Interreg
Latvija–Lietuva
European Regional Development Fund

LLI-49 Project

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.

Catch crops and their growing potentials in Venta and Lielupe RBDs

2019

This report has been produced with the financial assistance of the European Union. The contents of this report are the sole responsibility of the Centre for Environmental Policy (Lithuania), Vytautas Magnus University (Lithuania) and Institute of Agricultural Resources and Economics (Latvia) and can under no circumstances be regarded as reflecting the position of the European Union.

Project implementation period: April 1, 2017 – September 31, 2019
Project number: LLI-49
Project acronym: CATCH POLLUTION
Project budget: 230 609 EUR
Project supported by Interreg V-A Latvia-Lithuania Cross Border cooperation programme 2014-2020 http://www.latlit.eu/
More info: www.europa.eu

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Abbreviations

AAPC	Centre for Environmental Policy
AREI	Institute of Agricultural Resources and Economics
CC	catch crops
K	potassium
LAMMC	Lithuanian Research Centre for Agriculture and Forestry
N	nitrogen
P	phosphorus
VDU ŽŪA	Vytautas Magnus University Agriculture Academy

Introduction

It is commonly agreed that catch crops, if selected and established properly, provide a range of benefits to the farm and the environment. Possibilities to use catch crops in a farming system are usually determined by several factors, such as crop rotations, soil conditions etc. To select best catch crop options and achieve best environmental and economic effect, physical, geographical and agricultural contexts must be considered. Unfortunately, farmers still lack practical information about establishment of catch crops and their potential benefits, and this is the main reason why catch cropping is still poorly used for soil cover between main crops in Lithuania and Latvia.

This report was elaborated jointly by the agricultural experts of Vytautas Magnus University Agriculture Academy (VDU ŽŪA) and Institute of Agricultural Resources and Economics (AREI), and environmental experts of the Center for Environmental Policy (AAPC) with the aim to review conditions for catch crop establishment, identify catch crops that can potentially be grown in Venta and Lielupe RBDs, estimate their growing potentials, and provide information about their main roles and effects.

Catch crops and their effects

Summer crops (leguminous, summer cereals, early potatoes) have short vegetation time. Including them in a crop rotation means that soil remains without a cover for about three months in a year. This period without a plant cover from August to October is suitable for growing catch crops. Catch crops do not occupy a separate field in a crop rotation. They are grown in the same field between main crops, therefore agricultural crops, needed by the farmer, grow in the soil during the entire vegetation period. When catch crops are included in rotation, a yield of at least two crops is obtained from the same field per year.

Catch crops provide several agronomic and environmental benefits.

- After the harvest of the main crop, catch crops immediately cover soil surface protecting it from direct atmospheric impacts, soil erosion, and drying.
- By accumulating nutrients in their biomass catch crops reduce nutrient leaching and transfer nutrients to the succeeding crop.
- Loosening of soil during sowing of catch crops creates favourable conditions for germination of not only catch crop but also weed seeds. Rapid growth of dense catch crop cover effectively supresses growth of weeds and prevents from spreading of their seeds.
- When grown constantly, catch crops increase soil organic carbon stocks, stimulate soil micro-biological and metabolic processes.
- Crops with deep-penetrating roots loosen soil and mobilise nutrients from deep soil layers that are not accessible to other crops.
- Catch crops increase biological diversity of crop rotation, suppress crop diseases and occurrence pests.

The three major categories of commonly grown catch crops are grasses/ cereals (e.g. oat, cocks' foot, Italian ryegrass), legumes (e.g. blue bitter lupine, white and red clover), and brassicas (e.g. oil radish, white mustard). Other crops (e.g. buckwheat, phacelia) can also be grown as catch crops. Catch crops of different categories have different properties. Grasses typically are the most cold-tolerant and produce residues most resistant to decomposition; legumes can contribute N through symbiotic dinitrogen (N_2) fixation; and brassicas can be the most rapid growing under warm conditions, have the ability to take up large quantities of N, and their residues mineralize N rapidly *(Delgado & Follett, 2010)*.

Retention of nutrients and reduction of nitrogen leaching

Catch crop capacities to retain nutrients and reduce nitrogen losses is one of the main arguments for including them in crop rotations.

