yield and nutrient uptake (Pathak, 2003). This model has been built with maize as the test crop, but it is possible to modify the modelto make it suitable to other crops (Jenssen, 1990).

3.2 Inputs

Nutrient inputs included in the balance assessments are presented based on Stoorvogel and Smaling (1990), and Haileslassie et al. (2005), but these inputs are used worldwide in nutrient balance calculations. In this chapter the inputs are introduced: mineral fertilizer, organic fertilizers, atmospheric deposition, BNF and sedimentation.

3.2.1 Mineral fertilizers

The main three macronutrients that are used the most as fertilizer are nitrogen, phosphorus and potassium. Fertilizers can provide substantial input of nutrients in agricultural ecosystems (Dalal, 1997). Most of the fertilizers are from concentrated materials of naturally-occurring minerals, these are mined or extracted from or deposits (Reetz Jr., 2016).

Different types of N fertilizers which are used: Ammonium fertilizers, nitrate fertilizers, ammonium nitrate fertilizers, amide fertilizers, solutions (contain more than one form of N, Slow- and controlled-release fertilizers and multi-nutrient fertilizers. (Reetz Jr., 2016.) Now a days, regular inputs of phosphate fertilizer obtain from mined rock is important for agriculture to supplement the phosphorus removed from the soil by growing and harvesting the crop, but phosphate rock is non-renewable resource (Cordell, 2009). Types of P fertilizers there is: Water-soluble types, partly water-soluble types, Slow-acting types, very slow-acting types and multi-nutrient fertilizers (Reetz Jr., 2016). Potassium fertilizers (K) also known as potash fertilizers are mostly obtained from geological saline deposits (Reetz Jr., 2016). Potassium fertilizer that is used most currently is potassium chloride (KCl) is natural mineral mined from deep deposit and side products from KCl mining; potassium sulphate and potassium nitrate are as well commercially obtainable but are more costly (Zörb, 2014).

3.2.2 Organic fertilizers

Organic fertilizers are naturally occurring material, farm waste (like crop residues, animal manure, compost and green manures), Residue from processing of plants products (like fibers, wood materials), residues from processing of animal products (like horn- or bone-meal), urban waste (like composted household refuse and sewage sludge) and soil inoculants (like living micro-organisms). There are important quality criteria for organic fertilizers like: C/N ratio, total P and K contents, total and easily mineralizable organic matter, dry matter content, total and quick-acting N and content of substances detrimental to plant growth or product quality. Many of the organic fertilizers are waste products so they can be quite cheap, especially if they are used nearby where they are produced. (Reetz Jr., 2016.)

3.2.3 Atmospheric deposition

Wet deposition happens by rain and snowfall, while dry deposition appear from gaseous and particulate move from the air to the top of aquatic and terrestrial landscape (Anderson, 2006). Nutrients come to atmospheric deposition from precipitation, dry deposition of aeolian dust and gaseous absorption by plants and soil. The location of original source affects the added amount of nutrients. It is quite hard to separate between net accessions and redistribution of nutrient that have been locally collected as plant or dust debris. (Dalal, 1997.) Atmospheric deposition is an important process which removes gases and particles from atmosphere, but it is also significant environmental issue in several parts of world. Because of the human activities the concentration of pollutants in the atmosphere is increased which cause more atmospheric deposition of pollutants. This has negative affect on land and marine ecosystems, human health and crop yields. (World Meteorological Organization, 2019.)

3.2.3 Biological nitrogen fixation

BNF is implemented by a specialized group of prokaryotes. The conversion of atmospheric nitrogen (N_2) to ammonia (NH_3) is done by utilize the enzyme nitrogenase as a catalyst. Ammonia is a form that can be used by plants (Santi, 2013).These prokaryotes include bacteria like Azospirillium, these form associative relationship with plants, aquatic organisms like cyanobacteria, free-living soil bacteria like Azotobacter and bacteria that forms symbioses with legumes and other plants like Rhizobuim (Wagner, 2011). Non-symbiotic N fixation by micro-organisms and symbiotic fixation of N by legumes are valuable sources of N under both agricultural and natural ecosystems (Dalal, 1997).

3.2.5 Sedimentation

Sedimentation happens when eroded material that is being moved by water will gather up onto the surface out of the water column, as the water flow slows down (Government of Western Australia, 2015). Different sized particles are moved and deposited into the water bodies and elsewhere along the water flow paths (De Sousa, 2019). Sedimentation is a natural process, but unsuitable land use and management practices in the catchment can speed up these processes and stimulation adaptation in the channel (Government of Western Australia, 2015). Sedimentation can be caused by natural occurrence, changes in gradient, erosion and obstruction of canals (De Sousa, 2019). In nutrient balance calculation sedimentation is very important to take into account in irrigated areas, on naturally flooded soils, and inland valleys (Henao and Baanante, 2006).

3.3 Outputs

Nutrient outputs included in the balance assessments are presented based on Stoorvogel and Smaling (1990), and Haileslassie (2005), but overall these outputs are used worldwide in nutrient balance calculations. In this chapter the outputs are introduced: harvested product, crop residue, leaching, gaseous losses and erosion.

3.3.1 Harvested products

The primary way the soil and fertilizer nutrients leave the field is by nutrient removal, the harvested portion of field crops (Roberts, 2015). Substantial methods for removing nutrient from soils are the harvest and removal of crop produce and residue (Henao and Baanante, 2006). When talking about nutrient uptake, it means the total amount of nutrients taken up by the crop entirely the growing season and included in the grain, leaves, stalks and roots (Roberts, 2015). Nutrient removal can be a valuable indicator of crop nutrient use efficiency (Pettygerove, 2009).

3.3.2 Crop residue

Crop residue is a portion of nutrients from the crop which is not used for the primary product but appears as loss or waste and is often returned to the soil. The amount of the nutrients that is returned to the soil depends of the crop. Residues of the crop will decompose over time and later release the nutrients for the following crops. (Roberts, 2015.) Crop residues are used differently in developed countries than in other countries. Developed countries have minimal economies alternative uses for the crop residue unlike many other countries uses residues for cattle feed, building materials, fibre and fuel for cooking and industries. If crop residue is not returned to soils and it is removed, significant amounts of nutrients are also removed. Also it has several beneficial results, when crop residue is returned to the soil. For example, crop residue provides substrate for microbial and meso-faunal activity which assists in nutrient cycling. They increase organic matter and reduce losses of total N, available P and exchangeable K, especially under zero tillage, and they support aggregation, infiltration and soil water retention and influence soil temperature. (Dalal, 1997.)

3.3.3 Leaching

Leaching is a process where water goes through the soil and take away some of the nutrients that plants use, like nitrates and sulphur (Dontigney, 2018.). Nitrate from the nutrients that effect on crop growth is most leached over the root zone (Dalal, 1997). Normally it occurs in minor levels with typical rainfall and the breakdown of organic materials on the surface and resupplies the soil (Dontigney, 2018). Also basic exchangeable cation, like calcium ion (Ca^{2+}), magnesium ion (Mg^{2+}) and potassium ions

(K^+) can be leached (Dalal, 1997). The effect of soil leaching can be more significant if there is excessive rainfall or irrigation. (Dontigney, 2018.)

3.3.4 Gaseous losses

Through denitrification and volatilisation, nitrogen is lost to the atmosphere (Stoorvogel and Smaling, 1990). Nitrogen volatilisation is high-temperature reaction that results of transforming of nitrogen matter to NO, NO_2 and more especially to NH_3 (OECD, 2007). This process mainly occurs in alkaline environments (Stoorvogel and Smaling, 1990). Volatilisation happens in stables just after excretion, during storage of livestock manure and it happens again when spreading of the manure on the soil. This can cause some emission, mainly of NH_3 and is part of pollution problem which is associated with excessive N surplus. The final stage in the process of reduction of nitrate to gaseous N_2 is denitrification. (OECD, 2007.) This process occurs under anaerobic conditions and is greatest in wet climates, on highly fertilized and clayey soils. (Stoorvogel and Smaling, 1990). Denitrification can also result in N_2O emissions (OECD, 2007). Decomposable organic matter, soil temperature and nitrate concentration increase and decrease in oxygen supply increases loss of nitrogen through denitrification (Dalal, 1997).

3.3.5 Erosion

Soil erosion is determined as the speeded up removal of topsoil from the land surface by water, wind or tillage (FAO, 2015). It is a geomorphic process and effect on the soil is quite low in natural ecosystem at steady state, because the pace of erosion loss is about the pace of soil formation (Sumithra, 2013). Water erosion happens when overland flow takes soil particles detached by fall impact or runoff, which can lead to channels like rills or gullies, wind erosion take place when loose, bare and dry soil is exposed to strong wind and it is common in semi-arid areas and tillage erosion is straight down-slope motion of soil by tillage implements where particles just redistribute in a field (FAO, 2015). Overall wind erosion impact on soil fertility reduces and water erosion impact on soil fertility increase with increasing rainfall (Dalal, 1997). Soil erosion can be fast or a slow process, when it is slow it goes relatively unnoticed but it can be happen in alarming rate and cause serious loss of topsoil (Sumithra, 2013). Soil erosion may reach to a most visible process of soil fertility depletion by removal of generally big amounts of fertile topsoil and it will effect on long term soil productivity by selectively removing organic matter and fine soil particle and leaving coarse particles. (Dalal, 1997.) This can cause reduced crop production potential in farmlands, lower surface water quality and damaged drained networks (Sumithra, 2013). Erosion can reduce water quality by the sediment made through erosion pollutes water streams with nutrients and sediments (FAO, 2015). Human actions that disturb ecosystem like deforestation and burning which clears vegetation and/ or land development (Dalal, 1997). It is one of the biggest processes leading to soil degradation. (Sumithra, 2013.)

