Ref. Ares(2023)5083151 - 21/07/2023

Horizon 2020 Programme
Research and Innovation Action

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme, under Grant Agreement ***No 773649****.*

Efficient Carbon, Nitrogen and Phosphorus cycling in the European Agri-food System and related up- and down-stream processes to mitigate emissions

Start date of project: 2018-09-01

Duration: 54 months

D1.4 Definition of best fertilization practices related to site, land-use / land-management, and climate.

Deliverable details	
Deliverable number	D1.4
Revision number	Circular Agronomics-E-0223-BFP
Author(s)	Andreas Muskolus
Due date	28.02.2023 (updated 30/04/2023)
Delivered date	28.02.2023
Reviewed by	Case study leaders, Víctor Riau
Dissemination level	Public
Contact person EC	Violeta Kuzmickaite

Contributing partners	
1.	Andreas Muskolus, IASP
2.	Belen Fernandez, IRTA
3.	Laura Ferron, WUR
4.	Florian Grassauer, AREC
5.	Marek Holba, ASIO
6.	Paolo Mantovi, FCSR

TABLE OF CONTENTS

1. Executive summary 3
2. Site-specific best management practices 4
3. Best management practices with respect to land use and land management 9
4. Best management practices with respect to climatic differences 14
5. Benchmarking the practices against the expected impacts 16

1. Executive summary

In Circular Agronomics a range of six case studies demonstrated typical European agricultural nutrient use situations and potential improvement options. In each case study "business as usual" scenarios were tested against new alternatives, which were expected to improve nutrient cycling. The improvements varied with respect to site specific aspects.

Current fertilizing practices depend on factors that are very flexible like type of crop grown, yield expected, and actual nutrient concentration in the soil, as well as soil binding conditions and weather. Those aspects are permanently subject to management decisions. However, in Circular Agronomics we also looked at more general aspects that influence agricultural fertilizing practice on a higher aggregated level. In General, fertilizing practices are influenced by **natural conditions**

- climate
- soil
- vegetation

or technological:

- spatial and quantitative abundance of nutrient sources and alternative usages of these
- storage and processing of manures, animal slurries, and biogas digestates
- application of mineral fertilizers (or absence of such e.g. due to organic farming schemes)
- physical/chemical soil condition management including tillage and carbon management
- application of chemicals for manipulation of chemical/biological processes in soils
- crop and genotype selection
- management of water from rainfall and irrigation

Site specific aspects of nutrient management may be seen as a result of the geographic situation as well as current structure and abundance of industry and population around a specific location, historical, economical, legal, and social aspects, and the availability of knowledge. Different sites may have some circumstances in common but differ in others. Unfortunately, there is no statistical data available on which fertilizing practice is used to what extent in which area. For this reason, the expert knowledge presented below must be considered with respect to the regional origins and working fields of the researchers who contributed to this report. Each of them has a specific view on agriculture (size of farms, crops, climate or geographical differences). However, the result may still not present a balanced view on the total of the EUs agriculture compared to a real statistical evaluation based on data. In addition, other aspects that might have been important to look at in the context of the project (like soil micro biota or cost of specific machinery, relation of crop phenology and nutrient demand, role of pests, pathogens and weeds related to tilling methods) unfortunately could only be included at a very basic level because no data were collected on this, or little information is available from the literature for the 12 specific practices identified.

Defined "best fertilization practices" should guide to reducing nutrient losses from agricultural systems and show new efficient ways how to include nutrients from outside of agriculture, inhering to the principles of sustainable development. Because nutrient management is often very complex and its success is influenced by parameters that cannot be controlled (like weather), the defined practices should be seen as science based "best recommendations" which are in most situations valid with respect to the condition referred to, but not independent of further aspects that may not be described. Therefore, a successful implementation of the best fertilization practices does need an understanding and evaluation of the specific situation in which the action is to be applied.

Twelve examples of best fertilizing management practices were defined by the six case study leaders. The recommendations are sorted by practices that are site-specific, refer to land use and land management, as well as climatic conditions. They are listed and supported with finding from the case studies below.

2. Site-specific best management practices

1. *At sites in which there is a high abundance of animal manure in relation to the available area of land, it is advised to process the organic fertilizers for improved physical/chemical characteristics and transportability.*

This recommendation is derived from the case studies in Catalonia, Emilia-Romagna, Brandenburg, and Gelderland. The specific technology used for processing may vary according to the substrate characteristics, marked situations as well as agronomic requirements.

When liquid organic material (like animal slurry or biogas digestate) is treated to remove nitrogen by vacuum treatment or via rectification, concentrated N fractions are produced. Diammoniumsulphate solution from the Pondus-Treatment facility and diammoniumcarbonate extracted in laboratory experiments (Soepenberg) proved to have similar fertilizing effects compared to conventional mineral (ammonium) fertilizer (Figure 1). The contents of heavy metals, dioxins/furanes and PCBs were below the detection limit.

