TALLINN UNIVERSITY OF TECHNOLOGY
SCHOOL OF ENGINEERING
Environmental engineering and Management

LITERATURE REVIEW OF THE EFFICIENCY OF SELECTED MEASURES TO REDUCE DIFFUSE LOAD FROM AGRICULTURE

PÕLLUMAJANDUSLIKU HAJUKOORMUSE VÄHENDAMISE VALITUD MEETMETE TÕHUSUSE HINDAMINE KIRJANDUSALLIKATE PÕHJAL

MASTER THESIS

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Tallinn 2023

(*On the reverse side of title page*)

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Department of Civil engineering and Architecture

THESIS TASK

Student: Eunice Ngwane Numfor, 21512EABM

Study programme, EABM03, Environmental Engineering and Management

main specialty: Environmental Engineering

Supervisor(s): Professor Emeritus, Arvo Iital

Thesis topic:

(In English) Literature Review of the Efficiency of Selected measures to reduce diffuse load from agriculture

(In Estonian) Põllumajandusliku hajukoormuse vähendamise valitud meetmete tõhususe hindamine kirjandusallikate põhjal

Thesis main objectives:

1. Compile data about agricultural pressures to the environment in Europe and globally;
2. To bring out the measures applied used to decrease the leaching of nutrients from agri-environmental practices based on literature sources;
3. To generalize the efficiency of measures based on literature sources;

Thesis tasks and time schedule:

No	Task description	Deadline
1.	Literature review to compile a list of agri-environmental measures	03.2023
2.	Literature review on the efficiency of the measures considered	04.2023
3.	Compiling of the thesis	05.2023

Language: English **Deadline for submission of thesis:** 29.05.2023

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PREFACE

The thesis topic "Literature review on the efficiency of selected measures to reduce diffuse load from agriculture" was initiated by Professor Emeritus Arvo Iital of Tallinn University of Technology. The whole work was done based on literature sources of different authors.

I will like to express my sincere gratitude to my supervisor, Arvo Iital for supporting me throughout the research period and taking out time to go through the work and have meetings with me to make this work a success.

I will also like to thank the entire Mfone's family and my classmates of the Environmental engineering and management program for their constant support.

This project is based on the efficiency selected agri-environmental measures to reduce nutrients from agriculture. With the world's growing population and economy, there is a need to produce more agricultural products to meet human need. In a bid to achieve this, there is usually an uncontrollable use of manure and fertilizers and farming techniques which leads to the loss of nutrients (nitrogen and phosphorus), contaminating the soil, air and water. This has detrimental effects on the ecosystem and human health. Some regulations and measures have been put in place by certain countries in order to reduce the loss of nutrients from agriculture. Some of which are Planting Catch crops, Controlled drainage below the surface, carrying out Liming, Composting solid manure, Good Agricultural Practice, and crop rotation. The cost and effectiveness of these measures are different. Also, not all the measures are applicable everywhere because of varying climate, soil types and topography. It is therefore important for each farmer to understand which measure is applicable to their terrain. More research has to be done on these measures and possible sensitization of the public to understand the importance of applying these measures. However, some countries have started the implementation of these measures especially in the developed world, which is not the case with developing countries. There are about a hundred measures but the work is based on measures which have ample information and have been studied by a couple of researchers. Reviewing the efficiency of 31 selected measures is therefore the basis of this work in view of defending a master thesis.

List of abbreviations and symbols

BMP: Best Management Practices

CAP: Common agricultural Practices

GHG: Greenhouse gases

EAP: Environment Action Program

EEA: European Environment Agency

EU: European Union

M1: Method 1

M2: Method 2

M3: method 3

M4: Method 4

N/N2: Nitrogen

N2O: Dinitrogen monoxide

NVZ: Nitrate vulnerable zones

P: Phosphorus

REACH: Registration, Evaluation, Authorization, and Restriction of Chemicals

TMDL: Total Maximum Daily Load

UK: United Kingdom

WFD: Water Framework Directive

1 INTRODUCTION

To meet all of human requirements, agriculture has always been in the lead. In order to meet the demands of an expanding population, many transgenic crops are grown now using this fundamentally altered technique. Many methods are used to increase agricultural yield, some of which could be harmful to people and the environment. The results of agricultural methods are altering the environment's natural elements, which ultimately has a negative impact on humanity in many ways. When these leftovers are not treated, they become uncontrollable contaminants. They destroy the environment all around us, farmland, livestock, and ecosystems. Because a healthy environment is vital for the improved health and vigor of its inhabitants, we should keep an eye on these measures to keep our surroundings healthy and long-lasting [4].

Nowadays, in a bid to improve agricultural yield, several enhancement methods are being used in the agricultural process. These range from the use of pesticides, fertilizers, and excessive irrigation amongst others. Nitrogen and Phosphorus for growing crops can be obtained through soil, chemical fertilizers, and organic manure. Other sources of nitrogen include irrigation water and atmospheric deposition, which makes up the majority of the air we breathe. A significant amount of the Nitrogen and Phosphorus added to and already existing in agricultural systems can be lost to the environment if not controlled effectively.

Excessive irrigation can have a negative effect on the water quality by generating erosion, conveying fertilizers, pesticides, and heavy metals, as well as by reducing the amount of water that naturally flows in streams and rivers. As a result of it, selenium can also accumulate, a dangerous substance that can harm waterfowl reproduction. Marine and freshwater habitats become too enriched when nutrients that control phytoplankton development are present in high amounts [2].

Although there are fewer farmers and less arable land, there is a rising demand for food. The sustainability of rural societies, food security, and low environmental impact must all be balanced [9]. Consequently, to maintain sustainability, there is a universal understanding that agriculture needs to perform better in terms of the environment by maximizing positive effects and minimizing negative ones [1]. Presented in table 1.1 below are therefore 31 selected measures to reduce diffuse load from agriculture. Table 1.1 presents the 31 measures under study in this work.

Table 1.1 Selected measures to reduce nutrient load from agriculture

Number	Measures
1	Restricting the amount of manure-derived nitrogen applied.
2	Decreased fertilization
3	Combining the supply of nutrients from manure and fertilizer
4	Methods for applying manure
5	Nutrient equilibrium
6	Land use; Making large grassland out of arable land
7	The wintertime plant cover
8	Planting crops on land in the spring rather than the fall.
9	Ploughing of ley on sandy soils during the Fall season
10	Planting Catch crops
11	Controlled drainage below the surface
12	Carrying out Liming
13	Composting solid manure
14	Good Agricultural Practice
15	Regulations for the use of plant protection products and storage of fertilizers
16	Fertilizing places that have an inclination
17	Highest nitrogen and phosphate concentrations offered by fertilizers
18	Spreading plan for liquid manure and fertilization plan
19	Limitations on keeping animals
20	Manure storage specifications
21	Maintaining manure in piles
22	Storage and transportation regulations for fertilizers and silage
23	Restrictions on agricultural activity in areas at risk from nitrate contamination
24	Specifications for grazing generally in water protection zones
25	Buffer strips and hedges
26	Meadows and pastures
27	Crop rotation
28	Strip cropping
29	Intercropping
30	No till agriculture
31	Early planting

2. LITERATURE REVIEW

In most aquatic and terrestrial ecosystems around the world, the growth of primary producers can be hampered by the availability of nitrogen (N) and/or phosphorus (P). In order to increase yields, fertilizers are frequently used in agriculture to get around these limitations. Excessive anthropogenic N and P inputs, on the other hand, have an effect on natural habitats and have far-reaching ecological and evolutionary effects, affecting anything from specific species to entire ecosystems. With significant nutrient redistribution among various ecosystems, the degree to which the global N and P cycles have been disrupted over the past century can be compared to a global fertilization experiment [11].

Although nitrogen is an essential nutrient for plants and crops, it is toxic in large doses to both people and the environment. Both human health and the health of natural ecosystems depend on pure, clean water. One of the primary factors contributing to water contamination in Europe is an excess of nitrogen from agricultural sources.

By leaching from fertilizer and manure, nitrates and organic nitrogen compounds make their way to surface water through runoff from agricultural areas. Nitrate contamination renders water unfit for human consumption. Nitrogen and other nutrients, particularly phosphorus, encourage the growth of algae in rivers, lakes, and marine environments. At modest concentrations, algae provide fish and other aquatic creatures with food. Algae will, however, develop abundantly in water systems with an excessive concentration of nutrients. This has an impact on the ecology naturally and may cause the water's oxygen levels to drop [11].

2.1 What is the problem?

The plants require nutrients like phosphorus (P) and nitrogen (N), among others. To ensure increased yields and high-quality goods, they are frequently utilized as fertilizers in agriculture. However, the rising demand for food has led to an increase in the production and usage of fertilizers, which are connected with significant inefficiencies and cause contamination of the soil, water, and air, which has an adverse impact on human health and the environment. 40% of the land in Europe is used for agriculture, which meets social needs for food production, pollination, and energy. The long-observed environmental effects are mixed: declining Greenhouse gas (GHG) emissions, fewer pesticide use but nutrient excess, diffuse water pollution, and substantial biodiversity loss on grasslands [9].

Globally, the amount of N and P entering the environment has already surpassed the safe planetary boundaries, posing a serious threat to both the environment and the climate. The

European Environment Agency (EEA) believes that throughout Europe, the limit for N losses is exceeded by a factor of 3.3 and the limit for P losses by a factor of 2 2. Europe contributes significantly to this type of pollution [11].

The shared goal of the Biodiversity and Farm to Fork strategies is to reduce nutrient losses in the ecosystem by at least 50% by 2030 while maintaining soil fertility. A important piece of legislation to accomplishing this goal and other goals of the EU Green Deal is Council Directive 91/676/EEC 5 regulating the protection of waters against pollution produced by nitrates from agricultural sources (often known as the "Nitrates Directive").

Eutrophication is a phenomenon that has detrimental effects on recreation, fisheries, and biodiversity. Both phosphorus and nitrogen contribute to eutrophication, however whereas phosphorus is the primary cause in fresh water, nitrogen is the primary contributor in marine water [11]. An example of how a body of water looks when eutrophication has occurred is shown in figure 2.1 below.

Figure 2.1 Example of Eutrophication. (Source; Environmental Protection Agency 2015)

2.2 Sources of diffuse load from agriculture

Nutrient load from agriculture has several sources. These sources could either be point sources or diffuse source. However, point sources are easier to control because the exact source of the pollution is known unlike in the case of diffuse sources which have countless sources of origin and are therefore difficult to control. Nutrient losses from diffuse sources are therefore a big threat to the environment [7].

2.2.1 Diffuse Sources or Non point Sources

Applying fertilizers and manure to fields is an example of a diffuse source of nutrient loss to the environment. Diffuse sources of nutrients are difficult to control because they are weather dependent. For instance, rain can transport manure and fertilizers from the fields [7]. However here are some techniques to control diffuse load from non-point sources;

- Manage animal waste to reduce losses to ground and surface water.
- Appropriate conservation practice systems and other pertinent best management practices should be used to lessen soil erosion and nutrient loss.
- On pasture and rangeland, planned grazing techniques should be employed [7].

An approved method for getting rid of insecticides, containers, and tank rinse water should be applied.

Collaboration with local conservation partners, such as Soil and Water Conservation Districts, to comprehend regional approaches [7].

2.3 Pressures evolving from agriculture

2.3.1 Nitrogen and Phosphorus load

Both nitrogen and phosphorus are essential for photosynthesis, cell growth, metabolism, and protein synthesis [49], but their natural sources and rates of supply are very different. While P is derived from rock phosphate, which is renewed with the uplift of continental rock, availability of nitrogen is theoretically limited. All of the planet's major biomes exhibit N and P co-limitation in their ecosystems. Today, huge human fertilizer inputs onto agricultural land are the main suppliers of N and P [5].

When crop products are harvested in agriculture, nutrients are also lost from ecosystems, which reduces the amount of plant litter that can decompose and the amount of nutrients that can be restored to the soil. Soil fertility is increased and maintained by adding fertilizers. However, when applied in excess, N and P may be lost through leaching, runoff, and erosion. For instance, an estimated 8 million tons of P are lost in runoff from arable land each year and an estimated 15 million tons of P are lost annually from crop fields due to erosion [5]. Additionally, nitrogen is eliminated from an environment as N_2 and N_2O gases that are produced by anaerobic ammonium oxidation (also known as anammox) and microbial denitrification, which occurs when bacteria consume nitrate as a source of oxygen. N and P will cause eutrophication once they enter aquatic systems before being recycled or buried as sediments [5].

2.3.2 Fertilizers

Since the 1960s, the global consumption of N- and P-based fertilizers has significantly expanded, but it is currently mostly being driven by agriculture in Asia [51]. Depending on genome structure, N and P availability may have various effects on the productivity of different plant taxa. For example, when nutrients are abundant, polyploid plants tend to enhance their biomass output and competitiveness more than diploid plants. That most crops are polyploid may be due in part to this higher yield [52].

In order to cycle or become buried as sediments, P will cause eutrophication. High soil nutrient demands are related to crops' normal selection for their rapid rate of biomass production. In fact, our existing agricultural systems are essentially "built" to meet this enormous need for nutrients. Due to agricultural crops' high critical nutrient requirements (N and P) for good development with significant product removal, this in turn has caused a high dependence on fertilizer inputs. This is not only financially costly but also biologically ineffective, environmentally unstable, and more likely to cause unintended harm to aquatic ecosystems through eutrophication. For instance, crops only absorb 30–40% of applied N, while P inputs are two–five times more than the quantity exported in the end product [5].

