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Optimal catch crop solutions to reduce pollution in the transboundary Venta and Lielupe river basins

Project acronym: CATCH POLLUTION

Joint Report on Activity AT1.1.

Environmental effects of catch crops

aplinkos apsaugos politikos centras
center for environmental policy

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Abbreviations

AAPC	Center for Environmental Policy
AREI	Institute of Agricultural Resources and Economics
CC	Catch crops
CO_2-e	Carbon dioxide equivalent
GHG	Greenhouse gas
N	Nitrogen
PAN	Plant available nitrogen
RBD	River basin district
SOC	Soil organic carbon
SOM	Soil organic matter
VDU ŽŪA	Vytautas Magnus University Agriculture Academy

Introduction

Catch crops[1] (CC) seeded in between of planting of main crops are known to bring positive environmental effects, such as reduction of nutrients leaching, improvement of soil quality, protection against soil erosion, reduction of weeds and pesticides use, etc. However, catch crop effects depend on their species and other factors such as soil type, whether conditions etc. To select the best catch cropping option, it is very important to understand their potential role, performance and effect.

The main task of this report is to provide a more detailed scientifically proven information about environmental effects of catch crops, highlight their advantages and investigate the best options for the particular needs. Report provides an assessment of potential catch crop effects in Lielupe and Venta river basin districts demonstrating a full range of environmental benefits that catch crops can bring.

This report was elaborated jointly by the agricultural experts of the Agriculture Academy of Vytautas Magnus University (VDU ŽŪA) and the Institute of Agricultural Resources and Economics (AREI), and environmental experts of the Center for Environmental Policy (AAPC).

Report provides detailed description and methodologies used for the assessment of the following effects of catch crops:

- Reduction of nutrient leaching
- Transferring of nutrients for the next main crop (nitrogen crediting)
- Reduction of greenhouse gas (GHG) emissions
- Increase of soil organic carbon (SOC) content
- Control of pests and diseases
- Reduction of soil erosion.

[1] In a wider context, they can also be referred to as cover crops.

1. Reduction of nutrient leaching

prepared by AAPC & VDU ŽŪA

Among all environmental effects that catch crops can provide, retention of nutrients is of the prime importance and concern in our study as it first of all focuses on the investigation of the catch crop potentials to facilitate reduction of the nutrient pollution of surface and ground waters from agriculture.

Due to intensive agricultural activities, rivers in Venta and Lielupe RBDs are suffering from the elevated nitrogen concentrations. By uptaking nutrients from the soil and utilizing them in the production of biomass catch crops prevent leaching into watercourses. Thus, including catch crops into crop rotations is one of the most promising measures for reduction of the nitrogen pollution in Venta and Lielupe RBDs.

1.1. Description of an effect

Soil microorganisms release nitrates from organic matter. Depending on the soil texture, amount of precipitation and nitrogen concentration, nitrogen leaching to a lesser or greater degree occurs in the soil *(Lewan, 1994)*.

Catch crops can be undersown in the main crop or sown after its harvesting. They utilize considerable amounts of nitrogen from the soil for the formation of the above-ground and below-ground biomass (biological accumulation of nitrates). As a result, nitrate leaching is decreased (*Figure 1*).

When stating the effect of catch crops on the nitrogen leaching, a distinction should be made between the effect after one year and a total effect over several years. The effect after one year indicates the reduction in the amount of nitrogen leached during autumn and winter in the crop year of the catch crop, while the total effect takes into account the amount of nitrogen released again at mineralisation of the catch crop the following year.

Where nitrate leaching is a serious problem, catch crops can beneficially fill any "fallow" periods in a rotation.

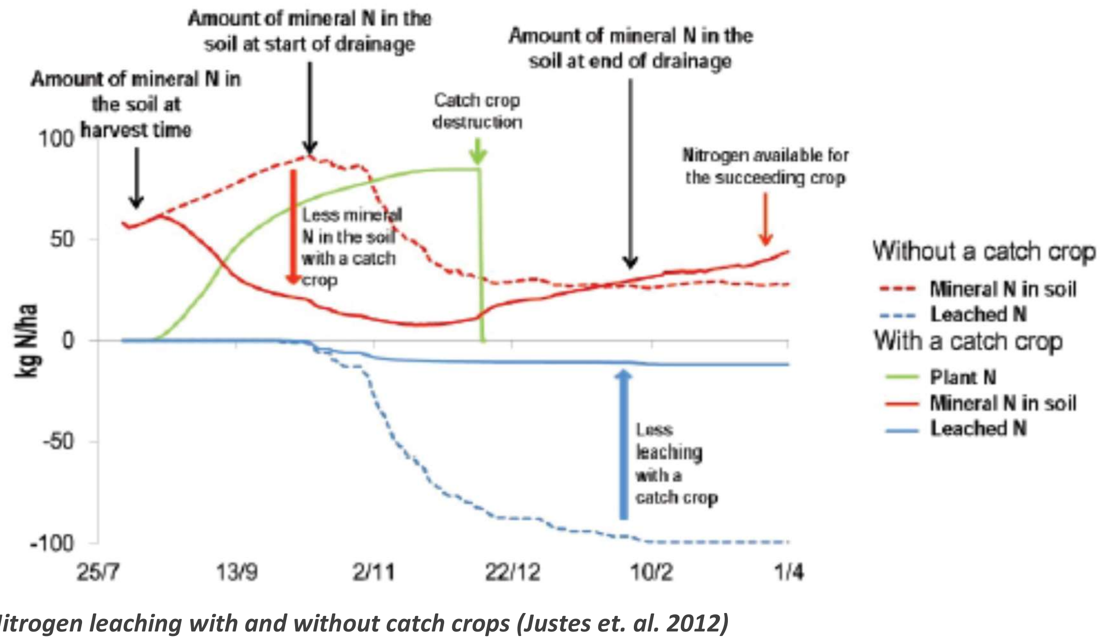

Figure 1. Nitrogen leaching with and without catch crops (Justes et. al. 2012)

1.2. Methodology for the assessment of an effect

Nutrient leaching reduction effect in Venta and Lielupe RBDs depends on the areas of catch crops and their nutrient retention capacities. Hence, the methodology for the assessment of nutrient pollution reduction effect focuses on the calculation of areas which can potentially be sown with catch crops and quantification of the potential leaching reduction rates (i.e. nutrient amounts, which can be retained by catch crops and prevented from leaching) under the particular climatic, soil and farming conditions.

In our study we calculate potential reduction of nitrogen loads in basins, sub-basins and sub-catchments of Venta and Lielupe RBDs by the following formula considering crop structure, estimated catch crop growing potential, typical nutrient leaching, and expected nutrient leaching reduction rates:

$$\text{RNL}=\sum_i A_{MCi} * P_{CC_i} * L_{MC_i} * R_{CC}/10\ 000$$

where

RNL – potential reduction of nitrogen load in the river basin/sub-basin, kg/year
A_{MCi} – area of the main crop i in the river basin/sub-basin, ha
P_{CC_i} – percentage of the main crop area that can potentially be sown with catch crops, %
L_{MC_i} – nitrogen leaching from the main crop fields, kg/ha/year
R_{CC} – potential reduction of nitrogen leaching if catch crops are introduced, %.

1.2.1. Assessment of the catch crop growing potential in Venta and Lielupe RBDs

For catch cropping appropriate niche in a crop rotation, sufficient to grow an adequate amount of catch crop biomass between the two main crops, is needed. Prevailing crop rotations are thus often limiting factor for including catch crops. In Venta and Lielupe RBDs prevailing crop rotations with dominating winter cereals and rape are not favourable for catch cropping. Experts estimate that growing of catch crops is reasonable when in the rotation early potatoes, winter barley, winter rape, winter wheat, winter rye, winter triticale and peas are succeeded by spring crops or fallow and when early potatoes and winter barley are succeeded by winter crop. Additionally, catch crops by broadcasting the seed can be sown in spring barley and spring wheat before their harvest.

The area, which can potentially be allocated for catch crops after the harvest of the mentioned main crops, is presented in *Table 1.*

Table 2 provides information about the areas devoted to main crops, as declared by farmers in 2016 and 2017. Catch crop growing potentials in basins and sub-basins of the Venta and Lielupe RBDS, as estimated by the project experts, are provided in *Table 3*.

It has to be taken into account that estimated catch crop growing potentials represent the maximum areas that can be used for catch crops. The actual area however will depend on how this potential will be utilized, i.e. on farmers' motivation and willingness to include catch crops into their rotations.

Table 1. Potential area for catch crops after the main crop (estimated by the project experts)

Preceding main crop	Area, which can potentially be allocated for catch crops after the harvest of the main crop (%)	
	in Lithuania	in Latvia
Winter wheat	30	30
Winter rye	10	10
Winter triticale	20	20
Winter barley	0*	10
Winter rape	0**	10

Preceding main crop	Area, which can potentially be allocated for catch crops after the harvest of the main crop (%)	
	in Lithuania	in Latvia
Potatoes	30	30
Pea	50	50
Spring barley	30	30
Spring wheat	20	20

[*] in Lithuania winter barley is usually used as a preceding crop for winter rapeseed and therefore it is assumed that there is no potential for catch cropping after winter barley.

[**] in Lithuania winter rape is the main preceding crop for winter wheat; after the harvest of winter rape catch crops could only be grown for short period (about 50 days) till the winter wheat sowing in mid-September. So, there is no possibility for catch crops.

Table 2. Areas of the main crops (Lithuanian declaration data from 2017 and Latvian declaration data from 2016)

River basin/ sub-basin	Area of the main crop, ha								
	winter wheat	winter rye	winter triticale	winter barley	winter rape	potatoes	pea	spring barley	spring wheat
Lielupė RBD:									
Mūša river (LT)	106682	1037	8682	1076	27950	825	24240	23827	23631
Lielupe small tributaries (LT)	55981	12	617	364	23708	69	9475	11929	5796
Nemunėlis river (LT)	15470	1075	4047	111	2650	229	7124	5538	6226
Lielupe RBD (LV)	120935	5735	1268	799	35762	2814	3927	13295	25415
Venta RBD:									
Venta river basin (LT)	59441	1226	6165	1092	15991	761	16799	17092	14993
Bartuva river basin (LT)	3709	208	804	28.5	572	171	2060	3316	3386
Šventoji river basin (LT)	2210	52	334	204	2966	51	1286	1100	3256
Venta RBD (LV)	104077	7546	2025	1059	28219	1544	2037	27406	37331

Table 3. Catch crop growing potentials in basins and sub-basins of the Venta and Lielupe RBD

River basin/ sub-basin	Land area which can potentially be sown with catch crops, ha	Percentage of the total arable land area, %
Lielupė RBD:		
Mūša river sub-basin (LT)	58087	22
Sub-basin of the Lielupe small tributaries (LT)	26415	22
Nemunėlis river sub-basin (LT)	12095	18
Latvian part of the Lielupe RBD(LV)	52643	20
Venta RBD:		
Venta river basin (LT)	35942	21
Bartuva river basin (LT)	4048	16
Šventoji river basin (LT)	2375	21
Latvian part of the Venta RBD (LV)	52480	20

1.2.2. Nutrient leaching in Venta and Lielupe RBDs

The amount of nitrogen lost from the soil by leaching highly depends on the soil properties, climatic conditions and farming practices. Monitoring data from the rivers having their basins in the areas of intensive agriculture demonstrates that the largest amounts of nitrogen are leached into rivers in the period from the late autumn to early spring. E.g., in the Platonis river (Lielupe RBD), where arable land makes 75% of the total basin area, 90-99% of the annual nitrogen load appears in the period from November to the end of April (*Figure 2*).

In the period of 2010-2016, average annual load of nitrogen transported by the Platonis river was 18 kg/ha. Taking into account that the Platonis river basin is dominated by the arable land this gives a good indication on potential nitrogen leaching from the fields of arable land.

To extend the knowledge on potential nitrogen leaching from the arable land in Venta and Lielupe RBDs, a review of literature with the focus on experimental studies performed in Lithuania and Latvia was carried out. Summarised information is provided in *Table 4*.

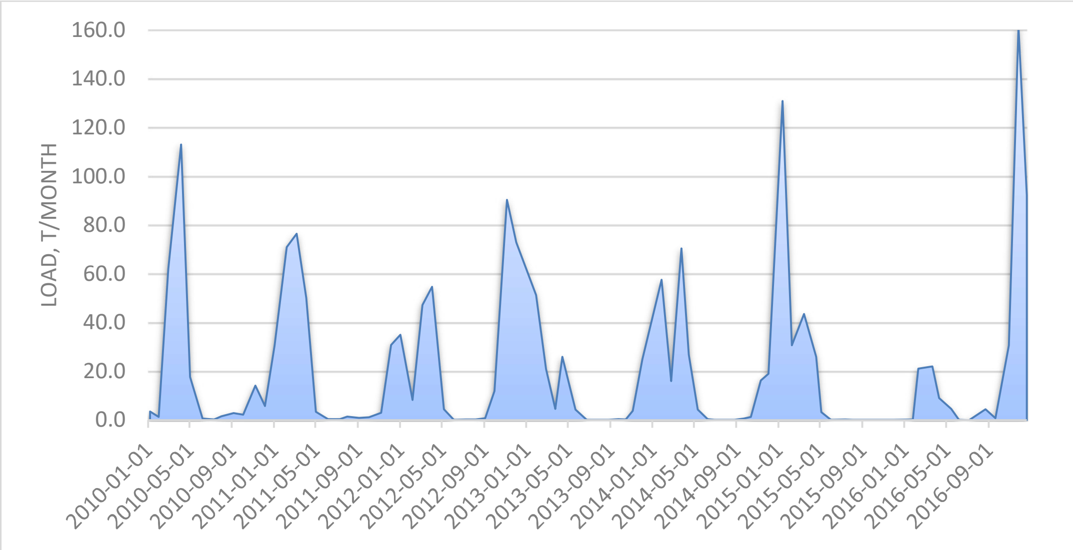

Figure 2. Total nitrogen load transported by the Platonis river in the period of 2010-2016 (source: environmental monitoring data, EPA (Lithuania))

Table 4. Summarised information about nitrate leaching from agricultural fields with different cropping system.

Average value of N total, kg/ha	Note	Source
17.9-19.2	Nitrogen leached from: row crops – 19.2 kg/ha, winter cereals – 17.3 kg/ha, summer cereals 17.1 kg/ha, pastures – 9.3 kg/ha. Average in arable land 17.9 kg/ha. (Lithuania)	*Gaigalis and Kutra, 2007*
18.9-22.4	N leached from fields under row crops **-** 22.4 kg/ha/year. N leaching from fields under spring and winter cereals - 18.9 and 16.5 kg/ha/year, and the lowest level of leaching was from fields under pastures (10.5 kg/ha/year). (Lithuania)	*Kutra, at al. 2006*
25	N leached from very small tile drainage plots: Biržai region, Pakamponys drainage plot: cereal – 25 kg/ ha year, pasture 11.8 kg/ha. Kėdainiai region Juodkiškis drainage plot: cereal – 24.7 kg/ ha year, pasture 4,7 kg/ha. (Lithuania)	*Rudzianskaite and Miseviciene, 2005*
50	Nitrate leaching from Graisupis basin in 1998 (different crops). (Lithuania)	*Bučienė at al., 2003*
10.2 – 17.8	Mellupīte monitoring station: small catchment - 10.2 kg/ha, field drainage - 17.9 kg/ha. Bērze monitoring station: small catchment - 14.6 kg/ha, field drainage - 17.8 kg/ha. (Latvia, Musa-Lielupe basin)	Jansons at al., 2011
18-20	Annual average N leaching for period 1995-2013 from two basins with dominating cereal crops: Berze (max 39, min 8, average 20 kg/ha year) and Mellupite (max 29, min 10, average 18 kg/ha year) research sites. (Latvia)	Siksnane and Lagzdiņš, 2017; Lagzdinš at al. 2015.

Based on the collected and analysed information, nitrogen leaching from the cereal fields in Venta and Lielupe RBDs was estimated to be at around 20 kg/ha. Nitrogen losses from potato fields were assumed to be around 26 kg/ha, from pea – 18 kg/ha.

1.2.3. Assessment of nutrient leaching reduction effect

There is a big number of factors such as climatic and soil conditions, farming practices etc. having significant influence on the nutrient uptake by catch crops. Effectiveness of catch crops can vary greatly under different conditions thus it is often difficult to predict.

Experimental studies are the primary and most reliable source of information about the catch crop nutrient retention rates under the particular climatic, soil and farming conditions. To obtain experimental data, the catch crop demonstration fields in Venta and Lielupe RBDs were established by the project on both Lithuanian and Latvian sides. Lysimeters were installed in the demonstration sites to take water samples and investigate leaching of nitrogen under the different catch crop schemes. Field experiments lasted two years (experiment results are described in a separate report).

Received experimental data is valuable for the analysis of potential catch crop effects in Venta and Lielupe RBDs, however, the study period is too short to make any firm conclusions. For this reason, our analysis instead relies on the results of a broad range of scientific studies and publications analysing nutrient retention capacities of catch crops in Lithuania, Latvia and other European (and in particular Scandinavian) countries.

Results from Lithuanian and Latvian experimental studies

In Lithuania and Latvia environmental effects, and in particular catch crop effectiveness with respect to reduction of nutrient leaching, are poorly investigated because there have been too little comprehensive long-term experimental studies covering measurements of nitrogen compounds in a leachate /drainage water which could constitute a solid basis for the quantitative assessment of the effect. However, some valuable studies demonstrating catch crop effects were carried out.

In Lithuania, intensive research on catch crops is carried out in Lithuanian Research Centre for Agriculture and Forestry, Vokė branch and Joniškėlis experimental station.

Researchers (*Arlauskienė & Maikštėnienė, 2008*) have found that cultivation of post-harvest catch crops on heavy loamy Cambisol after cereal harvesting decreased nitrate (NO_3-N) concentration in soil filtration water by 31.7 – 62.1 %.

Based on the results of lysimetric experiments performed on a sandy loam in 2002-2008, *Tripolskaja and Šidlauskas* (2010) concluded that green manure crops, grown after cereal harvesting, reduced atmospheric precipitation infiltration by on average 19,4-21,7 % during the autumn season and by 7-8.3 % per year. The use of red clover and straw as green manure, compared with the soil not fertilized with organic fertilizers, increased nitrogen leaching by on average 8 kg/ha (11.5 %) per year. However, fodder radish during the autumn season effectively utilised mineral nitrogen and at the same time reduced infiltration of precipitation. Due to the effects of both factors, the annual nitrate leaching losses decreased on average by 16.9 kg/ha, or 24.2 % compared with those occurring in the soil not applied with organic fertilizers and by 48.9 % and 47 % compared with the treatments with straw +N30 or clover and straw incorporation.

Results of Lithuanian scientists are in line with findings of other studies carried out in Scandinavian countries and described below.

Results from studies in Denmark, Sweden, Finland and France

To reduce leaching of nitrogen compounds into surface and coastal waters catch crops are extensively used as one of the key environmental measures in Denmark. Denmark having mandatory requirements for growing catch crops has one of largest experiences with catch crops in Europe.

Assessment of catch crop environmental effects is provided in the catalogue of Environmental Measures in Denmark *(Knudsen, Iemming)*. Leaching reduction is calculated from Kalkule Mark (the N-LES3 model) for clay soil and sandy soil respectively based on a change from a crop rotation without catch crops to a crop rotation with 20 percent catch crops.

In Kalkule Mark catch crops only appear as a collective designation and so the nitrogen-reducing effect cannot be differentiated for different species. This means that the model (N-LES3) that lies behind Kalkule Mark reveals value that can be considered as an average for different species. Thus, it can be expected that well-established cruciferous catch crops, such as white mustard or fodder radish, may result in a slightly higher effect while the effect of a grass catch crop will typically be slightly lower than the listed effect. However, the higher effect of cruciferous catch crops is conditional on a successful establishment, which under certain conditions may be difficult to achieve in practice. In general grass catch crops that have been undersown in spring are more successful. In practice the average leaching-reducing effects of the two types of catch crops can therefore be expected to be rather similar. The calculations with Kalkule Mark result in a higher effect of catch crops than stated in calculations made by the Faculty of Agricultural Sciences. Here the effects are 5-10 kg nitrogen per hectare lower than calculated with Kalkule Mark.

In Kalkule Mark it was estimated that reduction of N leaching from the root zone in clay soils can be 28-35 kg N/ ha, and from sandy soils – 45-52 kg N/ha (*Table 7*). For calculations of losses to the recipients, 60% retention from leaching to the root zone is assumed.

Table 5. Estimated nitrogen leaching by using the N-LES3 model at 1.2 LU*/ha (Østergaard, 2012)

	< 15 percent clay	> 15 percent clay
	Leaching kg N/ha	Leaching kg N/ha
Spring barley, followed by bare soil	78	51
Spring barley with catch crop	33	23
Winter wheat after winter wheat	85	58

**LU – livestock unit (The reference unit used for the calculation of livestock units (=1 LU) is the grazing equivalent of one adult dairy cow producing 3 000 kg of milk annually, without additional concentrated foodstuffs).*

The estimated effect with respect to coastal waters on clay soil is 11-14 kg/ha, and for sandy soils – 14-21 kg/ha per year.

In the River Basin Management Plans of Denmark, the average effect of catch crops in reduced loss of nitrogen from the root zone is 26 kg N/ha per year. Accounting for N-retention on a sub-basin level, the effect on reduced loading to the aquatic environment per hectare varies between 11-16 kg N/ha per year. The calculated total annual effect from 140 000 ha of targeted catch crops in reduced loading to the aquatic environment is 1950 tonnes of nitrogen, averaging to 13.9 kg N/ha per year *(Practical experience and knowledge exchange in support of the WFD implementation. 2012).*

Experiment in Denmark, which included three cropping systems (two organic and one conventional) with or without use of animal manure and catch crops, demonstrates quite similar reduction of nitrogen leaching as described above. Catch crops reduced N leaching by 23 kg N/ha, irrespective of conventional and organic management system, with legume-based catch crops being as effective as non-legumes. N leaching was calculated from measurements of nitrate in soil water. To achieve low N leaching, catch crop biomass had to reach a threshold level *(DeNotaris et al., 2018)*.

Sapkota et. al. 2012 simulated the root growth and biomass yield of three common catch crops (chicory (Cichorium intybus L.), fodder radish (Raphanus sativus L.) and perennial ryegrass (Lolium perenne L.)) and their effect on soil mineral N in different soil layers by using the FASSET model. The simulated results of catch crops root growth and mineral N in the soil profile were validated against two years (i.e. 2006 and 2007) of observations taken in Foulum and Flakkebjerg, Denmark. On average, the system with fodder radish was estimated to decrease N leaching from 2 m depth by 79% compared with the system without catch crops. Chicory and ryegrass correspondingly contributed to reducing N leaching from 2 m soil depths by 71 and 67% when compared with the system without catch crop.

The influence on nitrate leaching of ryegrass (Lolium perenne L.) used as a catch crop in spring barley (Hordeum vulgare L.) was investigated by *Thomsen (2005)* during three successive years in a lysimeter experiment on a sandy loam soil. The four fertilization levels initiated 15 years earlier were continued with barley either left unfertilized, or receiving 11 g N m^2/year (1N) in mineral fertilizer or with 1N or 1½N (16.5 g N m^2/year) in pig slurry. The ryegrass catch crops considerably reduced nitrate leaching. Nitrate losses at all four fertilization levels were reduced by 48–58% when ryegrass incorporated in autumn had been included in the barley growing. When the catch crop was incorporated in spring, reductions in leaching losses were even greater (73–76%).

Research done in Sweden showed that in sandy loam soils, without a catch crop 39.2 kg/ha of N-NO_3 leached per year, and when ryegrass was grown as a catch crop – the amount that leached was 10.3 kg ha^{-1}. Comparable results were obtained by *L. Engström et al. (2011)*: when Italian ryegrass was undersown in spring as a catch crop, leaching of nitrogen decreased by 12 kg ha^{-1}. An undersown catch crop of peas, grown until November, reduced leaching by 15 kg N ha^{-1}.