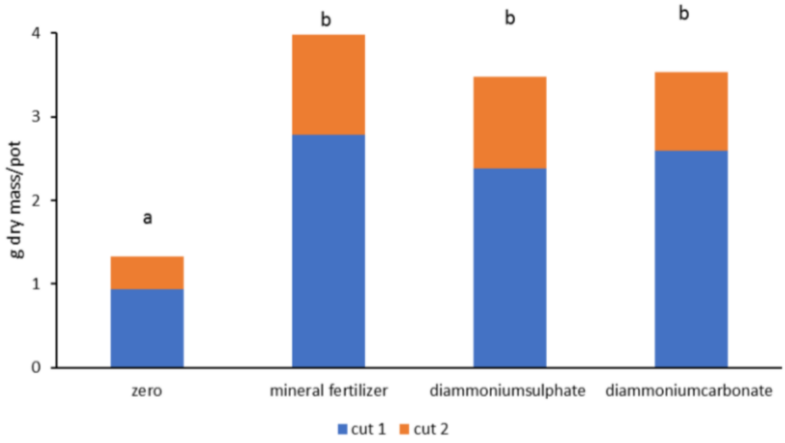


Figure 1. Yields of grass in a pot experiment with concentrated nitrogen extractions from animal slurry processing

In addition to the concentrated nutrient streams, residues may be produced that contain reduced concentrations of some nutrients (like active nitrogen) but are still of fertilizing value. These residues have different fertilizing characteristics than the original material. While animal slurry typically contains nitrogen in the form of ammonia and organically bound nitrogen in shares of 50:50, residues from ammonia removal treatment contain mostly organically bound nitrogen, requiring mineralization in the soil before plant uptake.

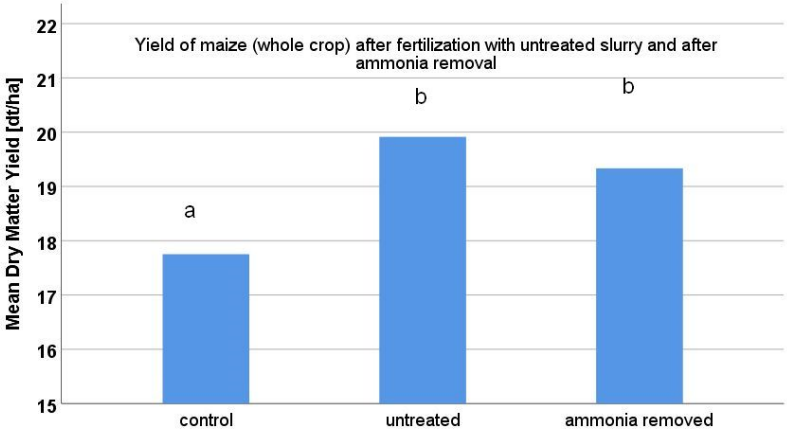


Figure 2. Yields of maize in a field experiment when fertilized with untreated slurry, slurry from which ammonia was removed ,as well as an unfertilized control in Germany at sandy soil in 2021 with no irrigation.

The dynamics of mineralization depend on factors like temperature, chemical and physical soil characteristics as well as soil moisture. If applied at the same amount as the original animal slurry its short-term fertilizing effect in tendency might be reduced (Figure 2).

Further samples of manure processing for better nutrient cycling are the drying of pig slurry in Catalonia and the use of slurry for drip irrigation after microfiltration in Emilia-Romagna. While in the Pondus-system (Figure 1 and 2) the extraction of reactive nitrogen and production of low transport costs fertilizer was in the focus, the approach in Catalonia was to remove water from slurries. In Emilia-Romagna, the use of slurry in fertigation was a third approach. The three different approaches also result from the different agricultural conditions in these areas. A lower soil mineralization activity in the colder region (Brandenburg) and limited ground water resources result in a more technical ammonia removal approach than favoured in the other case studies.

For benchmarking purpose, information is needed on the potential effect of the suggested practice per case of adoption and on the potential to reach wider use (high number of cases). Both depend on factors that may be very complex. Nevertheless, an assessment was done on these two factors based on the information available.

The processing of organic fertilizers can reduce nutrient losses in a wide range but also has its limits. Because only the ammonia share is treated effectively, the effect per case is assessed as `medium`.

All areas of high livestock density in the EU would potentially be suitable for manure processing. According to Eurostat 2020 areas with more than 1.5 livestock units per hectare can be found in Germany, Holland, Denmark, Ireland Spain, France, Italy, and Greece. (https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agri-environmental_indicator_-_livestock_patterns#Livestock_density_at_EU_level_in_2020) Half of all livestock is located in 31 % of all agricultural land in the EU. This suggests a high potential to reach wider use. However, as the treatments are associated with costs in form of energy and material, scaling effects may only suggest treatment if a certain concentration of slurry is reached per area.

PRO: Enables nutrient transport between regions of unbalanced supply and demand, reducing inefficient (tractor) local road transport to fields, reduced N emissions due to more defined end products, enables big and efficient agriculture

CON: High investments cost and reduced flexibility if investment was done, may lead to keeping high life stock densities in regions rather than keeping the pressure up on reducing the number of animals per region

2. *For the production of animal feed it is advised to use local sources as much as possible and to adapt animal diets.*

This recommendation is derived from the case studies in Lungau, Catalonia and Gelderland. Animal husbandry causes nutrient loss and emissions of climate gases during the production of feed, the keeping of the animals, as well as during storage and application of manure. In order to reduce feedstock production related emissions, the use of regionally produced feed is advised.

Adapting animal diets to their needs (production phase, animal specific parameters) reduces nutrients in manure and improves their availability for crops, allowing rate reduction and/or changing the timing of application into the field. Fodder legumes fix nitrogen from air and enrich regional N cycles without external inputs. Nitrogen removed from fields and grassland as fodder (Figure 3) are sustainable sources of nutrients. They can be used in a flexible way, for fodder and human food production.

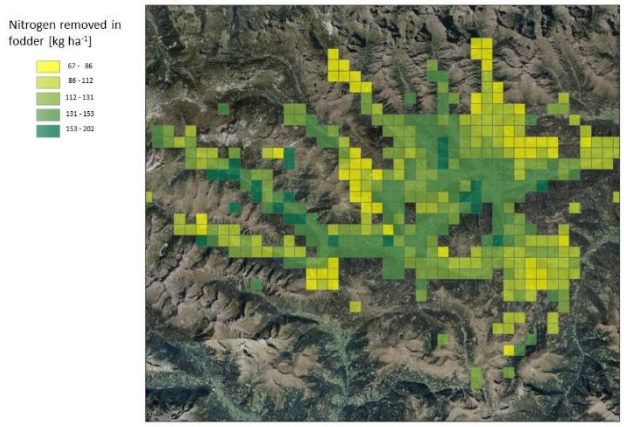


Figure 3. Spatial distribution of nitrogen removal from land as animal feed at Lungau (Austria)

Using local feed reduces area based emissions. However, product (meat, milk) based emissions may depend on a wide range of factors. A possible lower quantity of products per area must be seen in relation to higher process (and product) quality.