By choosing morphological and physiological traits that maximize nutrient uptake, optimizing traits that increase ribosome efficiency and lowering the carbon costs of nutrient uptake, for example, nutrient use efficiency in crops can be increased. Contrary to the 28:1 ratio found in all vascular plants, crops have a high P content with a 15:1 N:P ratio. High levels of P in grain crops are also undesirable since P is primarily stored as the indigestible compound phytate, which inhibits the absorption of other nutrients by non-ruminant animals like humans. One solution would be to use genomic techniques to decrease P absorption and/or P concentrations in seeds and grains because this form of P is indigestible and ends up in our sewage and waterways.

The "green revolution," which has seen approximately half of the world's land converted to agriculture, depends heavily on fertilizers. In most natural systems, nitrogen (N) and phosphorus (P) are the predominant rate-limiting nutrients and the main ingredients of agrochemical fertilizers. The effects of N and P losses from agricultural land, such as runoff and leaching, can affect many organizational levels and scales in both time and space, endangering crucial ecosystem services. Excessive loadings occur in nature: N and P are extrinsic drivers that frequently directly affect biodiversity, and have effects on biodiversity directly, as well as indirectly through (ii) increased local extinction due to the dominance of a few competitive species, (iii) altered plant community structure, and (iv) decreased functional trait diversity of communities [5].

2.4 Situation in Europe and the world

2.4.1 Description of land use globally

Because it significantly affects the functioning of the earth's ecosystems, land use is a crucial component of maintaining a sustainable global environment. Globally, there are major disparities between industrialized and developing nations in terms of land use practices. A large portion of the natural vegetation on the continent of Europe has been transformed into agricultural or urban land as a result of centuries of human activity [26].

More than one-third of the earth's land surface is used for agriculture, making it the most major land use in the world [28]. In addition to grasslands, marshes, deserts, and urban areas, forests make up around 30% of the earth's land surface [28]. Figure 2.2 below shows the agricultural regions worldwide.

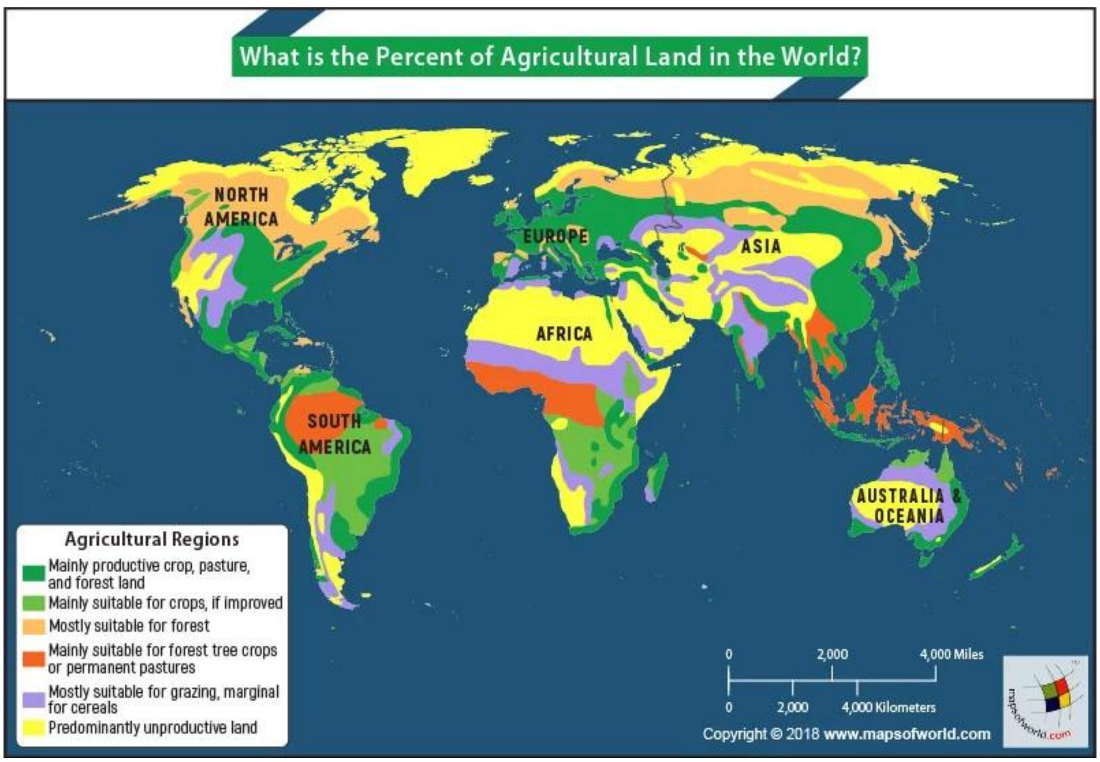

Figure 2.2 Agricultural distribution worldwide

(Source, https://www.mapsofworld.com/answers/world/percent-agricultural-land-world/#)

2.4.2 Description of land use in Europe

Approximately 40% of the EU's land area is used for agriculture, while the remaining 40% is made up of forests, according to the European Environment Agency (EEA). Urban areas

(5.8%), wetlands and peatlands (3.3%), and other regions including quarries, landfills, and transportation infrastructure (10.8%) are examples of alternative land uses [27].

Significant environmental effects of land use practices in Europe and around the world include deforestation, habitat loss, soil erosion, water pollution, and greenhouse gas emissions. Governments, public society, and the corporate sector will need to work together to promote sustainable land use practices and safeguard important ecosystems in order to address these concerns [27].

2.4.3 Livestock density data

Livestock density varies greatly around the globe, with some locations having significantly higher numbers than others. Around 1 billion cattle, 1.5 billion pigs, 1.2 billion sheep, and 20 billion chickens make up the world's livestock population [19]. India has the highest density of cattle, whereas China has the highest density of pigs. Australia has the highest density of sheep, whereas the United States has the highest density of poultry [19].

Data on livestock density is useful for understanding the distribution and level of animal production in various parts of the world. Production of cattle has a big impact on the economy and the environment in Europe [18]. According to Eurostat data from 2021, there are about 80 million cattle, 150 million pigs, 87 million sheep, and 590 million chickens in the European Union (EU). Ireland has the largest density of cattle, whereas the Netherlands has the highest density of pigs. Romania has the highest density of sheep, and Spain has the highest density of chickens [18].

Almost 47% of the total area of the EU27 plus the UK is used for agriculture. Between 2010 and 2019, the agricultural output increased by 14.5%. According to estimates, 81% of agricultural nitrogen intake into aquatic systems and 87% of agricultural ammonia emissions into the atmosphere come from livestock farming. The countries with the greatest livestock densities, measured in livestock units per hectare, were the Netherlands (3.8), Malta (2.9), and Belgium (2.8), all of which have steady livestock levels since 2005 [12].

2.4.4 Nutrient balance

The differential between the nutrients entering and leaving a farming system (mostly fertilizers) is known as the nutritional balance (mainly crops and fodder) [12]. A nutrient excess is when more nutrients are present than the plants can use, which could be harmful to the environment. A nutrient deficit happens when the soil is mined, which increases the danger of soil fertility loss and can limit agricultural productivity [12]. In order to produce food while protecting the environment, it is essential to have a sustainable nutritional balance.

Nutrient imbalances are a major concern worldwide, particularly in developing nations with intensive agricultural systems. The global average nutrient balance for croplands was positive, indicating a surplus of nutrients that could cause environmental pollution. Regions with the greatest nutrient imbalances were Asia and Africa, where nutrient inputs were significantly higher than outputs [106].

According to agricultural techniques, soil types, and climatic factors, nutrient balances in Europe vary greatly among nations. Although it was encouraged by Eurostat, not all Member States utilize the uniform technique to compute nutritional balances, which makes comparisons difficult. Moreover, some Member States fail to submit nutritional balance reports to Eurostat [12]. However, many EU nations have recently reached a negative nutrient balance, which indicates a decrease in nutrient surpluses, according to the European Commission's report on the condition of the environment in Europe [27]. However, due mostly to heavy livestock husbandry and excessive fertilizer use, several locations, like the Baltic Sea and the Black Sea, still have substantial nutrient imbalances [96]. Overall, the nitrogen balance, which measures nitrogen losses from agricultural land to the environment, reduced from 2000 to 2015, which is a positive development. However, there were no additional drops between 2010 and 2015. In the EU, nitrogen losses from agricultural land to the environment continue to remain on the average at an undesirable level. To manage the nitrogen nutrient cycle in the EU sustainably, further measures are required [48]. The gross nitrogen balance in Europe according to the European Environment Agency is presented on figure 2.3 below.

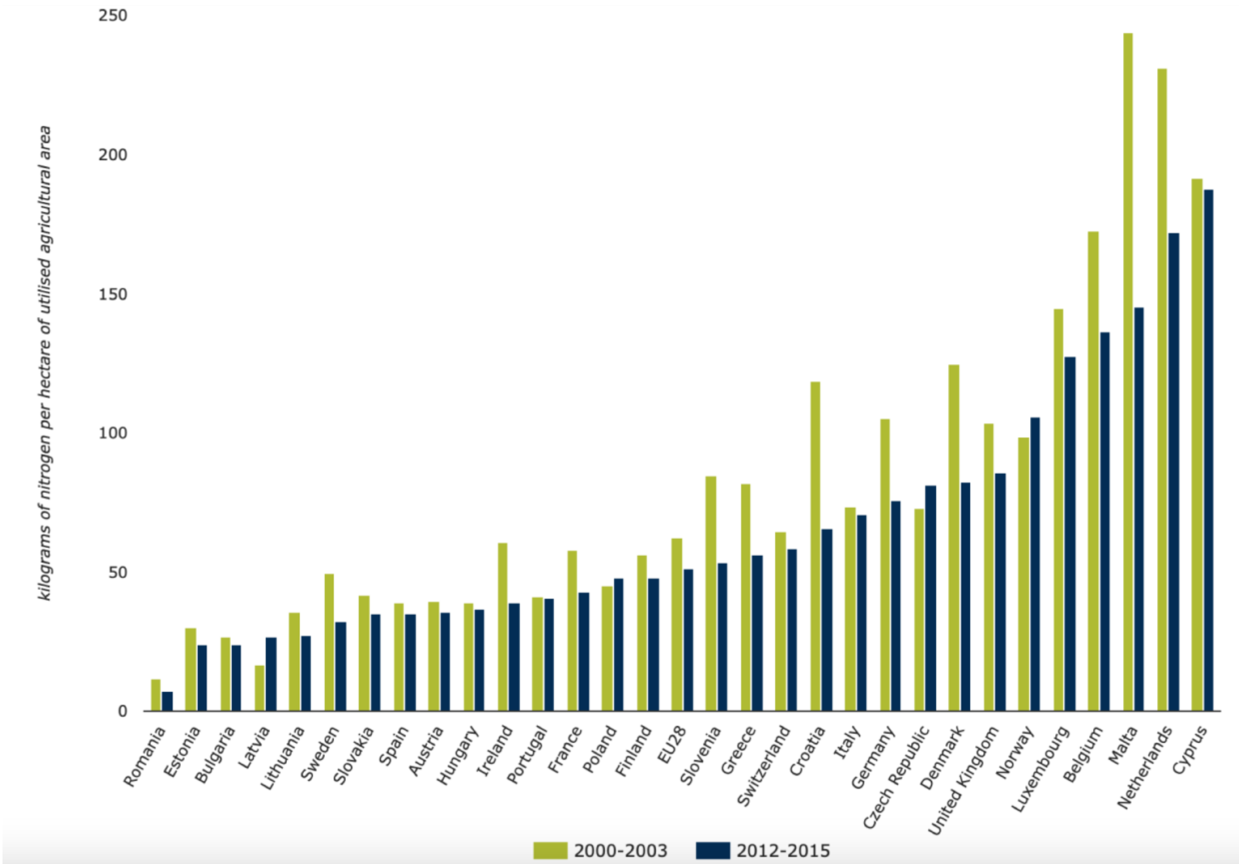

Figure 2.3 Gross nitrogen balance by country in Europe (Source: European Environment Agency, 2018)

The chart compares the average values of the Gross Nitrogen Balance in kilograms of nutrients per hectare of utilized agricultural area (UAA) per year for two time periods (2000-2003 and 2012-2015), at the level of the Member States/ nations, and also shows the averages for the EU28 for the two periods for better comparison.

The promotion of sustainable agricultural practices, such as lowering fertilizer usage, enhancing soil management, and improving animal production systems, has been the main focus of efforts to improve nutrient balances in Europe and around the world [19]. To aid with these efforts, a number of policy tools have also been put in place, including incentive programs and rules for nutrient management [19].

2.4.5 Nutrient losses

Agricultural n-discharge into the environment

13 Member States have regrettably not submitted information regarding the role of agriculture to nitrogen release in the aquatic environment. Based on the information provided by those who took part, agriculture is the main source, accounting for an average of 77% of the total nitrogen load released into the environment, ranging from 22% to 99%. We see an uneven picture when compared to the previous reporting period: of the 14 Member States that

provided data for the two most recent reporting periods, six of them had a decrease in the portion of nitrogen discharge that could be attributable to agriculture, while eight saw an increase [12].

The net nitrogen and phosphate balances for EU27+UK marginally rose at EU-28 level over the reporting years 2008-2011 and 2012-2015, going from 31.8 to 32.5 kg N/ha and from 1.8 to 2.0 kg P/ha, respectively. The N balances for Belgium, Cyprus, Luxembourg, and the Netherlands are higher than 100 kg/ha over the 2016–2019 time frame. For Cyprus, Ireland, and Malta, the phosphorus balances are greater than 20 kg/ha. The only drop in the phosphate balance during 2008 for those Member States demonstrating considerable nutritional surplus was seen in Malta [12].