Results from three field experiments on a sandy soil in south-west Sweden where undersown catch crops (perennial ryegrass) were used, demonstrated that undersown catch crops efficiently reduce nitrogen losses when mineral fertilizer or manure are applied at normal rates (90-110 kg N ha). Over five years, undersown and grown until spring catch crops reduced nitrogen leaching by 60% on average (corresponding to 20-50 kg N/ha and year) compared with soil which was stubble cultivated in August – September and ploughed in November (*Aronsson, 2000*).

In Uppsala, Sweden, the study was conducted to evaluate the effect of a perennial ryegrass (Lolium perenne L.) cover crop interseeded in barley (Hordeum vulgare L.) on NO_3–N leaching and availability of N to the main crop. The catch crop reduced concentrations of NO_3–N in the leachate considerably (<5 mg/l, compared with 10 to 18 mg/l without catch crop) at most sampling times from November 1992 to April 1994, and reduced the total amount of NO_3–N leached (22 compared with 8 kg/ha) (*Bergström, Jokela, 2000*).

According to a Finnish study, undersowing of ryegrass with barley reduced nitrate leaching by 27-68% depending on soil *(Revised Palette of Measures ... 2013).*

There are other studies which demonstrate that the use of catch crops reduce nitrogen leaching by 50% or more (*Martinez & Guiraud, 1990; Nygaard Slarensen, 1991; Gladwin & Beckwith, 1992; Thomsen et al., 1993; Lewan, 1994; Francis et al. 1995; Davies et al., 1996; Mlaller Hansen & Djurhuus, 1997; Shepherd, 1999; Thomsen & Christensen, 1999*).

Scientists observe that catch crop effectiveness is highly correlated with rooting depth *(Delgado et al., 2007; Thorup-Kristensen, 2001)*. Catch crop rooting depth varies with interactions of species, soil properties, climate, and planting date. Timely establishment of catch crops is critical for efficient reduction of nitrogen leaching. When catch crops were planted during summer (planting August 1 in Denmark following horticultural crops), *Thorup-Kristensen (2001)* found that broadleaf crops grew deeper roots faster than cereals or annual ryegrass. Thus, planting catch crops as soon as possible in late summer or early autumn is important for maximizing rapid root extension and N uptake *(Francis et al., 1998)*. In other words, the deeper-rooted crops have higher N use efficiencies, better nitrate scavenging abilities, and lower nitrate leaching potential. The deeper-rooted catch crops function like vertical filter strips to scavenge nitrates from soil and recover nitrates from underground water *(Delgado et al., 2007)*.

Studies in Denmark have shown that oil radish reduces nitrate leaching better than ryegrass due to deeper rooting depth and higher N uptake. Though under conditions with low residual N, and low nitrate concentrations in deeper layers, ryegrass will have nearly same effect as oil radish *(Pedersen et. al. 2005) (Table 6).*

Species of catch crop is one of the major factors affecting leaching of nitrogen. *Shipley et al. (1992)* report that in their 2-year experimental study which was conducted in Maryland's Coastal Plain (US) the average reduction in nitrate leaching was about 70% for grass or brassica covers and about 23% for legume covers. The greater effectiveness of the grass cover crops was attributed to a faster and deeper fall root growth along with greater cool-season growth and winter hardiness. These results show that grasses are superior to legumes in conserving nitrogen.

Table 6. Reduction of nitrogen leaching under different soil and precipitation conditions (Pedersen et. al. 2005).

Precipitation	Soil type	Catch crop	Soil depth	
			1.0 m	2.0 m
Low	Sand	Ryegrass	55 %	55 %
High	Sand	Oil radish	95 %	90 %
Low	Sand	Ryegrass	65 %	65 %
High	Sand	Oil radish	90 %	90 %
Low	Sandy clay loam	Ryegrass	60 %	40 %
High	Sandy clay loam	Oil radish	95 %	85 %
Low	Sandy clay loam	Ryegrass	65 %	55 %
High	Sandy clay loam	Oil radish	90 %	95 %

Simulation study by *Justes et. al. (2012)* carried out to investigate potential effects of catch crops in France demonstrates higher effect of non – leguminous catch crops as well. For non-leguminous catch crops, the reduction of the nitrate concentration in drained water was generally more than 50% (or 75% for a large number of sites with high precipitation) on the optimum emergence and destruction dates (dates differ depending on the soil and weather). Simulations show that mustard (Brassicaceae) and Italian ryegrass (Poaceae) are equally efficient in reducing the nitrate content of drained water for the same emergence dates. Mustard, however, due to its rapid growth and its greater rooting depth, is more effective when the growth period is short (short fallow period or late sowing in September), or in deep soil. Vetch (a legume) is only ca. half as effective in reducing leaching as mustard or ryegrass – although its water consumption is equally high. Vetch obtains its nitrogen through symbiotic fixation and this legume therefore absorbs less of the available mineral nitrogen in the soil. Despite their reduced efficiency, legume crops are nevertheless useful for reducing the nitrate leaching and concentration, and are therefore preferable to bare soil. *Thomsen and Christensen* (1999) have documented that Italian ryegrass was the best at reducing nitrogen leaching from the soil to deeper soil horizons, compared with other catch crops. Other researchers point out that post-harvest catch crops, especially those of Brassicaceae family are very effective for biological nitrogen accumulation *(Köphe, 1994; Van Dam and Leffelaar, 1998)*. Fabaceae plants are important suppliers of nitrogen in the organic farming system. Researchers recommend growing them in mixtures with Poaceae sp. plants in order to prevent the risk of nitrogen leaching *(Torstensson, 1998; Olesen et al., 2000)*.

Experiment in Sweden reveals that catch crop effects can be significantly determined by management practices. Three long-term field experiments on a sandy soil in south-west Sweden were carried out. The effects of different liquid manure application rates and times, catch crops, and spring ploughing were compared with systems using applications of fertilizer N only combined with traditional autumn tillage, where the straw was usually removed. Autumn application of manure, and spring application at double the normal rate, considerably increased leaching in treatments without a catch crop. An undersown catch crop decreased leaching by approximately 60% compared with conventional autumn tillage and using fertilizer or normal application rates of spring-applied manure. When compared with spring ploughing or using double the normal rate of manure, the reduction in leaching due to catch crops varied between 35 and 50%. *(Torstensson, 1998)*.

Some studies indicate that after discontinuation of catch crops there is a risk of increase in N leaching. In the study of *Sapkota et. al. (2012),* discontinuation of catch crops increased the amount of N leaching by 13–18% compared with systems without catch crops, because of mineralization of the accumulated N in organic matter from the catch crops in the subsequent years. Experimental study of *Lewan (1994)* also demonstrated increased N leaching after discontinuation of catch crops. In this study effects of Italian ryegrass were investigated in the 4-year experiment in Southern Sweden which was performed on four tile-drained sandy soil field plots sown with spring cereals. On two of the plots, Italian rye grass was undersown and ploughed down the following spring during three of the years. The other two plots were treated in a conventional way and served as controls. Soil nitrate levels were substantially reduced (by 80-90 %) in the catch-crop treatment, but increased during the fourth year when no catch crop was grown *(Lewan, 1994).*

Summary of nitrogen leaching reduction rates

Summarised information about catch crop effects with respect to reduction of nitrogen leaching is provided in *Table 7*.

Table 7. Summarised information about catch crop potentials to reduce nitrogen leaching

Reduction of nitrogen leaching		Notes, explanations	Source
kg/ha	%		
	32-62	Effect of post-harvest catch crops on heavy loamy *Cambisol* after cereal harvesting	*Arlauskienė, Maikštėnienė, 2008*
17	24	Effect of fodder radish compared with the losses occurring in the soil not applied with organic fertilizers	*Tripolskaja and Šidlauskas (2010)*
	49-47	Effect of fodder radish compared with the treatments with straw +N_{30} or clover and straw incorporation	
14	64	The study was carried out in Sweden to evaluate the effect of a perennial ryegrass (*Lolium perenne* L.) catch crop interseeded in barley (*Hordeum vulgare* L.) on NO_3–N leaching.	*Bergström, Jokela, 2000*
28-35		Estimated reduction in nitrogen leaching from the root zone for clay soils	*Knudsen and Iemming. Environmental measures in Denmark*
40-51		Estimated reduction in nitrogen leaching from the root zone for sandy soils	
11-14		Estimated effect on clay soils with respect to coastal waters	
14-24		Estimated effect on sandy soils with respect to coastal waters	
26		Reduction of nitrogen leaching from the root zone	*Practical experience and knowledge exchange in support of the WFD implementation, 2012*
11-16		Reduction of nitrogen loading to the aquatic environment accounting for N-retention on a sub-basin level	
23		Reduction of nitrogen leaching from the root zone estimated from experiments in Denmark in organic and conventional management systems	*De Notaris et al., 2018*
27-52	79	Estimated reduction of N leaching from 2 m depth in the system with fodder radish	*Sapkota et. al. 2012*
18-49	67	Estimated reduction of N leaching from 2 m depth in the system with ryegrass	
	48-58	Estimated reduction of leaching under different fertilisation schemes when ryegrass was included into growing of barley and incorporated in autumn	*Thomsen, 2005*
	73-76	Estimated reduction of leaching under different fertilisation schemes when ryegrass was included into growing of barley and incorporated in spring	
12-15		Estimated reduction of leaching when Italian ryegrass and peas were undersown as catch crops	*Engström et al. 2011*
20-50	30-80	Experiment in Sweden with undersown perennial ryegrass in sandy soil	*Aronsson, 2000*
	55-65	Ryegrass effect on the reduction of nitrogen leaching from the soil profile of 1 m depth	*Pedersen et. al. 2005*
	90-95	Oil radish effect on the reduction of nitrogen leaching from the soil profile of 1 m depth	

Reduction of nitrogen leaching		Notes, explanations	Source
kg/ha	%		
	40-65	Ryegrass effect on the reduction of nitrogen leaching from the soil profile of 2 m depth	
	80-95	Oil radish effect on the reduction of nitrogen leaching from the soil profile of 2 m depth	
		The study shows that a major factor affecting leaching is the species of catch crop:	
	70	average reduction in nitrogen leaching for grasses and brassica.	*Shipley et al. 1992*
	23	average reduction in nitrogen leaching for legumes.	
	50-75	The reduction of the nitrate concentration in drained water for non-leguminous catch crops	*Justes et. al. 2012*
	60	The effect of an undersown catch crop compared with conventional autumn tillage and using fertilizer or normal application rates of spring-applied manure.	*Torstensson, 1998*
	35-50	The effect of an undersown catch crop when compared with spring ploughing or using double the normal rate of manure.	
	80-90	The effect of Italian rye grass undersown in spring cereals on sandy soil	*Lewan, 1994*

Main findings from the literature analysis are the following:

- In a number of studies catch crops have proved to be an effective measure for reduction of nitrogen leaching. In most cases catch crops reduce nitrogen leaching by over 50%.
- Catch crop effectiveness with respect to reduction of nitrogen leaching is highly determined by the root depth. Timely establishment of catch crop is critical to ensure sufficient depth of roots. Thus, planting catch crops as soon as possible in late summer or early autumn is important for maximizing environmental effects.
- Different species of catch crops depending on their root depth have different potentials to scavenge nitrogen from soil. Broadleaf catch crops (radish, winter rape, phacelia) grow deeper roots faster than cereals (rye, oats) or annual ryegrass. Therefore, they have larger nitrogen leaching reduction capacities.
- Grasses and brassica usually have significantly higher nitrogen retention rate and leaching reduction potential than legumes.
- Reduction of leaching is larger when catch crops are incorporated in spring instead of autumn.

Taking into account prevailing crop rotations, soil and climatic conditions, as well as farming practices, **Latvian and Lithuanian agricultural experts assume that white and brown mustard together with oil and root radishes will be the most popular choices among farmers for catch cropping.** As seen from the literature analysis, crops of brassica family have large nutrient retention capacities. Assuming timely establishment of catch crops (which is proposed to be not later than August 15) and spring incorporation of residues, **experts predict that catch crops may reduce annual nitrogen leaching by at least 60%.**

1.3. Results/conclusions

Potential reduction of nitrogen loads in basins, sub-basins and sub-catchments of Venta and Lielupe RBDs was calculated based on the crop structure, catch crop growing potentials, and expected nutrient leaching reduction rates.

Calculated potential reduction of nitrogen loads is presented in *Figure 3*. *Table 8* provides assessment results summarized by river basins/ sub-basins. In the table, the following information is provided:

- entire reduction of the nitrogen load for the whole river basin/sub-basin;
- load reduction in sub-catchments of water bodies at risk, and
- pollution reduction objectives set for sub-basins of water bodies at risk and representing reduction which is needed to achieve environmental objectives of the Water Framework Directive (WFD).

Results of the carried-out assessment indicate that application of catch crops, if full catch crop growing potential is utilized, may reduce nitrogen load by

- approx. **1800 t/year in the Lielupe RBD** (around 1200 t/year on the Lithuanian side and around 600 t/year on the Latvian side);
- approx. **1100 t/year in the Venta RBD** (around 550 t/year on the Lithuanian side and around 630 t/year on the Latvian side).

Table 8. ***Expected reduction of nitrogen loads in basins and sub-basins of Venta and Lielupe RBDs and pollution reduction objectives***

	River basin/sub-basin	Potential reduction of nitrogen load in the whole basin/sub-basin, t/year	Potential reduction of nitrogen load in sub-catchments of water bodies at risk, t/year	Pollution reduction objectives set for sub-catchments of water bodies at risk, t/year
1.	**Lielupe RBD:**	**1750**	**1230**	**5400**
	Mūša sub-basin (LT)	680	530	3000
	Nemunėlis sub-basin (LT)	140	-	-
	Lielupė small tributaries sub-basin (LT)	300	300	1800
	Latvian part of the Lielupe basin (LV)	630	400	600
2.	**Venta RBD:**	**1130**	**190**	**520**
	Bartuva basin (LT)	50	-	-
	Venta basin (LT)	420	100	400
	Šventoji basin (LT)	30	-	-
	Latvian part of the Venta basin (LV)	630	90	120

The level to which environmental objectives can be achieved by introducing catch crops in the sub-catchments of water bodies at risk is presented in *Figure 4*. As seen from the figure, in some sub-catchments (mainly on the Latvian part of Venta and Lielupe RBDs) introduction of catch crops may facilitate full achievement of environmental objectives, however in most of water bodies at risk (especially in Lithuania) current catch crop growing potential is not sufficient to achieve objectives of the WFD.

The largest reduction of nitrogen load in order to achieve good status of water bodies at risk is needed in the sub-basins of the Lielupe small tributaries and the Mūša river, on the Lithuanian side. These sub-basins are characterized by intensive agricultural activities and high nitrogen concentrations in rivers, and thus require substantial cut of the nitrogen loading. Calculation results show that only about 20% of the required pollution reduction can be achieved by introducing catch crops in the mentioned sub-basins. On the Lithuanian part of the Venta RBD catch crops may facilitate achievement of the environmental objectives by approx. 30%. For the Latvian part of both RBDs considerably lower pollution reduction objectives are set. Thus, here on average 70-80% of the set objectives can be achieved by introducing catch crops.

It is very important to note, that provided results are based on a number of assumptions and thus should be treated with care and as rather indicative. Calculation results represent the maximum effect that could be achieved if full catch crop growing potential was utilized. Actual effect of catch crops will largely depend on the farmers' motivation and willingness to include catch crops into their crop rotations and the level to which catch crop growing potential will be utilized. Moreover, catch crop potentials to retain nutrients vary in a very wide scale depending on species, climatic conditions and farming practices. Depending on the climatic conditions, catch crop biomass and, respectively the effect, may drastically differ in different years. Farmers' choices of catch crop species will also be very important.

Provided numbers represent only direct effect of catch crops, i.e. prevention of nitrogen leaching by uptake in the biomass. Additionally, in a long-term perspective, indirect catch crop effect, such as reduction of nitrogen leaching due to increase in soil organic matter, can be expected.

The actual catch crop effect will depend on a number of factors and is difficult to predict, however some general conclusions from the carried-out assessment can be made. It can be concluded that catch crops may significantly contribute to the reduction of the agricultural pollution and achievement of the environmental goals in Venta and Lielupe RBDs but, standing alone, will not be sufficient to reduce pollution to the required level. For the full achievement of environmental objectives, application of catch crops has to be combined with other environmental measures.

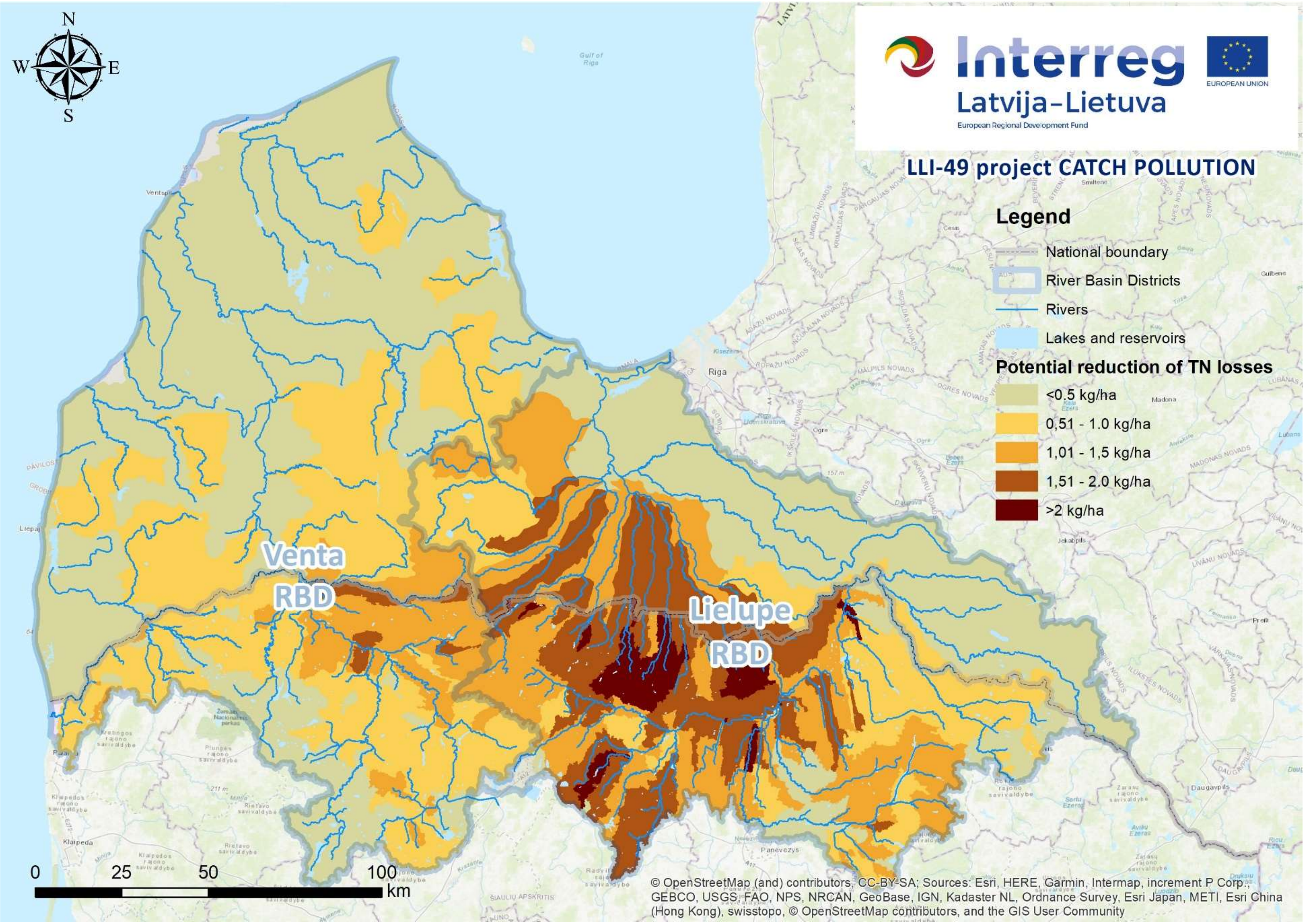

Figure 3. Expected reduction of nitrogen loads (kg/ha) in sub-catchments of surface water bodies if full catch crop potential is utilized

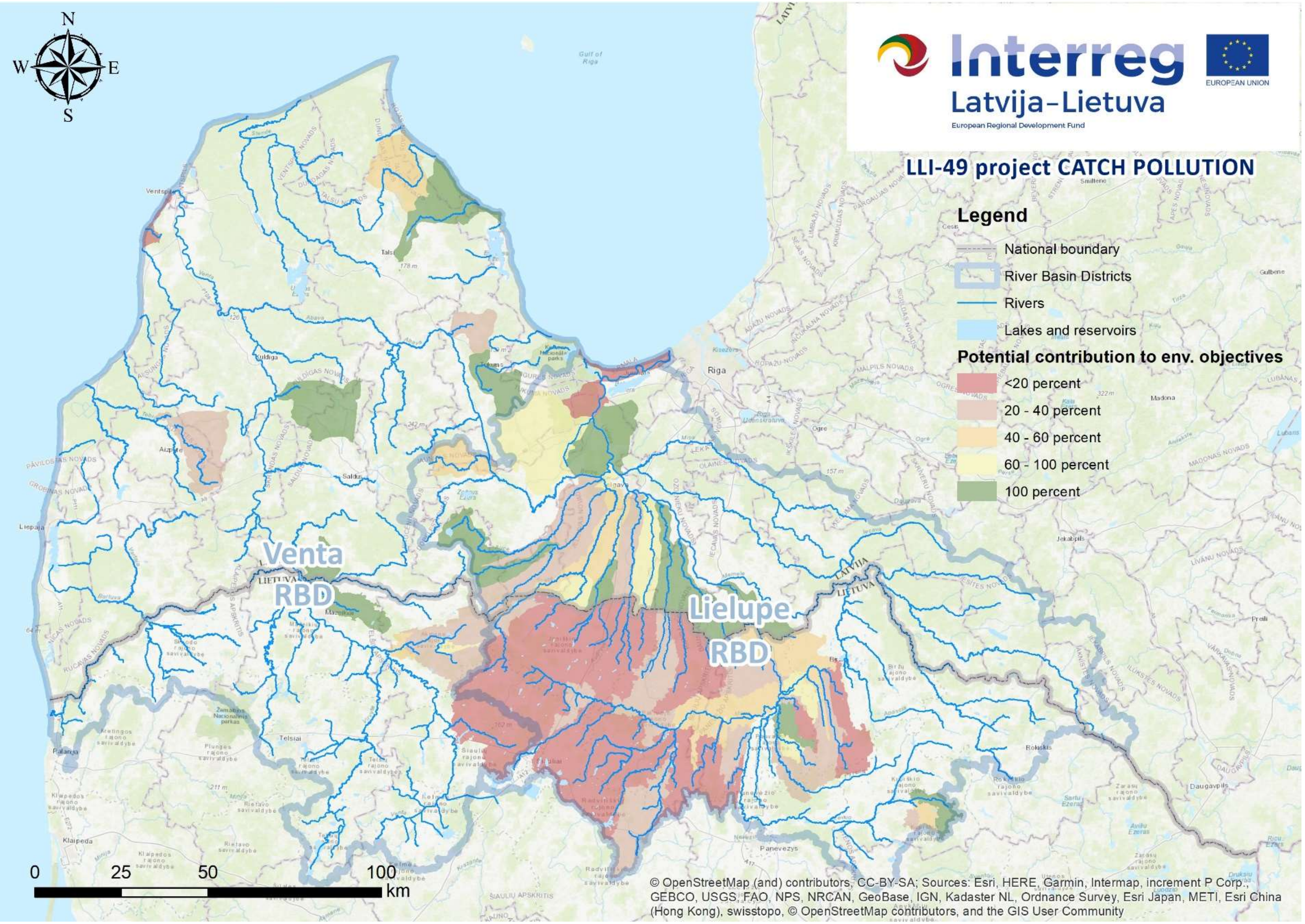

Figure 4. Expected achievement of environmental objectives in sub-basins of water bodies at risk if full catch crop potential is utilized (as ratio between expected and required reduction of nitrogen load).

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2. Transferring of nutrients for succeeding crops

prepared by AAPC

2.1. Description of the effect

Included in a crop rotations catch crops scavenge nitrogen from the soil and thereby reduce nitrogen losses by leaching or volatilisation. As the catch crop residue decomposes, the organic nitrogen in its tissue is converted to ammonium (NH_4) and then to nitrate (NO_3), which are the dominant forms of nitrogen plants use in an agricultural system (*Gaskin et al., 2016*). This mineralized nitrogen may be utilized by the succeeding crops, and thereby reduce the demand for fertilizer nitrogen input (*Thorup-Kristenssen, 1994*).