Changing animal diets can have a significant effect on nutrient cycling as shown in the case studies. Because animals need a certain minimum turnover of nutrients the effect per case is also limited – ending in our assessment rank "medium" for the effect per case. Currently 75 million cattle and 130 million pigs and kept in the EU. The numbers are decreasing but still the potential seems "high".

PRO: Closing regional nutrient cycles, reducing emissions, improving biodiversity, shaping landscapes valuable for tourism

CON: Increasing cost per unit product, reducing income from regions that are specialized in protein feed production

3. *Nutrient streams from households and the industry should be prioritised to be used as fertilizer if plant and soil effects suggest to do so.*

This recommendation is derived from the case studies in South Moravia and Gelderland. Technological, hygienic and economical aspects also determine if a nutrient stream should be redirected to agriculture or is to be disposed of. Acid whey is rarely used as a fertilizer until now. The findings in Circular Agronomics suggest its suitability if used in sufficient amounts. It can have negative effects on growth when applied in too large quantities but as long as its chemical characteristics (pH-value, salt content) are considered, it is a valuable fertilizer (Figure 4).

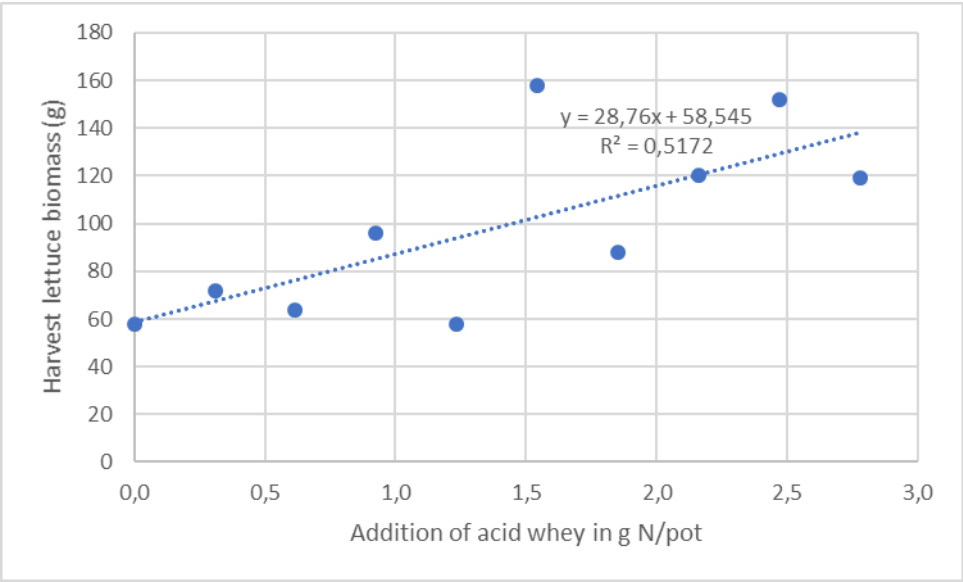


Figure 4: Effect of acid whey on growth of lettuce in pot experiment

In a field experiment with maize in South Moravia, a low nitrate leaching potential from acid whey application could be demonstrated (Figure 5).

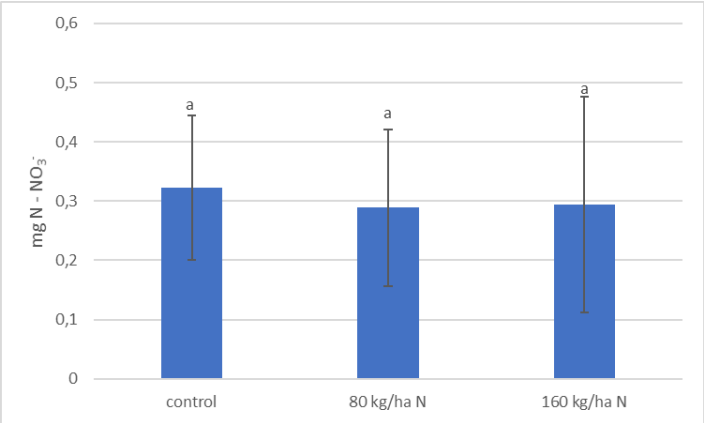


Figure 5. Leaching of nitrate from topsoil after acid whey application to maize during one growing season

A further sample of redirecting a nutrient stream back to agricultural land is the use of Struvite in Gelderland. Recycling nutrients has a large effect in if a single case is looked at because mostly it is the only option to bring nitrogen and phosphorus back into the production cycle. The alternative could be the total loss of nutrients. When waste from households or industry is recycled into a valuable fertilizer, it may still be a potential source of organic pollutants. In order to safeguard the development of recycling from those sources the potential presence of organic pollutants needs to be considered (https://www.nature.com/articles/srep25446).

There is no statistical information on the abundance and potential of industrial nutrient streams. In a number of cases (food industry), nutrients are already used as fertilizer or animal feed – the potential to reach wider use is therefore seen as "medium".

PRO: If not used in agriculture, nutrients in most cases will be totally lost from the cycle, new products of bio economy may be created with new sources of income

CON: waste streams may have efficient utilisations outside of agriculture (e.g. in the use of their carbon) and may need to be replaced by other (fossil?) sources, the costs of the fertilizing product may be higher than a purpose-produced product.