The Seventh Environment Action Programme (7th EAP) asks for increased efforts to increase the efficiency of fertilizer use and manage the nutrient cycle more sustainably. In this context, nitrogen (N), one of the primary components of many fertilizers used in agricultural production, is a crucial nutrient. Strong nitrogen losses from agricultural land to the environment have a detrimental effect on ecosystems and biodiversity. Over the study period (2000–2015), nitrogen losses from agricultural land in the EU decreased, which was expected to have a favorable impact on soil, water, and air quality, as well as, subsequently, on biota and ecosystems. Improved nitrogen management procedures, particularly modifications to fertilizer delivery methods, are a significant contributor to this decline [48].

Average nitrogen losses did not, however, fall any more from 2010 to 2015, the most recent year of the period under consideration. Despite significant regional variations, the EU as a whole still has an unacceptable nitrogen surplus in agricultural land due to the resulting environmental losses, necessitating additional measures to regulate the nitrogen nutrient cycle in the EU in a sustainable manner [48]. The rates at which organic manures and fertilizers have been applied in different types of systems of agriculture can be seen on figure 2.4 below.

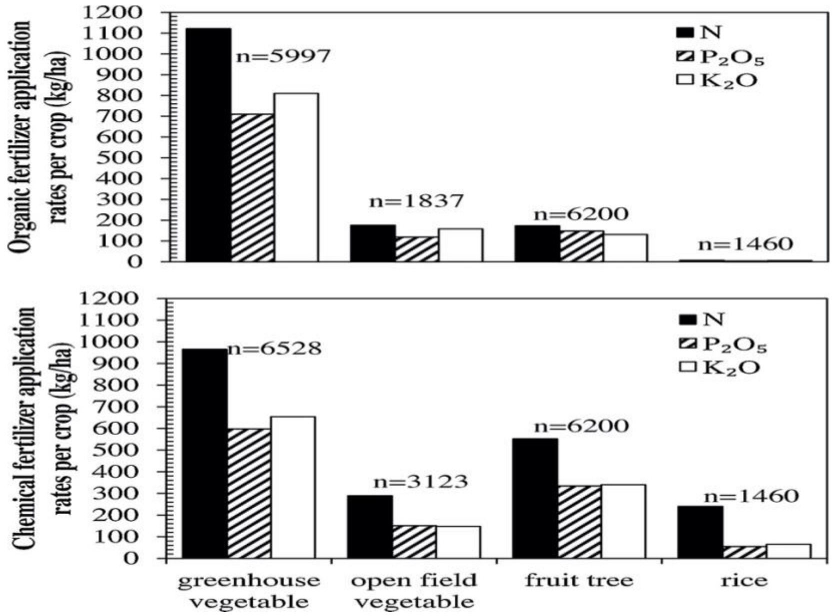

Figure 2.4 Application rates (kg/ha/crop) of nutrients through manures and inorganic fertilizers to various agricultural systems, where n= the weighted mean of the three nutrients in the systems. (Source: Chadwick D. et al., 2015)

2.5 Reporting and observation

EU Member States are obligated to submit reports on the following;

- amounts of nitrate in surface and groundwater
- surface water eutrophication
- evaluation of a program's effects on agricultural practices and water quality
- update of NVZs and (a) program(s) of action Prediction of future changes in water quality

The Member States' four-yearly reports serve as the foundation for the European Commission's four-yearly report on the implementation of the Directive [11].

To guarantee complete adherence to the Directive, the European Commission maintains ongoing communication with Member States. This conversation focuses on the action programs' content, the requirement for further measures, for new or updated NVZ designations, and for strengthened water quality monitoring. The Commission also takes into account the hazards of ammonia emissions from fertilizers, which are governed by the National Emission reduction Commitments Directive, as well as the standards for water quality under the WFD and MSFD [11].

2.6 Describing and comparing agri-environmental measures to control diffuse load of N and P.

Farmers receiving the common agricultural policy (CAP) subsidies must adhere to EU standards for excellent agricultural and environmental condition of land in addition to the statutory management obligations.

These requirements are intended to:

- Maintaining soil organic matter and soil structure;
- maintaining permanent grassland;
- maintaining the organic matter and structure of the soil
- protecting biodiversity and ensuring the retention of landscape features, such as prohibiting the cutting of hedges and trees during the bird breeding and rearing season;
- protecting and managing water through the establishment of buffer strips along water courses, authorizing the use of water for irrigation, and protecting and managing biodiversity

Through the use of Total Maximum Daily Load (TMDL) programs, the US Environmental Protection Agency and States are working together in a coordinated integrated effort to address agricultural point source (such as feedlots) and diffuse (such as crop production, pasture) pollution. The Water Framework Directive (WFD) and Nitrate Directive are leading initiatives in European Union member states [13].

The 4Rs of nutrient management the right nutrient source at the right rate at the right time in the right place—are used to manage nutrients in order to increase crop nutrient use efficiency and decrease nutrient losses to surface water, groundwater, and the atmosphere.

2.6.1 Best Management Practices (BMPs)

A vast array of structural and non-structural Best Management Practices (BMPs) have been created since the impact of agricultural pollution was detected and measured between 1970 and 1980. There are many manuals and publications that describe this. BMPs are typically divided into four groups:

(1) source controls (such as erosion control, soil conservation, and targeted fertilizer applications); (2) hydrologic modifications of the source area (less commonly used in agriculture);

(3) reduction of the delivery of pollutants between the sources and receiving water body (such as riparian buffers, infiltration); and

(4) capture, storage, and treatment (for example, ponds, wetlands).

BMPs have historically been used to reduce the amount of contaminants (sediment, fertilizers, and organic carbon) that are transported from agricultural sources to receiving water bodies. As a result, many agricultural diffuse pollution reduction projects aim to reduce nitrogen loads, with the decrease of nitrate concentration in large receiving water bodies having a continental economic and ecological significance as the endpoint (for example, Baltic Sea, Gulf of Mexico, Chesapeake Bay).

Additional frequent endpoints include phosphorus levels in lakes or chlorophyll, livestock-related bacterial contamination, dissolved oxygen loss from manure applications or algal respiration, and sediment [13].

The GBRs for rural land use are expected to be organized around the following primary pressures: 1. Management of fertilizer and manure;

2. management of land and livestock;
3. management and use of pesticides and veterinary medications;
4. management of surface water run-off; and
5. planning tools (e.g. diffuse pollution audits).

One of the main causes of diffuse nitrogen emissions is agricultural activities. In order to assess the potential of "best available techniques"—measures in agricultural production to reduce the nitrogen surplus in surface soils—a method based on cost-effectiveness analysis is being developed. An indicator for the effectiveness value of measures is created using data from the national nitrogen soil surface balance. Internal costs are estimated considering the change in gross output and the induced change in direct and indirect production costs. Cost-effectiveness ratios are calculated and used to rate the various methods taken into consideration. Although the bulk of environmentally friendly actions have associated expenses, there are some that are both environmentally and economically advantageous. The fundamental subject is the economic assessment of agricultural strategies to minimize the nitrogen surplus in agricultural land of chosen nations in the Danube River Basin [13]. The various methods and their usage as examples to evaluate the excess nitrogen in agriculture at the soil level. The approach is based on cost-effectiveness analysis and evaluates the effects of the potential interventions to cut nitrogen emissions from agricultural output using the OECD's nutrient balance calculation system [13].

2.6.2 Cost-effectiveness analysis

In order to perform a cost-effectiveness analysis, it is necessary to first determine the yearly average internal costs of a given measure for the utilized agricultural area (UAA) to which it is being applied. The impact of a measure on the altered nitrogen surplus in the topsoil must then be calculated. Lastly, the cost-effectiveness ratios for the interventions taken can be estimated in terms of the annual cost occurring per unit of nitrogen surplus in the surface soil that is annually averted [13].

Calculating the national nitrogen soil surface balance before and after implementing the measure allows for the determination of the effects of certain measures on the soil surface. The OECD-calculation scheme is used for this computation. A positive balance is referred to as a surplus. The nitrogen soil surface balance is computed as the difference between the total yearly amount of nitrogen inputs entering the soil and the total annual quantity of nitrogen outputs leaving the soil. The difference in direct production costs, indirect production costs, and the change in the gross output of the agricultural producer caused by the measure make up the measure's long-term internal costs [13].

2.6.3 Overview of agri-environmental measures

Application of fertilizers with precision in terms of quantity and timing (Method 1, M1)

The water frame work directive and the nitrate directive have set standards on the maximum amount of fertilizers to be applied and also on the time of the application. The Best available techniques for this measure include:

- Timely application rates
- Chemical soil analysis
- Field-level soil surface balance
- Prohibition of fertilizer application during the winter

Objective of measure

This measure ensures a 10% less use of mineral fertilizers

a) **lowering manure's nitrogen emissions (Method 2, M2)**

- Using a hose spreader
- Measuring the capacity of the manure storage facility
- Using accurate straw bedding in animal housing [13]

Objective of measure

A 25% reduction in the ammonia emissions from manure.

a) **Improvement of plant productivity through the use of capital-intensive manufacturing methods (Method 3, M3).**

- Irrigation that is driven by demand
- plant protection that is driven by demand
- enhancing plant nutrition

Objective of measure

higher plant productivity

a) **Reducing the amount of nitrogen that is directly emitted into the water (Method 4, M4).**

- Little to no soil tillage
- Zero tillage
- Mulch seeding
- Cover crops

Objective of measure

Reduction of surface runoff by 20% and erosion by 75%

Costs of the Measures

The internal costs incurred by the agricultural producer when implementing a measure vary significantly depending on the area on which it is applied (taking only those areas that are a part of the Danube River Basin into consideration), on the structure of production regarding the types of agricultural products, as well as on the cost levels in the countries under investigation. Measures that increase net earnings as well as those that impose additional costs on agricultural producers are spotlighted. In Germany, Austria, the Czech Republic, the Slovak Republic, Hungary, and Slovenia, Measure M3 is commercially successful. However, because the cost of the machinery required to implement the measure is high relative to the level of overall costs in Romania, Bulgaria, and Ukraine, this measure imposes costs and therefore reduces net profits [13].

The labor-intensive measure M4, on the other hand, is lucrative in Romania, Bulgaria, and Ukraine due to low labor costs, whereas its adoption imposes expenses on the agricultural producers in other nations.

The cost-effectiveness ratio

The cost-effectiveness ratios of individual measures were estimated using the basic variables of the costs of measures and the effects of measures regarding the difference of the nitrogen soil surface surplus. The most effective policies from the perspective of cost-effectiveness are those that are economically successful and environmentally friendly at the same time, such as M3 in all EU member states and M4 in Romania, Bulgaria, and Ukraine. The least preferred measure, M2, has the highest cost-effectiveness ratios across all of the countries evaluated due to the substantial investment required. The overall cost-effectiveness ratios will be highest if every measure is implemented simultaneously [13].

Each of the countries will have positive overall cost-effectiveness ratios. Austria, Germany, and Slovenia have the highest cost-effectiveness ratios, while Hungary has the lowest. They therefore represent a financial burden on agricultural producers as a whole [13].

Measures ranked according to cost-effectiveness Ratios

Profitable measures should be adopted first, as shown by the ranking of the measures based on their Cost Effectiveness Ratios. There is a significant gap between the predicted impacts and the expenses of implementing all the different initiatives in the various countries. Profitable actions can often have a substantial impact in many nations; for instance, in Romania, reducing the nitrogen surplus by 80% can be done so profitably. Despite evidence demonstrating the long-term profitability of particular interventions, significant investment costs might impede their implementation [13].

2.7 Goals of the study

- Compile data about agricultural pressures to the environment in Europe and globally;
- To bring out the measures applied used to decrease the leaching of nutrients from agri-environmental practices based on literature sources;
- To generalize the efficiency of measures based on literature sources;
- To evaluate the costs patterning to these measures.

3 METHODOLOGY

This study was done based on reviewing various literature sources. The data sources varied from journals to articles to website. From journals, it was easier to come out with articles containing data on agri-environmental measures. With these data sources, I was able to bring out the problem associated with the loss of diffuse load from agriculture. Thereafter, bring out the measures put in place by some European countries to curb the leaching of these nutrients from agricultural practices. These data also aided in bringing out and assessing the efficiency of each of the measures taken into account. For each measure, the quantity or percentage of the nutrients (nitrogen and/ or phosphorus) reduced upon application of the measure was brought out with the help of the data sources. The costs of each of the measures as well as maintenance costs if applicable was evaluated by making reference to the literature sources.

A total of 31 measures were analysed. 31 were assessed because these are the measures wherein reliable valid data was found. This is because some measures were not explicit enough and no available data on previous research, and in other cases, the data was outdated. A total of 108 sources were assessed giving more importance to recent sources which would be a better reflection of the present state of the agri-environmental sector.

4 MEASURES APPLIED TO REDUCE DIFFUSE LOAD FROM AGRICULTURE

The Nitrates Directive, which the EU implemented in 1991, sought to lessen water contamination brought on or generated by nitrate from agricultural sources. The Directive demands that either the entire Member State's territory or specific nitrate vulnerable zones (NVZs) implement agricultural action program measures [10]. To encourage best practices in the usage and storage of fertilizer and manure, action program measures are needed in four main areas:

1. Limiting the application of inorganic N fertilizer to crops' needs;
2. Limiting the use of organic manure;
3. Restrictions on the time of year when slurry and manure can be applied to sandy and shallow soils;
4. Maintaining agricultural records for cropping, livestock counts, and fertilizers administration.

The directive has not been well implemented overall throughout Europe. Yet, the synthesis of Member States' reports for 2000 concludes that 'Member States have in the recent years shown a true willingness to improve implementation. They understand that costs associated with treating drinking water for nitrates or with eutrophication in reservoirs and coastal waters continue to rise. Additionally, the efforts allocated to urban wastewater treatment will be insufficient for nutrients without a comparable focus upon the agricultural sources of nitrate.