3.4 Soil nutrient depletion

Nutrient depletion or nutrient mining means the net loss of plant nutrients from the soil because more nutrients are outflowing than inflowing and as a result negative nutrient balance (Drechsel, 2001). The amount of the nutrients stocks in the soil decrease when outputs from the soil surpass inputs. The pace of nutrient depletion project the difference between output and inputs and it can be displayed in terms an amount of nutrient per unit of area and per unit of time (kg/ha/yr). But over a long period of time, system adapts to the changing levels of inputs and outputs, so measure of the relative pace of change in the soil store is more suitable, with the units of reciprocal time. (Dalal, 1997.)

Depletion of soil nutrients is a natural result of cultivating soil for cereal grain cropping, which happens when the nutrients removed in crops are not refill. There can be large losses of nutrients through soil erosion and runoff, leaching and volatilisation, denitrification of N and crop residue removal or burning. These factors like carrying capacity of land, erosions and land-use intensity can effect on land degradation in addition to nutrient mining. Efficiency of nutrient use can be decreased because of the development of harmful soil conditions for plant growth, like acidification, reduced biological availability, structural degradation and diseases. Following grain yield decrease and the quality of grain weaken with increasing period of cultivation unless action is used to restore fertility. It is unsustainable do agricultural production which involves ongoing cultivation and grain cropping without restoring nutrients. It is hard to make a decision for agriculturalists to determine the level of the soil nutrient assets and crop productivity to be maintained, equivalent with economic sustainability and without resulting environmental degradation. (Dalal, 1997; Drechsel, 2001.)

There has been estimated by Food and Agriculture Organization of United Nations (FAO), that the actual supporting capacity of land varies between 10 to 500 persons km^2. The critical standard is determined by reduced availability of, or access to, resources, like water, fuelwood or fertile land and the increasing need of a growing population. The results of these limitations are lessening fallow periods, restricting soil fertility renewal and increasing cultivation of marginal soils. The speed of soil degradation will depend on soil fertility levels, and it also range with farmer’s possibilities and limitations for soil conservation and nutrient renewal. The input availability and/or high cost can effect on the quantities applied. Also, increasing (nitrogen) fertilization does not always recover the negative nutrient balance because of the higher nutrient outflow by leaching and crop uptake. (Drechsel, 2001.)

3.5 Soil nutrient accumulation

Fertilizers and other soil amendments are applied onto agricultural soil over time and it can lead to the gradual accumulation of many elements that is a risk for soil quality and for soil function. Agricultural soils obtain many different types of additions like commercial fertilizers compost, animal manure and waste-derived fertilizers. If it is not accurately managed; additions can effect on chemical properties of soils and connected water bodies. If exceeding crop need of nitrogen and phosphorus inputs it will increase the risk of losses to water bodies and it can lead to contamination of surface water and groundwater. (Della Peruta, 2016.)

Too much use of nitrogen fertilizers has led to accumulation of substantial amounts of nitrogen over crop absorption in soils, mostly in the form of nitrate. Excess of nitrate in soils can cause problems because it is prone to loss by leaching or denitrification and it is both environmentally and economically unwanted. Uniform monoculture, undue fertilization and high-intensity anthropogenic disturbance within greenhouse cultivation change the process of soil nitrogen transformation and speed up the accumulation of nitrate. (Quan, 2016.)

Fertilizer use and livestock production growth at the same time has more than tripled global phosphorus flows. This has resulting in phosphorus accumulation in some agricultural soils which works as a driver of eutrophication in coastal systems and freshwater. Results show phosphorus fertilizer use can be contributing to soil phosphorus accumulation in fast developing regions. The global phosphorus cycle has basically changed because of increased phosphorus fertilizer use and livestock production. There was huge variation in the sizes of these phosphorus imbalances across most regions, especially Europe and South America. High phosphorus fertilizer application comparative to crop phosphorus use caused in a further proportion of the intense phosphorus surpluses globally than manure phosphorus application. It is also associated with areas of comparatively low phosphorus use efficiency. Even though manure was a major driver of phosphorus surpluses in some regions with high livestock densities, phosphorus shortfall were very common in regions producing feed crops. (MacDonald, 2011.)

Agriculture is one of the largest sources of new nutrients to the Baltic Sea, contributing about half of total waterborne phosphorus and nitrogen inputs. There is lot of fertiliser and livestock feed that is brought to the catchment is converted into manure but quite often the nutrients in manure are not used efficiently in crop production. Accumulation of nutrients is result of the inefficiency in agricultural soils and grows the risk of losses to streams lakes and for example Baltic Sea. These nutrient losses can be reducing by improving manure management and replacing mineral fertilizers with manure. Also when decreasing the number of animals in regions with high densities and import of livestock feed may also decrease agricultural nutrient excess. When the sea becomes eutrophic over the decade it will take decades to recover from it. When decreasing nutrient leakage on land, it will not only have a good impact on the sea but also lakes, groundwater and rivers. (McCrackin, 2016.)

4 MATERIAL AND METHODS

The estimation for nutrient balance was made based on Stoorvogel and Smaling (1990), and Haileslassie (2005) studies and some slight modification were done. For calculating the nutrient balance is used four inputs and three outputs (Table 1). Internal flows are not taken into account. The four inputs that are used: mineral fertilizer, organic fertilizer or manure, atmospheric deposition and BNF and three outputs that are used: harvested product, crop residue and gaseous losses. Outputs are reduced from the inputs to get the total net nutrient balance and expressed in tonnes of nutrients per year (t/a). Balance that is positive means there is accumulation in soil and negative balance means there is nutrient depletion in soil (Haileslassie, 2005). These calculations are based on production years 1961-2016 in Ethiopia, Ivory Coast and Finland.

Table 1 Inputs and outputs of nutrient balance

Inputs	Outputs
IN_1: mineral fertilizer	OUT_1: harvested products
IN_2: manure	OUT_2: residues removed
IN_3: atmospheric deposition	OUT_3: gaseous losses
IN_4: biological nitrogen fixation	

4.1 Nutrient inputs

The first nutrient input (IN_1) mineral fertilizer originates from International Fertilizer Association statistical information (IFASTAT) database (IFA, 2019). According to them the consumption Database is estimation of fertilizer consumption by product, by country/region and by year and reflects plant nutrition uses only. Nutrients are displayed in N, phosphorus pentoxide (P_2O_5) and potassium oxide (K_2O) and all statistics are available in nutrient metric tonnes (ifa, 2019). Nutrients are converted from P_2O_5 and K_2O to P and K.

The second nutrient input (IN_2) manure is calculating using (FAO, 2019a). The element manure (N content) is used for the three countries, it is given in kilograms. Average manure nutrient composition is18.3 g N/kg, 4.5 g P/kg and 21.3 g K/kg on dry weight base values were used to calculate manure nutrient results (Haileslassie, 2005).

The atmospheric deposition (IN_3) nutrient input is calculated using the method of Stoorvogel and Smaling (1990), and Haileslassie (2005) studies (Equation 1). For the calculation are needed the average annual rainfall (mm) and coefficients of 0.014 for N, 0.053 for P and 0.11 for K. Annual rainfall is from World Bank Group (2019).

$$IN_3 = coefficients\ value * (rainfall)^{\frac{1}{2}} \qquad (1)$$

Biological nitrogen fixation (BNF) (IN_4) is calculated by multiplying annual and country specifics cultivation areas of pulses, rice and grazing land with BNF coefficients from Herridge et al. (2008).

Sedimentation is left out from the calculation. There was not relevant data available about precipitation for these countries, which was needed to calculate sedimentation.

4.2 Nutrient outputs

The first output harvested products (OUT_1) data is from (FAO, 2019b). These quantities from FAO are multiply with average values for each crop which are from Stoorvogel and Smaling (1990), IPNI (2014), Horticulture (2017), Strik (2013), Yara UK (2018), SLTEC (2018) and Kumar Ray (2015) (appendix I).

Removed crop residue (OUT_2) daat is also from (FAO, 2019c) as an N content in kilograms. It was calculated with the N, P, and K content of crop residue values from appendix I. There are minimum and maximum for crop residue values and here is used the average of those values.

Gaseous losses (OUT_3) values are from Sainju (2017). These values range from 10 to 20 % for inorganic N fertilizer and 15 to 30 % for manure and losses was calculated from the average of those values.

Erosion and leaching are not included nutrient balance calculation because there was not enough data available to calculate those values for entire countries.

5 RESULTS

5.1 Nutrient inputs

In tables 2, 3 and 4 can be found nutrients inputs for each country. In those tables can be seen how the amounts of inputs have change every 10 years. In Ethiopia (table 2) there were not any mineral fertilizer (IN_1) inputs in 1961. Nitrogen and phosphorus inputs have change a lot over 50 years. There is not that much changes with potassium fertilizer, some years there has been applied potassium fertilizers, but not every year. Organic fertilizer or manure (IN_2) has remained almost same for many years, but almost doubled between 2001 and 2011, for each nutrient. Slight increase can be seen before 2011 in potassium fertilizer use. Atmospheric deposition (IN_3) amounts are quite small and have remained almost same during those years. Also there is not big fluctuation in nitrogen fixation (IN_4) during those 50 years.

Table 2 Nutrient inputs in Ethiopia in every 10 years from 1961 to 2011 (t/a)

Year	IN_1			IN_2			IN_3			IN_4
	N	P	K	N	P	K	N	P	K	N
1961	0	0	0	22500	5 540	26 200	0,005	0,002	0,004	235
1971	5 600	3 710	1 700	24900	6 120	29 000	0,004	0,002	0,003	242
1981	16 000	13 100	0	25200	6 190	29 300	0,004	0,001	0,003	241
1991	26 500	17 300	0	28600	7 040	33 300	0,004	0,001	0,003	222
2001	111 000	41 800	0	28200	6 940	32 800	0,004	0,001	0,003	199
2011	130 000	54 600	0	51400	12 600	59 800	0,004	0,001	0,003	215

For Ivory Coast (table 3) mineral fertilizer (IN_1) use has been increasing during those 50 years. Mineral fertilizer use has increased strongly every 10 years from the 1961 to 2001, but from 2001 to 2011 nitrogen and phosphorus fertilizer use has decreased. Also, manure (IN_2) use has been increasing. Atmospheric deposition is much bigger in Ivory Coast than in Ethiopia and also it has been increased every 10 year. Nitrogen fixation (IN_4) is not as much as it is in Ethiopia and it has stayed quite same throughout the years.