4. *Application of dried acidified digestate results in similar soil nitrate levels and crop N uptake than with chemical fertiliser. However, it leads to higher soil total N content, better maintaining the soil N stock and potentially reducing fertiliser needs in the long term.*

This recommendation is derived from the Catalonia case study.

If digestate from biogas production is acidified and dried in order to improve transport and storage, the fertilizer demonstrated similar yields like conventional mineral fertilizer. Furthermore, it has the ability to build up carbon in the soil and consequently organically bound nitrogen stocks (Figure 6). In situations of low nitrate leaching potential (controlled irrigation) this can significantly improve soil fertility.

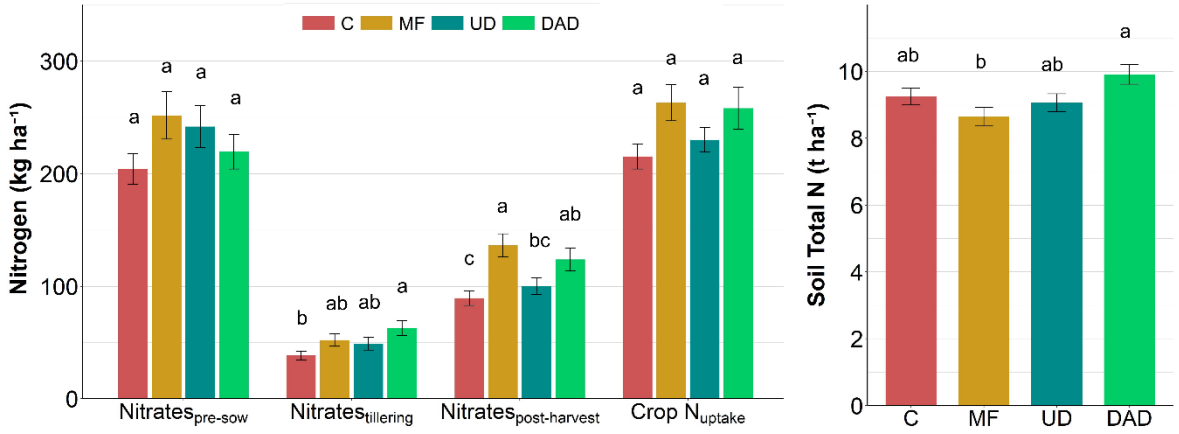


Figure 6. (a) Soil nitrate concentration (kg N-NO3- ha-1) at pre-sowing, cereal tillering and at post-harvest and crop N uptake (kg N ha-1) average according to fertilisation for three seasons (2019 to 2022) and 5 irrigated winter crops (barley, canola, pea, triticale and wheat). (b) Soil total N (t ha-1) average according to fertilisation after three growing seasons. Different letters represent significant differences at $p<0.05$. C=Control; MF=Mineral Fertiliser; UD=Untreated Digestate; DAD=Dried Acidified Digestate.

The acidification and drying of animal slurries can help improving nutrient cycles in specific situations. The effect in a single case compared to the other best practice samples was ranked “medium”. The potential of the technology to find wider use seems large if the total number of animals in the EU is taken into account but the dependency on warm weather limits the potential wider use to “medium”.

PRO: higher soil N stock, reducing fertiliser needs in the long term due to increased C-stocks in soil, better pest management

CON: High Investment costs, external material needed (acid), dependency on warm weather.

5. *Diversifying winter crop rotations by integrating non-cereal crops can bring yield stability to winter wheat. However, a full cereal rotation might be overall more appropriate for water limited systems*

This recommendation is derived from the Catalonia case study.

Crop rotations diversify risks, interrupt disease transmissions routes, and balance nutrient demands from different crops. But crops differ in profitability and such which are good for the soil might have no marked value at all. In the Catalonia case study, it was demonstrated that cereals benefit from less profitable crops like peas in the crop rotations (Figure 7). Consequently, the nutrient balance of the whole crop rotation must be taken into account and not just the single crop. Often, the various positive effect of legume pre-crops (reduction of pests and diseases, improvement of soil structure, reduction of specific weeds) are larger than the pure nutrient effect (https://chembioagro.springeropen.com/articles/10.1186/s40538-016-0085-1).