The source of nitrate pollution can be addressed. For instance, Denmark started a national nitrate management plan prior to the directive's implementation. It set annual nitrogen "budgets" on fields and offered advice to farmers on how to utilize fertilizers effectively. As a result, Danish farming systems' nitrate leakage has been significantly reduced [10].

Inconsistent nitrate pollution patterns across Europe are a result of the Nitrates Directive's inconsistent implementation. Nitrate levels in European waterways are on the decline. The majority of river sites in Germany and Denmark reported declining trends, showing that national and EU policies to decrease nitrate pollution are working. Several river sites in the Czech Republic, Latvia, Hungary, and Poland also reported declining nitrate levels. They are probably linked to the decline in agricultural production that has occurred in these nations since they switched to market-oriented economies [10].

4.1 Manure and fertilizer management

4.1.1 Restricting the amount of manure-derived nitrogen applied.

A soil nutrient overload may result from the overapplication of manure to agricultural land. This may cause nutrient flow into water sources, resulting in eutrophication and water pollution. The risk of nutrient overload is reduced by limiting the amount of manure applied and ensuring that nutrient application rates are in line with crop requirements. For instance, in Estonia, the Regulation limits the annual application of nitrogen from manure to 170 kg/ha in areas that are already nitrate polluted [8]. The Commission may adopt implementing decisions (commonly referred to as derogations), which permit the application of higher maximum limits of nitrogen from manure in specific areas and under specific circumstances, at the request of EU Member States, provided that they provide scientific justification that this shall not result in higher pollution. Such derogations do not free Member States from the Directive's water quality goals or any of its other requirements [8]. Some works which were done on this are presented on table 4.1 below.

Table 4.1 Works done on restricting the amount of manure-derived nitrogen applied.

Sources	Year published	Figures (reduced P or N load)
Huang., et al	2022	The effects of lowering nitrogen fertilizer treatment along with organic fertilizer on the development and nitrogen fate of banana seedlings were examined. Results showed that 35.46% less nitrogen was lost by leaching.
Liang H., et al	2022	When green manure application rates (fresh matter) are less than 30 t/ha, N losses by ammonia volatilization, leaching, and runoff are reduced by 5.5%, 25.1%, and 30.6%, respectively.

4.1.2 Decreased fertilization

The residual nitrate in the soil after harvest and the amount of soluble phosphorus in the short term will both decrease if the amounts of nitrogen and phosphorus fertilizers are reduced by a specific percentage below the economic optimum. Fertilizers with lower phosphorus content over time can lessen the quantity of phosphorus lost as particle phosphorus [10].

Effectiveness

Although there will be less residual soil nitrate available for leaching in the fall, the nitrate mineralized from soil organic matter won't be affected. In the long run, there will be less soluble phosphorus loss when soil phosphorus reserves are reduced [10].

Costs

There would be a great deal of opposition to this strategy because it will affect crop production and crop quality. Reduced phosphorus fertilizer use would have an immediate effect on crops, such as potatoes and some vegetable crops, that are particularly responsive to phosphorus. All crops, excluding legumes, would be immediately impacted by a reduction in nitrate fertilizers. Some studies which were done on this measure are presented on table 4.2 below.

Table 4.2 Works done to decrease diffuse load by decreasing fertilization.

Sources	Year published	Figures (reduced P or N load)
Shen H., et al	2023	Following 75% traditional nitrogen rate , polymer coated area, and urea plus organic fertilizer treatments, the amount of residual nitrate nitrogen in a 0-160-cm soil profile reduced by 42.0%, 25.4%, and 9.7%, respectively.
J. Fernández-Ortega., et al.	2022	In rainfed and irrigated systems, respectively, modified fertilizer rates might cut the amount of N2O released from the soil per unit of grain by 27% and 40%, respectively, without influencing crop yields.

4.1.3 Combining the supply of nutrients from manure and fertilizer

Calculating the nutrients given by manure applications using manure analysis will assist identify the quantity and appropriate time of additional fertilizers the crop will need. The amount of fertilizer inputs and nitrate and phosphorus losses can be decreased by better accounting for the nutrients in manure [8].

Effectiveness

In order to maintain adequate levels in the soils and achieve the highest level of economic production, mineral fertilizer applications are decreased. When mineral fertilizers are utilized to supplement the nutrients provided by manure, the procedure is effective.

Costs

Instead of raising costs, this approach saves money. It will cost money to invest in education and counselling in order to adopt this strategy. Some works which were done on this measure are presented on table 4.3 below.

Table 4.3 Works done to decrease diffuse load by combining the supply of nutrients from manure and fertilizer

Sources	Year published	Figures (reduced P or N load)
Shen H., et al	2023	Following 75% traditional nitrogen rate (U), polymer coated area (PCU), and urea plus organic fertilizer (U+OM) treatments, the amount of residual nitrate nitrogen in a 0-160-cm soil profile reduced by 42.0%, 25.4%, and 9.7%, respectively.
Gao H., et al	2022	N2O emissions in the chemical fertilizer plus organic manure (CF + M), chemical fertilizer reduction (CFR), chemical fertilizer reduction plus organic manure (CFR + M), and organic manure (M) treatments dropped by 16.8%, 23.9%, 42.0%, and 39.4%, respectively, in comparison to the Chemical Fertilization treatment.

4.1.4 Methods for applying manure

Leaching into watercourses can be stopped right away by reducing manure surface application and encouraging injection methods and mulching. These techniques will aid in reducing drain flow losses and the exposure of manure to surface runoff [8].

Effectiveness

The slurry can be applied directly to the soil's active layer by injection. Slots can be carved into the soil, and the slurry can be applied while they are still open. Direct ground injection systems are also in use; they function by injecting pressurized slurry directly into the ground. When compared to surface application, the injection of slurry effectively boosts the utilization of manure nutrients.

Costs

Small farms have the highest added costs. With large farms, the fixed expenses are spread out over a greater volume of manure, and the additional costs per ton are lower. Some studies which were done on this measure are presented on table 4.4 below.

Table 4.4 Works done to decrease diffuse load by considering methods for applying manure

Sources	Year published	Figures (reduced P or N load)
Liu Z., et al	2022	Mulching enhanced the amount of harvested nitrogen removed (47.9-179.9 kg N ha-1) and reduced the amount of nitrogen lost by leaching (8.8–35.9 kg N ha−1).
Yang Y., et al	2021	Improved the stocks of soil total phosphorus at 16.0% after application and monitoring on a field

4.1.5 Nutrient equilibrium

The creation of nutrient balances gives farmers a tool for long-term fertilization planning. The effectiveness of nutrient utilization is revealed by nutrient balances, which also assist in pinpointing the cropping stages during which nutrients are lost. It is feasible to strengthen the water protection measures for each farm and parcel through the computation of nutrient balances [10].

Effectiveness

The amount of surplus nutrients in the soil can be minimized by using nutrient balances to plan fertilization. Additionally, it guarantees that the soil is fertile enough to maximize the effective utilization of nutrients already present in the soil. By increasing the precision with which fertilizers are used based on the crop, the yield, and the features of the parcel to the economic optimum, it will be possible to make sure that the vital crop nutrients are only available in the appropriate amounts for the crop to absorb at the precise time.

Costs

This approach is economical. The main issue, which is too many nutrients in the environment, may be measured directly by nutrient losses. Farmers are free to choose the best cost-effective strategy for reducing nutrient loss. It will cost money to invest in education and counseling in order to adopt this strategy [10]. Some works which were done on this measure are presented on table 4.5 below.

Table 4.5 Works done to decrease diffuse load by ting nutrient equilibrium

Sources	Year published	Figures (reduced P or N load)
Güldner D., et al	2017	15% of the nitrogen and 29% of the phosphorus extracted by grains were recycled from imported plant material.
Nowak B., et al	2015	With a high local supply (85%, 52%, and 54% for inflows of N, P, and K in the mixed district, respectively), the cycling index remained low (5%, 20%, and 10% for N, P, and K in the mixed district).

4.2 Creating codes of good agricultural practice that farmers can apply on a voluntary basis.

These codes should include restrictions on the times that nitrogen fertilizers can be sprayed on land so that they are used only when crops need them and to reduce nutrient losses to waters [11].

Measures to prevent nitrate losses from leaching and run-off include: limiting the conditions for fertilizer application (on steeply sloping ground, frozen or snow-covered ground, near water courses, etc.); requiring a minimum storage capacity for livestock manure; and using crop rotations, soil winter cover, and catch crops to prevent nitrate run-off during wet seasons [11].

4.2.1 Land use; Making large grassland out of arable land

By converting arable land to grassland, vegetation cover helps shield the soil from erosion, stabilizes the soil structure, and lowers the possibility of sediment discharge. More so, arable land that is converted to grassland requires less extensive chemical input, which lowers nutrient runoff and improves water quality. It will be more effective to switch from intensive agriculture to extensive grassland. This approach works well in regions that historically have been used for grazing and are valuable for conservation [16].

Effectiveness

Because of the minimal inputs, converting arable land to extensive grassland is particularly effective at lowering nitrogen since nitrogen does not build up in the soil. It is possible to cut nitrate losses by 95% by converting to ungrazed grassland. Significant short-term reductions in the leaching of soluble phosphorus are not, however, obtained in soils with high phosphorus contents because the elevated levels of phosphorus will continue to be recycled through the soil. The immediate result will be a reduction in soil erosion and phosphorus losses in surface runoff due to a permanent vegetation cover. Changing from grazed to ungrazed grassland can reduce phosphorus by 50% [10].

Costs

Without incentives, farmers are unlikely to make this drastic adjustment in how they use their property. Some works which were done on this measure are presented on table 4.6 below.

Table 4.6 Works done to decrease diffuse load by making large grassland out of arable land

Sources	Year published	Figures (reduced P or N load)
Kim D.G. et al.,	2023	Total nitrogen (TN) dropped 26%, when grassland was converted to farmland. Therefore converting arable land to grassland will reduce nitrogen losses.
Schipper et al.,	2014	According to a study from the Netherlands, converting cropland to grassland significantly reduces nitrogen and phosphorus losses, especially when done in conjunction with other best management practices like lowering fertilizer inputs and maximizing fertilizer application timing and technique. The study found that by enhancing soil structure and nutrient retention, grassland management can aid in reducing nitrogen loss.

4.2.2 The wintertime plant cover

Wintertime plant cover will lessen soil erosion and leaching of nitrogen and phosphorus [16].

Effectiveness

Without the plant cover, excessive winter rainfall can cause nitrate loss through leaching and phosphorus loss through sediment transport in surface runoff. Wintertime plant cover shields the topsoil of the fields from the corrosive powers of rain, melt, and runoff waters. Also, it lessens the susceptibility of the topsoil to silting by increasing the amount of organic matter in the fields' topsoil, which contributes to the improvement of soil structure. Wintertime plant cover can minimize nitrate leaching by 10–70% and erosion by 10–40% [16].

Costs

The technique is quite simple to use. The price of this method depends on the plant selected, the location, and whether the farmer can use their own equipment or hire a contractor. Some works which were done on this measure are presented on table 4.7 below.

Table 4.7 Studies carried out on how wintertime plant cover decreases nutrients

Sources	Year published	Figures (reduced P or N load)
Martin E.R et al	2021	Total phosphorus decreased by a factor of (p = 0.01) and Phosphate by (p = 0.04) in mg/L
		Wintertime plant cover can minimize nitrate leaching by 10–70% and erosion by 10–40%.
Hanharan B. R. et al	2018	During the winter and spring, NO3-N losses from tiles draining fields with cover crops were 69–90% lower than those from tiles draining fields without cover crops.

4.2.3 Planting crops on land in the spring rather than the fall.

The cultivation of land in autumn stimulates nitrogen mineralization from organic matter reserves at a time when crop nitrogen uptake is low, increasing the potential for over-winter leaching losses. By cultivating in the spring, less mineralized nitrogen will be leached, and the nitrogen will be available for uptake by established spring crops [16].

Effectiveness

The risk of nitrate leaching rises as a result of soil cultivation, which causes organic nitrogen to mineralize. The soil's temperature, moisture content, and nitrogen balance from the previous crop all have a significant impact on how much mineralization occurs. It is best to cultivate in the spring since the bare soil is not exposed over the winter and a crop is quickly produced to take up nitrogen and give surface cover [16].

Costs

Late autumn ploughing of land for spring crops allows for the winter's frost action and wetting and drying cycles to break down soil clods. The following spring crop might also be established earlier thanks to autumn ploughing. If ploughing is delayed until late autumn on medium to heavy soils, the delayed cultivation may cause the spring crop to be drilled into a drying seedbed. The establishment and productivity may be impacted by this. Some works which were done on this measure are presented on table 4.8 below.

Table 4.8 Studies carried out on how planting crops in spring rather than fall decreases nutrients

Sources	Year published	Figures (reduced P or N load)
Hirsh S.M. et al	2020	In late fall, winter cereal or mix cover crops reduced soil NO3 in the upper 60 cm by 67% and 56%, respectively, compared to a no cover crop control. Radish lowered soil NO3 in the upper 90 cm by 66%.
Hanharan B.R. et al	2018	During the winter and spring, NO3-N losses from tiles draining fields with cover crops were 69–90% lower than those from tiles draining fields without cover crops.

4.2.4 Ploughing of ley on sandy soils during the Fall season

The timing of ley ploughing is crucial to nitrogen leaching. It should be ploughed later in the autumn rather than earlier in the autumn from the perspective of leaching. Ploughing in the spring is also beneficial, but the enormous volumes of organic-N typically release their nitrogen too late to meet crop demand and may instead leach out the following autumn. This is a solution for sandy soils because ploughing in late autumn or early spring is generally not an option on clay soils [54].