Table 3 Nutrient inputs in Ivory Coast in every 10 years from 1961 to 2011 (t/a)

Year	IN_1			IN_2			IN_3			IN_4
	N	P	K	N	P	K	N	P	K	N
1961	1 700	306	4 230	1 040	255	1 210	1,04	0,255	0,255	76,6
1971	6 500	1 530	11 600	2 000	493	2 330	2,00	0,493	0,493	79,3
1981	13 300	3 840	18 800	3 660	899	4 260	3,66	0,899	0,899	84,7
1991	16 200	3 710	11 600	4 450	1 090	5 170	4,45	1,09	1,09	93,8
2001	30 000	7 200	13 300	4 440	1 090	5 170	4,44	1,09	1,09	85,0
2011	25 700	4 890	18 300	5 650	1 390	6 580	5,65	1,39	1,39	87,3

In Finland mineral (table 3) fertilizer (IN_1) use is higher than in Ethiopia and Ivory Coast except phosphorus in Ethiopia past couple of decades. Also, use of fertilizer has been decreased between 2001 and 2011. Nitrogen is most used fertilizer in Finland. Manure (IN_2) use has also been decreasing past couple of decades. Potassium has been decreasing from 1961 to 2011 it is quite the opposite of the Ethiopia potassium use in manure.

Atmospheric deposition (IN_3) is much bigger in Finland than in Ethiopia and Ivory Coast. Also, it has been decreasing during these 50 years. Nitrogen fixation (IN_4) nutrient input in Ethiopia and Ivory Coast is much bigger than in Finland and the amounts are very small in Finland.

Table 4 Nutrient inputs in Finland in every 10 years from 1961 to 2011 (t/a)

Year	IN_1			IN_2			IN_3			IN_4
	N	P	K	N	P	K	N	P	K	N
1961	19 000	43 200	75 500	47 400	11 700	55 200	47,4	11,7	55,2	0,802
1971	9 900	79 000	117 000	43 300	10 700	50 400	43,3	10,7	50,4	0,884
1981	10 600	64 000	112 000	40 900	10 000	47 600	40,9	10,1	47,6	1,33
1991	19 500	36 600	73 600	30 800	7 570	35 800	30,8	7,60	35,8	1,66
2001	165 000	22 700	56 500	25 600	6 290	29 800	25,6	6,29	29,8	0,776
2011	143 000	10 500	29 900	23 200	5 700	26 900	23,2	5,69	26,9	0,831

5.2 Nutrient outputs

The nutrient outputs for each country can be found in tables 5, 6 and 7. In those tables values are presented in every 10 years. In Ethiopia (table 5) harvested product (OUT_1) nutrients has been increasing during these 50 years. Nutrients from residue removal (OUT_2) have increased during past two decades before that it has been remained quite steady. Gaseous losses (OUT_3) have doubled from the 2001 to 2011 before that amounts has been quite stable.

Table 5 Nutrient outputs in Ethiopia in every 10 years from 1961 to 2011 (t/a)

Year	OUT_1			OUT_2			OUT_3
	N	P	K	N	P	K	N
1961	106 000	52 100	51 300	52 400	43 800	264 000	264
1971	137 000	68 000	66 400	63 100	53 000	313 000	313
1981	154 000	77 400	77 400	60 100	50 200	293 000	293
1991	169 000	79 400	86 900	56 200	42 700	270 000	270
2001	239 000	118 000	118 000	107 000	80 200	484 000	484
2011	460 000	234 000	222 000	180 000	136 000	802 000	802

In Ivory Coast (table 6) nutrients in harvested product (OUT_1) have been increasing during the period under review. It has been multiplied from the 1961 to 2011, but it is much less than in Ethiopia. Nutrients from residue removal (OUT_2) have also multiplied from the 1961. Increase of gaseous losses (OUT_3) is huge from the 1961 to 2011 and it is also bigger in Ivory Coast than in Ethiopia. Nutrient losses have increased during this period of time.

Table 6 Nutrient outputs in Ivory Coast in every 10 years from 1961 to 2011 (t/a)

Year	OUT_1			OUT_2			OUT_3
	N	P	K	N	P	K	N
1961	21 400	9 410	19 800	7 200	3 430	25 400	234
1971	43 400	20 200	33 600	12 700	6 100	43 800	452
1981	81 800	38 700	59 600	15 500	7 420	52 600	825
1991	119 000	57 100	79 200	23 600	11 300	82 700	1 000
2001	152 000	71 700	104 000	13 700	6 730	49 800	1 000
2011	182 000	82 300	118 000	22 100	10 700	75 200	1280

In Finland (table 7) nitrogen from harvested removal (OUT_1) has been increasing during this period of time. Phosphorus has remained quite same and Potassium haves a little bit of fluctuation between years 1961-2011. Harvested removal is smaller in Finland than it is in Ethiopia and Ivory Coast. Nutrients from residue removal (OUT_2) have been increasing during this time. The amount of nutrient in residue removal is bigger in Finland than in Ivory Coast, but lesser than in Ethiopia. The amount of nutrients from gaseous losses (OUT_3) has some variation between years 1961 and 2011. Gaseous losses from Finland are the smallest out of the three countries.

Table 7 Nutrient outputs in Finland in every 10 years from 1961 to 2011 (t/a)

Year	OUT_1			OUT_2			OUT_3
	N	P	K	N	P	K	N
1961	42 100	22 100	25 900	27 000	15 900	111 000	111
1971	59 600	30 700	31 600	38 600	19 800	149 000	149
1981	47 000	23 100	27 400	31 400	14 700	116 000	116
1991	68 000	32 300	40 400	41 300	19 500	161 000	161
2001	72 200	34 700	42 600	44 200	21 300	173 000	173
2011	73 100	34 900	38 500	43 900	24 500	197 000	197

5.3 Nutrient balance

Nutrient balance results in every 10 year from 1961 to 2011 are presented in Table 8. In Ethiopia throughout decades nutrient balance has been negative. It has been increasing throughout years especially last decades. Potassium loss is the biggest in Ethiopia, but also the other nutrients lost are bigger in Ethiopia than they are in Ivory Coast and Finland. The result as a whole of nutrient balance for Ethiopia, Ivory Coast and Finland for years 1961-2016 are in appendix II. In Ivory Coast nutrient balance has been negative during these years. The loss of nutrients has been increasing. In Finland nutrient balance has been fluctuated throughout the years. Nitrogen has been negative for four decades, but turned to positive in couple last decades. Phosphorus amount has been but turned to negative. Potassium amounts have been mostly negative but in 1981 it has been positive, after that potassium loss has been increasing strongly in Finland.

Table 8 Nutrient balance in Ethiopia, Ivory Coast and Finland in every 10 years from 1961 to 2011 (t/a)

Year	**BALANCE (Ethiopia)**			**BALANCE (Ivory Coast)**			**BALANCE (Finland)**		
	N	P	K	N	P	K	N	P	K
1961	-135000	-90 400	-289 000	-26 000	-12 300	-39 700	-2 730	16 800	-5 730
1971	-169000	-107 000	-349 000	-47 900	-24 200	-63 400	-45 100	39 200	-12 800
1981	-173000	-91 400	-341 000	-81 100	-41 400	-89 200	-27 000	35 800	15 300
1991	-171000	-75 400	-323 000	-123 000	-63 500	-145 000	-59 100	-7 560	-91 400
2001	-207000	-95 500	-569 000	-132 000	-70 000	-135 000	74 000	-27 000	-129 000
2011	-459000	-232 000	-964 000	-174 000	-86 700	-168 000	49 000	-43 200	-179 000

In Figure 1 can be seen the cumulative of nutrient balance between years 1961-2016. Nutrient loss is most severe in Ethiopia (Figure 1). There can be seen the how severe potassium losses are in Ethiopia. Also in Ivory Coast and Finland, potassium losses are biggest out of three nutrients when it cumulates throughout the years. At the moment, it seems that phosphorus in Finland is the only one that is positive and nitrogen is little below zero.

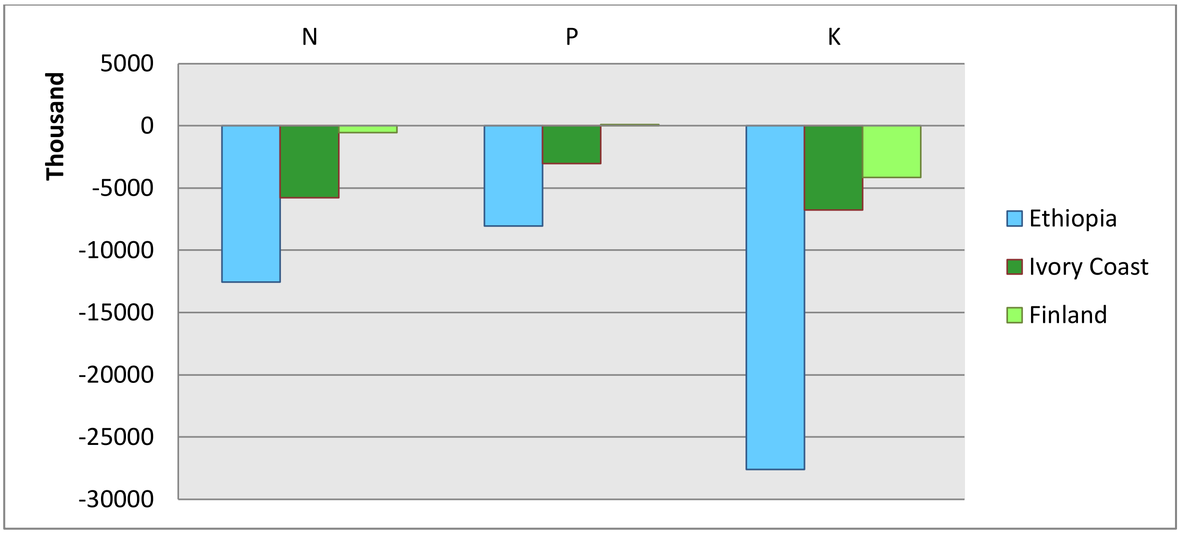

Figure 1 Nutrient balance cumulative for years 1961-2016 (t/ a)

From Figure 2 can be seen how the nutrient balance is evolving throughout the years. The balance of nitrogen and phosphorus has been quite stable until 2001 and after that they begin to decrease a lot especially nitrogen. Potassium started to decrease little bit earlier in 1993. It decreased from negative 300 000 tonnes to about negative 1 300 000 tonnes between years 1990-2016. Overall the losses of nutrients are most severe in the 2016. Nutrient depletion is at the worst at the moment than it has ever been in the reviewed period of time.