To make it possible for farmers to reduce fertilization as a consequence of catch crops, the nitrogen effect of catch crops must be high and predictable (*Bowden et al., 1988*). It has to be considered that only a portion of the nitrogen contained in the catch crop residues will be released as NH_4 and NO_3 during the life cycle of the following cash crop (see *Figure 5*). The nitrogen released can be lost to the following cash crop through the same processes that affect nitrogen fertilizer: ammonia volatilization, denitrification, leaching, or immobilization (*Gaskin et al. 2016)*. Quantification of nitrogen supplied to the following main crop from the decomposition of the catch crop residues is thus one of the challenges faced by farmers who use catch crops in their rotations.

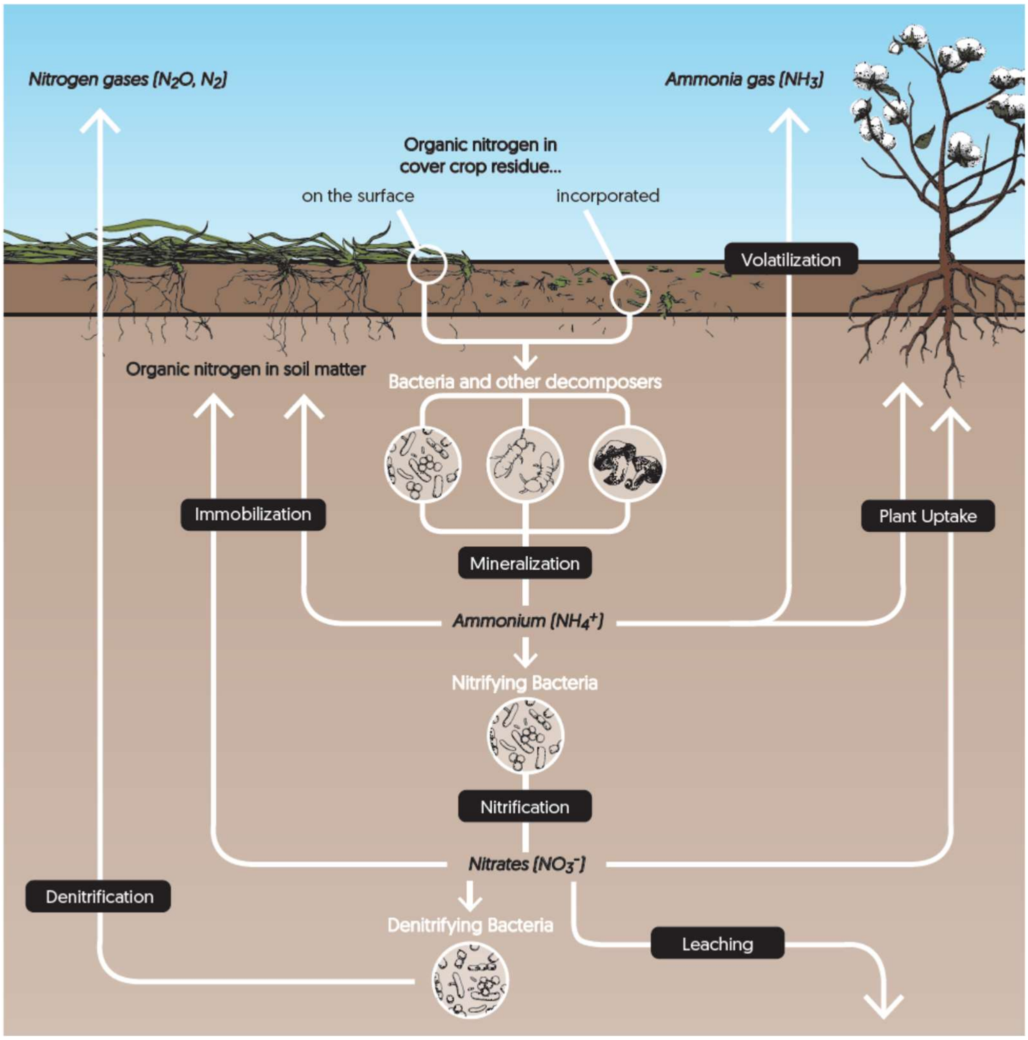

Figure 5. A schematic of nitrogen mineralization from catch crop residue showing the plant does not take up all of the mineralized organic nitrogen (Gaskin et al. 2016).

Many studies have examined inorganic nitrogen differences between soils with and without plant residues. These studies indicated that changes in inorganic nitrogen were always linked to the chemical characteristics of the plant residue, especially the C:N ratio (*Chen et al., 2014*). This can be explained by the activity of soil microorganisms.

Soil microorganisms have a C:N ratio near 8:1. They must acquire enough carbon and nitrogen from the environment in which they live to maintain that ratio of carbon and nitrogen in their bodies. Because soil microorganisms burn carbon as a source of energy, not all of the carbon a soil microorganism eats remains in its body; a certain amount is lost as carbon dioxide during respiration. To acquire the carbon and nitrogen a soil microorganism needs to stay alive (body maintenance + energy) it needs a diet with a C:N ratio near 24:1, with 16 parts of carbon used for energy and eight parts for maintenance. It is this C:N ratio (24:1) that rules the soil (*USDA NRCS, 2011*). Materials added to the soil with a C:N ratio greater than 24:1 will result in a temporary nitrogen deficit (immobilization), because the microbes will have to find additional nitrogen to go with the excess carbon to consume the crop residue. This additional nitrogen will have to come from any excess nitrogen available in the soil. Adding materials with a C:N ratio less than 24:1 will result in a temporary nitrogen surplus (mineralization). Since crop residue contains a lesser portion of carbon to nitrogen than the 24:1, perfectly balanced diet soil microorganisms need, the microbes will consume it and leave the excess nitrogen in the soil. This surplus nitrogen in the soil will be available for growing plants, or for soil microorganisms to use to decompose other residues that might have a C:N ratio greater than 24:1 (*USDA NRCS, 2011*).

Scientists define three process types regarding the effects of returning plant residues to soils: mineralisation process, immobilisation–mineralisation process and immobilisation process *(Chen et al. 2014)*. For mineralisation process, no net immobilisation occurs. In contrast, net immobilisation occurs in the early stages followed by net mineralisation for immobilisation–mineralisation process. Thus, immobilisation–mineralisation process is characterised by net mineralisation at the end of the experiment. For immobilisation process, no net mineralisation occurs throughout the experiment.

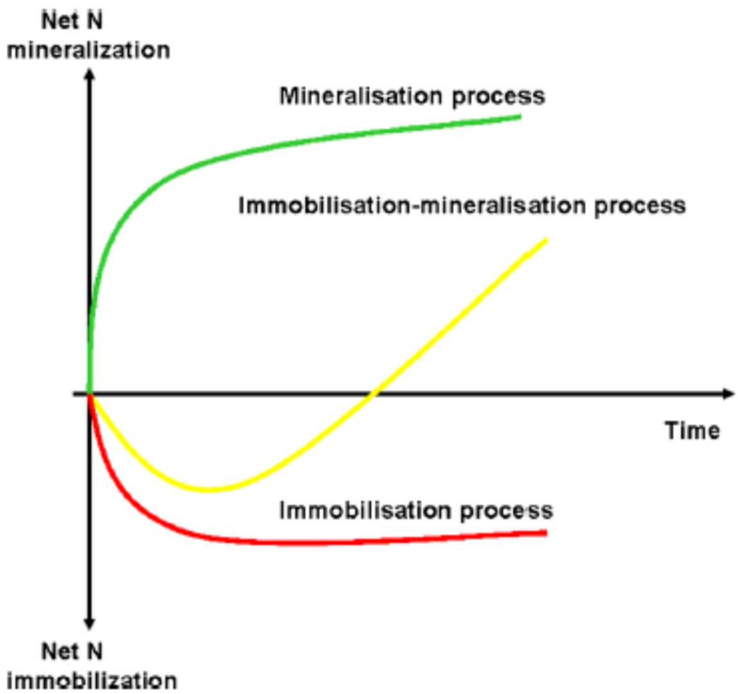

Figure 6. Sketch of three different process types regarding the effects of returning plant residues on soil inorganic nitrogen over the limited experimental period. Net N mineralisation indicates that surplus inorganic nitrogen occurs in after plant residues are returned to the soil relative to the blank soil. Net N immobilisation indicates that the inorganic nitrogen concentration after returning plant residues to the soil is less than in the blank soil **(Chen et al. 2014).**

Several studies *(De Neve and Hofman, 1996; Chaves et al. 2004; Vigil and Kissel, 1991; Trinsoutrot et al. 2000)* have determined empirical critical C:N ratio values for net immobilisation and mineralisation that are helpful for distinguishing the immobilisation process from the mineralisation process and immobilisation process. Studies demonstrated that typically, compared to soils without plant residues, only plant residues with C:N ratios <24 increased the mineral N concentration. The critical C:N ratio ranges from 24 to 44, which suggests that the C:N ratio of plant residues that cause immobilisation process should be greater than 44.

Quite a wide research focussing on defining the relationship between catch crop residue C:N ratio and expected release of plant available nitrogen (PAN) (i.e. NH_4+NO_3) is done in the United States. As an example, the results from a few studies, *R Flynn (New Mexico State University, 2008) and Sullivan and Andrews (2012)*, are presented in *Figure 7 a and b*.

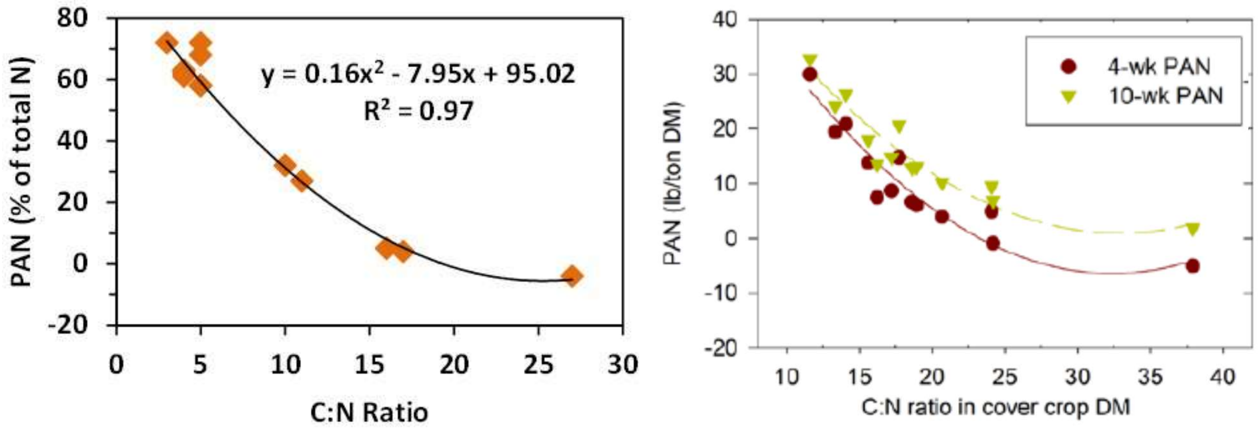

Figure 7. a) relationship between C:N ratio and PAN after 4 weeks (at 22^{0}C) (based on data from R. Flynn, 2008, New Mexico State University); b) PAN from catch crop residues (oat + vetch, rye + vetch, and oat + clover) as related to C:N ratio.

Figure 8 provides an overview of C:N ranges of different catch crop residues and associated nitrogen fate processes in the soil.

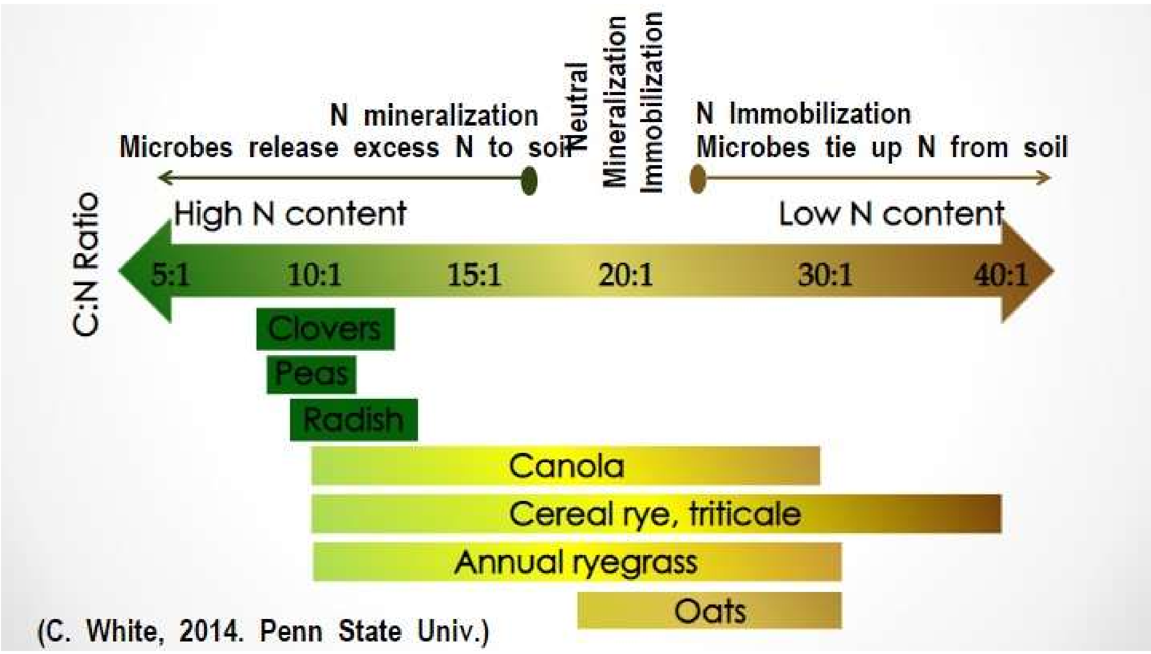

Figure 8. C:N ratios of catch crop residues and the consequent nitrogen processes in soil (from the presentation of Chen, G, University of Maryland).

Though C:N ratio is often used as the main predictor of catch crop PAN release, scientists notice that N content (%) in a catch crop residue also has a good correlation with produced mineral nitrogen and thus can be used as a reliable PAN predictor. Since most catch crops contain 40 percent C in dry mass, the C:N ratio is usually just an indirect way to express crop N percentage *(Sullivan and Andrews, 2012)*. Based on the above assumption, scientists argue that %N can be a more useful index of PAN because it yields a linear relationship with PAN, instead of the curvilinear relationship found using C:N ratio.

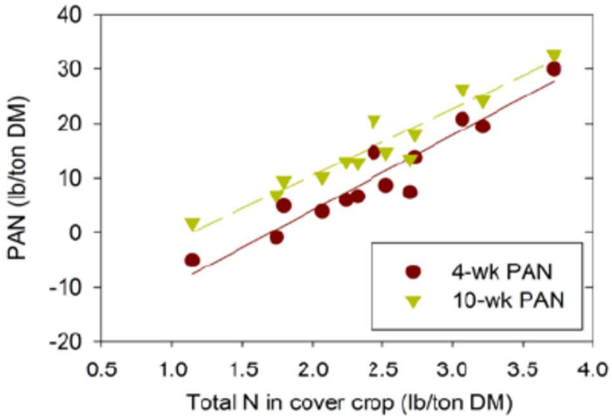

Figure 9. PAN from catch crop residues (oat + vetch, rye + vetch, and oat + clover) as related to N percentage in catch crop dry mass.

Along with the composition and quality of the residue, climatic factors such as temperature and moisture have a huge influence on the mineralisation process. The soil organisms responsible for decomposition work best at warm temperatures and are less energetic during cool spring months. Research shows that soil microbial activity peaks when 60 percent of the soil pores are filled with water, and declines significantly when moisture levels are higher or lower. This 60 percent water-filled pore space roughly corresponds to field capacity, or the amount of water left in the soil when it is allowed to drain for 24 hours after a good soaking rain. Microbes are sensitive to soil chemistry as well. Most soil bacteria need a pH of between 6 and 8 to perform at peak; fungi (the slow decomposers) are still active at very low pH. Soil microorganisms also need most of the same nutrients that plants require, so low-fertility soils support smaller populations of primary decomposers, compared with high-fertility soils. N-release rates or fertilizer replacement values for a given catch crop will not be identical in fields of different fertility *(SARE, 2012)*.

Tillage also affects decomposition of plant residues in a number of ways. First, any tillage increases soil contact with residues and increases the microbes' access to them. Second, tillage breaks the residue into smaller pieces, providing more edges for microbes to munch. Third, tillage will temporarily decrease the density of the soil, generally allowing it to drain and therefore warm up more quickly. All told, residues incorporated into the soil tend to decompose and release nutrients much faster than those left on the surface, as in a no-till system.

Research demonstrates that the nitrogen mineralization can be expected to be high in the first year, but what is not mineralized this year will mineralize very slowly over the succeeding years (*Jensen, 1991; 1992; Ladd et al., 1983*).

2.2. Methodology for the assessment of an effect

Methods for the assessment of nitrogen mineralisation and release of PAN from the catch crop residue vary from the simple steady – state approaches to complex dynamic models of nitrogen fate in the soil. Simple and comprehensive methods are convenient to use and provide quick answers. For their simplicity popular are approaches based on the pre-defined relations between catch crop residue C:N ratio or N contents and predicted PAN release. Additionally, there are indexes (e.g. plant residue quality index, plant residue quality index modified, organic matter quality index) which were gradually developed by researchers based on their correlations with soil inorganic nitrogen concentrations. Indexes that integrate plant residue properties and the soil factors can be used to predict soil inorganic nitrogen changes due to plant residues *(Chen et al. 2014)*. Nevertheless, those methods, though simple and easy to use, have one major disadvantage. They predict net nitrogen mineralisation but cannot predict changes in nitrogen mineralisation with time. Prediction models based on the first-order kinetic model can solve this problem *(Chen et al. 2014)*.

The N mineralisation of plant residues as a function of time can often be described as a first-order kinetic reaction:

$$A=A_0\,(1-e^{-kt}),$$

where
A_0 is the amount of mineralizable N,
k is the mineralization rate constant.

Existing research is too limited for obtaining a universal curve, thus a number of variations of the first order kinetic model exist to describe mineralization of catch crop residue *(Chen et al. 2014)*.

For the assessment of catch crop potentials to supply nitrogen for the following main crop in Venta and Lielupe RBDs, two methods were selected and applied in our study. The first is based on the defined relations between N content in the catch crop residue and potential release of PAN. This method allows predicting PAN release in 4 and 10 weeks after termination of catch crops. In the second method, N mineralization kinetics is described by a simple dynamic model. The method allows predicting PAN release in time based on the C:N ratio of the residue.

Method 1

The method was developed in the United States, for the regions of Oregon and Washington. Scientists have developed a simple and easy to use method for the assessment of PAN release from catch crops based on their observation that a laboratory analysis for catch crop total N as a percentage in dry matter (DM) is a good predictor of a catch crop's capacity to release PAN for the summer crop. To estimate PAN release from the particular catch crop, farmer only needs to know N contents in dry cover crop mass and refer to the table with defined relationship between catch crop N concentration and expected PAN release (see *Table 9*). For the intermediate values, linear interpolation has to be applied because %N has a linear relationship with PAN.

Table 9. Predicted PAN release from catch crops (Sullivan & Andrews, 2012)

Your catch crop total N			Predicted PAN release[2], lb PAN/ton dry mass		Predicted PAN release, kg PAN/ton dry mass	
% N in dry mass	lb N/ton in dry mass[1]	kg N/ ton dry mass	4 weeks	10 weeks	4 weeks	10 weeks
1	20	9	<0	0	0	0
1.5	30	14	3	9	1,4	4,1
2	40	18	7	14	3,2	6,4
2.5	50	23	12	20	5,45	9,1
3	60	27	19	28	8,6	12,7
3.5[3]	70	32	28	37	12,7	16,8

[1] *"typical value" for the catch crop. 1% N in DM = 20 lb N/dry ton.*

[2] *PAN predictions: 4- and 10-week predictions are estimated by incubation of catch crop residue in moist soil at 72°F (22 ^{0}C)*

[3] *Few catch crop samples in Oregon studies contained more than 3.5 percent N when sampled in mid-April, so 4- and 10-week PAN predictions are not available from our data.*

Considering application of this method for Lithuania and Latvia, it is important to note that it was developed for different climatic conditions. The method predicts PAN release at soil temperature of 22^{0}C while in

Lithuania and Latvia mineralization of catch crop residues usually takes place under much lower temperatures. Scientists declare that catch crop residue decomposition at soil temperature of 50°F (10^0C) proceeds two to three times slower than it does at temperature of 70°F (21^0C). Thus, it can be assumed that the PAN release in Lithuania and Latvia can be expected to be 2-3 times slower than specified in *Table 9*. Potential PAN release rates for Lithuanian and Latvian climatic conditions as estimated by the project experts are presented in *Table 10*.

Table 10. PAN release values adjusted for Lithuanian and Latvian conditions

Your catch crop total N		Predicted PAN release, kg PAN/ton dry mass	
% N in dry mass	kg N/ ton dry mass	4 weeks	10 weeks
1	9	0	0
1.5	14	0,7	2,0
2	18	1,6	3,2
2.5	23	2,7	4,5
3	27	4,3	6,4
3.5	32	6,4	8,4

Method 2

Simple dynamic nitrogen mineralization model was developed by the French scientists *(Nicolardot et al. 2001)* based on the laboratory experiments of decomposition of crop residues under non-limiting nitrogen conditions. The model was parameterised using apparent N mineralisation kinetics obtained for 27 different residues (organs of oilseed rape plants) that exhibited very wide variations in chemical composition and nitrogen content. The nitrogen mineralization model was later validated by taking into account 21 residues which had not been used for the parameterisation. Validation of the model has demonstrated that kinetics of N immobilisation or mineralisation due to decomposition of residues in soil were well predicted.

Seven parameters are used to describe N fluxes in the model. The model requires input data about the C:N ratio of the crop residue. Three model parameters are calculated using hyperbolic relationships established between these parameters and the residues C:N ratio. Three other model parameters are fixed. The model thus is parameterised against the residue C:N ratio as a unique criterion.

Mineralization of nitrogen in the model is estimated by the formula:

$$N_{MIN} = N_{RO}(\alpha_N - \beta_N e^{-kt} - \gamma_N e^{-\lambda}\ )$$

where

N_{RO} - nitrogen added by the plant residues (kg/ha);

K - decomposition rate constant of residue (nday-1) (*nday= 'normalized day' = day at 15^0C and optimum water content*);

λ - decomposition rate constant of microbial biomass (nday^{-1});

$\alpha_N, \beta_N, \gamma_N$ - coefficients linked to the seven parameters of the model:

$$\alpha_N = 1 - \frac{w_H}{w_R} Yh$$

$$\beta_N = 1 - \frac{kw_B - \lambda h w_H}{w_R(k - \lambda)} Y$$

$$\gamma_N = \frac{k(w_B - hw_{H)}}{w_R(k - \lambda)} Y$$

where

k - decomposition rate constant of residue (nday-1) (nday= 'normalized day' = day at 15^{0}C and optimum water content);

λ- decomposition rate constant of microbial biomass (nday^{-1});

Y - assimilation yield of residue-C by microbial biomass (g*g^{-1});

h - humification rate of microbial biomass (g*g^{-1});

w_B - N:C ratio of the newly-formed microbial biomass (g*g^{-1});

w_R - N:C ratio of the plant residue (g*g^{-1});

w_H - N:C ratio of the newly-formed humified organic matter (g*g^{-1});

$$k = 0.07 + \frac{1.94}{R}$$

$$h = 1 - \frac{0.69\,R}{11.2 + R}$$

$$w_R = \frac{1}{R}$$

$$w_B = \frac{1}{R_b}$$

$$w_H = \frac{1}{R_h}$$

where

R - residue C:N ratio;

R_b - C:N ratio of zymogenous microbial biomass (g*g^{-1})

R_h - C:N ratio of newly-formed humified organic matter (g*g^{-1});

$$R_b = 16.1 - \frac{123}{R}$$

Rb = 7.8 when *R* < 14.8

Input data

Input data required for the selected assessment methods are:

- N content in the catch crop residue (%) (Method 1);
- Catch crop dry biomass (t/ha) (Method 1);
- C:N ratio of the catch crop residue (Method 2);
- Amount of N added to the soil with the catch crop residue (t/ha) (Method 2).