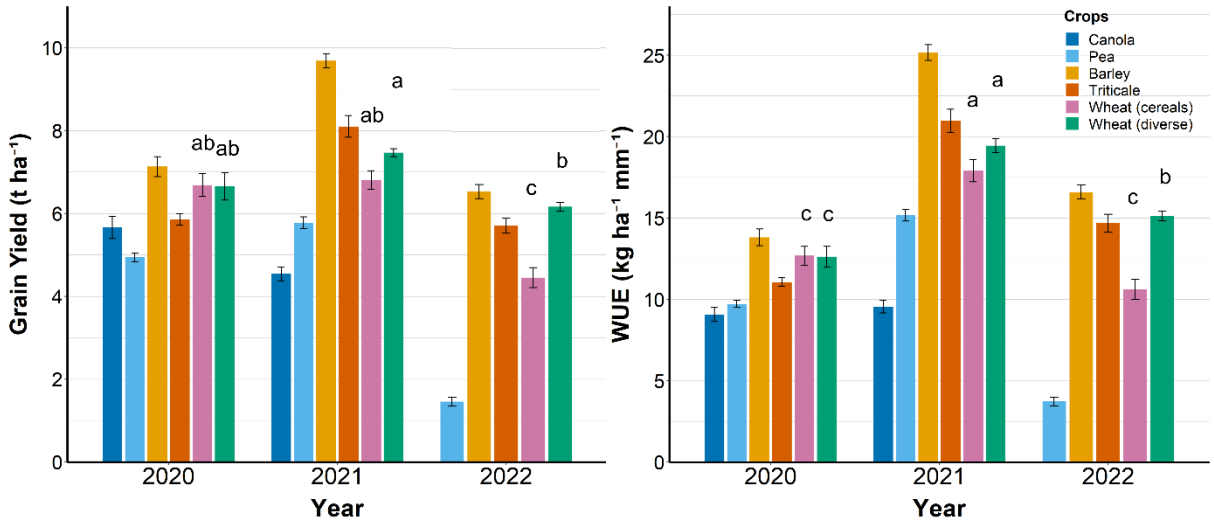


Figure 7. Grain yield (a; t ha-1) and water use efficiency (b; kg ha-1 mm-1) means of wheat according to crop precedent (triticale or pea in 2021 and barley-triticale or canola-pea in 2022) and the remaining crops in rotation. Different letters represent significant differences according to the crop precedents of wheat along the three seasons ($p<0.05$). No data for canola in 2022 due to crop failure

Many crop rotations in the EU contain a high concentration of cash crops that are basically cereals (Eurostat 2020). Changing the rotations to higher shares of legumes and other broad-leaved crops has an effect on the overall nutrient balance that was assessed as "medium" compared to other possible actions. However, introducing legumes in crop rotations would technically be possible at most crop regions in Europe. The potential to reach wider use is therefore "high".

PRO: Positive effects on nutrients cycling and biodiversity

CON: Reduced income for farms

3. Best management practices with respect to land use and land management

6. *It is advised to select genotypes for nutrient efficiency rather than for yield potential.*

This recommendation is derived from the case studies in Brandenburg and South Moravia. The nitrogen efficiency of cereals like winter wheat is determined by:

- Efficiency of root system to take up nutrients
- Efficiency of nutrient incorporation into plant material
- Efficiency of storing nutrients in harvested parts (harvest index, protein content)

Especially under sub-optimal growth conditions, genotypes vary in the single aspects of efficiencies listed above, depending on their breeding history. For different uses (like making bread or fodder) a wide choice of genotypes has been developed. They differ in yield potential and quality potential (like protein content). Because total amounts of nutrients taken up, strongly depend on weather conditions, while the process of storing the nutrients in the harvested plants is less influenced by weather, it is suggested to select genotypes with high genotypic protein contents. Findings from Brandenburg and South Moravia show higher total nitrogen use potential of high-protein genotypes under drought conditions (Figure 8).

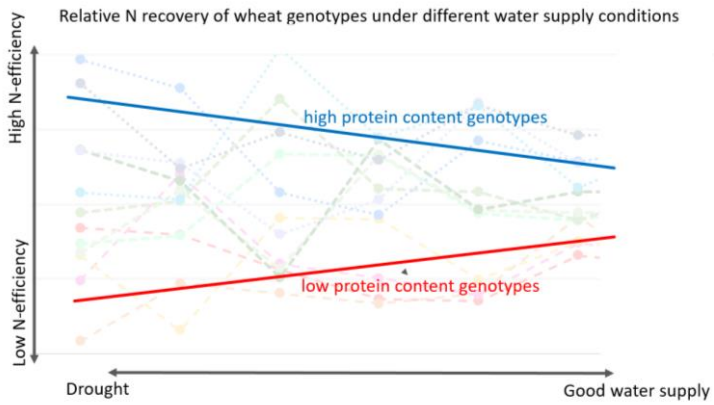


Figure 8. Relative N-efficiency of 12 winter wheat genotypes under different situation of water supply

The use of more nitrogen-efficient genotypes allows for reducing nitrogen from fertilizers inputs. Currently used genotypes often have a long breeding history in Europe. They are optimised with respect to yield, quality, or disease control. Nutrient efficiency may have been at least an indirect goal in the breeding history because it is partly linked to yields and quality. The shift to making it a new breeding goal may release "medium" potential if a single case is looked at. However, the principle can be applied to most breeding situations in cereal crops – a "high" potential is seen for it to reach wider use.

PRO: Efficient practice with high potential to generate income also for plant breeders

CON: Cost of plant breeding may raise – resulting in more expensive seeds

7. *The timing of organic fertilization should be chosen according to physical/chemical parameters of the fertilizer, crop uptake and expected rainfall*

These recommendations are derived from the case study in Brandenburg and Catalonia

Nutrient uptake of crops follows a typical seasonal pattern but also depends and the availability of growth conditions like water, temperature and solar radiation. The challenge in using organic fertilizers like manure and animal slurries it to synchronize the timing of supply and demand. Organic fertilizers need some time for the nutrients to become available by mineralization. If mineralization is too slow, especially nitrogen may become available too late and will result in reduced yields. If nitrogen becomes available too early, it will be prone to leaching in case of high rainfall events. For maize it is often suggested to fertilize sometime after seeding because the time of main nutrient pickup might be 8 to 12 weeks after seeding. However, this proved not to be the case in the experiments at the case study Brandenburg. Especially in dry conditions an early application was successful because there was little loss of nutrients and more time for mineralization. This, however changed from year to year (Figure 9). If more rainfall is to be expected, the timing between application and nutrient uptake needs to be closer in order to reduce the time in which the nutrients are exposed to washing out. Additionally, the history of the crop development within the growing season is reflected by the plant phenology like the green colour. Modern devices (N-sensors, drones) enable to indicate a deficiency of nitrogen in crops and help managing fertilization rates and timing.