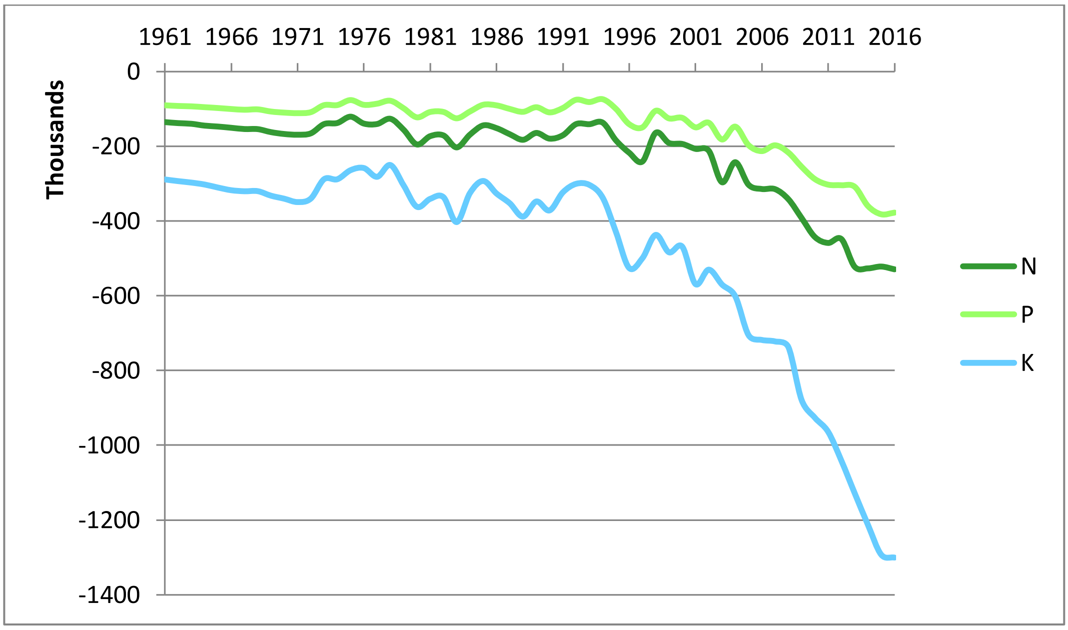

Figure 2 Nutrient balance in Ethiopia between years 1961-2016 (t/a)

In Ivory Coast the decreasing of nutrient balance started earlier than in Ethiopia (Figure 2 and 3). It has started already decrease from the 1961s. For phosphorus the decrease is not as severe as it is for the nitrogen and potassium. Nitrogen and Potassium have been decreasing almost the same pace. The sharpest drop for nitrogen and potassium happened between years 2011-2016, the drop is almost 200 000 tonnes in five years.

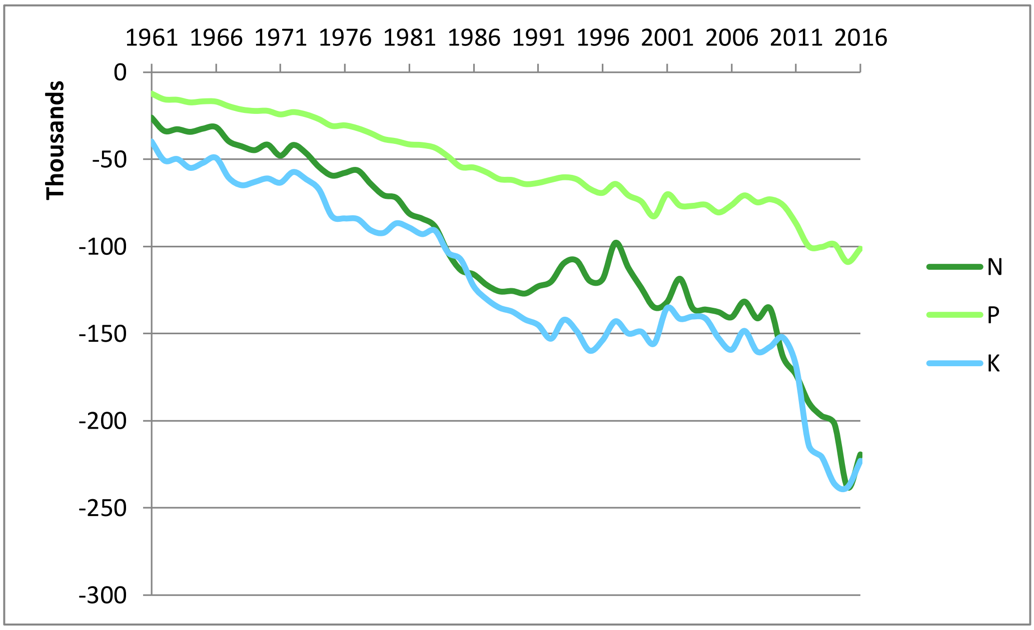

Figure 3 Nutrient balance in Ivory Coast between years 1961-2016 (t/a)

Nutrient balance in Finland has quite much fluctuation in this period of time. Nitrogen balance has been negative from 1961 but huge switch occurred in 1998 when it increased to over 100 000 tonnes, after that it has little bit decreased. This nitrogen difference is due to missing values in the data that was used in this work. Phosphorus balance is quite the opposite of the nitrogen. It has been positive until 1990 and after that it turned to negative balance. Potassium balance has been positive in 1961 and went under zero in 1992 and have stayed there, in 2016 it was little over negative 150 000.

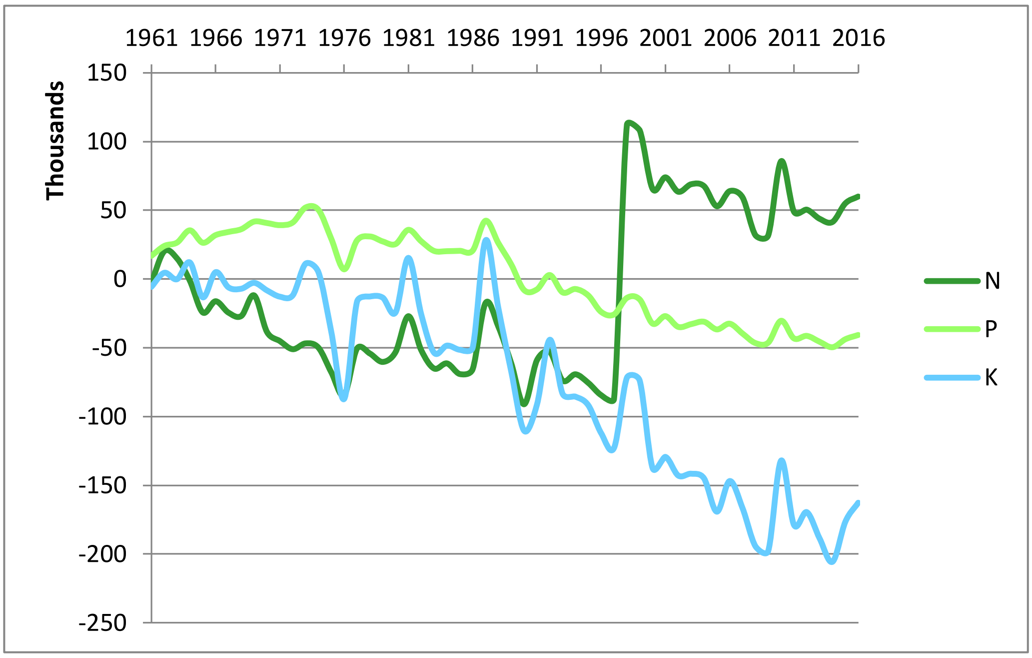

Figure 4 Nutrient balance in Finland between years 1961-2016 (t/a)

Nitrogen balance in each country is presented in Figure 5. There can be seen how the nitrogen balance differ from each other. Most negative it is in Ethiopia over 500 000 000 tonnes. In Finland nitrogen balance is positive at the moment. Ivory Coast and Finland have some cross overs throughout the years, but in Ivory Coast it has continued to decrease over the years.