Required data were obtained by summarizing available information from the local experimental studies (including the project demonstration sites) and literature references. They are provided in *Table 11*.

Table 11. Catch crop data used for the assessment of potential release of PAN

Cath crop	C:N ratio of the residue	Typical production of biomass, t/ha	N content in the biomass, %	Amount of N added to soil with the plant residues under typical production of biomass, kg/ha
White mustard	12	2.3	3.8	87.4
Brown mustard	12	2.3	3.8	87.4
Spring rape	13	1.6	3.6	55.8
Winter rape	13	1.6	3.6	55.8
Oil (forage) radish	12	3.0	3.7	109.2
Root (tillage) radish	13	2.1	3.4	69.7
Winter turnip rape	13	1.7	3.4	56.1
Winter rye	15	1.3	3.0	37.5
White clover	14	2.1	3.2	65.6
Red clover	14	2.1	3.2	65.6
White melilot	14	2.0	3.2	62.4
Italian ryegrass	18	1.4	2.5	35.0
Perennial ryegrass	18	1.4	2.5	35.0
Phacelia	14	2.1	3.2	65.6
Cock's foot	17	1.9	2.6	48.1
Oat and black oat	17	1.9	2.6	48.1
Buckwheat	19	1.9	2.4	44.4
Winter vetch	10	1.7	4.5	74.3
Pea	11	1.9	4.0	74.0
Blue bitter lupin	11	2.1	4.0	82.0
Bean	10	2.0	4.5	87.8

For the calculation of the total amount of mineral nitrogen that could potentially be credited to the subsequent main crop, potential areas of catch crops have been predicted by the project experts considering estimated catch crop growing potentials, crop structure and expected preferences of farmers *(Table 12)*.

Table 12. ***Expected catch crop areas in basins and sub-basins of Venta and Lielupe RBDs as predicted by the project experts***

Catch crops	Potential catch crop area, ha							
	Lielupe RBD				Venta RBD			
	Mūša sub-basin (LT)	Lielupė small trib. sub-basin (LT)	Nemunėlis sub-basin (LT)	Lielupe basin (LV)	Venta basin (LT)	Bartuva basin (LT)	Šventoji basin (LT)	Venta basin (LV)
White and brown mustard	32167	13963	7241	24503	20487	2715	1612	28158
Spring and winter rape	643	240	188	241	454	59	34	142
Fodder and root radish	14022	6852	2540	13472	8222	637	377	11578
Italian and perennial ryegrass	1635	842	249	1887	921	61	35	1626
Winter rye	376	143	110	642	263	33	20	482
Oats	1286	480	377	1717	908	118	69	1250
Buckwheat	255	96	75	118	179	23	14	73
Red, white, Persian or Egyptian clovers	4405	2113	817	4915	2631	269	142	4880
Peas	12	1	3	118	11	3	1	85
Vetch	2643	1350	401	4219	1505	106	58	3508
Phacelia	642	336	95	810	359	23	13	698

2.3. Results/conclusions

Potential PAN release from the catch crop residue as estimated by the project experts by Method 1 is provided in *Table 13*. *Table 14* provides results of Method 2 calculations.

Table 13. Potential release of PAN in 4 and 10 weeks as calculated by the project experts by Method 1

Cath crop	Potential PAN release in 4 weeks, kg/ha	Potential PAN release in 10 weeks, kg/ha
White mustard	17	21
Brown mustard	17	21
Spring rape	10	13
Winter rape	10	13
Oil (forage) radish	19	25
Root (tillage) radish	11	16
Winter turnip rape	9	13
Winter rye	5	8
White clover	10	15
Red clover	10	15
White melilot	10	14
Italian ryegrass	4	6
Perennial ryegrass	4	6
Phacelia	10	15
Cock's foot	6	10
Oat and black oat	6	10
Buckwheat	6	8
Winter vetch	17	20
Pea	15	19
Blue bitter lupin	16	21
Bean	20	23

Table 14. Potential release of PAN as calculated by the project experts by Method 2

Cath crop	Potential PAN release (kg/ha) in							
	20 days	40 days	60 days	80 days	100 days	120 days	140 days	160 days
White mustard	10	17	22	26	30	32	35	36
Brown mustard	10	17	22	26	30	32	35	36
Spring rape	4	8	12	15	17	19	21	22
Winter rape	4	8	12	15	17	19	21	22
Oil (forage) radish	10	18	25	31	35	39	42	44
Root (tillage) radish	1	7	12	16	19	21	24	25
Winter turnip rape	1	5	9	13	15	17	19	20
Winter rye	-3	0	3	5	7	9	10	11
White clover	-2	3	8	12	15	18	20	22
Red clover	-2	3	8	12	15	18	20	22
White melilot	-2	3	7	11	14	17	19	21
Italian ryegrass	-4	-2	1	3	4	6	7	8
Perennial ryegrass	-4	-2	1	3	4	6	7	8
Phacelia	-2	3	8	12	15	18	20	22
Cock's foot	-5	-2	2	5	7	9	10	12

Cath crop	Potential PAN release (kg/ha) in							
	20 days	40 days	60 days	80 days	100 days	120 days	140 days	160 days
Oat and black oat	-5	-2	2	5	7	9	10	12
Buckwheat	-6	-3	0	3	5	7	8	9
Winter vetch	18	23	27	30	32	34	35	37
Pea	11	17	21	25	27	29	31	33
Blue bitter lupin	13	19	23	27	30	33	35	36
Bean	21	27	32	35	38	40	42	43

Method 1 results demonstrate expected amount of the plant available nitrogen released from the catch crop residue in 4 and 10 weeks after the beginning of the residue mineralisation process.

Method 2 results illustrate mineral nitrogen dynamics over the mineralisation period of 160 days which usually starts when the temperature exceeds +5^{0}C. Negative values in *Table 14* show immobilisation of nitrogen, while positive – release. As seen from the results of Method 2 calculations, decomposition of catch crop residues in some cases can be associated with temporary immobilisation of the soil nitrogen. Catch crops with low C:N ratios (e.g. legumes and brassicas) mineralize fast and not immobilise soil nitrogen. Meanwhile residues with higher C:N (such as grasses and cereals) may immobilise soil nitrogen for short periods of 20-40 days but release mineral nitrogen afterwards.

If to compare results of two calculations it can be noticed that results of both calculations are consistent in general, however Method 1 indicates more rapid mineralisation of some catch crop residues. Based on the results of Method 2, for grasses and cereals a longer time period (over 100 days) might be needed to produce the amounts of N that are calculated by Method 1.

Both methods show that legumes have the largest potential for nitrogen crediting. Based on the results of Method 2, they can be expected to leave approx. 30-40 kg of mineral nitrogen for the next cash crop. The similar amount (i.e. about 40 kg/ha) can also be credited by mustards and oil radishes. While 2/3 of the legume nitrogen is fixed from the atmosphere, mustards and oil radishes retain nitrogen from soil providing a dual benefit: they prevent excessive nitrogen from leaching and transfer to the subsequent crop.

Grasses and cereals usually have lower potential for release of PAN than that of legumes or mustards, however they also positively contribute to mineral nitrogen pool and can also be considered as potential sources of nitrogen decreasing the demand for the use of mineral fertilisers.

Taking into account potential catch crop areas as predicted by the project experts, it was estimated that each year approx. **5.2 thousand tonnes of mineral nitrogen** can be credited for the subsequent crops **in the Lielupe RBD** and **3.3 thousand tonnes in the Venta RBD** if full catch crop growing potential is utilised (see *Table 15*).

Table 15. ***Expected nitrogen crediting in basins and sub-basins of Venta and Lielupe RBDs***

River basin/sub-basin	Transferring of nitrogen to the subsequent crop, t/year
Lielupe RBD:	***5 204***
Mūša sub-basin (LT)	2040
Nemunėlis sub-basin (LT)	422
Lielupė small tributaries sub-basin (LT)	931
Latvian part of the Lielupe basin (LV)	1811
Venta RBD:	***3 301***
Bartuva basin (LT)	141
Venta basin (LT)	1258
Šventoji basin (LT)	83
Latvian part of the Venta basin (LV)	1819

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3. Reduction of greenhouse gas (GHG) emissions

prepared by AAPC

3.1. Description of an effect

Abilities to scavenge nitrogen, protect soil from erosion and improve its health are usually named as the main benefits of catch crops. Climate change mitigation and adaptation may be additional, important ecosystem services provided by catch crops, but they lie outside of the traditional list of catch cropping benefits *(Kaya & Quemada, 2017)*. Increasing climate change awareness raises a need to better explore and exploit catch crop potentials to reduce emissions of GHG.

Soil C sequestration (storage) is the main mode of GHG mitigation, removing CO_2 from the atmosphere *(Eagle et al. 2012)*. GHG mitigation effect is also related to reduction of nitrous oxide (N_2O) and methane (CH_4) emissions or increasing their uptake in the system.

Soil carbon sequestration is a process in which CO_2 is removed from the atmosphere and stored in the soil carbon pool. Soil organic carbon (SOC) levels result from the interactions of several ecosystem processes, of which photosynthesis, respiration, and decomposition are key. Photosynthesis is the fixation of atmospheric CO_2 into plant biomass. Decomposition of plant biomass by soil microbes results in carbon loss as CO_2 from the soil due to microbial respiration, while a small proportion of the original carbon is retained in the soil through the formation of humus *(Ontl & Schulte, 2012)*. The amount of carbon retained in a soil depends on the productivity of the above-ground and below-ground biomass and also the efficiency of the soil micro-organisms in breaking down plant material. Brake down of plant residue (i.e. mineralisation process) is determined by the digestibility of the material, the microbial community present, soil moisture content and other environmental conditions.

N_2O fluxes from agricultural soils largely result from denitrification of nitrate. By scavenging nitrogen from the soil catch crops often reduce nitrate concentrations, so, there is reason to expect that they may reduce the flux of N_2O from soils to the atmosphere. On the other hand, high C inputs may stimulate denitrification since the process is driven by heterotrophic respiration *(Mitchell et al. 2013)*. Likewise, high N inputs immediately following legume cover crop termination may lead to high nitrification and subsequent denitrification rates that could elevate N_2O losses *(Kaya & Quemada, 2017)*.

Among the major biogenic CH_4 sources are the anaerobic decomposition of organic matter in wetland soils, flooded soils, and crop residues under very wet field conditions. Still, there are quite few studies investigating the cover crop field impact on CH_4 fluxes. Existing research (*Robertson et al., 2000; Guardia et al., 2016)* demonstrates that cover crops have no effect on CH_4 fluxes from soils.

It is widely assumed that cover crops i) have a low carbon sequestering affect and ii) they release N_2O during the residue decomposition phase following crop destruction, iii) ultimately producing a mixed result in terms of GHG balance. The analysis of the resent scientific literature largely contradicts these assumptions, indicating broadly positive effect of catch crops on GHG balance *(Justes, 2017)*.

3.2. Methodology of assessment of an effect

In our study, we estimate catch crop GHG mitigation effect as the sum effect related to changes in CO_2 and N_2O emissions. Referring to studies demonstrating minor catch crop effect with respect to CH_4 fluxes (*Robertson et al., 2000; Guardia et al., 2016)*, we exclude CH_4 emissions from the assessment.

3.2.1. Assessment of potential changes in CO_2 balance

Two distinct approaches were applied in our study for the assessment of potential changes in CO_2 balance resulting from the application of catch crops in Venta and Lielupe RBDs. The first method relies on the results and findings of various research studies and publications that provide carbon sequestration rates. The second method comprises simple mass balance calculations where potential change in CO_2 balance is estimated as a difference between plant accumulated CO_2-C and that released back to the atmosphere in the result of the plant residue mineralisation process.

Assessment based on the reported carbon sequestration rates

Soil carbon sequestration is the process, which removes carbon dioxide from the atmosphere and adds carbon to the soil (via plant photosynthesis and decomposition and transformation). Scientists agree that soil carbon sequestration is the main process determining climate change mitigation effect of cover crop and provide quite similar carbon sequestration rates resulting from the cover crop application.

Experiments in France reveal that cover crops contribute to the sequestration of carbon in the soil by on average 300 ± 150 kg C/ha/year (which corresponds to 1,1 ± 0,5 t CO_2/ha/yr[2]); this storage, however, tends to decrease after a few years *(Justes et al. 2012)*. Scientists observe that greenhouse gas balance of cover crops has a high degree of variability depending on the biomass produced.

Quite similar carbon sequestration rate associated with introducing of cover crops has been estimated in United States. On the basis of a total of 31 field observations, an average soil C sequestration rate of 1.3 t CO_2/ha/ year was yielded (*Eagle et. al. 2012*).

The meta-analysis of Poeplau and Don *(2015)* which was conducted with the aim to quantify the effect of cover crop green manuring on SOC stocks has shown the annual change in soil carbon of 0.32±0.08 Mg C ha/year (which equals to 1,2±0.3 t CO_2/ha/year) within the first ~50 years. This estimate was made by deriving a carbon response function describing SOC stock changes as a function of time. For the analysis, data from 139 plots at 37 different sites were compiled. Mean soil depth of the samples used in this analysis was 22 cm, so it likely provides a conservative estimate of soil C sequestration.

Results of the above-mentioned studies suggest that catch crops can potentially sequester approx. 1.2 t CO_2/ha/yr. We apply this rate in our calculations of the catch crop CO_2 mitigation effect in Venta and Lielupe RBD:

$$CO_{2\ basin/RBD} = 1.2 * CC_{area\ basin/RBD}$$

where:

$CO_{2\ basin/RBD}$ - net mitigation of the CO_2 balance in river basin/river basin district, t CO_2/year

1.2 - average CO_2 sequestration rate as reported by various research studies, t CO_2/ha/year

CC_{area} - catch crop area in river basin / river basin district (*see data in Table 16*)

[2] *Conversion factor 3,66 is used because each gram of C sequestered in soil equates to 3.66 fewer grams of CO_2 in the atmosphere*

Table 16. ***Potential catch crop areas in basins and sub-basins of Venta and Lielupe RBDs***

River basin/sub-basin	Potential area of catch crops, ha
Lielupe RBD:	***149240***
Mūša sub-basin (LT)	58087
Nemunėlis sub-basin (LT)	12095
Lielupė small tributaries sub-basin (LT)	26415
Latvian part of the Lielupe basin (LV)	52643
Venta RBD:	***94845***
Bartuva basin (LT)	4048
Venta basin (LT)	35942
Šventoji basin (LT)	2375
Latvian part of the Venta basin (LV)	52480

Calculation of the CO_2 mass balance

To validate the estimate based on the generalised research results a simple mass balance was calculated taking into consideration the expected structure and productivity of catch crops in Venta and Lielupe RBDs.

CO_2 mass balance was calculated as the difference between CO_2 accumulated by plants from the atmosphere and that released back in the result of the residue mineralisation process:

$$CO_2 = CO_{2\,uptake} - CO_{2\,release}$$

where

CO_2 - net CO_2 mitigation effect, t CO_2/year

$CO_{2\,uptake}$ - catch crop CO_2 uptake from the atmosphere, t CO_2/year

$CO_{2\,release}$ - CO_2 release into the atmosphere from the residue mineralisation, t CO_2/year

Plant carbon uptake from the atmosphere was estimated by accounting for the potential catch crop biomass production and carbon content in the biomass:

$$CO_{2\,uptake} = \sum_{i=1}^{n} (CC_{i\,biomass} * CC_{i\,area} * 0.45 * 3.66)$$

where

$CO_{2\,uptake}$ - CO_2 uptake by catch crops, t CO_2/year

$CC_{i\,biomass}$ - biomass produced by particular catch crop, t/ha

$CC_{i\,area}$ - area of particular catch crop, ha

0.45 - carbon content in catch crop biomass, as share of the total mass

3.66 - conversion factor from C to CO_2

Catch crop biomass was estimated as a sum of above-ground and below ground biomass. Potential above-ground biomass of each catch crop was estimated from the experimental studies carried out in Lithuania, Latvia and other Nordic European countries. For the assessment of belowground biomass, which is usually not measured in catch crop experiments, based on the results of the Danish study *(Hu et. al., 2018)*, the assumption was made that catch crop root biomass can be reliably estimated by taking fixed roots amounts. The study of Hu et. al. *(2018)* estimates that catch crop belowground biomass (dry) in conventional farms amounts to around 0.75 t/ha, however results from the project demonstration sites indicate a lower value – approx. 0.45 t/ha. The later value from the project experiments was used in our calculations. Predicted typical production of catch crop biomass is provided in Table 17.

Potential areas of different catch crops in Venta and Lielupe RBDs have been predicted by agronomy scientists considering current crop structure, catch crop compatibility with prevailing main crops, and potential preferences of farmers *(see Table 17)*.

Plant carbon content is assumed based on the references of Romavoskaja et al. *(2013)*, Chirinda et al. *(2012)*, Ma et al. *(2018), Noe (2018)* which report quite similar numbers for above-ground and below-ground biomass carbon contents equating to approx. 45 %.

Table 17. ***Estimated catch crop areas and biomass production in basins and sub-basins of Venta and Lielupe RBDs***

Catch crop	Expected biomass, t/ha	Predicted catch crop area, ha							
		Lielupe (LT)			Venta (LT)			Lielupe (LV)	Venta (LV)
		Mūša	Lielupė	Nemunėlis	Venta	Bartuva	Šventoji		
White and brown mustard	2,3	32167	13963	7241	20487	2715	1612	24503	28158
Spring and winter rape	1,6	643	240	188	454	59	34	241	142
Fodder and root radish	3	14022	6852	2540	8222	637	377	13472	11578
Italian and perennial ryegrass	1.4	1635	842	249	921	61	35	1887	1626
Winter rye	1.3	376	143	110	263	33	20	642	482
Oats	1.9	1286	480	377	908	118	69	1717	1250
Buckwheat	1.9	255	96	75	179	23	14	118	73
Clovers	2.1	4405	2113	817	2631	269	142	4915	4880
Peas	1,9	12	1	3	11	3	1	118	85
Vetch	1.7	2643	1350	401	1505	106	58	4219	3508
Phacelia	2,1	642	336	95	359	23	13	810	698
Total catch crop area		**58086**	**26415**	**12095**	**35942**	**4048**	**2375**	**52643**	**52480**

A number of experimental studies conducted to investigate carbon mineralisation demonstrate that usually up to 50-70% of the carbon applied with the plant residues is mineralised and released back into the atmosphere in the form of CO_2 within one year.

Justes et al. (*2009*) investigated C mineralization kinetics of 25 catch crop residues, which organic C:N ratio varied from 9.5 to 34. Authors report that 59% to 68% residue-C was mineralized after 168 days incubation. Decomposition rates were rather similar for the different CC residues.

Experiments of Nguyen *(2016)* showed that 50-70 % of crop residue-C (where C:N ratios of crops varied from 9 to 71) was mineralized in 63 days from application to the soil. Higher production of CO_2-C emission was found in lower C:N ratio and small lignin content residues. In all treatments after 1 week to the end of trial cumulative of CO_2-C emission from clay was always significantly higher than that in sand soil. The CO_2-C release from added residues was more rapid when placed on the surface rather than mixed with soil.

Hoorman & Islam *(2010)* state that one hundred grams (g) of dead plant material yields about 60–80 g of carbon dioxide.

Based on the above, we predict that mineralisation rate of the catch crop residue-C in Venta and Lielupe RBDs might be on the higher end of the reported range, because catch crops will mainly have low C:N rations and low content of lignin (<15%). Besides, both RBDs are dominated by heavier soils where, as shown in Nguyen

(2016), mineralisation of carbon is likely to be higher than in sand. Therefore, in our calculations we assume that CO_2-C emissions from the catch crop residue will make 65% of the total applied residue-C:

$$CO_{2\,release} = 0.65 * CO_{2\,uptake}$$

where

$CO_{2\,release}$ - CO₂ release from the plant residue mineralisation, t/year

0.65 - fraction of the plant accumulated CO_2 released back into the atmosphere in the residue mineralisation process

$CO_{2\,uptake}$ - catch crop CO_2 uptake from the atmosphere, t/year

Calculation of the CO_2 emissions resulting from additional field operations

Scientists draw attention to the fact that introduction of catch crops may necessitate additional field operations, and consequent increases in fuel-source GHG emissions *(Paustian et al. 2004)*. *Kaye & Quemada (2017)* in their review assume that cover crops may require two extra field passes, i.e., to plant and to kill the cover crop. To estimate CO_2 emissions resulting from extra field operations they take a typical value of 2.8 g CO_2 e/m^2 /year. This rate was applied in our study as well.

3.2.2. Assessment of potential changes in N_2O balance

The studies conducted to measure cover crop impact on N_2O emissions conclude that high C inputs from non-legume cover crops can stimulate N_2O production *(Justes 2017, Mitchel et al. 2013, Sanz Cobena et al. 2014, Guardia et al. 2016)* though total N_2O increase from cover crop fields is usually minor or negligible. When cover crops do alter N_2O emissions, the effect may be an increase or decrease of about 0.01 g N/m^2 /year *(Basche et al. 2014; Mitchell et al. 2013; Sanz-Cobena et al. 2014; Guardia et al. 2016)* relative to fallow.

A 0.01 g N/m^2 /year change in N_2O emissions is 0.016 g N_2O/m^2 /year. The 100-year warming potential of a gram of N_2O is 298 times greater than a gram of CO_2 thus 0.016 g N_2O equals to roughly 4.7 g CO_2 e/m^2 /year.

3.3. Results/conclusions

Catch crop impact on GHG balance is estimated by adding together their contributions to carbon sequestration, CO_2 and N_2O emissions.

Assessment of potential carbon sequestration rates

For the assessment of potential carbon sequestration rates two methodologies were applied. The first fully relied on the results of various research studies investigating kinetics of the carbon mineralisation process. The second method comprised simple mass balance calculations taking into account potential plant carbon uptake from the atmosphere and release of CO_2 in the result of the residue mineralisation process.

Results derived from the analysis of scientific publications

Potential change in CO_2 balance resulting from the catch crop application in Venta and Lielupe RBDs as calculated based on the carbon sequestration rates reported in a number of scientific publications is provided in Table 18. Assuming that catch crops can potentially sequester approx. 1,2 t CO_2/ha/year, it was estimated that potential catch crop CO_2 emission mitigation effect associated with soil carbon sequestration in Venta and Lielupe RBDs can amount to 114 and 180 thou t CO_2/year respectively.

Table 18. ***Estimated change in CO_2 balance based on scientific references***

River basin/sub-basin	Change in CO_2 balance, thou t CO_2/year
Lielupe RBD:	***180***
Mūša sub-basin (LT)	70
Nemunėlis sub-basin (LT)	15
Lielupė small tributaries sub-basin (LT)	32
Latvian part of the Lielupe basin (LV)	63
Venta RBD:	***114***
Bartuva basin (LT)	5
Venta basin (LT)	43
Šventoji basin (LT)	3
Latvian part of the Venta basin (LV)	63

Results of the mass balance calculations

Mass balance calculations were performed to validate results of the theoretical assessment based on the publication data and to consider local conditions, such as predicted structure and productivity of catch crops in Venta and Lielupe RBDs. Potential change in CO_2 balance was estimated as the difference between plant CO_2 uptake and release back to the atmosphere through the residue mineralisation process. Results of the mass balance calculations are presented in *Table 19*.