Effectiveness

Leaching from leys cultivated early in the autumn can be significant because a lot of organic nitrogen is converted into nitrate throughout the process, especially if the ley contains clover or if there is a lot of above-ground biomass. In such situations, delaying ley farming from early to late fall is an efficient approach to reduce leaching. Up to a point where the soil's clay content prevents the use of late ploughing or spring ploughing, the efficacy of clay soils declines as soil clay content rises [54].

Costs

If cultivation is done so late in the fall that winter wheat cannot be sown, the most expenditure is incurred. When ley is grown prior to winter wheat, winter wheat yields are frequently higher than when cereals are grown first. If this situation arises, expenditures may be significant, but they are minimal if the timing of ley cultivation does not affect the choice of the following crop in the crop rotation [54]. Some works which were done on this measure are presented on table 4.9 below.

Table 4.9 Studies carried out on how ploughing of ley on sandy soil in autumn decreases nutrients

Sources	Year published	Figures (reduced P or N load)
Valkama E. et al	2016	In mineral soils, there is a minimal reduction in N leaching loss of no more than 3 kg ha-1 year-1.
Biernat L. et al	2020	The conventional method produced 50% lower N leaching loads per grain equivalent when used as a measure of eco-efficiency using the functional unit "nitrate leaching per grain equivalent." This resulted from the greatly increased land use efficiency.

4.2.5 Planting Catch crops

Any crop that is cultivated with the main goal of capturing extra nitrogen in soils that may otherwise be lost through leaching is referred to as a catch crop. Fast-growing crops known as "catch crops" are planted after or in between successive plantings of a primary crop [53].

Effectiveness

Catch crops take in more nutrients while guarding the soil's surface. The amount of nitrate leaching decreases the longer the soil is covered with vegetation. Catch crops can also increase the amount of organic matter in the soil and enhance soil structure. A Finnish study found that, depending on the soil, under sowing ryegrass with barley decreased nitrate leaching by 27–68% [53].

Costs

Using this strategy is not too difficult. The seeds must be purchased, the catch crop must be sown, and the catch crop must be finished [53]. Some works which were done on this measure are presented on table 4.10 below.

Table 4.10 Studies carried out on how planting catch crops decreases nutrient load

Sources	Year published	Figures (reduced P or N load)
Vogeler I. et al	2022	In simulations, catch crops were shown to minimize nitrogen (N) leaching by 38–64% when planted annually and by 21–39% when cultivated only every two years.

Waele J. De et al	2020	If sown at the start of August, catch crops that were planted after winter cereals and fertilized with pig slurry had the capacity to absorb 35-43% of the applied mineral N.

4.2.6 Controlled drainage below the surface

Regulated subsurface drainage strengthens the drainage systems, enabling the plants to use the drainage waters from the arable regions in an effective manner. Drainage waters are regulated during runoff and returned to the arable land for irrigation, thereby decreasing nutrient loss [16].

Effectiveness

Regulated subsurface drainage will stop nutrient leaching from arable regions into watercourses through ditch waters and return the nutrients dissolved in the water to the root zone of the plants. A 40% reduction in nitrate can be attained with controlled subsurface drainage [16].

Costs

The expense will be most effectively covered when particular plants, like potatoes, are cultivated. Some works which were done on this measure are presented on table 4.11 below.

Table 4.11 Studies carried out on how controlling drainage below the surface decreases nutrient load

Sources	Year published	Figures (reduced P or N load)
Steidl J. et al	2019	2.9% less nitrogen was added to the environment overall during the four years of monitoring.
Wesström I. et al	2014	After carrying out controlled drainage strategies, the average annual loss of NO3-N, Total-N, PO4-P, and Total-P through the drainage system was 40% lower.

4.2.7 Carrying out Liming

Liming is the process of adding lime to soil (usually calcium carbonate) in order to raise soil pH levels and decrease acidity, which can aid to improve soil health and crops' ability to absorb nutrients. Plants have a tough time absorbing nutrients in acidic soil. On acidic soils, phosphorus's usefulness is particularly diminished. As phosphorus is strongly bonded to soil particles, it can easily be carried by runoff water from fields to watercourses. When the pH is higher than 6.0, phosphorus intake will significantly rise [10].

Effectiveness

With reduced phosphorus fertilizer rates on acidic soils, liming aids in achieving respectable yields. By ensuring that phosphorus is used effectively, liming tries to stop nutrients from leaking into waterways.

Costs

After application, it can take 5 to 10 years for the expense of the lime to be recouped. The economics of using lime on rented land require particular attention. Liming on rented land is less profitable and is dependent on the length of the rental arrangement. Some works which were done on this measure are presented on table 4.12 below.

Table 4.12 Studies carried out on how carrying out liming decreases nutrient load

Sources	Year published	Figures (reduced P or N load)
Gibbons J.M., et al	2014	Liming soils to pH 6.0 was predicted to reduce N-leaching and N2O emissions by 394 percent
Hooda et al.,	2019	According to an American study, liming can lessen phosphorus loss in soils with high phosphorus saturation levels. According to the study, liming can assist raise soil calcium levels and lower phosphorus' solubility in soil, which lowers the likelihood of nutrient runoff.

4.2.8 Composting solid manure

In order to inactivate pathogens and raise temperatures that lower the amount of readily accessible nitrate in manures, composting requires aerobic microbial metabolism. When something gets composted, it becomes more stable, simpler to spread, and more desirable to disseminate over a wider area [10].

Effectiveness

The readily available nitrate content of manure is often lowered from 25% to 10% of the total nitrates, hence nitrate losses in land spreading are considerably smaller.

Costs

On individual farms, solid manure composting can be done with conventional farm machinery. Some works which were done on this measure are presented on table 4.13 below.

Table 4.13 Studies carried out on how composting solid manure decreases nutrient load

Sources	Year published	Figures (reduced P or N load)
Hashimoto., et al.	2014	Composting resulted in the formation of resistant hydroxyapatite, which decreased the bioavailability of P in manure. During a 7-day composting period, the manure's HCl-Pi concentration rose by 64%.
Lü et al.,	2013	NH_4^+-N decreases during composting to <400 mg kg^{-1}
Kelling et al.,	2018	According to a study from the United States, composting dairy manure can reduce nitrogen loss by up to 53% and phosphorus loss by up to 65% when compared to uncomposted manure. Composting is a useful technique for lowering nutrient loss and enhancing overall environmental sustainability, according to this study.

4.3 Establishing nitrate vulnerable zones (NVZs).

Tracts of land that contribute to nitrate pollution and drain into polluted or potentially polluted waters; or EU Member States may opt to apply the measures to the entire region (instead of designating NVZs) [85].

A study done in the UK indicated that the creation of NVZs in the late 1990s significantly decreased groundwater nitrate concentrations. The study found that the implementation of NVZs altered fertilizer application rates and timing, resulting in a decrease in nutrient runoff and an improvement in water quality [85].

4.4 Establishing action programs that must be followed by farmers in NVZs

Thea action programs includes measures already mandated by Codes of Good Agricultural Practice, as well as additional measures like limiting the application of fertilizer (mineral and organic), accounting for crop needs, all nitrogen inputs, and soil nitrogen supply, and applying a maximum amount of livestock manure (170 kg nitrogen/ha/year), among others. At least every four years, the Action Plans must be amended [85].

4.4.1 Good Agricultural Practice

In order to reduce the risks that agricultural activities pose to the environment, it is important to follow good agricultural practices, which are generally recognized production techniques and methods that are appropriate for the area's natural and climatic conditions and take into account broader environmental factors [85]. Some studies which were done on this measure are presented on table 4.14 below.

Table 4.14 Studies carried out on how good agricultural practice decreases nutrient load

Sources	Year published	Figures (reduced P or N load)	Method
Wu L et al.	2021	On a 10 bare slope and 120 mm/hr, N loss can be exacerbated by (traditional flat planting + 3% biochar) to (horizontal ridge planting + 6% biochar), however, N loss on 10 vegetated slopes saw overall significant reductions in N loss because vegetation along with a horizontal ridge or suitable biochar prevents erosion and holds onto sediment	To measure the process and implications of agricultural interventions on slope runoff N fractions, laboratory intermittent rainstorms were used.
Beaudoin et al	2005	The soil type had the biggest impact on nitrate content, which ranged from 31 mg L-1 in deep loamy soils to 92 mg L-1 in shallow sandy soils and was associated with the soil's ability to store water. The pea-wheat rotation produced the highest concentration (66 mg L1) while the sugarbeet-wheat rotation produced the lowest concentration (38 mg L1). The catch crops were able to lower the mean concentration by 50% at	A small catchment area (187 ha) that is nearly totally covered by arable agriculture is used to investigate the effectiveness of "Good Agricultural Practices" (GAP) for minimizing nitrate contamination. On 36 sites representative of different crops (wheat, sugarbeet, pea, barley, oilseed rape) and soil types (loam, loamy clay and rocks, sand loam and limestone, sand), soil water

		the yearly scale and 23% at the rotation scale despite their limited growth (mean biomass = 0.8 Mg ha1).	and mineral nitrogen (SMN) were measured three times per year for eight years (1991-1999).

4.4.2 Regulations for the use of plant protection products and storage of fertilizers

By applying this measure, environmental contamination, protection of the quality of water and safe storage and handling of chemicals will be addressed. It's crucial to realize that laws may differ amongst EU member states. According to the Estonian Water Act, from 1st November to 20th March, as well as whenever the land is frozen, covered with snow, periodically flooded, or saturated with water, liquid manure must not be distributed. Starting on October 15, the Environmental Board may forbid spreading liquid manure dependent on the weather [8]. From 20th September to 20th March, as well as any other time the land is frozen, covered in snow, frequently flooded, or saturated with water, the broadcast spreading of liquid manure is banned [8]. From 1st December to 20th March, as well as at any other time the ground is frozen, covered in snow, occasionally flooded, or saturated with water, semi-liquid, solid, and deep litter manure and other organic fertilizers are not permitted to be distributed [8]. Usage of fertilizers, pesticides, and other practices that could degrade water quality are prohibited in regions close to springs and sinkholes, up to 10 meters from the water's edge or the edge of a sinkhole, respectively. When the ground is frozen, covered in snow, periodically flooded, or wet, mineral fertilizers may not be applied. From 15 October to 20 March, no nitrogen-containing mineral fertilizers may be spread [8]. Within 24 hours of the manure spreading being finished, soil must be integrated into a field where no crops are already growing as rapidly as feasible.

From November 1st through November 30th, manure may be applied to crop-growing areas that are under cultivation as long as it is absorbed into the soil within 24 hours [8].

Fertilizer storage is governed by the REACH regulation, which stands for Registration, Evaluation, Authorization, and Restriction of Chemicals. It mandates that fertilizer-related compounds be registered and that safety data sheets for the fertilizers being stored be readily available [107]. REACH also wants to make sure that chemicals are used and handled safely. EU rules may outline fertilizer storage requirements, such as the need for adequate ventilation, protection from moisture and direct sunlight, and avoidance of temperature extremes. Storage areas should be kept up carefully and shielded from any fire or explosive sources [107]. Regulations often stipulate for the implementation of appropriate spill containment measures, such as bunds or containment systems, to stop fertilizers from leaking or spilling into the environment. Additionally, there ought to be equipment for effective cleanup and spill reaction kits. Fertilizer storage facilities should abide by environmental protection laws, notably those that deal with preventing fertilizer runoff into bodies of water. To reduce environmental consequences, best management techniques include the use of containment systems and runoff control measures may be needed [107].

Some studies which were done on this measure are presented on table 4.15 below.

Table 4.15 Studies carried out on how regulations for the use of plant protection products and storage of fertilizers decreases nutrient load

Sources	Year published	Figures (reduced P or N load)
Bundesamt für Verbraucherschutz und Lebensmittelsicherheit,	2017	Regulations on the use of plant protection products in the European Union were found to significantly reduce the amount of pesticide residues in drinking water and surface water, according to a study conducted there. This study found that restrictions on plant protection products can be very important for reducing nutrient loss and enhancing the sustainability of the environment as a whole.
Böhlke et al.,	2009	limits on fertilizer storage: According to a study done in the United States, limits on fertilizer storage have significantly decreased the amount of nitrate in groundwater. According to this study, limitations on fertilizer storage can be extremely helpful in preventing nitrogen loss and enhancing the sustainability of the environment as a whole.
Pandey A. et al	2018	At three different sites in Denmark with different soil types (coarse sand, loamy sand, and sandy loam), crop rotation periods of four years, and climatic conditions, N flow dynamics were examined in a variety of arable cropping systems. With increasing nitrogen intake, the nitrate-N leaching increased at rates of 0.13–0.22 kg N kg1 N input and at rates of 0.2–0.27 kg N kg1 N surplus.

4.4.3 Fertilizing places that have an inclination

When fertilizer is applied to sloped ground, it can readily wash away during irrigation or rain, causing runoff of nutrients. This runoff may lead to local water body eutrophication and water pollution. From 1 October to 20 March, putting fertilizer on the surface is banned if the land is inclined by 5–10%. If the slope of the ground is greater than 10%, it is forbidden to spread fertilizer on a crop area [8].

In Estonia in particular, the Estonian Topographic Database's elevation data must be used as the primary foundation for determining the inclination of the ground. The inclination of the ground must be assessed using on-site surveying if it is not possible to use the information stored in the Estonian Topographic Database to do so. Some works which were done on this measure are presented on table 4.16 below.