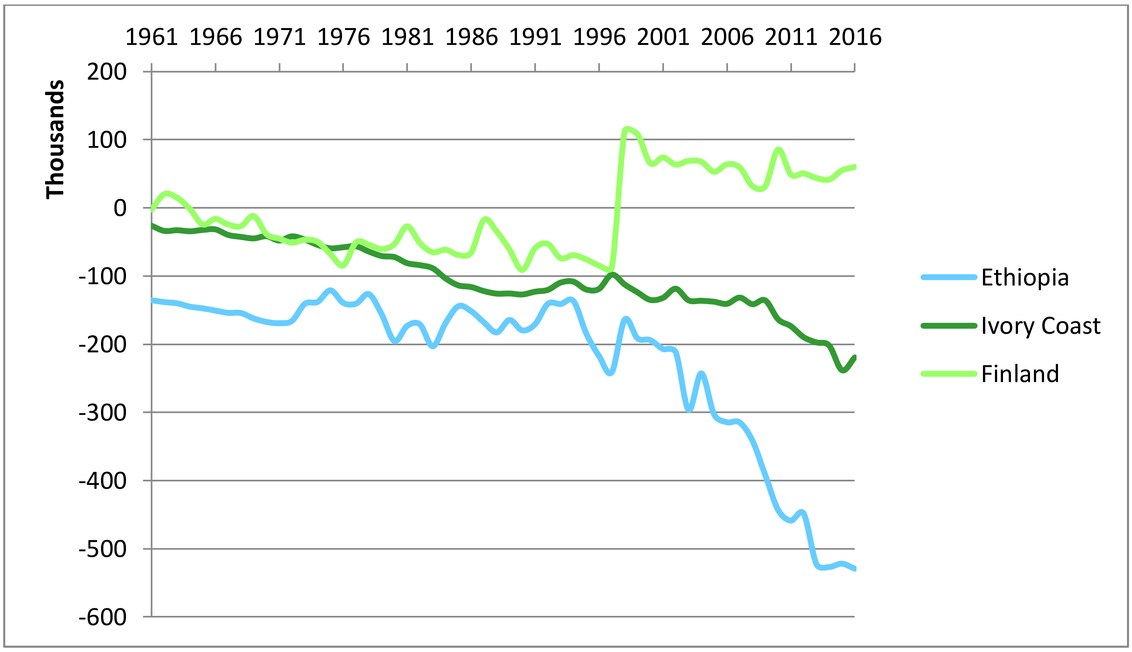

Figure 5 Nitrogen balance in Ethiopia, Ivory Coast and Finland, between years 1961-2016 (t/a)

Phosphorus balance throughout the reviewed period of time in selected countries is presented in Figure 6. Phosphorus balance has been most stable in Ivory Coast between years 1961-2016, it has been decreasing but not that severe than in Ethiopia. Phosphorus balance has been negative the whole period but stayed quite long pretty stable in Ethiopia. It was getting better in 1991 but started to decrease from 1998 to 2016, it decreased from about negative 50 000 000 to negative 250 000 000. In Finland phosphorus balance has been positive, but after 1992 it turned to negative and has stayed there.

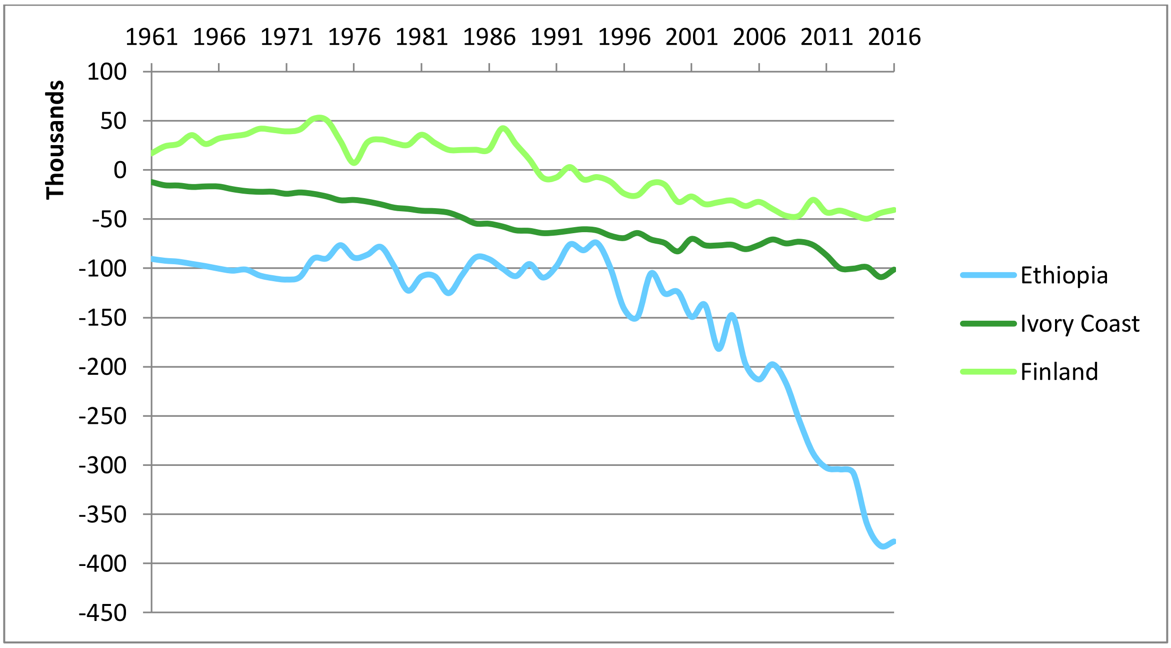

Figure 6 Phosphorus balance in Ethiopia, Ivory Coast and Finland between years 1961-2016 (t/a)

Potassium balance in each country between years 1961-2016 is presented in Figure 7. There can be seen how similar potassium balance have been in Ivory Coast and Finland throughout years. Potassium balance in Ethiopia has been more than negative 1 000 000 tonnes this whole reviewed period of time and dropped dramatically from the 1992 to the 2016. Both in Finland and Ivory Coast potassium balance is about negative 200 000 tonnes in 2016. Only in Finland potassium balance has been positive at some points between years 1961-2016.

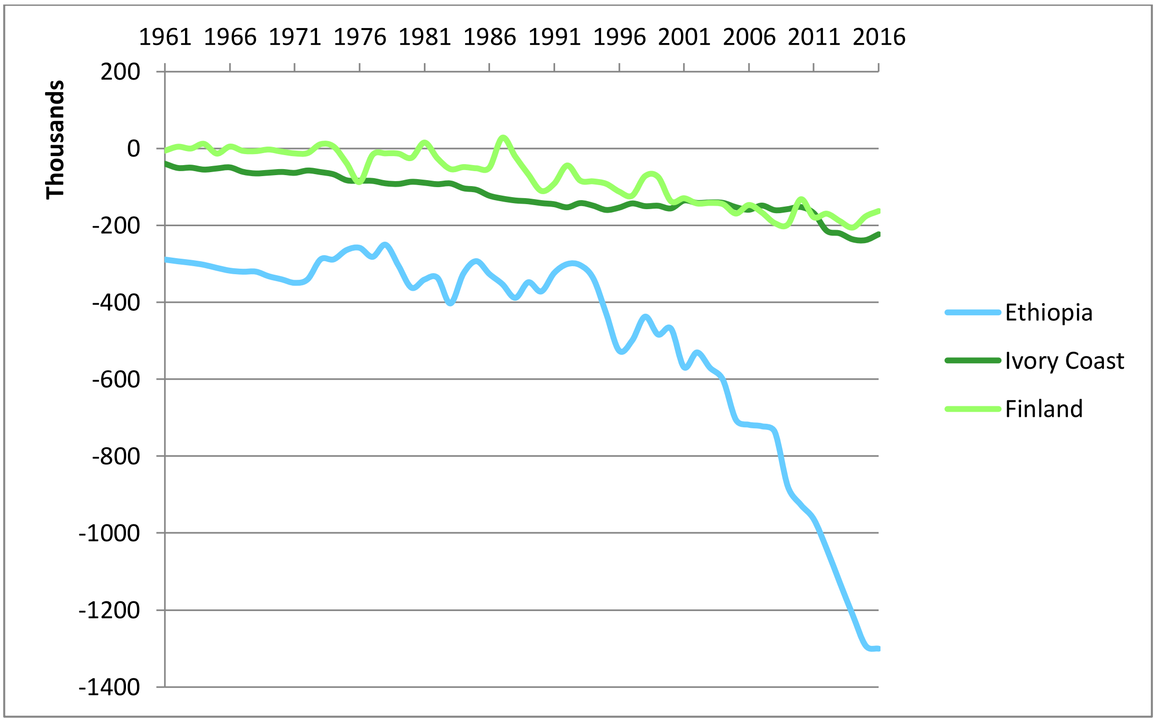

Figure 7 Potassium balance in Ethiopia, Ivory Coast and Finland between years 1961-2016 (t/a)

6 DISCUSSION

6.1 Differences in nutrient balance

6.1.1 Ethiopia

In Ethiopia, mineral fertilizer use has been increasing between years 1961-2016s especially nitrogen and phosphorus. Last couple of years nitrogen fertilizer use is over 200 000 tonnes per year which is huge different from the 1961s when it was zero. Potassium fertilizer use varies more than the other fertilizers. There have been years when potassium fertilizers have not been used at all. This might be due the availability of mineral fertilizer in Ethiopia. Mineral fertilizers are either too hard to get or expensive (Chianu, 2012). Small use of potassium fertilizers and manure or not enough manure applied has contributed potassium depletion in soils. Very much needed organic resources, important source of potassium are used for example as construction and fuel (Chianu, 2012). Manure use has been quite steady until 2005s, when it has been increasing dramatically, especially nitrogen and potassium content in manure. Even though fertilizer and manure use has been increasing the nutrient balance has still been decreasing at an alarming rate. Nutrient content in atmospheric deposition is very small and does not affect the results.

Nitrogen fixation amount is bigger in Ethiopia than in Finland, but still impact on the nutrient balance results is small. Nutrients in harvested product have been increasing throughout the time of period but especially it started to increase strongly after 1994s. This can be due the increased used mineral fertilizer and manure which can lead to increasing amount of harvesting product. Potassium content has been increasing much more than other nutrients in residue removal. It has also started to increase from the 1994s just like in harvested product. This can be resulted from the same reasons than in harvested product. The nitrogen amounts in gaseous losses are smaller in Ethiopia than in Finland and also do not have that big impacts on the nutrient balance results. Nutrient balance has been decreasing in Ethiopia especially after 2006. Potassium depletion is very severe in each of these countries especially in Ethiopia. In Ethiopia and Ivory Coast phosphorus depletion has gotten worse over the time, unlike in Finland where it occurred in 2001s. This might be due the decreasing use of phosphorus fertilizers. The most severe phosphorus depletion is in Ethiopia. Even though both mineral fertilizer and manure use has been increasing it has not been enough to make soils fertile. It can mean that there is needed to increase the food production and the land had been cultivated more intensively than they have before. Food production will decrease because of nutrient imbalance.