Table 19. ***Estimated change in CO_2 balance based on the results of mass balance calculations***

River basin/sub-basin	CO_2 uptake by plants from the atmosphere, thou t CO_2/year	CO_2 release in the residue mineralisation process, thou t CO_2/year	Net CO_2 mitigation, thou t CO_2/year
Lielupe RBD:	***576***	***374***	***202***
Mūša sub-basin (LT)	225	146	79
Nemunėlis sub-basin (LT)	47	30	16
Lielupė small tributaries sub-basin (LT)	103	67	36
Latvian part of the Lielupe basin (LV)	201	131	70
Venta RBD:	***364***	***237***	***127***
Bartuva basin (LT)	15	10	5
Venta basin (LT)	139	90	49
Šventoji basin (LT)	9	6	3
Latvian part of the Venta basin (LV)	201	130	71

Mass balance calculations indicate larger catch crop CO_2 mitigation effect than the assessment based on literature references, however, results are comparable. Different time scales on which carbon sequestration values are derived can be one of the factors explaining the difference. Mass balance calculations account only for direct losses of CO_2 through the residue mineralisation process in a duration of approx. one year while scientific publications summarise results from longer observations representing long-term trends. In a longer perspective, carbon may also be lost through other pathways (e.g. leaching or emission of VOCs), additionally, incorporation of catch crops may enhance mineralisation of existing SOC pool. Thus, SOC sequestration effect decreases with time. We can conclude that results of both calculations are consistent.

Impact on CO_2 and N_2O emissions

Table 20 summarises potential increase in CO_2 and N_2O emissions related to establishment of catch crops in Venta and Lielupe RBDs. Assessment results demonstrate that establishment of catch crops may increase annual emissions of greenhouse gasses (CO_2 and N_2O) by approx. 11 thou t CO_2-e in Lielupe RBD and by 7.2 thou t CO_2-e in Venta RBD.

Table 20. ***Potential increase in CO_2 and N_2O emissions in Venta and Lielupe RBDs due to establishment of catch crops***

	Potential increase of N_2O emissions, thou t CO_2-e/yr	Potential increase in CO_2 emissions due to extra operations, thou t/yr
Lielupe RBD:	***7***	***4,1***
Mūša sub-basin (LT)	2,7	1,6
Nemunėlis sub-basin (LT)	0,6	0,3
Lielupė small tributaries sub-basin (LT)	1,2	0,7
Latvian part of the Lielupe basin (LV)	2,5	1,5
Venta RBD:	***4,5***	***2,7***
Bartuva basin (LT)	0,2	0,1
Venta basin (LT)	1,7	1
Šventoji basin (LT)	0,1	0,1
Latvian part of the Venta basin (LV)	2,5	1,5

Catch crop effect of GHG emissions

Total catch crop GHG mitigation effect in Venta and Lielupe RBDs as estimated by summarising potential contributions to carbon sequestration and emissions of CO_2 and N_2O is provided in Table 21.

Performed assessment suggest that application of catch crops may result in decrease of annual GHG emissions by almost 170 thou t CO_2-e in Lielupe RBD and by 107 thou t CO_2-e in Venta RBD.

Table 21. ***Potential reduction of GHG emissions in Venta and Lielupe RBDs due to application of catch crops***

	Catch crop GHG mitigation effect, thou t CO_2-e/yr
Lielupe RBD:	***168,9***
Mūša sub-basin (LT)	65,7
Nemunėlis sub-basin (LT)	14,1
Lielupė small tributaries sub-basin (LT)	30,1
Latvian part of the Lielupe basin (LV)	59
Venta RBD:	***106,8***
Bartuva basin (LT)	4,7
Venta basin (LT)	40,3
Šventoji basin (LT)	2,8
Latvian part of the Venta basin (LV)	59

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4. Increase of soil organic carbon content

prepared by AAPC

4.1. Description of an effect

Soil organic carbon (SOC), a component of organic matter, is vital to essential soil functions and to the ecosystem services. Decline in soil organic carbon under conventional farming raises concerns on how alternative management practices may increase SOC sequestration and improve agricultural sustainability. One of the ways to increase SOC stocks is enhanced adding of plant residues to the soil. Here catch crops may play an important role by producing a large residue biomass which left in the field can potentially be converted to the SOC.

Microorganisms digest up to 90% of the organic carbon that enters a soil in organic residues. In doing so, they respire the carbon back into the atmosphere as carbon dioxide. While up to 30% of organic inputs can eventually be converted to humus, depending on soil type and climate. Plant materials that are succulent and rich in proteins and sugars will release nutrients rapidly but leave behind little long-term organic matter. Plant materials that are woodier or more fibrous will release nutrients much more slowly, perhaps even tie up nutrients temporarily, but will promote more stable organic matter, or humus, leading to better soil physical conditions, increased nutrient-holding capacity and higher cation exchange capacity *(SARE, 2012*). Research demonstrates that no-till or conservation tillage systems enhance the capacity of catch crops to build organic matter.

Benefits of soil organic matter (SOM) include improvement of soil quality through increased retention of water and nutrients, resulting in greater productivity of plants in natural environments and agricultural settings. SOM improves soil structure and reduces erosion, leading to improved water quality in groundwater and surface waters, and ultimately to increased food security and decreased negative impacts to ecosystems *(Ontl & Schulte, 2012)*.

4.2. Methodology of assessment of an effect

In order to formulate methodological background for the assessment of catch crop effect with respect to SOC stocks in the fields of Venta and Lielupe RBDs, a review of the existing research investigating catch crop potentials to maintain or increase SOC stocks was conducted. In this respect, of the particular importance were studies conducted in Lithuania, in sites located in the Lielupe RBD.

The study of Arlauskienė & Maikštėnienė *(2009)* investigated SOC changes under intensive farming in Northern part of Lithuania. The impact of red clover, white mustard and mixture of white clover and Italian ryegrass in two schemes - with and without incorporation of winter wheat straw - was analysed.

The study demonstrated that in comparison to the situation before the experiment SOC levels tended to increase in all catch crop variants though chemical composition (C:N ratio) of some catch crops was not favourable for humification and SOC accumulation. Authors note that the highest humification rates are characteristic to crops with C:N ratio ranging from 15 to 20. Under lower C: N, large part of the organic biomass mineralises and does not add to the SOC stock. Thus, biomass of leguminous and brassicas is usually mineralised to large extent. The study demonstrated that humification of incorporated organic matter was more intensive when instead of incorporating alone, catch crop biomass was incorporated together with winter wheat straw. After two years, in comparison to control field, incorporation of catch crop and straw biomass increased SOC content by 0,01-0,05%. This equals to SOC increase by approx. 0.3 – 1.5 t /ha.

Another study carried out in Lithuania by Romanovskaja et. al. (2013) that analyzed catch crop impact on formation of humus also reveals that humification is most intensive when plant biomass C:N ratio ranges between 15 and 25. Under C:N lower than 15, catch crop biomass is mineralized to the end decomposition product, while under C:N larger than 25 decomposition of organic matter slows down and formation of humus decreases. The study demonstrated close relation between humification intensity and biomass content of cellulose and lignin. More humus was formed when the cellulose content in plant biomass was 20–28%, and the lignin content was 14–17%.

The study of Nguyen *(2016)* confirms the importance of C:N ratio on the breakdown of added residues, though the relationship between overall C:N ratio and net N mineralized is reported to be much higher than that with the amount of mineralised carbon (i.e. CO_2 release). In the experiments conducted by Nguyen *(2016)*, percentage of C mineralization was in high correlation with stable components of residue such as cellulose and lignin. Author concludes, that residues which are rich in nitrogen (i.e. nitrogen content >2.5%) and low in lignin (i.e. lignin content <15 %) have little or negative effect on SOM and only residues with lignin content above 15 % reliably increase both active and passive pools of SOM.

Results of the reviewed studies lead to the general conclusion that the largest contribution to SOC pool can be expected from the catch crop residues which are high in lignin and have C:N ratio in the interval between 15 and 25. Respectively, residues which are low in lignin and have C:N ratio below 15 are expected to have little effect on SOC stocks.

Concentrations of cellulose and lignin are greater in grasses and more mature plant material compared with legumes and young plant material *(Ranells & Wagger, 1996)*. Based on the above and accounting for the average catch crop C:N ratios, we predict that grasses will typically contribute to SOC pool most, while the effect of legumes will be minor.

In our assessment, we calculate annual catch crop contribution to SOC as a fixed proportion of the residue inputs defined by a humification rate. As the relative decomposability of catch crop residues typically differs significantly between shoot and root components, with the “better” quality shoot material being subject to more rapid mineralization *(Quemada & Cabrera, 1995),* we take different humification rates for above-ground and below-ground biomass.

For grasses and cereals, we take humification rate of 0.22 for shoots and 0.4 for roots as reported by Clivot et al. *(2018)*, Justes et al. *(2009)*, Thomsen & Christensen *(2004)*. For legumes, which are prone to rapid mineralisation and thus expected to have a significantly lower humification rate, we take values for herbaceous residues (0.1 for shoots and 0.2 for roots) as summarised from different studies by Aguilera et al. *(2018)*. For Brassicas we assume humification rates to be an average between the rates taken for grasses and legumes.

$$SOC = \sum_i \left(CC_{i\,C_{ag_{biomass}}} * H_{i\,shoots}\right) + \left(CC_{i\,C_{bg_{biomass}}} * H_{i\,roots}\right)$$

$$CC_{i\,C_{ag_{biomass}}} = CC_{i\,area} * CC_{i\,ag\_biomass} * 0.45$$

$$CC_{i\,C_{bg_{biomass}}} = CC_{i\,area} * CC_{i\,bg\_biomass} * 0.45$$

where

SOC – catch crop contribution to SOC pool, t/year

$CC_{i\,C_{ag_{biomass}}}$ – carbon introduced with catch crop above-ground biomass, t/year

$CC_{i\,C_{bg_{biomass}}}$ – carbon introduced with catch crop below-ground biomass, t/year

$H_{i\,shoots}$ – humification rate of shoots (0.22 for grasses, 0.1 for legumes and 0.17 for brassicas)

$H_{i\,roots}$ – humification rate of roots (0.4 for grasses, 0.2 for legumes and 0.3 for brassicas)

$CC_{i\,area}$ – area of particular catch crop, ha (see Table 17)

0.45 – carbon content in catch crop biomass, as share of the total mass

$CC_{i\,ag\_biomass}$ – expected above-ground biomass of the particular catch crop, t/ha

$CC_{i\,bg\_biomass}$ – below-ground biomass of the particular catch crop, t/ha

4.3. Results/conclusions

Analysis of scientific publications has revealed that grasses have the largest potential to contribute to SOC pool as in comparison with other catch crops they usually contain more lignin which is stable and resistant to mineralization. Results of our assessment suggest that under the typical production of the biomass as predicted for Venta and Lielupe RBD, grasses (e.g. Italian ryegrass) may contribute to SOC stocks by approx. 200 - 220 kg C/ha/year. The contribution of brassicas (e.g. mustard or oil radish) can be rather similar (in the range of 150 – 200 kg C/ha), while expected SOC inputs from leguminous catch crops are under 150 kg C/ha/year. Taking into account the predicted structure of catch crops in Venta and Lielupe RBD (as presented in Table 17) we estimate that the average catch crop SOC inputs may amount to approx. 200 kg C/ha/year.

It has to be admitted that these estimates represent *potential* catch crop contribution to SOC pool however when predicting the effect for longer perspective and for the particular field one should consider that SOC stocks are largely affected by management practices (e.g. tillage, manure inputs etc.) and therefore catch crop impact under specific management conditions may significantly differ from the estimated values.

In general, our estimates are in good agreement with data reported in scientific publications. Poeplau and Don *(2015)* in their meta-analysis conclude that cover crop green manuring influences the annual SOC change of 0.32±0.08 Mg C ha/year. Arrouays et al. (2002) indicate that the introduction of a catch crop in the rotation may induce a C sequestration of 160±80 kg C/ha/year. Lehuger et al. (2007) estimated a C sequestration of 135 kg C/ha/year in the topsoil layer, mainly due to the C inputs by the catch crops and crop residues.

Taking into consideration current potential for catch cropping in Venta and Lielupe RBDs and predicted structure of catch crops (as presented in Table 17) we estimate that catch crops may contribute to SOC stock by approx. 30 thou t C/year in the Lielupe RBD and by 19 thou t C/year in the Venta RBD (see *Table 22*).

Table 22. ***Estimated catch crop contribution to SOC in Venta and Lielupe RBDs***

	Potential catch crop contribution to SOC, thou t C/year
Lielupe RBD:	***29.6***
Mūša sub-basin (LT)	11.6
Nemunėlis sub-basin (LT)	2.4
Lielupė small tributaries sub-basin (LT)	5.3
Latvian part of the Lielupe basin (LV)	10.3
Venta RBD:	***18.8***
Bartuva basin (LT)	0.8
Venta basin (LT)	7.2
Šventoji basin (LT)	0.5
Latvian part of the Venta basin (LV)	10.4

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5. Control of pests and diseases

prepared by AREI

5.1. Description of an effect

One of the important effects of a catch crop is its ability to suppress and reduce harmful organisms: weeds, diseases and pests. Weeds may directly reduce crop yield and quality and increase harvest costs. Prevention is better than cure: it is the most effective method for dealing with weeds. Growing of catch crops is one possible preventive measure *(Bastiaans et al, 2007)*. Catch crops occupy the space and utilize the resources that would otherwise be available to weeds. Incorporated or soil surface-placed cover crop residues can inhibit or retard germination and establishment of weeds; phenolics from legume may contribute to weed control through allelopathy *(Ohno et al, 2000)*. Incorporated residues of allelopathic catch crops can also inhibit or retard germination, emergence and growth of weeds. For this purpose, catch crops that have a high level of allelochemicals seem to be well-suited (*Krudhof et al, 2009*).

However, when choosing catch crops, it is important to avoid growing biologically similar species together too often, to prevent transferring common pests and diseases. Recently, it has also been discussed that catch crops may influence the degradation potential of the soil for pesticides *(Thorup-Kristensen et al., 2003)*. In arable fields of Latvia, 150 different weed taxa, at species or genus level, were registered during a three-year period of monitoring within frame of two projects on weeds, supported by Ministry of Agriculture (*LAAPC, 2017*). Most common weed taxa in fields of conventional farms were *Viola spp., Equisetum arvense L., Fallopia convolvulus (L.) Á.Löve, Lamium spp., Galium aparine L., Elytrigia repens (L.) Nevski, Veronica spp*. Regional conditions (climate, soils, topography) and weather conditions, as well as interaction of both factors had a significant ($p<0.05$) impact on the number of weed plants, number of weed species, and Menhinick's index of biological diversity. The differences in above mentioned weed community were significantly ($p<0.05$) influenced also by increasing proportion of cereals in crop sequence, up to 80–100% *(Lapiņš et al., 2016)*.

5.2. Methodology of assessment of an effect

5.2.1. Weed suppression

Competition from weeds is important biological factor that can negatively affect crop production, because they use the same resources (nutrients, light, space and water) that would otherwise be available to the crop. It can be a direct harmfulness for crop production (crop yield loss, harvest pollution by weed debris) (*Pacanovski, 2014*), technical harmfulness (harvesting problems due to green weed biomass blocking the harvest combine) or indirect harmfulness due to pest survival and dispersal by weeds (increase in yield loss due to weed-borne disease and parasite risk) (*Colbach, Cordeau, 2018*). The magnitude of yield loss most importantly is affected by weed density and time of emergence relative to the crop, but there are also numerous of other agronomic and environmental factor (*Gallandt, Weiner, 2015*), for example, climate, soil type, catch crop species (*Daryanto et al., 2018*), production system (*Wittwer et al., 2017*), competitiveness of the crop (*Pacanovski, 2014*), weed species and others.

Herbicides are widely used for the direct weed management and reduction of weeds density in conventional agriculture, while in organic farming weed control is carried out by manual and agrotechnical measures and crop rotation. In any case weed suppress is associated with additional production costs, and in order to be efficient, weed control measures should prevent the yield and its quality loss in main crop caused by weeds infestation.

Various linear, hyperbolic, and sigmoidal regression models have been proposed to predict yield loss from early estimation of weeds. Crop yield loss is estimated by using weed free yield as a reference and either use percent yield loss in relation to yield without weeds, which can be estimated by using the yield loss function on weed density or coverage (*Ali et al., 2013*). Excluding other factors, the crop yield loss is predicted to grow with increasing weed biomass and vice versa – reducing weeds density should reduce the threat of yield loss.

Many field experiments have shown the ability of various catch crops to reduce weed density and biomass (overview of the results and judgements of the project experts are given in *Table 23*). Consequently, catch crops can be a component in the weed control strategy and possibly can cause economic and environmental benefits to conventional farming by reducing the need of herbicides (*Salmasi, 2015; Strum et al., 2016*). Cover crops have a positive effect on the smothering of weeds ,also in sustainable and organic farming systems, where it is vitally important (*Wittwer et al., 2017*) because non-chemical weed control means employed are less effective than the use of herbicides in intensive farming (*Masilionyte et al., 2017*), but there is a lack of scientific bases to assume that catch crops could replace part of agrotechnical measures for weed control in organic farming (*Wittwer et al., 2017*).

Table 23. Catch crop effect on weed density in the following main crop

Catch crop	Reduction of weed density, %	Source
White mustard	93-94	https://link.springer.com/article/10.1007%2Fs10343-011-0263-9 https://www.sciencedirect.com/science/article/pii/S026121941100144X
Brown mustard	50	Expert judgement
Spring rape	80	Expert judgement based on http://agronomy.emu.ee/vol04Spec/p4S34.pdf (relative comparison)
Winter rape	80	Expert judgement
Oil radish	90	Expert judgement based on http://enst.umd.edu/sites/enst.umd.edu/files/_docs/FS824ForageRadish_NewMultipurposecovercrop.pdf (qualitative evaluation)
Fodder radish	80	Expert judgement
Root radish	80	Expert judgement
Turnip	80	Expert judgement
Winter rye	74 -78	https://www.sare.org/Learning-Center/Books/Managing-Cover-Crops-Profitably-3rd-Edition/Text-Version/Nonlegume-Cover-Crops/Cereal-Rye https://www.tandfonline.com/doi/pdf/10.1626/pps.13.80
White clover	12	Expert judgement
Red clover	62.2	http://agronomy.emu.ee/vol04Spec/p4S32.pdf
White melilot	60	Expert judgement
Italian ryegrass	26.4	http://agronomy.emu.ee/vol04Spec/p4S32.pdf
Perrenial ryegrass	13.9	http://agronomy.emu.ee/vol04Spec/p4S32.pdf
Phacelia	30	Expert judgement
Cock's foot	42.3	http://agronomy.emu.ee/vol04Spec/p4S32.pdf
Oats	90	https://link.springer.com/article/10.1007%2Fs10343-011-0263-9
Buckwheat	90	Expert judgement
Winter vetch	30	https://www.tandfonline.com/doi/pdf/10.1626/pps.13.80
Pea	10	Expert judgement
Faba bean	40	Expert judgement

5.2.2. Control of pests and diseases

The role of catch crops on pest and disease control is uncertain. There are a lot of studies arguing that catch crops can be targeted to reduce the impact of pests and diseases on high value crops (*ELSOMS, 2018*). For example, brassica family catch crop species contain isothiocyanates (ITCs), derivatives of glucosinolates, that have noted pesticide properties and incorporation of brassica residue allows for biofumigant allelopathic suppression of soilborne diseases, nematodes, and weed species (*Price, Norsworthy, 2013*). Species such as oil radish and mustard produce root secretions resulting in a sharp decline in nematode numbers in the soil (*ELSOMS, 2018*). Catch crops improve biodiversity in such a way providing habitat for beneficial insects which help in suppressing the pests.

On the other hand, catch crops can also harbour crop pests and pathogens (if the catch crop is from the same family as main crop). By increasing soil moisture, the catch crops can facilitate some pathogens to develop (*Vukicevich ,2016*).

Although there are some studies where catch crops are described as potentially an interesting alternative way to fight soil-borne plant diseases instead of using chemical pesticides (*Soldevilla Martinez, 2009*), it is not possible to assess the potential economic effect of substitution because none of the catch crop species is as universal as chemical pesticides are. Therefore, qualitative evaluation is appropriate to understand the possible effects of catch crops on pest and disease control.

Both insects and plant pathogens are consumers, i.e. they derive their energy from the crop (*Harzler, 2009*), to insure the positive effect of catch crops in pests and disease control, it is important to know the biological impact of each catch crop and to select one that do not allow the pests or disease to develop. The results of qualitative analyses for possible positive effect of catch crop on pest and disease control are summarized in *Table 24*.

Table 24. Possible effect of catch crops on pest and disease control

Family	Catch crops species (studied)	Biological impact	Affected main crop	Reference
Brassica	White Mustard Oil radish	Reduces number of nematodes in the soil	Potatoes, carrots, sugar beet	https://www.elsoms.com/catch-crops
	White Mustard Oil radish Spring rape Winter rape	Toxic effect on a range of fungal and soil borne diseases and nematodes		https://www.elsoms.com/catch-crops https://www.sare.org/Learning-Center/Books/Crop-Rotation-on-Organic-Farms/Text-Version/Physical-and-Biological-Processes-In-Crop-Production/Managing-Plant-Diseases-With-Crop-Rotation
Boragina-ceae	Phacelia	Reduces club root disease	Brassica	https://www.elsoms.com/catch-crops
Poaceae	Oat	Reduces club root disease Reduces the problem of corn rootworm eggs Reduces root-knot nematodes and vegetable crop diseases caused by Rhizoctonia	Brassica Corn Vegetables	https://www.elsoms.com/catch-crops https://poga.ca/images/pdf/poga-documents/oat-grower-manual-2017.pdf https://www.sare.org/Learning-Center/Books/Managing-Cover-Crops-Profitably-3rd-Edition/Text-Version/Nonlegume-Cover-Crops/Oats
	Ryegrass	Delayes the apothecia formation of Sclerotinia sclerotiorum	Winter rape, Sping rape, Peas, Beans	https://stud.epsilon.slu.se/417/1/soldevilla_m_090808.pdf
	Winter rye	Rye reduces insect pest that attack other cereals.	Cereals, Legumes, Potatoes, Peas Corn, Soybeans	https://www.sare.org/Learning-Center/Books/Managing-Cover-Crops-Profitably-3rd-Edition/Text-Version/Nonlegume-Cover-Crops/Cereal-Rye

		Reduces root-knot nematodes, harmful nematodes		
Polygona-ceae	Buckwheat	Attracts beneficial insects and pollinators	Not specified	https://articles.extension.org/pages/18572/buckwheat-for-cover-cropping-in-organic-farming
Legumes	Winter vetch	Incorporated into soil reduces fusarium wilt	Crucifers, peas	https://www.sare.org/Learning-Center/Books/Crop-Rotation-on-Organic-Farms/Text-Version/Physical-and-Biological-Processes-In-Crop-Production/Managing-Plant-Diseases-With-Crop-Rotation

5.3. Results/conclusions

Catch crop potentials to reduce weeds and to control pests and diseases have been investigated by analysing data provided in scientific publications.

The analysis performed by the project experts demonstrates that catch crops can play an important role in the weed control strategy and can bring economic and environmental benefits both to conventional and organic farming systems. Of all proposed catch crops, white mustard, rape, radish, winter rye, oats and buckwheat have revealed to have the largest weed reduction capacities. They can reduce weed density by over 70%. In comparison, weed reduction potential of pea, white clover, winter vetch, phacelia and Italian and perennial ryegrasses does not exceed 30%.

Based on the catch crop capacities to fight weeds, experts have rated them into three classes: of low, medium and large weed reduction capacity. Catch crops that have been estimated to reduce weed density by over 70% were attributed to the group of the large weed reduction capacity. Those which reduce weed density by 30-70% have been classified as of the medium capacity, and the remaining ones (<30%) – of the low (*Table 25*).

Table 25. Catch crop capacities to reduce weeds

Catch crop	Reduction of weed density, %	Weed reduction capacity
White mustard	93-94	Large
Brown mustard	50	Medium
Spring rape	80	Large
Winter rape	80	Large
Oil radish	90	Large
Fodder radish	80	Large
Root radish	80	Large
Turnip	80	Large
Winter rye	74 -78	Large
White clover	12	Low
Red clover	62.2	Medium
White melilot	60	Medium
Italian ryegrass	26.4	Low
Perennial ryegrass	13.9	Low
Phacelia	30	Low
Cock's foot	42.3	Medium
Oats	90	Large
Buckwheat	90	Large
Winter vetch	30	Low
Pea	10	Low
Faba bean	40	Medium

It should be considered, however, that the rating is based on the results of individual field experiments recorded in publications, where the use of a particular catch crop is just one of the factors influencing the results, so the evaluation should be perceived as informative rather than absolute.