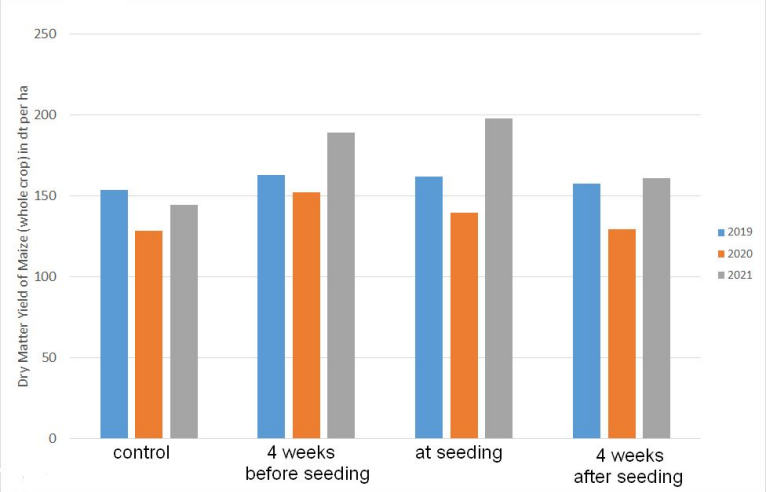


Figure 9. Yield of maize after fertilization with cattle slurry for weeks before seeding, at the time pf seeding and four weeks after seeding.

The timing of fertilizer application has a strong effect of its efficiency. Regulations are in place to prevent fertilization during times of no nutrient uptake (mostly winter). However, current regulations still allow for a wide range or timings. Within the scope of the regulations, the timing effect on nutrient use efficiency is still “high”. Only “medium” potential was identified by the case study leaders concerning the potential to further tighten the regulations. In addition, in many cases the weather decides weeks after fertilization if the timing was at its optimum or not leading to limited predictability only.

PRO: Relatively simple method that not requires specific technology

CON: Higher cost may result from higher storage capacity and more efficient application

8. *Adapted slurry application techniques reduce nitrogen losses during and after application.*

This recommendation is derived from the case study in Brandenburg.

Ammonia gas emits during and after application when animal slurry gets in contact with air. In order to reduce ammonia emissions, the surface area in which air get in contact with the fertilizer as well as the time of exposure must be reduced. When slurry is spread by a traditional splash plate, the fertilizer is in contact with air at a large surface. Better adapted are technologies that transport the liquid in pipes to the soil surface and place it in bands rather than broadly at the soil. A further reduction of ammonia emissions is achieved by immediate incorporation into the soil because it reduces the area and time of exposure (experimental setup in Figure 10). However, this requires costly machines and may reduce area performance.

Because slurry application technologies have the potential to reduce emissions if the single case was assessed, its effect is seen “high”. However, at the farm level, slurry application techniques are influenced by a number of factors including available finances. Machines that enable an improved use of nutrients are more expensive and often need more time to do the work. They are more specific and can hardly be used in permanent crops or spring fertilization of winter crops. Their overall potential to reach wider use is therefore seen as “medium”.

PRO: Efficient method with high effect

CON: High machinery cost



Figure 10. Incorporation of animal slurry in bands into the soil (experimental setup). Maize was later planted directly above the fertilizer bands.

9. *Conservation tillage strategies, up to no-tillage, should be used where appropriate in order to minimise energy consumption, increase soil organic matter and build up a larger nutrient buffer in the soil*

This recommendation is derived from the case study in Emilia Romagna.

For decades, the plough was the traditional tool for tillage at farms in Europe. The principle was developed under conditions of nutrient scarcity (no mineral fertilizers) and the absence of chemical herbicides. Its use stimulates mineralization in the soil and helps organically bound nutrients to become plant available. However, in more recent times production goals and technological options have changed. The plant availability of nutrients is less a subject of tillage and weeds are controlled by herbicides. Reducing tillage activities or consequently using a no-till technology is more close to a natural ecosystem because in nature the soil is rarely turned around but its structure is build up by living organisms. While the plough mixes the topsoil, reduced tillage allows for the development of zones with different concentrations of carbon, nutrients and water in the topsoil. This heterogeneity provides a better buffer capacity in case of extreme incidents like flooding, strong winds or drought. While in single cases ploughing results in higher yields because of accelerated mineralization processes or

better weed control, it may reduce the long-term resilience of agricultural systems. The shift to reduced tillage, however, may result in an increased complexity of weed management and the control of pests and diseases.



Figure 11. Tillage systems from No-Till to plough in pictures

Changing tillage strategies can have some effect on improving nutrient cycling due to the accumulation of carbon and nutrients in the soil. The processes require a number of years until positive effects become visible. More intensive herbicide use may be necessary. The effect compared to other measures for this reason was ranked “medium”. Ploughing is the traditions method of tillage in most crop areas of Europe, for this reason the potential for wide use of the technology is assessed “high”.

PRO: Reduced soil erosion, build up of carbon in the soil

CON: High investments costs, management of weeds, pest, and diseases more complex

4. Best management practices with respect to climatic differences

10. Dry conditions require a reduction of the nutrient amounts applied and a higher rate of flexibility

When calculating the amount of nutrients to be applied, the potential uptake during the growth season must be realistically assessed. Farmers hope for good yields and qualities of their products and therefore tend to apply amounts sufficiently. However, in many cases weather became less predictable in recent years and drought led to increased balance surpluses. According to national and regional fertilizer regulations the yield prediction is calculated on the basis of average yields from previous 3 to 5 years. This takes into account yield reduction because of drought, but limits the nutrient supply in years of favourable weather conditions. In order to reduce application effort and costs, for the nitrogen supply of winter wheat stabilized "all-in-one-dosage" of slow-release fertilizers can be applied. Under average weather conditions these fertilizers match supply and demand sufficiently but the total amount of nutrients cannot be reduced in case growth conditions are worse than expected. The use of short term plant-available nutrients like ammonium and nitrate in 3 or more dosages maintains flexibility: In case the nutrients cannot be taken up, a dosage can be reduced or cancelled. In the case study in Brandenburg, the effect of weather on nitrogen balances was demonstrated (Figure 12). The uptake varied up to 50 kg N per ha between the years and conditions.