Table 4.16 Studies carried out on how methods for fertilizing places that have an inclination decreases nutrient load

Sources	Year published	Figures (reduced P or N load)
Baker et al.,	2019	In sloping terrain, regulations on fertilizer application rates and timing can help to reduce nutrient runoff and improve water quality, according to a study conducted in the United States. The study found that decreasing fertilizer application rates and keeping fertilizer treatments to times when crops are actively growing can reduce nitrogen loss and safeguard the environment.
Xiao et al.,	2019	On sloping land, reducing fertilizer application rates and putting in place soil conservation measures can help to prevent nitrogen loss and improve soil fertility, according to another Chinese study. According to the study, using conservation tillage practices and applying fertilizers at rates that correspond to crop demand can help to lower erosion and nutrient loss.

4.4.4 Highest nitrogen and phosphate concentrations offered by fertilizers

Through runoff and leaching, excessive nitrogen and phosphate levels in fertilizers can cause water pollution. When nutrient-rich fertilizers are used excessively or improperly, the extra nutrients can infiltrate water bodies and cause eutrophication. Limiting the amount of nitrogen and phosphate applied can help lower the danger of water contamination and save aquatic habitats. This is made possible by regulations on nutrient concentrations in fertilizers. For every hectare of land under cultivation, up to 170 kg of nitrogen from manure, including the nitrogen in manure that cattle leave on the land when grazing, may be applied annually. The agricultural producer is required to keep records for each field detailing the addition and removal of nitrogen and phosphorus from the soil [8]. The minister in charge of the relevant area shall issue regulations outlining the requirements and process for maintaining records of the incorporation of nitrogen and phosphorus into the soil and their withdrawal from the soil. The use of fertilizers on naturally occurring grasslands is forbidden, with the exception of the nitrogen and phosphorus found in manure that livestock leave behind after grazing, which must not exceed the maximum quantities of nitrogen and phosphorus stated [8].

According to the Estonian Water Act, per hectare of land under cultivation, up to 25 kg of phosphorus with manure, including the phosphorus in manure left on the land by cattle while grazing, may be applied annually. The amount of phosphorus in manure that is spread on the land that is being farmed may be increased or decreased, but only with the understanding that the average amount of phosphorus applied over a five-year period must not exceed 25 kg per hectare [8]. Some works which were done on this measure are presented on table 4.17 below.

Table 4.17 Studies carried out on how regulating nitrogen and phosphates in fertilizers decreases nutrient load

Sources	Year published	Figures (reduced P or N load)
Long G. Q., et al	2011	In a field lysimeter experiment conducted from 2002 to 2009, the effects of long-term pig manure application to a red soil in subtropical China on nitrate leaching were examined. During the study, nitrate levels in the drainage and nitrate leaching under low manure application (150 kg N /ha/y) did not rise. It's interesting to note that after applying a lot of manure (600 kg N /ha/year), the nitrate concentrations in drainage water

		climbed dramatically for the first four years before stabilizing at 13 mg/l for the following four.
Zimmer et al.,	2015	According to a German study, utilizing fertilizers with higher nitrogen and phosphorus concentrations can raise the risk of nutrient losses in agricultural soils. According to the study, applying fertilizers with lower nutrient concentrations can aid in reducing nitrogen loss and enhancing soil quality.

4.4.5 Spreading plan for liquid manure and fertilization plan

A fertilization and spreading plan provides instructions for accurate and even application, ensuring proper fertilizer distribution and fostering balanced nutrient levels in the soil. Only a spreading plan for liquid manure that has been approved by the Environmental Board may be used to spread liquid manure in an amount equivalent to 400 or more livestock units according to the Estonian Water Act. Every year before planting, or before the start of a vegetative season for permanent crops, anyone involved in agriculture who utilizes 50 hectares or more of area under cultivation and uses fertilizers containing nitrogen is required to create a fertilization plan. A field record may contain a fertilization strategy. A fertilization plan's data must be kept for ten years [8].

A rule issued by the minister in charge of the relevant area must specify the list of information that must be included in a fertilization plan as well as the process for maintaining the plan [8]. Some works which were done on this measure are presented on table 4.18 below.

Table 4.18 Studies carried out on how spreading plan for liquid manure and fertilization plan decreases nutrient load

Sources	Year published	Figures (reduced P or N load)
Wang et al.	2011	In contrast to utilizing exclusively inorganic fertilizers, Wang et al. (2011) discovered that employing a combination of organic and inorganic fertilizers increased crop yields and decreased nutrient losses.
Schindelbeck et al.	2015	To better control nutrient treatment rates and timing, Schindelbeck et al. (2015) stress the significance of implementing precision agriculture approaches.

Bouwman et al.	2013	Bouwman et al. (2013) contend that decreasing livestock production can be a successful tactic for minimizing nutrient losses from agricultural systems.

4.4.6 Limitations on keeping animals

Limiting the number of animals kept can reduce the amount of manure produced, making it simpler to put appropriate manure management techniques into place and preserve water quality. The amount of land used by a farming operation for maintaining animals must allow for the dispersion of manure at the greatest quantities of nitrogen and phosphorus that manure can offer. More animals may be kept as long as the excess manure is transferred under a contract with the recipient of manure if the amount of manure produced by the undertaking exceeds the maximum levels of nitrogen and phosphorus delivered by manure per one hectare of a crop area. The person ordering the service must save the paperwork pertaining to the service's provision as an annex to the spreading or sale agreement if the removal service rendered by a third party is utilized for manure removal [20].

Effectiveness

According to the research, restricting the number of animals can be a useful tactic for minimizing nutritional loss. However, the success of this strategy may be influenced by elements like the type of farming system and the local environmental situation [20]. Some works which were done on this measure are presented on table 4.19 below.

Table 4.19 Studies carried out on how limitations on keeping animals decreases nutrient load

Sources	Year published	Figures (reduced P or N load)
Mikkelsen et al.	2004	Decreasing pasture grazing pressure through lower stocking rates led to less nitrogen and phosphate loss.
Sommer et al.	2017	In a similar vein, Sommer et al.'s research discovered that decreasing the number of animals and modifying grazing time and intensity resulted in lower nitrogen and phosphorus losses from pastures.

4.4.7 Manure storage specifications

Nutrient runoff, which occurs when too many nutrients from manure enter water bodies and cause water contamination, can result from improper manure handling and storage. This can also cause odors and affect air quality and cause pathogen transmission. Depending on the type of manure, storage facilities for manure or for manure and liquid manure must be present in all livestock buildings housing more than five livestock units. Depending on the technology used in the livestock building, the storage facilities for manure or for manure and liquid manure must allow for the storage of manure and liquid manure excreted by the livestock for a minimum of eight months as well as the storage of wastewater from the building, if necessary. For the purposes of determining the capacity of a manure storage facility, the amounts of manure that the cattle left on the grazing ground throughout the grazing season may be omitted [8].

It is necessary to have a storage facility that can accommodate the residual amount of manure if a livestock building where animals are maintained on deep litter is unable to accommodate the maximum quantity specified.

Storage facilities for manure or for liquid manure and livestock buildings must be leak-proof, and their design must guarantee safety and the prevention of leaks during storage facility operation, including when the facility is being filled and emptied. Some works which were done on this measure are presented on table 4.20 below.

Table 4.20 Studies carried out on how manure storage specifications decrease nutrient load

Sources	Year published	Figures (reduced P or N load)
Bicudo et al.,	2018	Covered manure storage: According to a study done in the US, compared to uncovered storage, covered manure storage can reduce ammonia volatilization by up to 96% and phosphate loss by up to 65%. According to this study, covering manure storage is a very efficient way to decrease nitrogen loss and raise overall environmental sustainability.
Zvomuya et al.,	2010	Solid-liquid separation: According to a Canadian study, solid-liquid separation of dairy manure can minimize nitrogen loss by up to 60% and phosphorus loss by up to 70%. According to this study, covering manure storage may be more successful in preventing nutrient loss than solid-liquid separation.

4.4.8 Maintaining manure in piles

Nutrients from manure can be lost through leaching, volatilization, and runoff if it is not correctly handled or stored, which can cause environmental contamination and eutrophication of water sources. Nutrient losses can be limited or eliminated by keeping manure in piles because composting or storing under regulated conditions helps preserve nutrients and lowers the likelihood of runoff. Only solid manure and deep litter manure may be stored in stacks on land that is being farmed for up to two months before spreading, provided that it does not exceed the amount needed for one vegetation season [8].

Deep litter manure may be stored in stacks for up to eight months if its volume does not exceed that required for one vegetation period. The Environmental Board must be notified of the location of the stack at least 14 days before the stack is set up, and the notice must be submitted via the information system.

Between the first of November and the last day of December, stacking of solid and deep litter manure is not permitted.

A manure stack must be placed on level ground at least 50 meters away from any water source, well, or sinkhole. It is forbidden to erect a manure stack above a drainage pipe for a land improvement system, near an unprotected groundwater source, in a wet area, or in an area that has recently been flooded [8]. Some works which were done on this measure are presented on table 4.21 below.

Table 4.21 Studies carried out on how maintaining manure in piles decreases nutrient load

Sources	Year published	Figures (reduced P or N load)
Lehrsch et al.,	2016	According to a US study, keeping dairy manure in heaps can cut nitrogen loss by up to 55% compared to surface-applied manure. However, phosphorus loss was not significantly different. This study did point out that piling dung can result in other environmental issues such as odors and the possibility of runoff and leaching.

4.4.9 Storage and transportation regulations for fertilizers and silage

Fertilizers and silage must be carried and stored in a way that prevents environmental release. A regulation issued by the minister in charge of the relevant area shall specify the conditions for the transport and storage of fertilizers and silage. By lowering the possibility of spills, leaks, and other kinds of pollution, restrictions for the storage and transportation of fertilizers and silage can be a successful strategy for decreasing nutrient loss in agricultural systems [8].

Effectiveness

The type and quantity of materials being stored or carried, the enforcement and monitoring of regulations, and the degree of compliance by farmers and other stakeholders can all affect how effective a regulation is [88]. Some works which were done on this measure are presented on table 4.22 below.

Table 4.22 Studies carried out on how storage and transportation regulations for fertilizer and silage decreases nutrient load

Sources	Year published	Figures (reduced P or N load)
Baldwin et al.,	2017	According to a UK study, setting rules for the handling and storage of fertilizers can help to prevent nitrogen loss and enhance water quality. According to the study, fertilizer storage in covered containers and reducing the possibility of spills and leaks can help reduce nutrient runoff and safeguard the environment.
Tabacco et al.,	2017	Another Italian study discovered that silage transportation regulations can lower nutrient losses and raise the caliber of feed for animals. According to the study, silage's nutritional content can be improved by employing covered trailers and cutting down on travel time.

4.4.10 Restrictions on agricultural activity in areas at risk from nitrate contamination

In order to prevent nitrate pollution from agricultural sources, the European Commission's Nitrates Directive (91/676/EEC) imposes mandatory measures, such as limitations on the application of fertilizers and manure in regions at danger from nitrate contamination [95].

It is permitted to prohibit the following in karst areas, unprotected groundwater nitrate sensitive zones, and soil depths up to two meters:

a) annual application of 100 kg of nitrogen dispersed with mineral fertilizers per hectare of land under cultivation;

b) restriction of cattle to 1.5 livestock units per hectare of land under cultivation;

c) usage of sewage sludge.

Use of fertilizers, plant protection chemicals, and storage of manure in a manure stack near significant springs and sinkholes within 50 meters of the water's edge or the edge of a sinkhole are all prohibited in nitrate-vulnerable zones [8].

A person engaged in agriculture must cover at least 30% of the area utilized for cultivation in a nitrate-vulnerable zone from 1 November to 31 March with vegetation. A third of the aforementioned proportion might be stubble [8].

Plant cover refers to winter crops such as cereals, rapeseed oil, turnip rapeseed, herbaceous grasses, leguminous crops, and gastronomic and medicinal herbs [8]. Some works which were done on this measure are presented on table 4.23 below.

Table 4.23 Studies carried out on how restrictions on agricultural activity in areas at risk from nitrate contamination decreases nutrient load

Sources	Year published	Figures (reduced P or N load)
European Environment Agency (EEA),	2018	In most EU Member States, nitrate concentrations in surface and ground waters have decreased, according to an evaluation of the Directive's implementation.
Powers et al.,	2018	According to a study conducted in the United States, restrictions on agricultural activity in sensitive regions and other rules to reduce nutrient pollution in the Chesapeake Bay watershed have significantly decreased the amount of nutrients that are discharged into the Bay.

4.4.11 Specifications for grazing generally in water protection zones

Animal waste, including excrement and urine, can be directly deposited into water bodies because of unregulated grazing in water protection zones. This may result in nutrient enrichment, bacterial contamination, and a decline in the quality of the water. Grazing within a water protection zone must not result in any of the following:

a) bank erosion or littering of a water body;

b) destruction of aquatic life or spawning grounds;

c) adverse effects on public access to a water body or use of a shore path;

d) destruction of a water object protected by cultural or natural heritage;

e) other significant environmental nuisances in a water body;

f) harm to the efficient operation of a land improvement system [8].

Some works which were done on this measure are presented on table 4.24 below.

Table 4.24 Studies carried out on how specifications for grazing generally in water protection zones decreases nutrient load

Sources	Year published	Figures (reduced P or N load)
Ulén et al.,	2015	Keeping cattle off of streams can also help to prevent fertilizer loss. A Swedish study found that installing riparian buffer strips and fencing off watercourses significantly reduced nitrogen and phosphorus loss from agricultural lands.
Wheeler et al.,	2010	According to a New Zealand study, nitrate leaching was decreased by 40% when sheep were rotated between paddocks as opposed to continuous grazing.
Cullen et al.,	2019	Similar to the previous study, another Australian study found that rotational grazing and lower stocking rates reduced nutrient loss from grazing systems by 60–70%.