The analysis shows that the role of catch crops on pest and disease control is uncertain. On one hand catch crops improve biodiversity in such a way providing habitat for beneficial insects which help in suppressing the pests but on the other hand, they can also harbour crop pests and pathogens if the catch crop is from the same family as the main crop is grown. Thus, in order to avoid the risk of crop diseases proper catch crop choices are very important.

Potential catch crop benefits with respect to control of pests and diseases are summarised in *Table 26*.

Table 26. Catch crop capacities to control pests and diseases

Catch crop	Impact
White mustard	Reduces nematodes Controls fungal diseases
Brown mustard	
Spring rape	Controls fungal diseases
Winter rape	Controls fungal diseases
Oil radish	Reduces nematodes Controls fungal diseases
Fodder radish	
Root radish	
Turnip	
Winter rye	Rye reduces insect pest that attack other cereals. Reduces root-knot nematodes
White clover	
Red clover	
White melilot	
Italian ryegrass	Delays the apothecia formation of Sclerotinia sclerotiorum
Perennial ryegrass	Delays the apothecia formation of Sclerotinia sclerotiorum
Phacelia	Reduces club root disease
Cock's foot	
Oats	Reduces club root disease Reduces root-knot nematodes and vegetable crop diseases
Buckwheat	Attracts beneficial insects and pollinators
Winter vetch	Incorporated into soil reduces fusarium wilt
Pea	
Faba bean	

Some catch crops show positive effects on reduction of pests and diseases; however, it is not possible to assess the potential economic effect and make any ratings because none of the catch crop species is universal.

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6. Reduction of soil erosion

prepared by AREI, AAPC, and VDU ŽŪA

6.1. Description of an effect

Soil erosion is a natural geological process which, as a result of agricultural activity, can be reinforced and/or minimized through soil management. Soil erosion causes problems in the field where it takes place (on-site), but affects also the surrounding environment (off-site). In parts of the field, where the soil is washed, a lack of nutrients, pesticides, and organic matter occurs; whereas in other parts, the washed material accumulates and leads to an overdose of nutrients and pesticides *(Blume et al., 2010)*. The erosion induces a deterioration of soil structure which reduces the infiltration rate, and thus, increases runoff. This means that less water is available for plants *(Pimentel, 2006)*. In the long term, top soil can get lost. Hence, fertility and productivity could decrease *(Lal, 2001)*.

Soil water erosion is influenced by many different factors - precipitation and its intensity, soil granulometric composition, slope length and steepness, soil cover, soil management *(Nikodemus et al., 2008*). The areas of soil erosion risk are predominantly divided by slope steepness in degrees, such as $<2^0$, $2\text{-}5^0$, $5\text{-}10^0$, $>10^0$. It is often assumed that fields with slopes of $<2^0$ are at lower risk of soil erosion *(DEFRA, 2005)*. Though erosion in flat areas may also occur, usually it is not very significant.

Using digital elevation model and field declaration data, project experts estimate that on the Lithuanian side of the Lielupe RBD about 88% of all fields which are potentially available for catch crops have slopes of $<2^0$. In the Venta RBD fields with slope $<2^0$ make approximately 73% of the total field area. It can be assumed that these fields are not vulnerable to soil erosion. Steep slopes with a steepness above 10^0 in arable land are located only in small areas (see *Table 27*). In Latvia, about 80% of the potential catch crop area in both RBDs is with the slope below 2^0.

Table 27. Percentage of areas suitable for catch cropping with different slopes (source: expert calculations based on the digital elevation model and crop declaration data)

RBD	Percentage of fields with slope			
	$<2^0$	$2^0\text{-}5^0$	$5^0\text{-}10^0$	$>10^0$
Lielupe (LT part)	87.6	12	0.4	0
Venta (LT part)	72.5	24	3.4	0.1
Lielupe (LV part)	86.8	12.4	0.7	0.1
Venta (LV part)	78.8	19.5	1.6	0.1

The most intensive erosion in agricultural lands usually takes place in autumn, winter and spring snow melt. Growing of catch crops could be one of the erosion mitigation measures in this period.

All three types of soil erosion - water erosion, wind erosion and mechanical erosion - are present in Lielupe and Venta RBDs. In relation to the use of catch crops, wind erosion and mechanical erosion were not evaluated because the effects of these types of erosion are not considered significant in the catch crop growing period. Additionally, there are no studies available on the effects of these types of erosion on arable lands of Venta and Lielupe RBDs. Water erosion, in particular associated with the soil loss caused by the raindrop impact, overland flow and rill erosion, is the most important type of erosion in arable lands of Venta and Lielupe RBDs. The erosion of gully or stream-channel is typical for steep slopes which are not prevalent in the areas of Venta and Lielupe RBDs.

Catch crops can play a major role in controlling soil erosion. Quick-growing crops hold soil in place, reduce crusting and protect against erosion due to wind and rain. They also can:

- slow the action of moving water, thus reducing its soil-carrying capacity, by creating an obstacle course of leaves, stems and roots through which the water must manoeuvre on its way downhill;
- increase the soil's ability to absorb and hold water, through improvement in pore structure, thereby preventing large quantities of water from moving across the soil surface;
- help stabilize soil particles in the cover crop root system.

The reduction in soil erosion due to cover cropping will be roughly proportional to the amount of cover on the soil *(SARE, 2012).*

Grasses, such as Italian ryegrass (*Lolium multiflorum*) and cereal rye (*Secale cereale*) are often selected for erosion control as they rapidly establish, protecting the soil from the direct impact of raindrops, have a fibrous root system that contributes to decreased soil erodibility, and have a high stem density which reduce runoff velocity *(Liedgens et al., 2004; Burney & Edwards, 2005)*. Other crops that contribute to erosion control are tap-rooted crops (e.g. forage radish, *Raphanus sativus,* and rapeseed*, Brassica napus*), which increase water infiltration and decrease soil compaction *(Chen & Weil, 2011; Pratt et al., 2014)*, thereby reducing runoff.

In Latvia, field investigations on the effects on water erosion from agricultural lands have been carried out mostly 40 years ago *(Stalbovs, 1974)*. However, they are mainly done on steep slopes above 10^0. The four-year studies showed that erosion is significantly affected by the amount of water runoff that can change significantly in annual terms. The results show that there are significant differences between grassland and cereals in the eroded soil weight. On four years average the dry weight of the soil eroded in the barley field was 334 kg/ha.

In Lithuania, the most extensive soil erosion research is performed in the Kaltinenai experimental station of the Lithuanian Research Centre for Agriculture and Forestry (LAMMC). Kaltinenai station is located in the Samogitian Highland, which also characterises Venta RBD and represents the areas sensitive to soil erosion. Results from these experimental investigations can be used as a good basis for the assessment of potential soil loss rates and catch crop erosion control effects in Venta and Lielupe RBDs.

LAMMC scientists estimate that in Lithuania in the fields with winter crops soil erosion rates vary from a few to a dozen tonnes per hectare, from the fields with summer crops – from a dozen to several dozen tonnes per hectare, and from the fields of potatoes erosion may exceed 100 t/ha (*Jankauskas & Jankauskiene, 2003; Jankauskas & Jankauskiene, 2004*) (*Table 28*).

Table 28. Average loss of soil in the period of 1983-2000 from the fields of differents crops and different slopes (Jankauskas & Jankauskiene, 2003; Jankauskas & Jankauskiene, 2004)

Crop	Loss of soil, t/ha		
	from the fields with slope 2^0-5^0	from the fields with slope 5^0-10^0	from the fields with slope 10^0-14^0
Perennial grasses	0	0	0.06
Rye	4.88	10.52	13.50
Barley	13.88	30.77	42.53
Potatoes	37.27	100.17	136.78

For the analysis of soil erosion and nutrient losses under different crop rotations, the following crop rotations were investigated:

- Crop rotation with black fallow (wheat → potatoes → undersown barley → mixture of clover and timothy grass→ barley → black fallow),
- Rotation of field crops (wheat → potatoes → barley → undersown barley → mixture of clover and timothy grass → mixture of clover and timothy grass),
- Rotation of cereals and grasses (wheat → undersown barley → mixture of clover and timothy grass → mixture of clover and timothy grass) and
- Rotation of grasses and cereals (wheat → undersown barley → mixture of cock's foot and fescue → mixture of cock's foot and fescue → mixture of cock's foot and fescue → mixture of cock's foot and fescue).

Results of the experimental research demonstrate that the highest soil loss rates are characteristic to rotations of field crops. In the fields with slopes of 2-5^0 under the field crop rotations 9.9 t/ha of soil can be lost annually. The amount of lost soil increases with the increasing slope. In the fields with slopes of 5-10^0, 23.4 t/ha of soil can be lost; in the fields with slope of 10-15^0 – 32.2 t/ha (LŽI, 2009) (*Figure 10*).

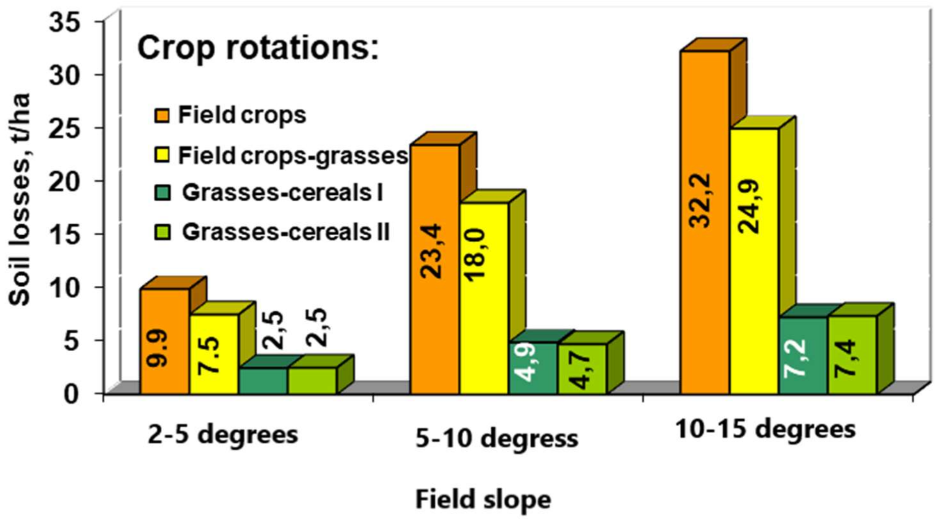

Figure 10. Soil loss from the fields with different slopes and crop rotations (t/ha) (LŽI, 2009)

Experimental data shows that erosion can be effectively controlled by introducing anti-erosion crop rotations. In antierosion crop rotation of cereals and grasses, where grasses were grown for 2 years, soil losses decreased by 23%. In antierosion crop rotation of grasses-cereals, where 4 fields were devoted for perennial grasses, soil losses decreased by 77,7% in comparison with the rotation where along with cereals and perennial grasses potatoes were grown (*Figure 10*).

Estimated losses of nitrogen presented in *Table 29*.

Table 29. Estimated losses of nitrogen from the different crop rotations and fields with different slopes (ASU, 2013)

Crop rotation	Losses of nitrogen, kg/ha		
	from the fields with slope 2^0-5^0	from the fields with slope 5^0-10^0	from the fields with slope >10^0
Crop rotation with black fallow	4.55	12.63	17.93
Field crops	2.60	6.18	8.53
Cereals – grasses	1.89	4.51	6.22
Grasses -cereals	1.22	2.35	3.57
Non-fertilized unused grassland	0.11	0.49	0.73
Fertilised and mown grassland	0.17	0.59	0.86

6.2. Methodology for the assessment of an effect

Soil erosion is often estimated by using Revised Universal Soil Loss Equation (RUSLE), which implements the concept that the four major factors of climate, soil, topography, and land use govern the rates of rill and inter-rill erosion. This method is widely used and could be the best option for the assessment of catch crop effects, however erosion assessment by RUSLE is rather time demanding and requires information (e.g. on soil erodibility) which is not readily available neither in Latvia nor in Lithuania. For this reason, detailed RUSLE calculations could not be performed within the frame of the project.

For the assessment of catch crop erosion control effects, two simple methods were applied. The first method is based on the results of the RUSLE model calculations performed by the Joint Research Centre (JRC) of the European Commission, and the second – based on the results of the research and field experiments carried out by the Lithuanian Research Centre for Agriculture and Forestry (LAMMC).

6.2.1. Methodology based on the JRC RUSLE calculations on NUTS-3 level

The methodology is based on the results of the RUSLE model calculations performed by the European Commission's Joint Research Centre (JRC) in 2015. Calculated by the model erosion rates and catch crop erosion reduction effects are used to assess the effect of catch crops on the reduction of soil loss and associated soil organic matter (SOM) and N in Venta and Lielupe RBDs. Protected from being lost SOM and N are expressed as benefits considering that it translates into less soil fertilisation needed.

To make the assessment, as a first step, rates of soil water erosion (SLE – soil loss by erosion, tonnes/ha per year) in the arable land of Venta and Lielupe RBDs at Nuts 3 level have been obtained from the RUSLE2015 model [3]. The model estimated soil loss in Europe, considering such input factors as rainfall erosivity, soil erodibility, cover-management practices (cover crops, tillage, plant residues), topography (relief) and support practices (contour farming, stone walls, grass margins) *(Panagos et al., 2015)*. According to the model results, in Latvia the mean soil erosion rate in the arable land of the Kurzeme region is 1.047 t/ha/year, while in Zemgale - 0.845 t/ha/year. This is mainly due to the fact that the Zemgale is located in plain areas comparable to the Kurzeme. The average soil loss rate for the Kurzeme has been applied to all sub-basin units in the Venta river basin, respectively the average rate of the Zemgale has been attributed to all Lielupe sub-basin units. As for Lithuania, the mean soil erosion rate from the model for the arable land of Klaipėda county has been estimated at 0.932 t/ha/year, for Panevėžys – 0.790 t/ha/year, for Šiauliai – 0.784 t/ha/year, and for Telšiai – 1.096 t/ha/year. The erosion rate of Klaipėda has been applied to the Bartuva and Šventoji basins, the respective indicator of Panevėžys was used for the Nemunėlis sub-basin, while for the Mūša sub-basin the average erosion rate of Panevėžys and Šiauliai was applied (both rates are very close). The erosion rate of Šiauliai has been attributed to the Lielupe small tributaries sub-basin, while the average erosion rate of Šiauliai and Telšiai is used for the Venta basin (as it occupies almost similar territories in both counties).

Erosion rates from the model for other countries and their regions can be seen in *Figure 11*.

Table 30. Erosion rates estimated for Venta and Lielupė RBDs from the RUSLE calculations performed by JRC

RBD, basin/sub-basin	Erosion rate, t/ha
Lielupe RBD (LT):	
Sub-basin of the Mūša river	0.787
Sub-basin of the Lielupė small tributaries	0.784
Sub-basin of the Nemunėlis river	0.790
Lielupė RBD (LV)	0.845
Venta RBD (LT):	
Venta river basin	0.940
Bartuva river basin	0.932
Šventoji river basin	0.932
Venta RBD (LV)	1.047

[3] http://ec.europa.eu/eurostat/statistics-explained/index.php/Agri-environmental_indicator_-_soil_erosion, Excel file, Map 3

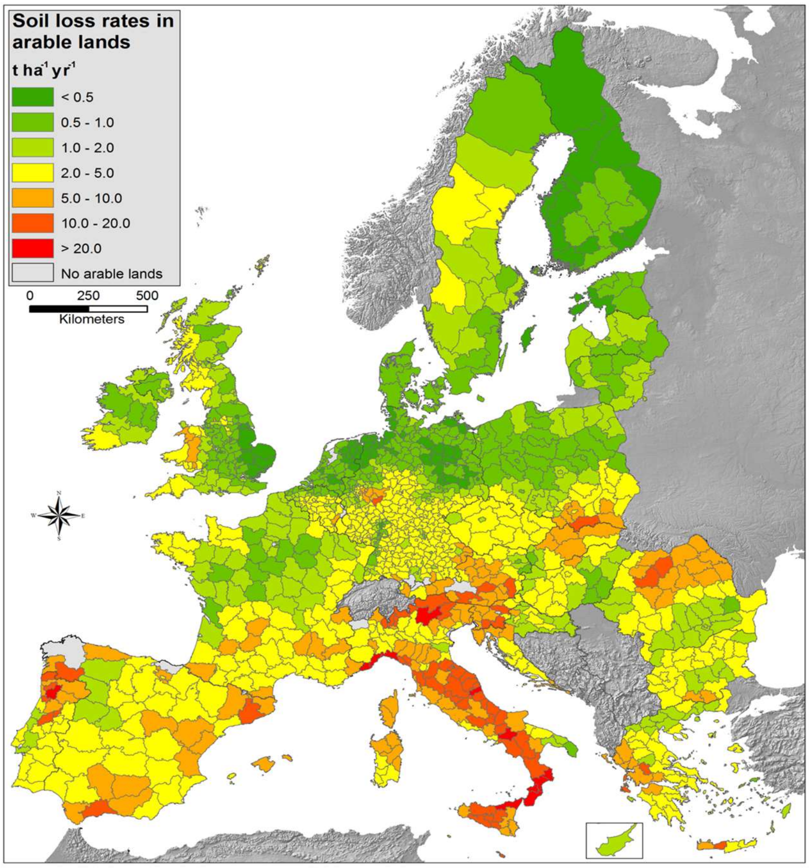

Figure 11. Mean soil erosion rates at NUTS 3 level for arable land (tonnes per ha per year), 2010, EU-28[4]

Further, the average content of SOM (*OMP – percentage of soil organic matter*) for the soils in each sub-basin unit in Venta and Lielupe RBDs was established. In Latvia, it has been done based on the unpublished data provided by the State Plant Protection Service (SPPS), which inter alia performs soil agrochemical analysis. For each sub-basin unit, the data for SOM contents were given for various sample points where soil agrochemical analysis was carried out during 2013-2016. Based on the data provided by the SPPS weighted average was calculated for each sub-basin unit (for 14 sub-basins, for which there were no agrochemical sample data available, the average SOM of the respective basin was applied).

SOM values in sub-basins of the Latvian part of Venta and Lielupe RBDs are presented in *Figure 12*. The average SOM contents in both RBDs is around 3.4%.

In Lithuania, there is no systematic and continuous monitoring of soil which would include measurements of soil organic carbon contents. Potential sources of information are LUCAS (land cover/use statistics) database and results of local scientific studies and experiments. Due to inappropriate soil sampling procedures involved in collection of LUCAS data, Lithuanian soil experts regard LUCAS soil organic carbon data as not reliable. Thus, assessment of SOM for the Lithuanian part of Venta and Lielupe RBDs in this study relies purely on the expert judgement. Assessment of potential SOM levels in the arable land is carried out based on the expert predicted soil humus content and assuming that humus makes 80% of SOM *(Pribyl D.W., 2010)*.

[4] JRC, EC, http://ec.europa.eu/eurostat/statistics-explained/index.php/Agri-environmental_indicator_-_soil_erosion, Excel file, Map 3

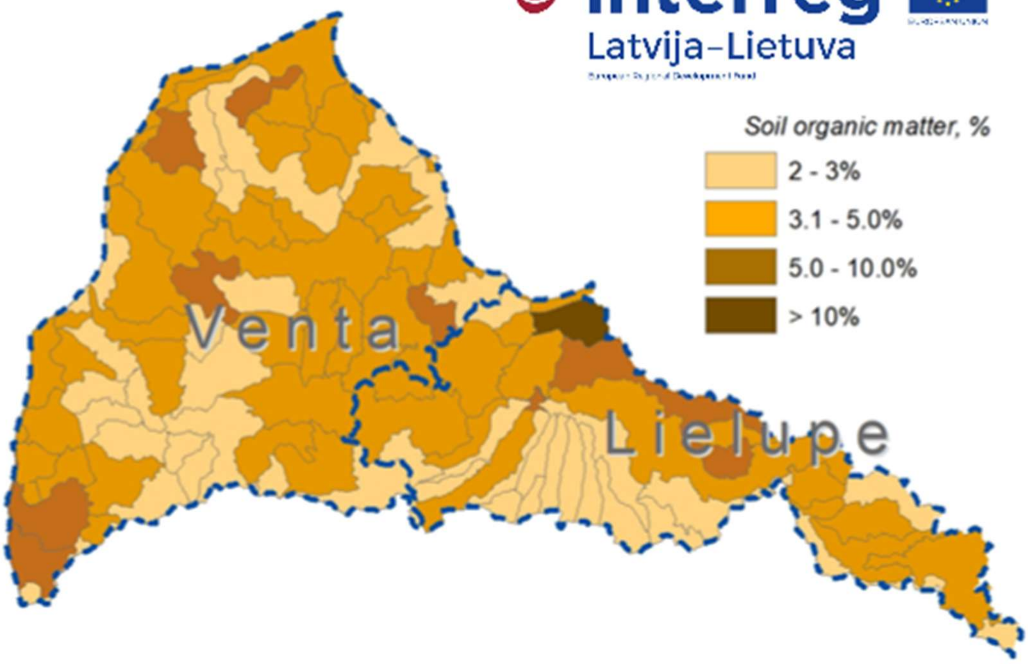

Figure 12. SOM contents (%) in sub-basins of the Latvian part of Venta and Lielupe RBDs

Table 31. Estimated SOM contents in the arable land of the Lithuanian part of Venta and Lielupė RBDs.

River basin/sub-basin	Humus content, %	Estimated SOM content, %
Lielupe RBD:		
Mūša	2.5	3.1
Lielupė small tributaries	2	2.5
Nemunėlis	2.5	3.1
Venta RBD:		
Venta	1.8	2.25
Bartuva	3	3.75
Šventoji	1.8	2.25

N content in soil for both countries was assumed as a standard content corresponding to 5.8% of SOM[5], and later, considering the share of SOM in each sub-basin unit, expressed as % of soil. The standard N content was also validated against the share of N from the LUCAS topsoil database of the JRC (the LUCAS topsoil data were retrieved and analysed for arable land in the respective Nuts 3 regions)[6].

Estimated N content in the soils of Venta and Lielupė RBDs is provided in *Table 32*. As there are 99 sub-basin units delineated on the Latvian side of Lielupe and Venta RBDs, in the table aggregated data for Latvia is presented.

Table 32. Estimated nitrogen content in the soil of Venta and Lielupė RBDs

RBD, basin/sub-basin	Estimated N content, %
Lielupe RBD (LT):	
Sub-basin of the Mūša river	0.18
Sub-basin of the Lielupė small tributaries	0.15

[5] https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_053264.pdf
[6] https://esdac.jrc.ec.europa.eu/content/lucas-2009-topsoil-data

RBD, basin/sub-basin	Estimated N content, %
Sub-basin of the Nemunėlis river	0.18
Lielupė RBD (LV)	0.19
Venta RBD (LT):	
Venta river basin	0.13
Bartuva river basin	0.22
Šventoji river basin	0.13
Venta RBD (LV)	0.23

When calculating erosion losses, it has been assumed that the contents of SOM and N in the soil lost by the erosion corresponds to the soil N and SOM contents estimated for the river basins/sub-basins. Similar approach has been used also by professor Al-Kaisi *(2015)* at Iowa State University.

It has been further assumed that catch crops reduce soil loss by water erosion (*CCER – soil loss reduction rate by catch crops, %)* by 20%. This assumption is based on the RUSLE2015 model, in which the reduction due to the application of cover crops considering literature analysis is estimated to be 20% *(Panagos et al., 2015)*. In the model, this reduction rate is applied to the area under cover crops, where cover crops are defined as the crops that are not normal winter crops or grassland but are sown specifically to protect bare soil in winter (and early spring) after the harvesting of summer crops; the economic interest of the cover crops is low – its main goal is to protect soil and nutrients *(Panagos et al., 2015)*. This definition at large corresponds to the concept of catch crops used in this project.

To estimate the areas of catch crops (CCA – catch crop area, ha), catch crop growing potentials have been assessed for each river basin/ sub-basin. Catch crop growing potentials have been estimated considering crop structure, prevailing crop rotations and intervals between the main crops (the niche between two main crops that is longer that 50 days was assumed sufficient for post-harvest catch crops). The CCA was assumed to be equal to catch crop growing potential. Estimated catch crop growing potentials in Venta and Lielupe RBDs are presented in *Table 33*.