6.1.2 Ivory Coast

Mineral fertilizer use has been increasing in Ivory Coast but not as much as in Ethiopia. Also use of mineral fertilizer is more steadily growing than it is in Ethiopia. Potassium fertilizer has been used more in Ivory Coast than in Ethiopia. The amounts applied of nitrogen and phosphorus fertilizers are almost same in these countries. In 1966 there has been quite a peak in manure use or nutrient content in it. Manure use has been increasing; it can be due to the increasing food production. The amount of atmospheric deposition is very small and does not have impact on the nutrient balance results. Also, nitrogen fixation does not have effects on the nutrient balance results. The amount of harvested product is increasing in Ivory Coast which means more nutrients are taken up by the products. Nitrogen taken up by harvest product is the highest over 250 000 tonnes and phosphorus is the lowest, little bit over 100 000 tonnes in 2017. Increase can be an outcome of producing more food and also increasing use of mineral fertilizer and manure. Also in Ivory Coast potassium content is the high in residue removal compared to other nutrients and overall it is high in Ethiopia and Finland too. The potassium content is increased from about 25 000 tonnes per year to almost 130 000 tonnes per year and it peaked in 2014 over 145 000 tonnes per year. In Ivory Coast, gaseous losses nutrient content is not as big as in Ethiopia. Also it has not had huge impact on the outcome, but it has been increasing throughout the years. Nutrient balance in Ivory Coast has been evenly decreasing. The biggest decrease begin in 2009 when nitrogen and potassium decreases from little bit under -150 000 tonnes to about -230 000 tonnes. It can mean that is needed to produce more food which leads to more intensive farming resulting nutrient depletion in soils. Also mineral fertilizer and manure use has been increasing in those years but still it has not been enough to keep soils fertile.

6.1.3 Finland

The nitrogen use has been increased due to maximize crop production and the excess of cheap fertilizer in the industrialized world, it has led to large nitrogen surplus and rising nitrogen losses (Erisman, 2011). Nitrogen balance in Finland was negative until 1998s when it turned to positive very quickly; this indicates missing values in the data. The nitrogen balance should be decreasing over the years because of decreasing use of nitrogen fertilizer. Nitrogen balance has decreased little bit over the years but it is still very high comparing to previous years. Both potassium and phosphorus fertilizers use has been decreasing in Finland and it might be one of the reason why both potassium and phosphorus balance are negative at the moment. The highest point for phosphorus and potassium fertilizer use was between years 1973-1974s. After that, use of them started to decrease slowly; it can be result of the better understanding of the consequences of over fertilizer use. The peak can also be seen in the figure 4, where the both balances are at high point between years 1973-1974. Phosphorus content in manure is quite low comparing to nitrogen and potassium in Finland. Also, the use of manure has been decreasing over the years which might be due the same reasons as decreasing fertilizer use, consequences of using too much added organic and mineral fertilizer to the environment. The use of manure or nutrient content in manure peaked in 1963s in Finland. The nutrient content in manure for nitrogen is little over 20 000 tonnes per year, phosphorus little over 5500 tonnes per year and potassium little over 25 000 tonnes per year, nowadays. Atmospheric deposition is very small in Finland, so it does not affect the results that much and same goes to nitrogen fixation. For the outputs harvested product has the biggest impact on the results in Finland. It has been very fluctuating over the years. The highest point was in 1990s for nitrogen, phosphorus and potassium to leave soil by harvesting the products. It could mean that production of the field was very good in that year. Also, year or two after, the nutrient output was very low, in harvested product that could be the result of the high peak. Weather also effects on the amount of harvested product, if weather conditions have been favorable it results more harvested products. Couple year before the highest peak of harvested product and before that, it was very high. So, it seems that harvested product results go in cycles. Between years 2000-2009s has been more stable it can be result of the steady apply of mineral and organic fertilizer. Nutrient leaving the soil by residue removing has also quite big impact on nutrient balance. Potassium loss from the residue removing is the biggest comparing to phosphorus and potassium losses. Nitrogen losses are over 100 000 tonnes per year almost throughout the time period reviewed. Unlike phosphorus and potassium losses that are or stays under 50 000 tonnes per year. Residue removal is affecting most nitrogen balance in Finland. Gaseous losses have a little bit of effect on nitrogen balance in Finland. There is potassium and little bit phosphorus depletion at the moment. Instead, nitrogen is accumulating in Finnish soils nowadays. Phosphorus can leave from soil by erosion to the rivers which can cause the lack of phosphorus in soils. For potassium, it seems like soils were quite fertile with K before but it turned around in 1980.

6.1.4 Reliability of the results

According to Marttinen (2017) the manure use in Finland was 19 300 t/v for phosphorus and 76 000 t/v for nitrogen in 2014-2016. According to FAO it was about 5 700 t/v for phosphorus and about 23 000 for nitrogen. There is big difference phosphorus and nitrogen content in manure between these sources. This can partly explain low nutrient balance results in this work. According to Luke (2016) data between 1990-1997 fertilizer use is much more than it is according to IFA (2019). It seems there might be missing some values or data from the IFA (2019) between years 1961-1997 for nitrogen in Finland. Because of this between years 1961-1990 fertilizer nitrogen use is less. This can be seen in the results, where nitrogen balance is less than it is in reality between those years. Most likely nitrogen balance in Finland has been more than it is at the moment. Marttinen et al. 2017 report more fertilizer use for nitrogen in 2014-2016 than IFAstat has in their data. According to Salo (2007) nitrogen balance has decreased from the 1990 to 2005. According to my results there is huge increase in 1998 which is not possible because fertilizer use has been decreasing in Finland and not increasing. Also this shows that there has to be mistake in nitrogen values in the data used in this work. According to Stoorvogel and Smaling (1990), erosion is the biggest output in Ethiopia and in Ivory Coast it is harvested product. Nitrogen balance is much smaller than it is in Stoorvogel and Smaling (1990) and Haileslassie (2005). This can be due to lack of two outputs and differences in the data. Phosphorus and potassium balances in these two articles are much more comparable but also lack of two outputs has effect on results. The same thing can explain some bigger differences in Ivory Coast results.

Before the population pressure was smaller in Sub-Saharan Africa, and farmers in have cleared land, grew crops and continued to clear more land. The land fallow was left to regain fertility. Nowadays farmers are forced to harvest the same area multiple times depleting the soil nutrients and not returning anything back to the soil (Henao and Baanante, 2006). This can be seen in both Figures 2 and 3; nutrient balance was closer to zero than it is now. Nutrient balance has been decreasing but last decade drop is more severe especially in Ethiopia. Farmers do not have good access to fertilizers and are forced to use less fertile soils on marginal land into production (Henao and Baanante, 2006). According to these results it seems there is nutrient depletion in Ethiopia and Ivory Coast and it is getting more severe every year. Intensive farming with low fertilizer use and the clearing of forest lands are primary causes of nutrient mining and land degradation (Henao and Baanante, 2006). The intensive land farming has been increasing because the nutrient balance has been decreasing over the years especially last decade. Agricultural lands have been degradation in rising pace because of population growth and migration with drought, land overuse and food shortage (Henao and Baanante, 2006). Nutrient balance has worsened due the increased intensity in cropping, lack of inputs and greater erosion in 2000s (Chianu, 2012). This can be seen also in the figures, how dramatically nutrient balance has decreased in 2000s. If nothing is done to decrease nutrient depletion and land degradation, it is going to be hard for farmers in African countries to grow enough food for increasing populations (Henao and Baanante, 1999b).

In this nutrient balance calculation, sedimentation, leaching losses and erosion fluxes are not included. There was not enough data to calculate these parameters for entire country. When these three outputs are not included, it will effect on the results. Output amount will be smaller than it is in reality. It means that nutrient depletion especially in Ethiopia and Ivory Coast is much severe than it is according to these results. Sedimentation does not have a big impact on the results, so the impact on nutrient balance is much smaller. Leaching losses would have impact on nutrient balance for nitrogen and potassium, but not phosphorus because it is usually tightly bound by soil particles (Stoorvogel and Smaling 1990). According to Stoorvogel and Smaling (1990) erosion has a big effect on the results in each nutrient. In Ethiopia, erosion were for nitrogen 402 200 tonnes in 1983 and 504 860 tonnes in 2000, for phosphorus 150 825 tonnes in 1983 and 189 322 tonnes in 2000 and for potassium 301 650 tonnes in 1983 and 378 645 tonnes in 2000 (Stoorvogel and Smaling 1990). In Ivory Coast erosion were nitrogen 71 615 tonnes in 1983 and 105 935 tonnes in 2000, for phosphorus 21 484 tonnes in 1983 and 31 780 tonnes in 2000 and for potassium 53 711 tonnes in 1983 and 79 451 tonnes in 2000 (Stoorvogel and Smaling 1990). for Nutrient depletion would be more severe in Ethiopia and Ivory Coast, if erosion could have been calculated. Calculations were made on country level. The nutrient depletion does not evenly distribute in the country, so there can be areas where nutrient depletion is more severe than it is in other areas. Also, variation in local conditions have impact on the nutrient depletion, which do not show on the results. These results are more overall look on the situation of nutrient balance in these countries over this period of time.

6.1 Policy and development

When the production is increasing without fertilizers, the nutrient recycling mechanisms can’t sustain soils fertility which leads to land degradation and soils fertility is unsuitable to sustain economic production (Henao and Baanante, 2006). Factors that are identified as main causes of low crop production, soil fertility decrease and eventually degradation of the agricultural soils in many countries in Africa are over all policy, biophysical constrains and socioeconomic and especially management practices and soil-related constraints (Julio and Baanante, 1999a).