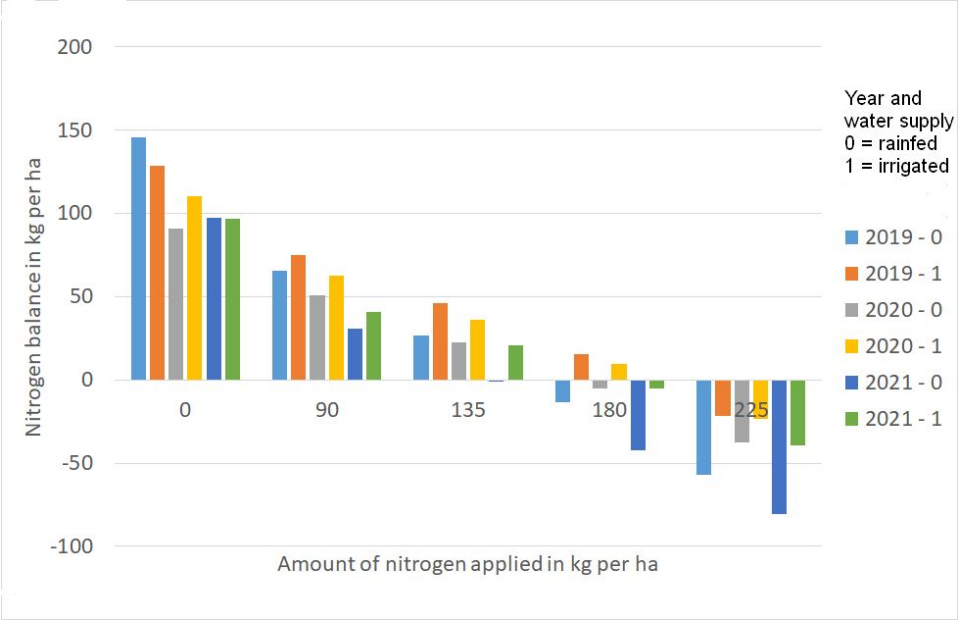


Figure 12. Nitrogen balance of winter wheat when fertilized with amount of 0 to 225 kg nitrogen per ha (average of 12 genotypes) in six different weather situations (three years, rain fed and irrigated)

Fertilizer application rates are calculated on the basis of yield expectations. If those are reduced during the cropping season application rates need to be reduced. The current fertilizing practice often does not allow for such adaptations. The nutrients saving potential in single cases can be "high". As with the background of climate change the relevance grows to most cropping regions in Europe, its potential to be used widely is also "high".

PRO: The only way to balanced nutrient flows in dry regions if irrigation is no option

CON: Reducing N amounts limits yields and quality even if the water supply is good, flexibility may be associated with higher costs (machinery, management costs, labour costs).

11. *Nitrification inhibitors should be used under conditions of potential nitrate leaching only*

This recommendation is derived from the case study in Brandenburg.

Nitrification inhibitors slow down bacteria activity in the soil that convert ammonium to nitrate. Plants take up nitrogen in form of nitrate, so the conversion is needed before plant uptake but in the form of nitrate, the nutrient is prone to leaching. In order to better synchronize plant nutrient availability and uptake by plants, nitrification inhibitors are used in animal slurry application, especially when the application is done a significant time before seeding. Application times are influenced by factors like soil driveability and storage capacity. In times of drought and high temperatures during the growing season, nitrification inhibitors cannot exploit their potential because no nutrients are lost due to leaching and the bacteria suppressing effect does not last long. The ecological side effects of highly complex molecules of the chemical nitrification inhibitors are also debated. In consequence, nitrification inhibitors should only be used under wet conditions when there the danger of leaching between fertilizer application and uptake.

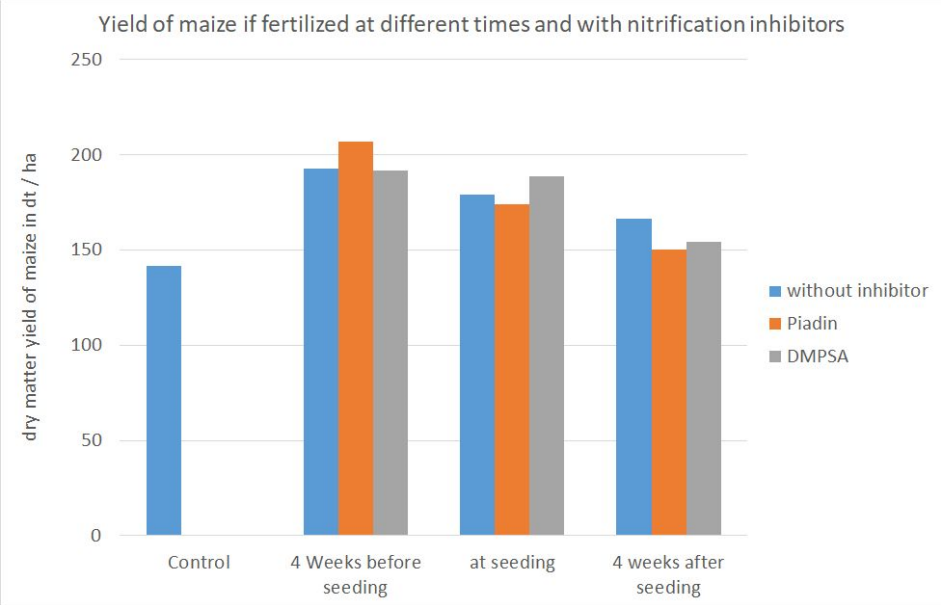


Figure 13. Yields of maize (whole crop) when fertilized with nitrification inhibitors 4 weeks before seeding, at the time of seeding and four weeks after seeding. The differences within one time were not significant.