Table 33. Estimated catch crop growing potentials in Venta and Lielupė RBDs

River basin/ sub-basin	Land area which can potentially be sown with catch crops, ha	Percentage of the total arable land area, %
Lielupė RBD:		
Mūša river sub-basin (LT)	58 087	22
Sub-basin of the Lielupe small tributaries (LT)	26 415	22
Nemunėlis river sub-basin (LT)	12 095	18
Latvian part of the Lielupe RBD(LV)	52 643	20
Venta RBD:		
Venta river basin (LT)	35 942	21
Bartuva river basin (LT)	4 048	16
Šventoji river basin (LT)	2 375	21
Latvian part of the Venta RBD (LV)	52 480	20

Considering potential catch crop area and erosion rate, annual loss of soil in each river basin/sub-basin can be estimated. Taking into account soil composition, it can be translated into certain SOM and N tonnes lost per year. By the application of catch crop erosion reduction rate, SOM and N protected by catch crops from being lost by water erosion is obtained.

$$TOMES\ (or\ TNES) = SLE * OMP\ (or\ NP) * CCA * CCER$$

where

TOMES – total soil organic matter saved from erosion, tonnes per year;

TNES – total N saved from erosion, tonnes per year;

SLE – soil loss by water erosion, tonnes/ha per year;

OMP – percentage of soil organic matter, %;

NP – percentage of N, %;

CCA – catch crop area, ha;

CCER – soil loss reduction rate by catch crops, %;

6.2.2. Methodology based on the Lithuanian experimental data

The methodology is based on the results and findings from the erosion studies carried out in Kaltinėnai experimental station of the Lithuanian Research Centre for Agriculture and Forestry. These studies provide information on soil erosion rates in the fields with different slopes under various crop rotations.

Based on the findings of Lithuanian and other scientists, fields with slopes less than 2^0 are usually not sensitive to soil erosion while the fields with larger slopes are subject to substantial soil losses. Thus, as a first step, assessment of arable land areas which are potentially susceptible to soil erosion has been done using digital elevation model and field declaration data. Assessment results are presented in *Table 34*. As seen from the table, the major part of fields which could potentially be used for catch crops are in flat areas with slopes less than 2^0 and thus are not at the risk of erosion. Calculations indicate that only approx. 12% of fields under catch crops on the Lithuanian side of the Lielupe RBD and 27% - in the Venta RBD can be negatively affected by erosion. Most of these fields have slopes in the interval of 2-5^0. In Latvia, about 13% of fields under catch crops in Lielupe RBD and 21% in Venta RBD can be negatively affected by erosion. Calculations for Latvia were made at the RBD level as the distribution of field slopes under catch crops was not available for sub-basin units.

Table 34. Areas of the fields with different slopes which will potentially be used for catch crops

RBD/ basin, sub-basin	Potential area of catch crops, ha	of that, fields with slope			
		$<2^0$	2^0-5^0	5^0-10^0	$>10^0$
Lielupė RBD (LT):	**96597**	**84706**	**11549**	**340**	**2**
Mūša river sub-basin	58 087	50772	7132	183	1,0
Lielupe small tributaries	26 415	24970	1441	3	0,2
Nemunėlis river sub-basin	12 095	8964	2976	154	1,2
Venta RBD (LT)	**42365**	**30712**	**10163**	**1459**	**30**
Venta river basin	35 942	26460	8139	1314	29,3
Bartuva river basin	4 048	2321	1594	132	1,2
Šventoji river basin	2 375	1932	430	13	0,0
Lielupe RBD (LV)	**52 643**	**45719**	**6505**	**385**	**33**
Venta RBD (LV)	**52 480**	**41331**	**10259**	**820**	**70**

As already previously mentioned, *Figure 10* demonstrates potential losses of soil under different crop rotations and field slopes. Based on the information in this figure, effect of catch crops is estimated as a difference between soil losses under field crop and cereal-grasses rotations (*Table 35*).

Table 35. Potential reduction of soil losses in the fields with different slopes if catch crops are introduced

Reduction of soil losses (t/ha) in the fields with slope			
$<2^0$	2^0-5^0	5^0-10^0	$>10^0$
0	2.2	5.4	7.3

Soil organic matter and nitrogen which are protected from being lost by soil erosion are estimated considering potential content of SOM and N in the eroded soil (see *Figure 12, Table 31, Table 32*).

$$TOMES\ (or\ TNES) = [\sum(CCA * CCER)] * OMP\ (or\ NP) * CCA$$

$$TOMESV\ (or\ TNESV) = TOMES\ (or\ TNES) * OMV\ (or\ NV),$$

where

TOMES – total soil organic matter saved from erosion, tonnes per year;

TNES – total N saved from erosion, tonnes per year;

CCER – soil loss reduction by catch crops per slope type, tonnes/ha per year;

CCA – catch crop area per slope type, ha;

OMP – percentage of soil organic matter, %;

NP – percentage of N, %;

6.3. Results/conclusions

6.3.1. Methodology based on the JRC RUSLE calculations on NUTS-3 level

According to the methodology described above and considering potential catch crop areas (*Table 33*), erosion rates (*Table 30*) and catch crop erosion control effect (reduction rate – 20%), it has been estimated that by introducing catch crops 8,895 tonnes of soil on the Latvian side of the Lielupe RBD and 10,990 tonnes on the Latvian side of the Venta can be protected from being lost every year (if full catch crop growing potential is utilised). In Lithuania, catch crop effect has been calculated at 15,193 tonnes a year in the Lielupe RBD and 7,952 tonnes in the Venta RBD.

Estimated reduction of soil loss in Venta and Lielupė RBDs is summarized in *Table 36*. As there are 99 sub-basin units in Lielupe and Venta river basin in Latvia, data for Latvia are presented as aggregates for Venta and Lielupe RDBs.

Considering potential content of SOM and N in the eroded soil (*Figure 12*, *Table 31*, *Table 32*), it was estimated that 285 tonnes of SOM (17 tonnes of N) can potentially be protected from being lost by erosion in the Lielupe RBD in Latvia, while in the Venta RBD protected SOM could amount to 400 tonnes (23 tonnes of N). In Lithuania, the amount of saved SOM has been estimated at 449 tonnes (26 tonnes of N) in the Lielupe RBD and 190 tonnes (11 tonnes of N) in the Venta RBD.

Table 36. Potential effect of catch crops with respect to reduction of soil erosion

	Reduction of soil loss, t/year	Nitrogen protected from being lost, t/year	SOM protected from being lost, t/year
Lielupė RBD (LT):	**15 193**	**26.0**	**448.9**
Mūša river sub-basin	9 141	16.6	285.7
Lielupe small tributaries	4 142	6.0	103.6
Nemunėlis river sub-basin	1 910	3.5	59.7
Venta RBD (LT)	**7 953**	**11.0**	**190.2**
Venta river basin	6 756	8.8	152.0
Bartuva river basin	754	1.6	28.3
Šventoji river basin	442	0.6	10.0
Lielupė RBD (LV)	**8 895**	**16.5**	**285.3**
Venta RBD (LV)	**10 990**	**23.2**	**400.1**

6.3.2. Methodology based on the Lithuanian experimental data

According to the methodology described above and considering potential catch crop areas by slopes (*Table 34*), and potential reduction of soil losses in the fields with different slopes if catch crops are grown (*Table 35*), it has been estimated that the reduction of soil loss due to the effect of catch crops could be expected at 16,631 tonnes a year in the Lielupe RBD and 27,509 tonnes in the Venta RBD in Latvia. In Lithuania, the potential reduction of soil loss has been estimated at 27,261 tonnes a year in the Lielupe RBD and 30,460 tonnes in the Venta RBD.

Estimated reduction of soil loss in Venta and Lielupe RBDs is summarized in *Table 37*. Calculations for Latvia were made at the RBD level as the distribution of field slopes under catch crops was not available for sub-basin units.

Considering potential content of SOM and N in the eroded soil (*Figure 12*, *Table 31*, *Table 32*), it was estimated that by introducing catch crops 533 tonnes of SOM (31 tonnes of N) can potentially be protected from being lost in the Lielupe RBD in Latvia, while in the Venta RBD protected SOM can amount to 1,002 tonnes (58 tonnes of N). In Lithuania, the amount of saved SOM has been estimated at 832 tonnes (48 tonnes of N) in the Lielupe RBD and 749 tonnes (43 tonnes of N) in the Venta RBD.

Table 37. Potential effect of catch crops with respect to reduction of soil erosion

	Reduction of soil loss, t/year	Nitrogen protected from being lost, t/year	SOM protected from being lost, t/year
Lielupė RBD (LT):	**27 261**	**48.3**	**832.0**
Mūša river sub-basin	16 686	30.2	521.4
Lielupe small tributaries	3 188	4.6	79.7
Nemunėlis river sub-basin	7 388	13.4	230.9
Venta RBD (LT)	**30 460**	**43.4**	**748.8**
Venta river basin	25 215	32.9	567.3
Bartuva river basin	4 228	9.2	158.6
Šventoji river basin	1 016	1.3	22.9
Lielupė RBD (LV)	**16 631**	**30.9**	**533.4**
Venta RBD (LV)	**27 509**	**58.1**	**1 001.5**

When analysing results of both calculations it can be concluded, that the methodology which relied on the RUSLE2015 model calculation results have revealed to provide a rather conservative estimate of the catch crop erosion control effect because the assessment was based on the average erosion rate derived from the model for arable land at NUTS-3 level. An alternative methodology which was based on the Lithuanian experimental data and accounted for catch crop effects under different field slopes and crop rotations enabled for a more complex assessment with more confident results.

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Summary

It is commonly agreed that catch crops provide benefits for farmers and environment and the interest for catch crops is increasingly growing. In Lithuania and Latvia application of catch crops is only taking its first steps and farmers still lack a comprehensive information on potential catch crop effects and benefits.

The aim of this study was to fill the knowledge gap and to inform farmers and decision makers on the full range of benefits that catch crops can provide. With this purpose an extensive review and analysis of relevant experiences, research, and experimental studies investigating catch crop effects was carried out. The study focused on the following main effects of catch crops:

- Reduction of nutrient leaching;
- Transferring of nitrogen for subsequent crops (nitrogen crediting);
- Reduction of greenhouse gas (GHG) emissions;
- Increase in soil organic carbon content;
- Control of pests and diseases;
- Reduction of soil erosion.

Reduction of nutrient leaching. While growing, catch crops utilize considerable amounts of nitrogen from the soil for the formation of the biomass (biological accumulation of nitrates), consequently nitrate leaching is decreased. Where nitrate leaching is a serious problem, catch crops can beneficially fill any “fallow” periods in a rotation.

Results of experimental research conducted in Lithuania, Latvia and other European (in particular Scandinavian) countries demonstrate that in most cases catch crops reduce nitrogen leaching by over 50%.

Different species of catch crops depending on their root depth have different potentials to scavenge nitrogen from soil. Broadleaf catch crops (radish, winter rape, phacelia) grow deeper roots faster than cereals (rye, oats) or annual ryegrass. Therefore, they have larger nitrogen leaching reduction capacities. In some cases, leaching reduction effect of fast-growing brassicas (e.g. oil radish) may even exceed 80%.

Legumes usually have significantly lower nitrogen retention rate and leaching reduction potential than grasses and brassica. Performance of legumes with respect to reduction N leaching is poor because instead of scavenging from the soil their fix nitrogen from the atmosphere.

Catch crop effectiveness is highly determined by the root depth. Timely establishment of catch crop is critical to ensure sufficient depth of roots. Therefore, planting catch crops as soon as possible in late summer or early autumn is important for maximizing their environmental effects.

It has been estimated that application of catch crops may protect approx. 12 kg/ha of nitrogen from being lost into water bodies by leaching. If full catch crop growing potential is utilized, nitrogen losses to water bodies could be reduced by approx. 1800 t/year in the Lielupe RBD and by approx. 1100 t/year in the Venta RBD.

Transferring of nitrogen for succeeding crops. Included in crop rotations catch crops scavenge nitrogen from the soil and thereby reduce nitrogen losses by leaching or volatilisation. As the catch crop residue decomposes, the organic nitrogen in its tissue is mineralised to ammonium (NH_4) and then to nitrate (NO_3), which can be latter utilized by the succeeding crops, and thereby reduce the demand for fertilizer nitrogen input.

It has to be considered that only a portion of the nitrogen contained in the catch crop residues will be released as NH_4 and NO_3 during the life cycle of the following cash crop. Scientists conclude that only plant residues with C:N ratios less than 24 increase concentration of the mineral N. Materials added to the soil with a C:N ratio greater than 24 will result in a temporary nitrogen deficit (immobilization).

Along with the composition and quality of the residue, climatic factors such as temperature and moisture have a huge influence on the mineralisation process. The soil organisms responsible for decomposition work best at warm temperatures and are less energetic during cool spring months.

Tillage also affects decomposition of plant residues in a number of ways. Residues incorporated into the soil tend to decompose and release nutrients much faster than those left on the surface, as in a no-till system.

Research demonstrates that the nitrogen mineralization can be expected to be high in the first year, but what is not mineralized this year will mineralize very slowly over the succeeding years.

Assessment shows that legumes have the largest potential for nitrogen crediting. Under the typical production of biomass, they can be expected to leave approx. 30-40 kg of mineral nitrogen for the next cash crop. The similar amount (i.e. about 40 kg/ha) can also be credited by mustards and oil radishes. While 2/3 of the legume nitrogen is fixed from the atmosphere, mustards and oil radishes retain nitrogen from soil providing a dual benefit: they prevent excessive nitrogen from leaching and transfer to the subsequent crop.

Grasses and cereals usually have lower potential for release of PAN than that of legumes or mustards, however they all positively contribute to mineral nitrogen pool (provide around 10 kg/ha of mineral N). Hence, all catch crops can be considered as potential sources of nitrogen facilitating reduced application of mineral fertilisers.

It has been estimated that if full catch crop growing potential was utilised, each year approx. 5 200 t of nitrogen could be credited for the succeeding cash crops in the Lielupe RBD and approx. 3 300 t - in the Venta RBD.

Reduction of greenhouse gas emissions. Catch crops have a positive effect on GHG balance through the soil C sequestration (storage) in which CO_2 is removed from the atmosphere and stored in the soil carbon pool. Our analysis indicate that catch crops can potentially sequester approx. 1.2 – 1.3 t CO_2/ha/year.

GHG mitigation effect is also related to changes in nitrous oxide (N_2O) emissions. Existing research with respect to catch crop impacts on emissions of N_2O is rather limited but it demonstrates that effect is usually minor. When catch crops do alter N_2O emissions, the effect may be an increase or decrease of about 0.01 g N/m^2/year, which equals to roughly 4.7 g CO_2 e/m^2 /year.

Establishment and termination of catch crops require extra operations which can result in increase of CO_2 emissions by approx. 2.8 g CO_2 e/m^2 /year.

In our study, we estimated catch crop GHG mitigation effect as the sum effect related to changes in CO_2 and N_2O emissions. Performed assessment suggest that catch crop GHG mitigation effect can be around 1.1 CO_2e/ha/year. If full catch crop growing potential is utilised, application of catch crops might facilitate decrease of annual GHG emissions by almost 170 thou t CO_2-e in the Lielupe RBD and by 107 thou t CO_2-e in the Venta RBD.

Increase in soil organic carbon (SOC) content. Catch crop potentials to increase SOC content are highly determined by the chemical composition of the residue. There is a close relation between humification intensity and biomass content of cellulose and lignin. C:N ratio of the residue also plays an important role. The largest contribution to SOC pool can be expected from the catch crop residues which are high in lignin (i.e. >15%) and have C:N ratio in the interval between 15 and 25. Respectively, residues which are low in lignin and have C:N ratio below 15 are expected to have little effect on SOC stocks.

Analysis has revealed that grasses have the largest potential to contribute to SOC pool because in comparison with other catch crops, they usually contain more lignin which is stable and resistant to mineralization. Results of our assessment suggest that under the typical production of the biomass as predicted for Venta and Lielupe RBDs, grasses (e.g. Italian ryegrass) may contribute to SOC stocks by approx. 200 - 220 kg C/ha/year. The contribution of brassicas (e.g. mustard or oil radish) can be rather similar (in the range of 150 – 200 kg C/ha), while expected SOC inputs from leguminous catch crops are under 150 kg C/ha/year. Taking into account the predicted structure of catch crops in Venta and Lielupe RBD we estimate that the average catch crop SOC inputs may amount to approx. 200 kg C/ha/year.

Taking into consideration current potential for catch cropping in Venta and Lielupe RBDs and predicted structure of catch crops we estimate that catch crops may contribute to SOC stock by approx. 30 thou t C/year in the Lielupe RBD and by 19 thou t C/year in the Venta RBD.

Control of pests and diseases. One of the important effects of a catch crop is its ability to suppress and reduce harmful organisms: weeds, diseases and pests. Catch crops occupy the space and utilize the resources that would otherwise be available to weeds. Incorporated or soil surface-placed catch crop residues can inhibit or retard germination and establishment of weeds; phenolics from legume may contribute to weed control through allelopathy. Incorporated residues of allelopathic catch crops can also inhibit or retard germination, emergence and growth of weeds.

The analysis performed by the project experts demonstrates that catch crops can play an important role in the weed control strategy and can bring economic and environmental benefits both to conventional and organic farming systems. Of all proposed catch crops, white mustard, rape, radish, winter rye, oats and buckwheat have revealed to have the largest weed reduction capacities. They can reduce weed density by over 70%. In comparison, weed reduction potential of pea, white clover, winter vetch, phacelia and Italian and perennial ryegrasses does not exceed 30%.

The analysis shows that the role of catch crops on pest and disease control is uncertain. On one hand catch crops improve biodiversity in such a way providing habitat for beneficial insects which help in suppressing the pests but on the other hand, they can also harbour crop pests and pathogens if the catch crop is from the same family as the main crop is grown. Thus, in order to avoid the risk of crop diseases proper catch crop choices are very important. When choosing catch crops, it is important to avoid growing biologically similar species together too often, to prevent transferring common pests and diseases.

Reduction of soil erosion. Catch crops can play a major role in controlling soil erosion. Quick-growing crops hold soil in place, reduce crusting and protect against erosion due to wind and rain. Grasses are often selected for erosion control as they rapidly establish, protecting the soil from the direct impact of raindrops, have a fibrous root system that contributes to decreased soil erodibility, and have a high stem density which reduce runoff velocity. Other crops that contribute to erosion control are tap-rooted crops (e.g. forage radish, *Raphanus sativus,* and rapeseed*, Brassica napus*), which increase water infiltration and decrease soil compaction, thereby reducing runoff.

Soil erosion usually takes place in the fields with slope larger than 2^0. Both in Lithuania and Latvia majority of fields that could potentially be used for catch crops are in flat areas and thus are not at the risk of erosion. Only about 13% of fields in the Lielupe RBD and 24% - in the Venta RBD can be negatively affected by erosion (most of these fields have slopes in the interval of $2\text{-}5^0$).

Study results indicate that application of catch crops (if their potential is fully utilised) can protect approx. 44 thou. tonnes of soil from being lost by water erosion in the Lielupe RBD and approx. 58 thou. tonnes – in the Venta RBD annually. This corresponds to 1.4 thou. tonnes of SOM and 80 tonnes of N protected from being lost in the Lielupe RBD and 1.8 thou. tonnes of SOM and 102 tonnes of N – in the Lielupe RBD.

All expected catch crop effects in Venta and Lielupe RBDs are summarised in *Table 38*.

Table 38. Potential effects of catch crops in basins and sub-basins of Venta and Lielupe RBDS

River basin/sub-basin	River basin area, km²	Potential effects of catch crops							
		Reduction of nitrogen leaching, t/year		Transferring of nitrogen to the subsequent crop, t/year	GHG mitigation effect, thou t CO_2-e/year	Production of SOC, thou t C/year	Amount of soil protected from being lost by water erosion, thou t/year	SOM protected from being lost by water erosion, t/year	Nitrogen protected from being lost by water erosion, t/year
		total reduction in river basin/sub-basin, t/year	of that reduction in sub-catchments of water bodies at risk, t/year						
Lielupe RBD:	***17789***	***1750***	***1230***	***5204***	***168.9***	***29.6***	***43.9***	***1365***	***79***
Mūša sub-basin (LT)	5296	680	530	2040	65.7	11.6	16.7	521	30
Nemunėlis sub-basin (LT)	1900	140	-	422	14.1	2.4	7.4	231	13
Lielupė small tributaries sub-basin (LT)	1750	300	300	931	30.1	5.3	3.2	80	5
Latvian part of the Lielupe basin (LV)	8843	630	400	1811	59	10.3	16.6	533	31
Venta RBD:	***21906***	***1130***	***190***	***3301***	***106.8***	***18.9***	***58.0***	***1750***	***102***
Bartuva basin (LT)	749	50	-	141	4.7	0.8	4.2	159	9
Venta basin (LT)	5137	420	100	1258	40.3	7.2	25.2	567	33
Šventoji basin (LT)	390	30	-	83	2.8	0.5	1.0	23	1.5
Latvian part of the Venta basin (LV)	15630	630	90	1819	59	10.4	27.5	1002	58

Santrauka

Atlikdami skirtingus vaidmenis, tarpiniai pasėliai teikia įvairią naudą. Norint gauti didžiausią efektą, svarbu žinoti ir suprasti jų potencialų vaidmenį bei savybes.

Paprastai yra atsižvelgiama į šiuos pagrindinius tarpinių pasėlių pranašumus:

- Maistinių medžiagų sulaikymas ir išplovimo mažinimas
- Maistinių medžiagų perdavimas kitiems pagrindiniams pasėliams
- Šiltnamio efektą sukeliančių dujų (ŠESD) išmetimo mažinimas
- Dirvožemio organinės anglies kiekio didinimas
- Pasėlių piktžolėtumo mažinimas ir kenkėjų bei ligų kontrolė
- Dirvožemio erozijos mažinimas.

Maistinių medžiagų sulaikymo ir išplovimo mažinimas

Augdami tarpiniai pasėlių augalai, požeminės ir antžeminės biomasės formavimui sunaudoja nemažą kiekį dirvožemyje esančio azoto (biologinis nitratų kaupimasis), todėl sumažėja nitratų išplovimas. Kuomet nitratų išsiplovimas yra rimta problema, tarpiniais pasėliais galima sėkmingai užpildyti rotacijoje susidarančius „tuščius“ laikotarpius.

Lietuvoje, Latvijoje ir kitose Europos (ypač Skandinavijos) šalyse atliktų eksperimentinių tyrimų rezultatai rodo, kad tarpiniai pasėliai azoto išplovimą dažniausiai sumažina daugiau nei 50 %.

Skirtingos tarpinių pasėlių augalų rūšys, priklausomai nuo jų šaknų gylio, turi skirtingą potencialą įsisavinti azotą iš dirvožemio. Plačialapių dengiamųjų augalų (ridikų, žieminių rapsų, facelijų) šaknys auga giliau ir greičiau nei javų (rugių, avižų) ar vienmečių svidrių, tad jie turi didesnį potencialą mažinti azoto išsiplovimą iš dirvožemio. Kai kuriais atvejais, greitai augantys bastutiniai augalai (pvz., aliejinių ridikų) azoto išsiplovimą gali sumažinti netgi daugiau nei 80 %.

Ankštiniai augalai paprastai turi žymiai mažesnę azoto sulaikymo gebą ir išplovimo sumažinimo potencialą nei žoliniai ir bastutiniai augalai. Ankštinių kultūrų vaidmuo mažinant azoto išplovimą yra menkas, nes dirvožemyje esantį azotą jie naudoja tik pradinėse augimo stadijose, o vėliau fiksuoja jį iš atmosferos.

Tarpinių pasėlių efektyvumą labai įtakoja šaknų gylis. Norint užtikrinti pakankamą šaknų gylį, labai svarbu juos pasėti tinkamu laiku. Todėl, norint gauti kuo didesnį aplinkosauginį efektą, tarpinius pasėlius svarbu pasėti kuo greičiau - vasaros pabaigoje arba rudens pradžioje.