Henao and Baanante (1999b) suggests that national government and donors should address the issue of nutrient depletion and land degradation through programs and policies that support increased productivity of land resources and maintenance of the resource base. For better policy and investment strategies to changing current direction, we need better understanding of the economics of nutrient mining and of the socioeconomic and agro climatic factors that make clears why soils are depleted by farmers (Henao and Baanante, 2006). When identifying the most suitable measures for turning trends nutrient depletion and the decrease in soil fertility, the most relevant are to improve understanding of the main causes of soil nutrient depletion and the continuous assessment and monitoring of plant nutrients in soils of agricultural lands (Julio and Baanante, 1999a). To make easier to choose set of policy measures and investments as main elements of a good strategy to change soil nutrient mining is needed to portray and estimate them in terms of expected results, effects on the countries and change in the incentives or barriers to exhaust soil nutrients (Henao and Baanante, 2006). There have been identified three demands for increasing per capita agricultural production: first one is allowing policy environment for the smallholder farming sector, the second one is conversing soil-fertility depletion and the third one is intensifying and diversifying land use with high value products. (Soil Science Society of America, 1997.) These policies and investment strategies should be made and execute nationally and also sometimes locally but at all times in context and as central part of a comprehensive policy approach to economic development (Henao and Baanante, 2006). Lot of countries and regions should combine natural resource management with sector and economic policies. (Henao and Baanante, 1999b.) The main policies are across-sectors development policies, land tenure policies, policies to improve agro-inputs supply efficiency, policies to expand the demand for agricultural products and stabilize price and social support programs for poverty alleviation and public health (Henao and Baanante, 2006).

According to Henao and Baanante (1999b), there is a need for major policy changes to form an environment that makes agricultural inputs easily available, which would motive farmers to use these inputs more efficiently, and it would make better local extension services and farmer support. This will require implementation of policies and investments that raise the cost of exhausting plant nutrient from the soil whereas reducing the cost and increasing the profitability of mineral and organic fertilizer use (Henao and Baanante, 2006). The main challenge might be increasing the use of fertilizer to balance nutrient depletion and make better soil productivity in Africa, but it does not mean that fertilizer levels should rise over basic requirements (Henao and Baanante, 1999b). Mineral fertilizer use must combine with wider spectrum of complementary technologies that increase nutrient use efficiency and inhibit nutrient losses (Julio and Baanante, 1999a). This kind of practices could decrease the mineral fertilizer need to maintain present average yields. (Henao and Baanante, 1999b.) Better technology and needed plant nutrients, have to be made obtainable to farmers (Henao and Baanante, 2006). Here are some of the technologies obtainable: first is intercrop and crop rotation systems, second is adoption of practice like incorporation of crop residue, use of biological nitrogen fixation, use of fodderbanks, use of gram legumes and addition of green and animal manure, and lastly increasing the productivity of the limited land resources by for example controlling erosion, producing irrigation and fertilizer and improved seeds (Henao and Baanante, 1999a).

Even if the situation seems quite dark Africa can capitalize on accessible opportunities to develop and decrease poverty. Most of the fertilizer is imported to the Africa even though Africa accounts for about 75% of the phosphorus deposits of agro-minerals in the world. To reverse this situation there have been some initiatives and innovations and these includes farmer adoption of proven technologies. These different innovations require policy and institutional support to get the needed effects. (Chianu, 2012.)

7 CONCLUSION

Globalization is made possible by fossil fuels, by transporting food, feed and products in different parts of the world. This may lead to nutrient depletion in one region and centralizing nutrients in another region for example in intensive livestock production (Erisman, 2011). This can be seen as a nutrient accumulation in Europe and nutrient depletion in Africa. According to these results we can see the difference between Finland and two African countries Ethiopia and Ivory Coast. Europe is one of the regions that has benefitted from the increase in nutrient availability, economically and socially (Erisman, 2011). It is reflected in the amount of food available in Europe.

The exact amount of nutrient losses that needs to be replaced can’t be concluded based on these calculations because of the missing estimates for erosion, leaching and sedimentation. Nutrient balance was positive only for phosphorus in Finland, whereas for the African countries it was negative. These figures also show how great nutrient losses would need to be replaced for nutrient balance to be at least zero and more, in order to soil to be fertile. But of course the nutrient balance is more severe than it is shown here because of missing components. Also, here you can only see the whole nutrient balance in a country and not specific areas. So, in some areas soils in that country might be more depleted than in other areas. The cumulative nutrient depletion is most severe in Ethiopia, especially potassium depletion. If nutrient mining of soils will continue, it leads to increasing poverty, environmental damage, food insecurity and social and political instability (Henao and Baanante, 2006). Action has to be taken to reverse the situation. According to the results, there is little bit nutrient depletion in Finland. This can be due to the data that was used in this work. In the data, Fertilizer amounts are much smaller than it should be before year 1998. In addition to nutrient depletion, in some parts of the world nutrient accumulation is the problem. This can lead to different kind of environmental effects like eutrophication. This is more a problem for example in Europe like in Finland.

This kind of imbalance need to change and make fertilizer more available to African countries. Nutrient imbalances can lead to food shortage because there are not enough nutrients in the land for food production. There are needed to changes by police measures and investments. For designing and applying the policy measures and investments to change the nutrient mining and following decrease in soil fertility, it is needed to update information about magnitude and intensity of soil nutrient depletion, and understanding of its main causes (Henao and Baanante, 2006). Especially these actions are needed in sub-Saharan Africa where the nutrient mining is very severe. It is necessary to return soil fertility, to achieve better crop yields and food production to make better the worsening food security conditions in Africa (Henao and Baanante, 2006). It is very necessary for the growing population in Africa. There policy action and investment strategies have to be seen as main contributors to the common goals of increased agricultural production, economic development, environmental protection, food security and land conservation (Henao and Baanante, 2006).

8 SUMMARY

The food production in the Africa is under concern in the world at the moment. Population is growing in there and more food is needed to feed the population. There has been lot of studies about soil degradation in the world and especially in the Africa. Many of these studies have used the method nutrient balance and it seemed to be suitable for the purpose of the thesis. There were some difficulties to find some data from the literature because of that some components needed to leave out from the nutrient balance calculations.

The calculation results clearly indicate that, there is nutrient depletion in soils in both country Ethiopia and Ivory Coast. It has been getting worse over the years and potassium depletion is the most severe out of the three nutrients. Finland has potassium depletion. The first big change in nutrient balance in Ethiopia with nitrogen has happened around 1996s. At the moment, In Finland potassium is exhausted from the soils, also phosphorus is going to same direction. Nitrogen is accumulating in to the soil but because of the data results show it started in 1998 but actually it has been accumulating throughout this period of time under review. In Ivory Coast nutrient nitrogen and potassium depletion is much worse than phosphorus depletion and in last five years it has really gotten more severe than before. The same trend can be seen in Ethiopia nutrient balance where the most severe decrease has happened last ten years. This nutrient imbalance can lead to low food production and from there to food shortage.

To change the situation in Africa, there need to be performed influential policy measures and investments. Also some information is needed from the agricultural soils to see the extent of nutrient depletion in that specific land and the causes of it. It will help to design the right actions for changing nutrient depletion.

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N, P and K content of harvested products and crop residues

(Adapted from Stoorvogel and Smaling (1990)

	Harvested Product (kg/ton)			Crop Residues (minimum - maximum		
	N	P2O5	K2O	N	P2O5	K2O
Almond[7]	60	7,5	68	-	-	-
Asparagus[3]	2,5	0,5	3	-	-	-
Bananas[1]	1,2	0,7	5,4	1,6	0,7	14,3
Barley[1]	15,5	6,4	7,2	7,0	2,3	25,2
Beans[3]	2,5	0,5	3	-	-	-
Berries[5]	1,587572	0,226796	1,360776	-	-	-
Broad beans, horse beans, dry[3]	25,5	2,6	15,3	-	-	-
Cabbages and other brassicas[3]	2,5	0,5	3	-	-	-
Cacao[1]	40,0	19,5	23,1	19,9	10,8	39,9
Cane[1]	0,6	0,5	1,4	0,3	0,7	0,4
Carrots and turnips	2,5	0,5	3	-	-	-
Cassava[1]	4,2	1,1	5,1	2,4-6,8	0,7-3,5	1,6-1,8
Cauliflowers and broccoli[3]	2,5	0,5	3	-	-	-
Cereals[1]	16,7	10,1	5,8	8,2-13,6	4,2-6,4	27,0-38,6
Chick peas[2]	46	8,4	50	-	-	-
Chillies and peppers, green[3]	2,5	0,5	3	-	-	-
Chillies and peppers, green[3]	2,5	0,5	3	-	-	-
Citrus[1]	1,8	0,5	2,8	0,6	0,5	5,9
Coconut[1]	61,0	16,5	11,8	27,0	13,1	30,4
Coffee[1]	35,0	6,0	20,2	4,3	8,7	11,1
Cotton[1]	18,7	22,2	10,8	11,4-16,4	11,1-16,7	31,4-40,2
Cucumbers and gherkins[3]	2,5	0,5	3	-	-	-
Fibres[1]	5,0	0,9	7,2	2,1	1,6	10,8
Fodder[1]	6,8	3,0	5,7	0,0	0,0	0,0
Garlic[4]	3,428571	0,622857	3,8	-	-	-
Ginger[4]	2,895	0,535	3,35	-	-	-
Grapes [2]	5,6	5,2	8,5	-	-	-
Groundnuts[1]	37,2	13,7	9,8	12,2-	2,8-8,2	11,6-