Investigation data demonstrates that increase of soil mineral N in autumn is influenced not only by intensive crop fertilization but also by intensive decomposition of the soil organic matter. In loamy soils of Northern Lithuania from 20 to 110 kg/ha of nitrogen can be left in soil after the harvest of main crops. That constitute a serious risk of water pollution. The risk of nitrogen leaching is highest is light soils with low sorption capacity. However, due to large amount of clay particles defining binding properties of heavy soils, uneven distribution of precipitation during vegetation period, and formation of vertical corridors, nitrogen can also be lost from heavy soils, not only through leaching but also through surface runoff after torrents.

Nitrogen surplus in the soil after the harvest depends on several factors:

- Species of grown crops. The largest surplus of nutrients is usually found in black fallow, after early potatoes, rape, maize, and vegetables; the lowest – after cereals and sugar beet.
- Soil productivity and other soil properties. The largest amounts of nitrogen are found in humus-rich, structured soils.
- Fertilization with organic and mineral fertilizers. Decomposition of organic fertilizers (manure, green manure) occurs during the entire vegetation period and, when there is no plant cover in the period of August – September, nutrients can be washed out from the soil.

Catch crop capacities to capture and accumulate soil nitrogen in the biomass can be ranked in the following order: oil radish>seradella>phacelia>white mustard>lupine>Italian ryegrass>buckwheat>peas.

In the experiments in Lithuania, the lowest amount of mineral nitrogen in soil was found when white mustard was introduced as catch crop after the harvest of the main crop. In comparison with other plants, white mustard is the best for retaining nitrogen from deeper soil layers. This feature of white mustard is determined by the root growth and penetration intensity. Sowing time of white mustard is also important. White mustard which was undersown in cereals in the period of their milk maturity had faster establishment of roots and hence started uptake of soil nitrogen earlier than the mustard sown after the harvest. During formation of grain, cereals utilize very small amounts of soil nitrogen, therefore this function is taken over by early sown mustard. The higher is nitrogen uptake from the soil, the larger above-ground biomass of catch crop is grown. Postharvest catch crops can retain up to 40 kg/ha of nitrogen from the soil layer of 0-40 cm and up to 20 kg/ha from deeper layers of 40 – 80 cm.

For retention of nitrogen, leguminous crops are not so effective as brassicas, however they also play an important role. Leguminous require nitrogen at the begging of growth before they start fixing it from the atmosphere. Often leguminous are grown in mixtures with brassicas and other leguminous crops.

Table 1. Catch crop impact on the mineral N content in soil (data from the experiments in LAMMC Joniškėlis experimental station, Lithuania)

Catch crops	Mineral N content in soil					
	in autumn, before incorporation of catch crop biomass				early in spring	
	0-40 cm	± difference	40-80 cm	±difference	0-40 cm	±difference
	kg/ha					
Without catch crops	70,3		35,6		66,2	
Blue bitter lupine	29,4	-40,9	28,6	-7,0	74,0	+7,8
Mixture of blue bitter lupine and oat	29,2	-41,1	20,7	-14,9	57,6	-8,6
White mustard undersown in cereals before harvest	24,7	-45,6	17,1	-18,5	88,1	+21,9
White mustard sown after the harvest	27,1	-43,2	18,1	-17,5	75,8	+9,6

Table 2. Impact of undersown red clover and postharvest white mustard catch crops on the mineral N content in soil (data from the experiments in LAMMC Joniškėlis experimental station, Lithuania)

Catch crops	Fertilization intensity	Mineral N content in soil			
		in autumn, before incorporation of catch crop biomass		early in spring	
		0-60 cm	± difference	0-60 cm	± difference
		kg/ha			
Without catch crops	NT	45,6		57,3	
	IT	43,0		55,3	
Red clover	NT	33,6	-12,0	72,0	14,6
	IT	31,6	-11,4	72,2	16,9
White mustard	NT	29,0	-16,7	50,7	-6,7
	IT	24,2	-18,8	56,9	1,6

Catch crop effect can be preliminary judged from the above-ground catch crop biomass. Catch crop germination, growth and development largely depends on the air temperature and precipitation during the vegetation period. Environmental effect of catch crops mainly depends on the catch crop biomass and the amount of nutrients accumulated in it.