Projekto metu buvo apskaičiuota, kad tarpinių pasėlių auginimas azoto išplovimą į vandens telkinius iš dirbamų laukų gali vidutiniškai sumažinti **maždaug 12 kg/ha**. Jei būtų panaudotas visas posėlinių tarpinių pasėlių auginimo potencialas, azoto išsiplovimas į **Lielupės UBR vandens telkinius** galėtų būti sumažintas apytiksliai **1800 t per metus, o į Ventos UBR telkinius** - maždaug **1100 t per metus.**

Azoto perdavimas kitiems pagrindiniams pasėliams (azoto kreditas)

Į sėjomainas įtraukiami tarpiniai pasėliai paima azotą iš dirvožemio ir taip sumažina azoto nuostolius dėl išsiplovimo ar išgaravimo. Yrant tarpinių pasėlių augalų liekanoms, jų audiniuose esantis organinis azotas mineralizuojamas į amonį (NH_4), o po to į nitratus (NO_3), kurie gali būti panaudoti po to augsiančių augalų. Taip sumažinamas tręšimo azotu poreikis.

Svarbu įvertinti į tai, kad tik dalis tarpinių pasėlių biomasėje esančio azoto bus atpalaiduota kaip NH_4 ir NO_3 per po to augsiančių pagrindinių pasėlių gyvavimo ciklą. Mokslininkai daro išvadą, kad tik augalų liekanos, kurių C:N santykis yra mažesnis nei 24, padidina mineralinio azoto koncentraciją dirvožemyje. Į dirvožemį įterpta biomasė, kurios C:N santykis didesnis nei 24 gali sukelti laikiną azoto deficitą (imobilizaciją).

Šalia augalų liekanų sudėties ir kokybės, mineralizacijos procesui didelę įtaką turi ir klimato veiksniai, tokie kaip temperatūra ir drėgmė. Už liekanų skaidymą atsakingi dirvožemio organizmai geriausiai veikia šilumoje ir yra mažiau veiklūs vėsiais pavasario mėnesiais.

Žemės dirbimas taip pat daro įtaką augalų liekanų skaidymuisi. Į dirvožemį įterpta biomasė paprastai skaidosi ir išskiria maistines medžiagas daug greičiau nei tą, kuri lieka paviršiuje, kaip taikant bearimio žemės dirbimo technologijas.

Tyrimai rodo, kad didžiausia biomasėje sukaupto azoto mineralizacija vyksta pirmaisiais metais po tarpinių pasėlių auginimo. Tai, kas pirmaisiais metais nėra mineralizuojama, per ateinančius metus mineralizuosis labai lėtai.

Projekto metu atlikto vertinimo rezultatai rodo, kad didžiausias azoto perdavimo kitiems augalams galimybes turi ankštiniai augalai. Užauginus standartinį ankštinių augalų biomasės kiekį, galima tikėtis, kad kitiems augalams bus perduota apie 30-40 kg/ha jiems reikalingo mineralinio azoto. Panašų kiekį (t. y. apie 40 kg/ha) taip pat gali perduoti garstyčios ir aliejiniai ridikai. Ankštiniai augalai 2/3 azoto fiksuoja iš atmosferos, tuo tarpu garstyčios ir aliejiniai ridikai įsisavina azotą iš dirvožemio, teikdami dvigubą naudą: jie apsaugo nuo perteklinio azoto išplovimo ir perduoda sukauptą azotą paskesniems augalams.

Žolės ir varpiniai augalai paprastai turi mažesnį augalams prieinamo mineralinio azoto atpalaidavimo potencialą nei ankštiniai ar bastutiniai, tačiau visi jie teigiamai prisideda prie mineralinio azoto atsargų kaupimo (pvz., žoliniai ir varpiniai augalai gali perduoti apie 10 kg/ha mineralinio N). Taigi, visi tarpiniai pasėlių augalai gali būti laikomi potencialiais azoto šaltiniais kitiems augalams, mažinančiais mineralinių trąšų naudojimo poreikį.

Projekto metu apskaičiuota, kad jei būtų panaudotas visas posėlinių tarpinių pasėlių auginimo potencialas, kiekvienais metais **Lielupės UBR paskesniems pasėliams galėtų būti perduota apytiksliai 5 200 t azoto, o Ventos UBR - apie 3 300 t**.

Šiltnamio efektą sukeliančių dujų (ŠESD) išmetimo mažinimas

Sekvestruodami[7] anglį, kuomet augant augalams CO_2 pašalinamas iš atmosferos, o įterpus biomasę sulaikomas kaip dirvožemio anglies atsargos, tarpiniai pasėliai daro teigiamą poveikį šiltnamio efektą sukeliančių dujų (ŠESD) balansui. Mūsų atlikti preliminarūs skaičiavimai rodo, kad tarpiniai pasėliai potencialiai gali surišti apie 1,2-1,3 t CO_2 /ha/metus.

ŠESD mažinimo poveikis taip pat susijęs su azoto oksido (N_2O) išmetimo pokyčiais. Tarpinių pasėlių poveikio N_2O išmetimams tyrimai yra gana riboti, tačiau jie rodo, kad šis poveikis paprastai yra nedidelis. Kai tarpiniai pasėliai turi įtakos N_2O išmetimui, jo emisijos gali, priklausomai nuo situacijos, išaugti arba sumažėti maždaug 0,01 g N/m^2 per metus, tai yra maždaug 4,7 g CO_2-e/m^2 per metus.

Tarpinių pasėlių sėjai ir panaikinimui reikalingos papildomos operacijos, dėl kurių CO_2 išmetimai gali padidėti apytiksliai 2,8 g CO_2 -e/m^2/metus.

Atliekant tarpinių pasėlių poveikio ŠESD balansui vertinimą, buvo skaičiuojamas suminis, su CO_2 ir N_2O išmetimų pokyčiais, susijęs poveikis. Atliktas vertinimas rodo, kad tarpinių pasėlių ŠESD mažinimo efektas gali siekti apie 1,1 CO_2-e/ha per metus. Jei būtų panaudotas visas posėlinių tarpinių pasėlių auginimo potencialas, tarpinių pasėlių auginimas **metinį ŠESD balansą Lielupės UBR galėtų sumažinti beveik 170 tūkst. t CO_2-e, o Ventos UBR – 107 tūkst. t CO_2-e.**

[7] *Sekvestracija – tai anglies dioksido geologinis saugojimas*

Dirvožemio organinės anglies kiekio didinimas

Tarpinių pasėlių potencialas padidinti organinės anglies kiekį dirvožemyje labai priklauso nuo pasėlių liekanų cheminės sudėties. Nustatytas glaudus ryšys tarp humifikacijos intensyvumo ir celiuliozės bei lignino kiekio biomasėje. Didžiausio indėlio kaupiant organinės anglies atsargas dirvožemyje galima tikėtis iš augalų, kurių biomasėje yra daug lignino (t.y. > 15 %) ir kurių C:N santykis yra tarp 15 ir 25. Atitinkamai iš liekanų, kuriose yra mažai lignino ir kurių C:N santykis yra mažesnis nei 15, tikimasi nedidelio poveikio kaupiant organinės anglies atsargas dirvožemyje.

Atlikti tyrimai rodo, kad žoliniai pasėliai turi didžiausią potencialą prisidėti prie organinės anglies kaupimo dirvožemyje, nes, palyginus su kitais tarpinių pasėlių augalais, juose paprastai yra daugiau lignino, kuris yra stabilus ir atsparus mineralizacijai. Projekto metu atliktos analizės rezultatai rodo, kad, užauginus standartinį biomasės kiekį, žoliniai augalai (pvz., gausiažiedės svidrės) Ventos ir Lielupės UBR dirvožemyje gali palikti apie 200-220 kg/ha organinės anglies per metus. Bastutinių augalų (pvz., garstyčių ar aliejinių ridikų) indėlis gali būti gana panašus (nuo 150 iki 200 kg C/ha), o ankštinių pasėlių indėlis kaupiant organinės anglies atsargas dirvožemyje tikėtina būtų mažesnis nei 150 kg C/ha/metus. Atsižvelgiant į numatomą tarpinių pasėlių struktūrą Ventos ir Lielupės UBR, buvo apskaičiuota, kad vidutiniškai tarpinių pasėlių augalų biomasė dirvožemį gali praturtinti apytiksliai 200 kg /ha organinės anglies per metus.

Įvertinus dabartinį posėlinių tarpinių pasėlių auginimo potencialą ir numatomą tarpinių pasėlių struktūrą Ventos ir Lielupės UBR, galima prognozuoti, kad tarpiniai pasėliai galėtų **padidinti organinės anglies atsargas Lielupės UBR dirvožemyje maždaug 30 tūkst. t C/metus, o Ventos UBR - 19 tūkst. t C/metus**.

Piktžolių, kenkėjų ir ligų kontrolė

Vienas iš svarbių tarpinių pasėlių auginimo efektų yra jų gebėjimas slopinti ir mažinti kenksmingų organizmų, t.y. piktžolių, ligų ir kenkėjų, paplitimą ir kiekį. Tarpiniai pasėliai užima erdvę ir naudoja išteklius, kurie priešingu atveju būtų prieinami piktžolėms. Į dirvožemį įterptos arba dirvožemio paviršiuje paliktos tarpinių pasėlių augalų liekanos gali slopinti arba sulėtinti piktžolių dygimą; ankštinių augalų išskiriamos biocheminės medžiagos taip pat gali prisidėti prie piktžolių kontrolės. Šis reiškinys, kuomet vieni augalai daro poveikį kitiems išskirdami biochemines medžiagas, vadinamas alelopatija. Alelopatinių savybių turinčių tarpinių pasėlių augalų liekanos gali slopinti arba sulėtinti piktžolių atsiradimą ir augimą.

Projekto ekspertų atlikta analizė rodo, kad tarpiniai pasėliai gali vaidinti svarbų vaidmenį piktžolių kontrolės strategijoje ir duoti finansinės naudos bei naudos aplinkai tiek tradicinio, tiek ekologinio ūkininkavimo sistemose. Iš visų siūlomų tarpinių pasėlių augalų, didžiausią piktžolių naikinimo potencialą turi baltosios garstyčios, rapsai, ridikai, žieminiai rugiai, avižos ir grikiai. Jie gali sumažinti piktžolių tankį daugiau kaip 70 %. Palyginimui, žirnių, baltųjų dobilų, žieminių vikių, facelijų ir gausiažiedžių bei daugiamečių svidrių piktžolių mažinimo potencialas neviršija 30 %.

Atlikta analizė rodo, kad tarpinių pasėlių vaidmuo kenkėjų ir ligų kontrolės srityje dar nėra gerai žinomas. Viena vertus, tarpiniai pasėliai didina biologinę įvairovę, sukurdami buveines naudingiems vabzdžiams, kurie padeda naikinti kenkėjus, tačiau kita vertus, jie taip pat gali suteikti prieglobstį kenkėjams ir patogenams, jei pasirinkti tarpinių pasėlių augalai yra iš tos pačios šeimos kaip ir pagrindinis augalas. Taigi, siekiant išvengti pagrindinių pasėlių ligų pavojaus, labai svarbu tinkamai pasirinkti tarpinių pasėlių augalus. Renkantis tarpinius pasėlius svarbu vengti per dažnai kartu auginti biologiškai panašias rūšis, kad nebūtų pernešami bendri kenkėjai ir ligos.

Dirvožemio erozijos mažinimas

Tarpiniai pasėliai gali atlikti svarbų vaidmenį kontroliuojant ir mažinant dirvožemio eroziją. Greitai augantys augalai sulaiko dirvožemį, sumažina plutos susidarymą dirvos paviršiuje ir apsaugo nuo erozijos, kurią sukelia vėjas ir lietus. Erozijos prevencijai dažnai pasirenkami žoliniai augalai, nes jie greitai įsitvirtina, apsaugodami dirvožemį nuo tiesioginio lietaus lašų poveikio. Šie augalai turi pluoštinę šaknų sistemą, kuri mažina dirvos dalelių nunešimą, ir didelį stiebų tankį, kuris sumažina nuotėkio greitį. Erozijos kontrolei taip pat yra naudingi liemeninę šaknų sistemą turintys augalai (pvz., pašariniai ridikai, *Raphanus sativus*, rapsai, *Brassica napus*). Jie padidina vandens infiltraciją, mažina dirvožemio suslėgimą ir vandens nuotėkį.

Dirvožemio erozija dažniausiai vyksta laukuose, kur paviršiaus nuolydis yra didesnis nei 2°. Tiek Lietuvoje, tiek Latvijoje dauguma laukų, kurie galėtų būti potencialiai naudojami tarpiniams pasėliams auginti, yra plokštumose, todėl erozijos pavojaus juose nėra. Tik apie 13 % laukų Lielupės UBR ir 24 % Ventos UBR gali būti neigiamai paveikti erozijos (daugumos šių laukų paviršiaus nuolydis yra 2-5°).

Tyrimo rezultatai rodo, kad posėlinių tarpinių pasėlių auginimas (jei jų auginimo potencialas būtų pilnai išnaudojamas) kasmet nuo praradimo dėl vandens erozijos **galėtų apsaugoti maždaug 44 tūkst. tonų dirvožemio Lielupės UBR ir apie 58 tūkst. tonų - Ventos UBR. Tai atitinka apie 1,4 tūkst. tonų organinės anglies ir 80 tonų azoto, apsaugotų nuo praradimo Lielupės UBR, ir 1,8 tūkst. tonų organinės anglies ir 102 tonų azoto Ventos UBR.**

Kopsavilkums

Uztvērējaugi pilda dažādas funkcijas un tiem ir dažādas priekšrocības. Lai no uztvērējaugiem gūtu maksimālu labumu, ir svarīgi pārzināt un saprast to potenciālo lomu un iedarbību. Uztvērējaugu svarīgākās priekšrocības ir šādas:

- Barības vielu aizturēšana un barības vielu noteču samazināšana;
- Barības vielu pārnese uz nākamo galveno kultūru;
- Siltumnīcefekta gāzu (SEG) emisiju samazināšana;
- Organiskā oglekļa satura daudzuma palielināšana augsnē;
- Nezāļu daudzuma samazināšana un kaitēkļu un slimību kontrole;
- Augsnes erozijas samazināšana.

Augšanas laikā uztvērējaugi no augsnes virskārtas savāc un uzkrāj ievērojamu daudzumu slāpekļa, ko izmanto savas biomasas veidošanai (nitrātu bioloģiskā akumulācija), tādējādi samazinot nitrātu noplūdi. Uztvērējaugu efektivitāti ļoti lielā mērā ietekmē sakņu dziļums. Latvijā, Lietuvā un citās Eiropas (galvenokārt Skandināvijas) valstīs veikto eksperimentālo pētījumu rezultāti apstiprina, ka lielākajā daļā gadījumu uztvērējaugi samazina slāpekļa noplūdi par vairāk kā 50 %. Dažādām uztvērējaugu sugām atkarībā no to sakņu dziļuma ir dažāds augsnes slāpekļa uzkrāšanas potenciāls. Tādi uztvērējaugi kā redīsi, rutki, ziemas rapsis un facēlija izdzen dziļākas saknes ātrāk nekā graudaugi (rudzi, auzas) vai viengadīgā airene. Tādēļ tie labāk spēj samazināt slāpekļa noplūdi. Dažos gadījumos ātri augošie krustzieži var samazināt slāpekļa noplūdi pat vairāk nekā par 80%. Pākšaugiem, salīdzinājumā ar graudzālēm un krustziežiem, parasti ir ievērojami zemāki slāpekļa aizturēšanas un noplūdes samazināšanas rādītāji un noplūdes samazināšanas potenciāls. Pākšaugu ietekme uz slāpekļa noplūdes samazināšanu ir neliela, jo tie saista galvenokārt atmosfērā, nevis augsnē esošo slāpekli.

Aprēķināts, ka uztvērējaugu izmantošana var novērst vairāk kā 10kg/ha slāpekļa noplūdi ūdenstilpēs, ja tiktu pilnībā izmantots uztvērējaugu audzēšanas potenciāls. Tādējādi slāpekļa noplūde ūdenstilpēs var tikt samazināta par apmēram 1800 t/gadā Lielupes baseinā un par apmēram 1100 t/gadā Ventas baseinā.

Uztvērējaugu biomasai sadaloties, organiskais slāpeklis mineralizācijas procesā pārvēršas amonija formā (NH4), bet vēlāk – nitrātu slāpeklī (NO3), kuru vēlāk var izmantot nākamie kultūraugi, tādējādi samazinot vajadzību pēc mēslošanas ar slāpekli saturošiem mēslošanas līdzekļiem. Pētījumi liecina, ka pirmajā gadā ir sagaidāma augsta slāpekļa mineralizācija, bet atliekas, kas šajā gadā nav mineralizējušās, ļoti lēni mineralizēsies nākamajos gados. Jāņem vērā, ka tikai daļa slāpekļa no uztvērējaugu atliekām nākamā kultūrauga dzīves cikla laikā izdalīsies NH4 un NO3 formā. Zinātnieki ir secinājuši, ka tikai tādu augu atliekas, kuru oglekļa/slāpekļa attiecība ir zemāka par 24, paaugstina minerālā slāpekļa koncentrāciju. Ja augsnei tiks pievienotas vielas, kuru oglekļa/slāpekļa attiecība ir lielāka par 24, rezultāts būs pagaidu slāpekļa deficīts (imobilizācija). Mineralizācijas procesu, papildus augu atlieku sastāvam un kvalitātei, būtiski ietekmē arī klimatiskie faktori, piemēram, temperatūra un mitrums. Augsnē esošie mikroorganismi, kas atbild par sadalīšanos, visefektīvāk strādā siltās temperatūrā un mazāk enerģiski auksto pavasara mēnešu laikā. Arī aršana dažādi ietekmē augu atlieku sadalīšanos. Augu atliekas, kas ir iestrādātas augsnē, parasti sadalās un atbrīvo barības vielas daudz ātrāk nekā atliekas, kas ir atstātas uz augsnes virsmas, piemēram, gadījumā, ja lauks netiek aparts. Saskaņā ar veikto pētījumu, pākšaugiem ir visaugstākais potenciāls pārpalikušā slāpekļa atdošanā. Pākšaugi atstās apmēram 30-40 kg minerālā slāpekļa nākamajiem kultūraugiem. Līdzīgu daudzumu var atdot arī sinepes un eļļas rutki. Divas trešdaļas no pākšaugiem pieejamā slāpekļa tie saista no atmosfēras, savukārt sinepes un eļļas rutki saista augsnē esošo slāpekli, šādi nodrošinot divpusēju labvēlīgu efektu – tie novērš pārpalikušā slāpekļa noplūdi un atdod to nākamajiem kultūraugiem. Graudzālēm un graudaugiem parasti ir zemāks augiem pieejamā slāpekļa izdalīšanas potenciāls nekā pākšaugiem vai sinepēm, tomēr tie labvēlīgi ietekmē minerālā slāpekļa krājumus (piem., graudzāles un graudaugi var nodrošināt minerālo slāpekli apmēram 10 kg/ha apjomā). Tādējādi visus uztvērējaugus var uzskatīt par potenciāliem slāpekļa avotiem, kas veicina minerālmēslu izmantošanas samazināšanu. Pētījuma ietvaros aprēķināts, ka gadījumā, ja pilnībā izmantotu uztvērējaugu audzēšanas potenciālu, tad katru gadu Lielupes baseinā nākamajiem kultūraugiem var tikt atdotas apmēram 5200t slāpekļa, savukārt Ventas 3300t slāpekļa.

Uztvērējaugiem ir pozitīva ietekme uz SEG līdzsvarošanu, pateicoties oglekļa piesaistei (uzkrāšanai), kā arī zināms SEG samazināšanas efekts ir saistīts arī ar izmaiņām slāpekļa oksīda (N2O) emisijās. Uztvērējaugu audzēšanas sagatavošanā un likvidēšanā ir nepieciešams veikt papildu darbības, kuru rezultātā var rasties CO2 emisijas, taču emisiju kopsumma uztvērējaugu audzēšanā nav negatīva.

Uztvērējaugu augsnes organiskās vielas satura palielināšanas potenciālu būtiski ietekmē augu atlieku ķīmiskais sastāvs. Pastāv cieša saistība starp humifikācijas intensitāti un celulozes un lignīna saturu biomasā. Svarīga loma ir arī oglekļa/slāpekļa attiecībai. Pētījuma ietvaros iegūtie rezultāti liecina, ka graudzālēm ir visaugstākais potenciāls uz augsnes organiskās vielas krājumu palielināšanu, jo salīdzinājumā ar citiem uztvērējaugiem tās parasti satur vairāk lignīna, kas turklāt ir stabils un noturīgs pret mineralizāciju.

Uztvērējaugiem ir zināma loma arī kaitīgo organismu – nezāļu, slimību un kaitēkļu, samazināšanā un apkarošanā gan tradicionālās lauksaimniecības, gan bioloģiskās lauksaimniecības sistēmās. Uztvērējaugi aizņem platības un izmanto resursus, kas citādi būtu pieejami nezālēm. Augsnē iestrādātas vai uz augsnes virsmas palikušas uztvērējaugu atliekas var kavēt vai palēnināt nezāļu dīgšanu un nezāļu veidošanos. Saskaņā ar līdz šim veiktiem pētījumiem un lauku izmēģinājumiem vislabākās spējas nezāļu samazināšanā uzrāda baltā sinepe, rapsis, redīsi, rutki, ziemas rudzi, auzas un griķi. Šie uztvērējaugi var samazināt nezāļu blīvumu par vairāk kā 70%. Salīdzinājumam – zirņu, ložņu āboliņa, smiltāja vīķa, facēlijas, kā arī daudzziedu airenes un daudzgadīgās airenes nezāļu samazināšanas potenciāls ir daudz zemāks un nepārsniedz 30%. Pētījuma ietvaros konstatētais liecina, ka uztvērējaugu loma kaitēkļu un slimību kontrolē ir neviennozīmīga. No vienas puses, uztvērējaugi palielina bioloģisko daudzveidību, nodrošinot dzīvotnes labvēlīgajiem kukaiņiem, kuri palīdz apkarot kaitēkļus. Savukārt no otras puses, tie var kalpot par slēptuvi kultūraugu kaitēkļiem un patogēnajiem organismiem, jo īpaši, ja uztvērējaugs ir no tās pašas dzimtas kā audzētais galvenais kultūraugs. Tādēļ ļoti svarīgi ir izvēlēties piemērotu uztvērējaugu. Nedrīkst pieļaut to, ka vienas dzimtas sugas tiek audzētas vienuviet, secīgi viena pēc otras – šādi var tikt novērsta šīm sugām kopēju kaitēkļu un slimību pārnese.

Uztvērējaugiem var būt būtiska loma augsnes erozijas kontrolē. Ātri augošās kultūras palīdz saglabāt augsni, samazina augsnes garozas veidošanos un aizsargā pret eroziju, kas var rasties vēja un lietus ietekmē. Erozijas kontrolei bieži vien tiek izmantotas tieši graudzāles, jo tās ātri izveido zelmeni, aizsargājot augsni pret tiešu lietus ietekmi, tām ir bārkšsaknes, kuras palīdz samazināt augsnes eroziju, kā arī tām ir augsts blīvums, kas samazina lietus noteces ātrumu. Erozijas kontroli īstenot palīdz arī augi, kuriem ir mietsakne (piem., eļļas rutks, Raphanus sativus, un rapsis, Brassica napus), kuri uzlabo ūdens iesūkšanos un samazina augsnes sablīvēšanos, tādējādi samazinot noteci. Lielākā daļa aramzemju lauku gan Latvijā, gan Lietuvā, kurus potenciāli var izmantot uztvērējaugu audzēšanai, atrodas līdzenās teritorijās un tādējādi nav pakļauti erozijas riskam. Tikai apmēram 13% lauku Lielupes un 24% lauku Ventas baseinā var ietekmēt plakniskā ūdens erozija (lielākajā daļā šo lauku nogāzes slīpums ir no 2 līdz 50). Iegūtie rezultāti liecina, ka uztvērējaugu izmantošana, pilnībā izmantojot to potenciālu, Lielupes baseinā var katru gadu pasargāt apmēram 44 tūkst. tonnas augsnes pret zudumu ūdens radītas erozijas rezultātā, savukārt Ventas baseinā šis rādītājs ir aptuveni 58 tūkst. tonnu. Jāņem vērā, ka noskalotā augsne satur arī zināmu daļu organiskās vielas, tādējādi netieši uztvērējaugu audzēšana samazina arī slāpekļa zudumus.