Nitrification inhibitors have been studied widely and show a range of positive to negative effects on nutrient efficiency. It is suggested that the highly complex chemical compositions may have unwanted effects on soil micro biota (https://www.sciencedirect.com/science/article/pii/S0048969721034458). As the delay in nitrification has limited effects on nutrient efficiency compared to other measures (timing, technique, amounts), its contribution was assessed as “low”. However, the use of NI is possible at most cereals and other non-legume crops – for this reason the mark “medium” was given to the use potential.

PRO: Costs for NI can be saved

CON: Conditions of nitrate leaching cannot be exactly forecasted during time of application, situations in which the use of NE might be beneficial might be missed.

12. *Mixing nutrient filtrates from organic wastes to irrigation water increases water and nutrient use efficiency*

This recommendation is derived from the case study in Emilia Romagna.

Fertigation is a common practice, especially in vegetable and fruit production. Because of small diameter holes in drip lines, the fertilizers need to be soluble and must not contain particle sizes above a certain diameter. Organic fertilizers like animal slurries and biogas digestates cannot be used for fertigation without filtering. A Special micro filter enables the nutrients to be separated in a small particle size fraction. In cases where a drip irrigation system exists near to a biogas plant the combination of the two via micro filtering improved nutrient use efficiency of the digestate application.



Figure 14. Micro-filtered biogas digestate is pumped into a drip irrigation system

In a single, specific case, fertigation of organic fertilizers can improve the efficiency of nutrients. If compared to alternatives (slurry application technologies, selection of crops, manure processing) it was ranked as a technique of “medium” effect. With the view on the total agriculture in Europe, not many situations were identified in which a biogas-plant and fertigation would be in the same area. The technology seems to be rather specific. For this reason, the potential of wide use was seen “low”.

PRO: Improved nutrient efficiency, may reduce transport costs

CON: Special technology needed, reduced flexibility under wet conditions (you need to irrigate in order to fertilize)

5. Benchmarking the practices against the expected impacts

The expected impact of each best management practice can be assessed according to the aspects below:

1. How much nutrients could be saved or recycled per case, area, or product? (potential per case)
2. Would the best practice be relevant to many cases or is it very specific? (potential to reach wider use)

Comparing and benchmarking the twelve mentioned best fertilization practices is difficult because they follow very different approaches. However, their magnitude and potential total impact can be assessed on the basis of expert knowledge. The more specific the case is in which the practice is to be adapted, the smaller the potential total impact. A great total impact can be reached with measures that are relevant to many situations and have a significant effect in each of them. In Table 1 a benchmarking was developed on the basis of best educated guess. According to this, reducing applications rates (and increasing flexibilization) as well as optimizing the timing of fertilizer application has the highest potentials in reducing nutrient leaks. In contrast, using nitrification inhibitors has the lowest expected impact.

Practice		Potential effect per case	Potential to reach wider use	PRO	CON
1	**Processing organic fertilizers**	medium	high	Enables nutrient transport between regions of unbalanced supply and demand, reducing inefficient (tractor) local road transport to fields, reduced N emissions due to more defined end products, enables big and efficient agriculture	High investments cost and reduced flexibility if investment was done, may lead to keeping high life stock densities in regions rather than keeping the pressure up on reducing the number of animals per region
2	**Adapting animal diets**	medium	high	Closing regional nutrient cycles, reducing emissions, improving biodiversity, shaping landscapes valuable for tourism	Increasing cost per unit product, reducing income from regions that are specialized in protein feed production
3	**Using nutrients from industry and households**	high	medium	If not used in agriculture, nutrients in most cases will be totally lost from the cycle, new products of bio economy may be created with new sources of income	waste streams may have efficient utilizations outside of agriculture (e.g. in the use of their carbon) and may need to be replaced by other (fossil?) sources, the costs of the fertilizing product may be higher than a purpose-produced product
4	**Application of dried acidified digestate**	medium	medium	higher soil N stock, reducing fertiliser needs in the long term due to increased C-stocks in soil, better pest management	High Investment costs, external material needed (acid), dependency on warm weather
5	**Diversifying crop rotations**	medium	high	Positive effects on nutrients cycling and biodiversity	Reduced income for farms
6	**Genotype selection for nutrient efficiency**	medium	high	Efficient practice with high potential to generate income also for plant breeders	Cost of plant breeding may raise – resulting in more expensive seeds
7	**Timing of organic fertilization**	high	medium	Relatively simple method that not requires specific technology	Higher cost may result from higher storage capacity and more efficient application
8	**Slurry application techniques**	high	medium	Efficient method with high effect	High machinery cost
9	**Conservation tillage strategies**	medium	high	Reduced soil erosion, buildup of carbon in the soil	High investments costs, management of weeds, pest, and diseases more complex

10	**Reduction of application rates**	high	high	The only way to balanced nutrient flows in dry regions if irrigation is no option	Reducing N amounts limits yields and quality even if the water supply is good, flexibility may be associated with higher costs (machinery, management costs, labour costs)
11	**Nitrification inhibitors**	low	medium	Costs for NI can be saved	Conditions of nitrate leaching cannot be exactly forecasted during time of application, situations in which the use of NE might be beneficial might be missed
12	**Organic fertilizer fertigation**	medium	low	Improved nutrient efficiency, may reduce transport costs	Special technology needed, reduced flexibility under wet conditions (you need to irrigate in order to fertilize)

Table 1: Comparison of best fertilization practice samples