				19,6		24,2
Lettuce and chicory[3]	2,4	0,8	5	-	-	-
Maize[1]	16,8	9,4	5,7	7,6-11,8	3,0-5,8	23,0-28,4
Millet[1]	19,2	13,7	6,5	16,1-24,6	8,4-9,8	66,3-77,1
Mustard seed[2]	33	15	11	-	-	-
Oil crops[1]	2,6	1,1	5,3	0,3	1,4	6,5
okra[3]	2,5	0,5	3	-	-	-
Onions[3]	2,5	0,8	3	-	-	-
Oranges[2]	2,6	0,8	3,6	-	-	-
Other fruit[1]	2,0	0,5	2,4	1,8	0,5	5,9
Other roots[1]	4,6	0,7	3,5	1,9	1,1	3,7
Palm oil[1]	2,9	1,6	4,9	3,3-4,1	1,2-1,4	2,5-5,5
Peach[2]	4,5	1,5	5,0	-	-	-
peas[2]	42	15	31	-	-	-
Plantain[1]	0,7	0,2	4,1	1,2	0,7	7,7
Potatoes[1]	4,4	3,0	8,3	2,3	1,6	5,4
Pulses[1]	20,0	7,8	13,3	10,4	2,3	15,7
Pumpkins, squash and gourds[3]	2,5	0,5	3	-	-	-
Raspberries[5]	1,587572	0,226796	1,360776	-	-	-
Rice[1]	11,6	7,8	4,1	9,0-13,6	3,6-7,0	34,0-51,8
Rubber[1]	6,9	2,7	5,5	1,0	0,5	4,8
Sesame[1]	30,0	14,0	8,1	15,0	12,4	25,3
Sorghum[1]	14,5	12,6	4,5	8,1-13,2	7,8-13,2	30,5-39,5
Soybeans[1]	62,1	25,1	24,0	13-22,2	6,3-7,3	16,4-18,2
Spices, nes[4]	29,875	5,45625	32,5625	-	-	-
Spinach[3]	2,5	0,5	3	-	-	-
Strawberries[6]	1-1,5	0,13	1,66-2,00	-	-	-
Sugar beets[2]	4,8	1,4	9,3	-	-	-
Sunflowers[1]	24,0	8,0	6,6	23,0	7,3	49,6
Sweet potatoes[1]	4,8	1,8	8,8	2,1	2,7	3,9
Tea[1]	35,0	8,7	16,1	0,1	0,0	0,0
Tobacco[1]	56,0	18,8	87,2	0,1	0,0	0,2
Tomatoes[2]	2,8	1,3	3,8	-	-	-
Vegetables[1]	9,0	2,1	3,1	3,2	3,2	9,4
Wheat[1]	22,3	9,9	7,0	4,3	4,1	32,0

[1]Stoorvogel and Smaling (1990),[2]IPNI (2014), [3]Horticulture (2017), [4]Kumar Ray (2015), [5]Strik (2013), [6]Yara UK (2018) and [7]SLTEC (2018))

Nutrient balance of Ethiopia, Ivory Coast and Finland (production years 1961-2016 in t/hr, yr)

	BALANCE (Ethiopia)			BALANCE (Ivory Coast)			BALANCE (Finland)		
	N	**P**	**K**	**N**	**P**	**K**	**N**	**P**	**K**
1961	-135403,595	-90442,065	-288832,350	-26048,376	-12279,156	-39739,043	-2733,940	16811,048	-5732,864
1962	-138171,361	-92277,636	-293369,427	-33736,188	-15587,893	-50706,046	20163,258	24032,489	4538,410
1963	-139936,888	-93256,256	-297258,891	-32734,234	-15843,570	-49846,231	14954,671	26524,066	-116,727
1964	-144847,559	-95513,608	-302485,559	-34244,426	-17334,032	-54916,471	-1325,852	35424,553	12043,584
1965	-147308,661	-97717,910	-310512,185	-32398,775	-16748,074	-52019,243	-24305,697	26379,861	-13327,389
1966	-150601,903	-100366,984	-317682,512	-31535,626	-16879,659	-49123,254	-16159,647	31939,424	5002,548
1967	-153969,819	-102385,288	-320445,010	-39676,041	-19542,554	-60634,537	-24444,376	34260,074	-6087,193
1968	-154213,547	-101313,836	-320176,549	-42552,709	-21456,460	-64869,086	-26867,078	36252,920	-7046,350
1969	-162275,550	-107186,718	-332280,157	-44748,984	-22242,836	-63008,470	-11913,309	41775,419	-2765,463
1970	-167269,324	-110025,886	-340387,286	-41559,656	-22185,754	-60983,530	-38557,461	40714,480	-8288,107
1971	-169157,225	-111436,798	-349361,572	-47921,141	-24241,109	-63414,084	-45110,996	39179,258	-12836,954
1972	-165539,142	-108814,342	-340095,959	-41749,752	-22899,640	-57273,568	-51030,981	41097,262	-11908,549
1973	-140681,514	-90044,611	-288105,742	-46526,689	-24286,819	-61448,804	-46793,014	52003,548	11157,382
1974	-137804,054	-89824,960	-288301,913	-54402,796	-27005,171	-67328,405	-49888,062	50313,120	4976,520
1975	-120890,886	-76463,682	-264043,669	-59334,024	-30853,054	-82686,655	-67817,293	29271,398	-38346,233
1976	-139337,821	-89117,736	-258323,438	-57764,818	-30498,585	-83924,067	-84445,512	7042,436	-87231,575
1977	-140484,647	-86103,731	-281773,628	-56353,779	-32214,189	-84330,731	-50548,687	28055,478	-16538,246
1978	-126519,541	-78310,700	-250220,409	-64040,289	-34981,642	-90641,645	-54163,555	30947,836	-12716,197
1979	-155953,600	-98494,988	-304913,342	-70559,546	-38344,945	-92231,793	-60295,109	27343,204	-13519,916
1980	-195267,453	-122673,094	-362047,448	-72153,345	-39607,371	-86689,703	-53151,871	25405,547	-24328,517
1981	-173010,730	-108281,485	-340800,766	-81095,096	-41420,964	-89179,870	-27020,940	35778,106	15383,179
1982	-171011,417	-108220,365	-336193,182	-84032,021	-41837,705	-92928,361	-51759,318	27417,307	-25749,784
1983	-203069,578	-125267,297	-402926,879	-88607,093	-43402,246	-90905,808	-65083,941	20434,586	-53616,501
1984	-168885,023	-107002,955	-325149,603	-103444,805	-48330,006	-103425,629	-61346,624	20263,255	-48404,450

1985	-144224,685	-89001,135	-292939,797	-113642,644	-54395,520	-107549,923	-69091,070	20506,085	-51464,116
1986	-151526,530	-90603,798	-326441,949	-116050,704	-54686,096	-122852,744	-65548,347	20654,839	-49915,192
1987	-167882,433	-100195,692	-352621,172	-122055,270	-57476,347	-130239,428	-17463,992	42384,003	28036,393
1988	-182704,041	-107901,601	-388297,131	-125794,204	-61396,304	-135169,806	-34635,629	26122,828	-21166,623
1989	-164421,934	-95637,979	-347794,204	-125569,866	-61890,045	-137437,278	-61223,275	10630,285	-67207,047
1990	-179648,026	-109386,839	-371690,767	-127004,640	-64226,365	-142003,282	-91078,719	-8010,402	-110294,361
1991	-170628,065	-97742,530	-323487,349	-122911,204	-63535,897	-145070,495	-59090,378	-7555,245	-91415,215
1992	-140713,180	-75650,850	-300574,990	-120226,146	-61760,106	-152959,079	-52915,119	2905,268	-44160,421
1993	-140968,580	-81679,843	-303455,404	-109601,188	-60295,333	-142067,002	-73811,716	-9720,456	-83491,008
1994	-136684,448	-74130,634	-337356,703	-108229,735	-61513,013	-148713,064	-69283,001	-7249,535	-85533,175
1995	-184151,308	-99853,572	-429129,861	-119750,965	-66892,943	-159849,750	-75537,551	-11987,133	-91801,852
1996	-217325,456	-140941,533	-525779,713	-118805,299	-69266,027	-153774,134	-84465,585	-23938,928	-112147,680
1997	-240834,909	-149475,967	-499455,380	-97885,165	-64117,913	-142917,583	-87149,555	-25748,766	-122802,202
1998	-164023,722	-105112,145	-437172,730	-112263,684	-70681,126	-149964,670	112060,927	-13736,061	-71788,566
1999	-191242,101	-125532,299	-483806,390	-123773,196	-74186,540	-148894,989	108097,332	-14888,412	-73946,323
2000	-193880,086	-124038,263	-468660,565	-134922,491	-82744,028	-155721,549	65525,266	-32423,923	-137484,601
2001	-206994,553	-149386,813	-568840,934	-131940,107	-70096,897	-135382,553	73968,259	-26976,257	-129342,183
2002	-211960,630	-137170,873	-530190,862	-118509,220	-76563,141	-141566,916	63465,268	-34815,445	-142951,075
2003	-296401,110	-181926,219	-570136,900	-135589,858	-76696,023	-140227,094	68931,432	-32808,160	-141566,355
2004	-242704,414	-147508,340	-601629,830	-136202,065	-76066,437	-141465,686	67594,959	-31050,955	-144905,684
2005	-303099,471	-197200,561	-705525,749	-137668,847	-80500,306	-152651,694	52948,743	-36655,819	-169191,218
2006	-314387,838	-213016,532	-718281,267	-140625,674	-76314,583	-159280,297	63947,838	-32479,403	-146889,739
2007	-314824,200	-197496,846	-722271,616	-131618,413	-70698,739	-148421,515	59362,471	-39647,135	-166647,349
2008	-341621,866	-216815,708	-737319,923	-141253,038	-74702,709	-160419,157	31881,915	-46559,598	-194299,245
2009	-392086,045	-255049,132	-878973,401	-135640,572	-72957,143	-157599,229	31800,959	-46236,552	-197678,583
2010	-442883,979	-287889,319	-926492,334	-163371,731	-76299,921	-152245,020	85674,878	-30340,741	-132014,508
2011	-458773,068	-302820,843	-964056,040	-173523,772	-86722,290	-168305,228	48963,704	-43187,261	-178824,237
2012	-448429,792	-304358,369	-1041569,109	-189629,533	-99937,254	-214086,555	50466,699	-41351,881	-169520,895

2013	-522618,925	-308381,143	-1128370,020	-197263,814	-100300,192	-220737,159	43809,051	-45625,944	-188700,733
2014	-526718,245	-359938,425	-1212971,831	-202022,776	-98780,567	-236333,944	41515,457	-49593,397	-205626,448
2015	-521864,179	-382019,136	-1292826,465	-238151,866	-108912,075	-238183,089	55045,975	-43795,204	-176495,725
2016	-529346,139	-377619,804	-1300621,183	-219335,817	-101272,618	-223036,855	59995,441	-40688,439	-162659,341