4.4.12 Buffer strips and hedges

At the edge of fields, arable land, transportation infrastructure, and waterways are buffer strips, which are natural vegetation-covered regions (such as grass, bushes, or trees). They can feature a variety of varied vegetation layouts, from only grass to mixtures of grass, trees, and shrubs. Buffer strips encourage the natural retention of water because they provide favorable conditions for efficient water infiltration and delaying surface flow due to their permanent vegetation [16]. They can also dramatically reduce the amount of agricultural run-off-derived suspended particles, nitrates, and phosphates. Buffer strips can be placed within fields, along field borders, on headlands, or elsewhere away from water bodies (e.g. beetle banks). As they intercept and restrict surface run-off water before it develops into a harmful flow, hedges over long, steep slopes may lessen soil erosion, especially where there is a margin or buffer strip alongside [14]. Figures 4.1 and 4.2 below show images of a hedgerow and beetle bank respectively.

Figure 4.1 Hedgerow Source: http://www.bbc.co.uk/nature/habitats/hedge

Figure 4.2 Beetle bank Source: http://commons.wikimedia.org/wiki/File:On_Fox_Hill_-_geograph.org.uk_-_816223.jpg?

Potential advantages with level

- Increase soil water retention
- Intercept pollution pathways
- Reduce erosion and/or sediment delivery
- Improve soils
- Create terrestrial habitats
- Slow runoff
- Increase evapotranspiration
- Increase infiltration and/or groundwater recharge
- Natural biomass production

- Biodiversity protection
- Climate change adaptation and mitigation
- Groundwater/aquifer recharge
- Absorb and/or retain carbon dioxide
- Enhancing status of biology quality aspects
- Flood risk reduction
- Erosion/sediment control
- Filtering of pollutants
- Preventing the deterioration of surface water status
- Preventing the deterioration of groundwater state
- Reduce flood risks by taking adequate and coordinated action
- Preserving significant habitat
- Increased use of green infrastructure and better ecosystem protection
- Sustainable agriculture and forestry
- Improved fish stock management
- Stopping the loss of biodiversity

This method has been adopted by several European countries such as Germany, Sweden, France, the United Kingdom, Italy, Portugal and Hungary [14].

Costs

Land Acquisition and Studies & Investigations

There is no change in who owns the land. Regarding the studies and investigation, this measure does not need prior studies to be conducted before implementation. Therefore, nothing is spent in this category.

Capital Costs

According to the European Commission of 2006, the establishment of a 3m buffer strip ranges between 400 to 600 euro per hectare (ha). For the creation of field margin, the rate of payment is between 454 euros (13 to 865 euros). The capital costs for the planting of hedgerows and their subsequent maintenance are about 4.73 euro/meter. A case study was carried out by the Scottish Government to confirm this [17]. For the process of planting or replanting a hedge, it costs 5.08 euro/meter. Coppicing a hedge and relaying a hedge costs 9.45 euro/meter [14].

Maintenance costs

The cost for maintaining a 3m buffer strip is about 75 to 150 euro/hectare according to the European Commission. The maintenance of hedgerows is about 63.75 euros per 100m [17]

Added expenses.

loss of agricultural revenue is about 140 euro/hectare/year according to the European Commission [17].

Some works which were done on this measure are presented on table 4.25 below.

Table 4.25 Studies carried out on how buffer strips and hedges decrease nutrient load

Sources	Year published	Figures (reduced P or N load)
Wang Q. et al.,	2017	Under various rainfall intensities and slope gradients, the effects of grass hedges (*Melilotus albus* and *Pennisetum alopecuroides*) on atrazine runoff were assessed. The plot-scale trials were conducted on a maize field. Grass hedges reduced surface runoff and atrazine loss by 27% to 72% and 37% to 76%, respectively. and Pennisetum was more effective than Melilotus, especially when there was more rain.
Angima S. d. et al.,	2002	Determine the quantity of soil that contour calliandra-Napier grass hedgerows (*Calliandra calothyrsus*) conserve, and then create a supporting practice. P-subfactor for central Kenyan conservation planning. By influencing the supply and availability of nutrients in the soil through biological N2 fixation, pulling nutrients from below the rooting zone of crops, and lowering nutrient losses from leaching and erosion such as P and N, trees in hedgerow systems can serve as soil erosion barriers and nutrient retention enhancers. Hedgerow utilization has been successful in Nigeria, Columbia, and Kenya, where there has been a 48–85% reduction in soil erosion.

4.4.13 Meadows and pastures

Meadows are places or fields used for mowing and haying when the predominant plant life is grass or other non-woody plants. Pastures are typically utilized for grazing and may be grassy, forested, moorland, or heathland. Meadows and pastures offer favorable conditions for the uptake and storage of water during momentary floods because of their rooted soils and their permanent cover. By absorbing nutrients and capturing sediments, they also safeguard water quality. The strategy has the ability to boost water retention in the landscape, reduce runoff, and temporarily store floodwater. Rooted vegetation keeps the soil covered at all times, which slows water runoff and increases infiltration into the soil. Compared to arable land, soil erosion rates are significantly lower, which could be advantageous for the quality of water [16]. An example of a meadow is presented in figure 4.3 below.

Figure 4.3 Scotch flooded Meadow in the UK [16].

Biophysical impacts associated with meadows and pastures

- Storing and Slowing Runoff through the increase of evapotranspiration, infiltration, and ground water recharge. It also increases the retention of ground water.
- It reduces pollution through the interception of pollution pathways and a decrease in the sources of pollution
- Ensures the conservation of soils through the decrease of erosion and soil delivery by ensuring a greater vegetation coverage. It also leads to soil improvement by improving the structure of the soil and organic matter content.
- Meadows and pastures reduce the risks of the occurrence of floods.
- Protection of important biological habitats.

Costs

Land Acquisition and Studies & Investigations

There is no change in who owns the land. Regarding the studies and investigation, this measure does not need prior studies to be conducted before implementation. Therefore, nothing is spent in this category [18].

Capital costs

No capital costs are required.

Cost of maintenance

Prices per hectare per year for grassland operations in 2013. €159 - €420 for grazing and

€189 - €358 for hay [18].

Additional expenses

154 euros in extra fees

Opportunity costs may arise from changing arable land to permanent grassland, albeit this is more likely to occur on the least productive arable land. Extra expenses per ha per year, annualized conversion costs over 20 years at 4% discount rate [14]:

Conversion from arable: €200 per ha or €14 per ha per year

Arable revenue loss: €140 per hectare per year [14].

Some works which were done on this measure are presented on table 4.26 below.

Table 4.26 Studies carried out on how meadows and pastures decrease nutrient load

Sources	Year published	Figures (reduced P or N load)
Waldhuber et al.,	2019	According to a research done in Switzerland, compared to farmland, meadows and pastures reduced nitrogen and phosphorus losses by 75% and 85%, respectively.
Schipanski et al.,	2014	In comparison to bare soil, planting grasses or legumes decreased nitrogen and phosphorus losses by 42% and 50%, respectively, according to a meta-analysis of 36 studies.

4.4.14 Crop rotation

Crop rotation is the technique for growing several crops that are dissimilar or different from one another in the same location over the course of several seasons. By alternating between deep-rooted and shallow-rooted plants, crop rotation, when implemented carefully (i.e., choosing an appropriate crop), can enhance soil structure and fertility. As a result, the risk of flooding downstream can be decreased by lowering erosion and increasing infiltration capacity [16]. The soil gains a number of advantages from it. The replenishment of nitrogen through the application of green manure in succession with cereals and other crops is a classic component of crop rotation. Moreover, crop rotation reduces the disease and pest buildup that frequently takes place when one species is repeatedly farmed. Crop rotation has generally been used for agronomic purposes rather than to meet environmental and water conservation goals, therefore new methods may be needed to ensure that the benefits of water retention may be realized [16]. An example of how crop rotation is effectuated in Northern Europe is represented on figure 4.4 below.

Figure 4.4 Crop rotation in Northern Europe [16]

Most of the EU-27 areas practice crop rotation extensively; on average, 86% of the EU-27's total arable land is used for this purpose [19]

Potatoes and beets can be included in crop rotation in areas with a continental climate, such as Eastern Germany, Poland, the Czech Republic, Hungary, Slovakia, Austria, and Romania.

Crop rotation should include high yielding cultivars in areas with an oceanic environment, such as Ireland, the UK, the Netherlands, Belgium, Denmark, the majority of France, western Germany, and Spain's oceanic coast (horticultural species and fruits) [19].

Rotations can include permanent cultivation (olives, fruits), legumes, beans, alfalfa, and maize under the Mediterranean environment (Spain, Italy, the South of France, Greece, and Cyprus) [19]. Figure 4.5 below shows the percentage at which crop rotation is carried out in different parts of the European continent.

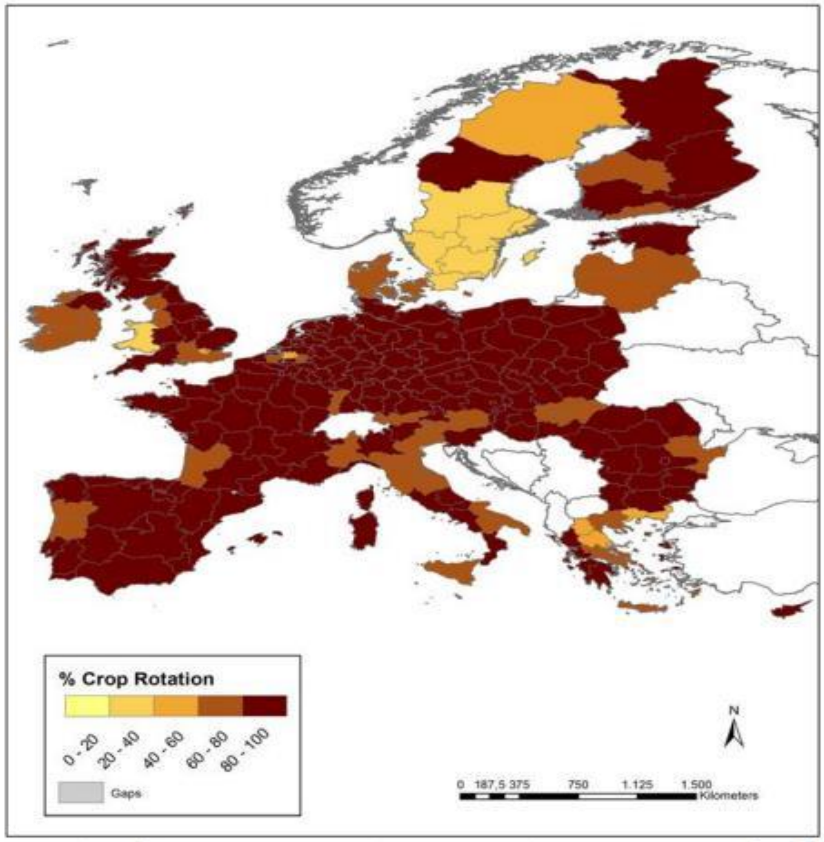

Figure 4.5 Crop rotation in Europe as a share of arable land [20]

Costs

Land Acquisition and Studies & Investigations

There is no change in who owns the land. Regarding the studies and investigation, this measure does not need prior studies to be conducted before implementation. Therefore, nothing is spent in this category. [16]

Capital costs

Expenses of Capital 32€/ha

For modifying crop rotations and raising the fallow index in crop rotations, an average cost of 32€/ha is estimated in the report Green Infrastructure Implementation and Efficiency. Increased agricultural diversification may need the purchase of specialized equipment or contractor fees for certain crops [16].

Maintenance Costs

400 euros per hectare for upkeep

Crop selection and sequencing will interact with nutritional requirements, insect pressures, and input prices to determine the ongoing costs of crop rotations. Context is likely to affect particular costs.

When comparing the input costs of wheat monoculture with pea-wheat-barley rotation, the following French example is used [21]:

- 387€/ha with tillage (22€/ha higher than monoculture wheat)
- decreased tillage: 407 €/ha (38 €/ha less than monoculture of wheat);
- No tillage costs 408 euros per hectare less than monoculture of wheat [21].

Added Charges

In Europe, subsidies for promoting crop rotation development are expected to reach 128 euros per hectare per year [22].

Some works which were done on this measure are presented on table 4.27 below.

Table 4.27 Studies carried out on how crop rotation decreases nutrient load

Sources	Year published	Figures (reduced P or N load)
Khan et al.,	2017	Crop rotation decreased nitrogen and phosphorus losses by 40% and 65%, respectively, compared to continuous corn production, according to a Canadian study
Zhang et al.,	2019	Crop rotation decreased nitrogen and phosphorus losses by 53% and 70%, respectively, compared to continuous corn production, according to a Chinese study
Jin et al.,	2016	Crop rotation decreased nitrogen and phosphorus losses by 33% and 50%, respectively, in comparison to continuous monoculture, according to an analysis of 39 studies.

4.4.15 Strip cropping

When a slope is too long or steep, or when there is no other way to stop soil erosion, one can utilize the agricultural technique known as strip cropping. It alternates strips of row crops like corn, soybeans, cotton, or sugar beets with strips of densely sown crops like hay, wheat, or other small grains. By building organic water dams, strip cropping prevents soil erosion and maintains the stability of the soil [16]. More effectively than others, some plant layers will take up water and minerals from the soil. Water typically washes away weaker soil when it comes in contact with it because it lacks the minerals that would make it stronger. The weaker soil can't wash away as easily as it normally would when strips of soil are strong enough to stop water from passing through them. Farmland remains fertile considerably longer as a result. Information on the scope of strip cropping in Europe is not readily available. In North America, the method has been widely used to reduce soil erosion caused by wind and water [16]. A representation of strip cropping can be seen on figure 4.6 below.

Figure 4.6 Strip cropping along contour lines [16]

Costs

Strip cropping's investment costs is estimated to be minimal but does not provide any information on them [22]. Strip cropping is also regarded by the US Department of Agriculture as one of the least expensive conservation methods to implement. This investment cost may alter the planned cropping sequences and includes labor and/or fuel. Some works which were done on this measure are presented on table 4.28 below.

Table 4.28 Studies carried out on how strip cropping decreases nutrient load

Sources	Year published	Figures (reduced P or N load)
Li et al.,	2018	In comparison to conventional tillage, strip cropping decreased nitrogen and phosphorus losses by 29% and 45%, respectively, according to a review of 15 studies.

Bandyopadhyay et al.,	2018	According to an Indian study, strip cropping reduces nitrogen and phosphorus losses by 53% and 57%, respectively, as compared to conventional tillage.

4.4.16 Intercropping

Growing two or more crops close together is known as intercropping. The main objective of intercropping is to increase the yield on a certain plot of land by utilizing resources that would otherwise go unused by a single crop. Better nutrient cycling and utilization are made possible by intercropping in the agroecosystem. Because various crops have varied nutrient needs and uptake patterns, there is less competition for nutrients among plants. Nutrient intake can be maximized and nutrient losses due to leaching or runoff can be reduced by intercropping complementing crops. Leguminous intercrops can also fix atmospheric nitrogen, lessening the demand for synthetic nitrogen fertilizers. Planting a crop with deep roots next to one with shallow roots or a tall crop next to one that needs some partial shade are examples of intercropping tactics. There are many different varieties of intercropping, including mixed intercropping, row cropping, relay cropping, etc., all of which alter the temporal and spatial combination to some extent [16]. An example of where cereal was intercropped with soya beans is shown on figure 4.7 below.

Figure 4.7 Intercropped cereal with soya beans [16]

Costs

Low Capital Expenses

Stella Consulting (2012) asserts that intercropping has a low capital cost.

Some works which were done on this measure are presented on table 4.29 below.

Table 4.29 Studies carried out on how intercropping decreases nutrient load

Sources	Year published	Figures (reduced P or N load)
De Sousa et al.,	2020	In contrast to monoculture, intercropping reduced nitrogen and phosphorus losses by 40% and 50%, respectively, according to a Brazilian study.
Xu et al.,	2018	According to a Chinese study, compared to monoculture, intercropping reduced nitrogen and phosphorus losses by 36% and 39%, respectively.

4.4.17 No till agriculture

A mechanical alteration of the soil is tillage. By compaction and pore transformation, intensive tillage can disrupt the soil structure, which increases erosion, reduces water retention, and reduces soil organic matter. Growing crops or pasture from year to year without tillage is known as no-till farming (also known as zero tillage or straight drilling). No-till farming is a method that improves soil nutrient cycling, organic matter retention, and the quantity of water that percolates into the soil. It can stop soil erosion in many agricultural areas. The boost in soil biological fertility, which increases soil resilience, is the most potent advantage of no-tillage farming. Maintaining organic matter and healthy soil structure can be achieved by cultivating the soil with discs or tines or by drilling directly into stubbles (no-till). This will increase water infiltration and retention, lowering the total phosphorus levels in surface runoff [10].

Effectiveness

Phosphorus in surface runoff will be reduced when farming systems are switched from intensive to minimal. The amount of dissolved phosphorus can rise over time when utilizing minimal cultivation systems because the phosphorus storage accumulates in the shallow topsoil, particularly on steep slopes with high phosphorus content. There should be the usage of buffer zones and more precise phosphorus fertilization. By reducing the mineralization of organic matter in soil in the fall season, nitrate leaching is often slightly reduced [53].

Figure 4.8 shows a no till seeder used for planting and figure 4.9 represents an image of maize plant growing on soil which was not tilled.

Figure 4.8 No till seeder [16]

Figure 4.9 Maize plant grown without soil tillage [16]

No-till adoption as a percentage of arable land in a few countries in 2010 (Eurostat):

Denmark 5.6% Estonia 6.6% Latvia 1.0% Poland 3.7% Finland 7.4% Sweden 0.6%

Costs

The costs of this method depend on how well it fits into the farm's crop rotation, how well the soils are suited for it, and whether hiring a contractor or buying farm equipment is more profitable.

Capital costs

Direct drilling is worth €10833.

As an alternative to plowing, no-till systems need direct drilling equipment. Rollers may be required before spring crop drilling if no-till is used in conjunction with winter cover crops.

The fixed costs for the machinery provided by for a 100 ha case study farm in Austria are far lower than those for a ploughing system, but they would probably still be an additional expense for farmers switching to no-till [23].

Cost of maintenance

Fuel (euro/ha): 30 to 67

Payroll expenses (€/ha): -21

Costs of herbicide (€/ha): 5 to 18.

Costs of fertilizers (€/ha): 16

As an example, 6.8 l/ha of fuel is used instead of 43.55 l/ha for stubble cultivation, plowing, secondary cultivation, and sowing, saving 84% in operational costs for no-till [24].

According to the soil type, winter wheat uses the following total amount of fuel:

Light: Direct sowing uses 37 l/ha compared to plowing's 73 l/ha, a 36 l/ha reduction.

Medium: 96 l/ha against 40 l/ha results in a 56 l/ha reduction.

Heavy: 42 l/ha as opposed to 120 l/ha results in a 78 l/ha reduction. Gasoline prices are calculated using 0.84 euros per liter.

Soane et al. (2012) report a reduction in labor expenses of €21/ha and a reduction in plowing and tillage expenditures of up to €67/ha. According to Biedermann (2013), additional pesticide and fertilizer expenses with no-till are 18 €/ha and 15.75 €/ha, or 15 kg N/ha more at a cost of €1.05/kg. The average total cost decrease per farm, according to Biedermann, is €24000. Some works which were done on this measure are presented on table 4.30 below.

Table 4.30 Studies carried out on how no till agriculture decreases nutrient load

Sources	Year published	Figures (reduced P or N load)
Zhang Y, et al	2020	N losses from plots of the minimum and no-till treatments were lower than those from plots of the conventional tillage treatment by 19.03 kg N ha-1 and 6.33 kg N ha-1, respectively.
Gatiboni et al.,	2013	According to a Brazilian study, no-till farming reduces nitrogen and phosphorus losses by 44% and 50%, respectively, when compared to conventional tillage.
Xu et al.,	2016	No-till agriculture reduced nitrogen and phosphorus losses by 29% and 44%, respectively, compared to conventional tillage, according to a meta-analysis of 63 research.

4.4.18 Early planting

Up to six weeks before the typical sowing season is considered early sowing. As a result, winter crops that can serve as cover throughout the winter can be established earlier and more quickly, and a root network that promotes soil protection can also develop. Since there is less time for the soil to be bare, water infiltration is increased and erosion and runoff are less significant. Early sowing can also lessen the effects of the summer drought on crops sown in the spring, particularly in the Mediterranean regions with their extremely high evapotranspiration rates. Farmers run the risk of losing the harvests due to the low temperatures because early-sown plants are frost-sensitive [16].

Although spring temperatures in northern nations can be acceptable in March, there is still a significant chance of frost until May. Because of the increased risk of soil erosion brought on by the low temperatures in northern nations, it may be desirable to avoid cultivation and preserve crop residues from previous seasons. This means that early sowing might need particular equipment (plastic tunnel covers, an on-site greenhouse, etc.) and that not all farmers can use it for all crops. Due to the likelihood that soils may be saturated before typical sowing periods, which increases the risk of soil compaction, early sowing of spring crops may also necessitate different cultivation techniques (lower tillage, controlled traffic farming).

There are limitations to planting winter crops early, such as the previous crop's (especially root crops') harvest date, which may be later in northern Europe. There are a number of trade-offs associated with early seeding for both spring and winter crops. For instance, various pest and disease concerns emerge that may call for management modifications [16].

Costs

Capital expenses are not incurred by the measure itself. To implement early planting, however, tillage and other methods may need to change, which may incur capital expenses. Some works which were done on this measure are presented on table 4.31 below.

Table 4.31 Studies carried out on how early planting decreases nutrient load

Sources	Year published	Figures (reduced P or N load)
Sweeney et al.,	2017	According to a U.S. study, early planting can cut nitrogen losses by up to 20% compared to later planting.
Sweeney et al.,	2019	When compared to later planting, early planting reduced phosphorus losses by up to 54%, according to a different study done in the US.

Chen et al.,	2018	According to a Chinese study, early planting can reduce nitrogen losses by up to 30% compared to later planting.
Li et al.,	2021	Early planting reduced nitrogen losses by an average of 13% compared to later planting, according to a meta-analysis of 23 research

CONCLUSION

Going through the various measures, it can be observed that some measures are very expensive as compared to others. Bearing in mind that every farmer would like to make gains from their agricultural activities, it therefore implies that most farmers will prefer the application of cost effective measures.

For the application of a given measure, it is important to know the goal of the measure. If goal is to control transport or loss of nutrients or maintain good quality water. Consequently, farmer must understand the type of measure suitable for the area being cultivated. Not all measures can necessarily be applied on all land and soil types. Another factor is that of climatic conditions. Seasons differ greatly globally. This makes some of the measures feasible in some countries and not others, for instance in the case of winter related measures and early planting measure. Also, the unset of certain seasons is never certain in some countries and applying measures such as regulations on the use of plant protection products and fertiliser storage with specific dates might be faulty with inconsistent season unset. Hence, right timing and spot are very crucial factors to be considered when choosing and applying a measure. This could go a long way to explain the reason why some farmers complain that the load of nutrients keeps increasing, for example in the Baltic sea and Black Sea despite the application of certain methods. It could possibly be as a result of wrong choice of methods or wrong timing of the application.

Furthermore, some the measures do not have enough representative data. Perhaps, more work must be done for some of the measures to bring out data and for better comprehension. This is also same with the effectiveness of certain measures. Given that the effectiveness of some measures was tested on a laboratory scale, it is important that actual field tests be carried out to confirm results. There are very few studies that compile on these measures into one document, making this work extremely important.

PROPOSALS

Some of the measures do not have enough representative data on efficiency and cost effectiveness. Perhaps, more work must be done for some of these measures to bring out data and for better comprehension. For example, more information should be provided on the types of land to be acceptable for each type of measure. Sufficient information is not given on soil types for certain measures. This is a big hindrance because there are varying soil types and soil samples must be considered before choosing a measure.

Studies which have been evaluated on a laboratory scale should be tested on appropriate fields for a better representation.

Measures which have low efficiency should be prioritized least by farmers. An example of such a measure is keeping manure in piles which has low efficiency due to the risk of other environmental issues like odors and the possibility of run offs.

Selecting methods depending on situation: The reduction of nutrient pollution is frequently impossible with one-size-fits-all methods. To make sure that they are appropriate and effective, agri-environmental policies should be tailored to particular climatic, soil, landscape, environmental and socioeconomic circumstances. This strategy would increase the effectiveness of the measures and produce better environmental results. Some measures are not feasible in certain locations while others are.

Using a variety of measures: It may be more efficient to combine several agri-environmental practices like crop rotation, cover crops, and reduced tillage. The combined benefits of these actions can dramatically lower agricultural nutrient losses. Although, this can be expensive, high efficiency will be assured. This leads to the next point which is;

Farmer incentives: Offering cash rewards to farmers who use agri-environmental initiatives can promote adoption of measures and increase efficiency. Subsidies and other forms of financial assistance that value the environmental services offered by farmers will go a long way to motivate other farmers to apply these measures given that some measures are expensive.

Monitoring and assessment; To ensure the success of agri-environmental interventions, regular monitoring and evaluation of their performance is crucial. A thorough monitoring programmer carrying out audits can offer information regarding nutrient losses, the efficiency of measures, and areas where further measures are needed.

Sensitization of the public: Support for agri-environmental measures can be increased by informing the public about the significance of nutrient management and how it affects the environment and human health. Schooling the population on the advantages of nutrient management can also persuade farmers to use more environmentally friendly methods of farming. For instance, through the use of billboards, the Ministry in charge of environmental affairs in synergy with the government in each country can go along way to create public awareness.

SUMMARY

The growing global population and economy has lead to more pressures on the agricultural sector. In a bid to satisfy the demands of the people, agricultural boosters such as the extensive use of fertilizers and manure are being used by several farmers to increase crop productivity. This indiscriminate use of fertilizers and manure has led to the leaching of nutrients (nitrogen and phosphorus) causing water pollution and consequent eutrophication. Several measures have been put in place by certain countries, mostly developed countries and the European Union to reduce diffuse load from agriculture. Unfortunately, most developing countries do not really implement these measures. Examples of the measures are carrying out liming, planting catch crops, manure storage specifications, crop rotation, nutrient equilibrium, good agricultural practice and many others. Applying some of these measures reduces the loss of nitrogen and phosphorus from agricultural land by a certain percentage specific to that measure according to studies effectuated. The cost and efficiency of these measures are different. For example, keeping manure in piles is one of the least efficient because of the other environmental problems associated with it like odor and leaching. But on the other hand, a measure such as creating buffer strips and hedges has several advantages like flood risk reduction, erosion/sediment control and filtering of pollutants. The choice of a measure by a farmer has to do with type of climate in that area, topography of the region and possibly the cost of implementation. Farmers need to understand the field being cultivated and take all these points into account before choosing a measure. Combining a number of these measures increases efficiency rather than sticking to just one type of measure. A total of 31 measures were examined in this work and this number was based on the availability of information and existing studies. This therefore means that so much work still has to be done on all existing measures to paint a clearer picture

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