Experiments in Lithuania demonstrate, that production of above-ground biomass of different catch crops significantly varies. In the experiments carried out in 2001 – 2003 and in 2003 – 2006 (see results in *Figure 1*), mixture of leguminous and grasses has revealed to be the least sensitive to unfavourable conditions. Biomass production of postharvest catch crops was largely influenced by meteorological conditions in the postharvest period and hence in different years it varied significantly. The largest above-ground biomass was produced by white mustard. In different experiments biomass of white mustard varied from 0.5 to 5.1 t/ha of dry mass. While production of under-sown leguminous depends on fertilization of the main crop, biomass production of post-harvest catch crops is determined by their growing agro-technologies and meteorological conditions.

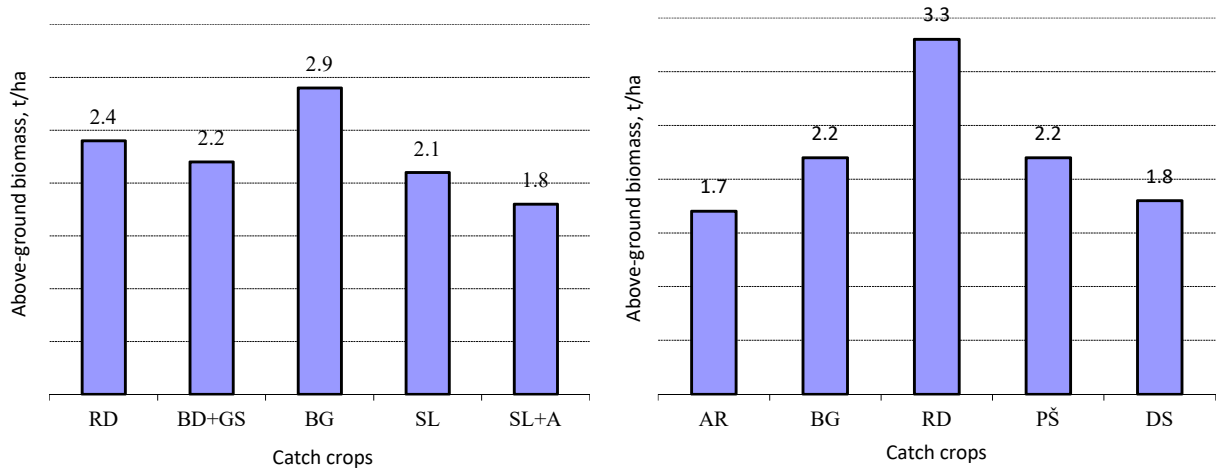


Figure 1. Production of catch crop above-ground biomass t/ha dry mass (experimental data from 2001-2003 and 2003-2006, LAMMC Joniškėlis experimental station). RD – red clover, BD+GS – mixture of white clover and Italian ryegrass, BG – white mustard, SL – blue bitter lupine, SL+A – mixture of blue bitter lupine and oat, AR – oil radish, PŠ – cocks' foot, GS – Italian ryegrass.

Accumulation of nutrients in the biomass and potential incorporation in the soil

Catch crop above-ground biomass is characterised by larger concentrations of nitrogen and larger variation of nitrogen concentrations than below-ground biomass. Among non-legume crops, the largest nitrogen content is observed in brassicas. Nitrogen content in the catch crop biomass can be determined by the development stage of the crop. The earlier is the development of the crop, the larger is nitrogen content in the biomass. Biomass nitrogen content can also be influenced by soil nitrogen and humus content, as well as by meteorological conditions.

Legumes are valued for biological fixation of nitrogen. In their biomass, a larger share of nitrogen (about 2/3) is fixed from the atmosphere and a smaller - taken from the soil. For this reason, legumes are not suitable as postharvest catch crops for retention of nutrients. However, when legumes are grown in mixtures with grasses, brassicas or other crops, not only fixation of nitrogen from the atmosphere but also retention from the soil is ensured.

Legumes, especially leguminous grasses with longer vegetation period, accumulate the largest amounts of nitrogen. Accumulation of nitrogen in the above-ground biomass of other crops depends on their nitrogen demand, applied agrotechnology, and nitrogen availability in soil. Moreover, some crops have ability to capture nutrients (phosphorus, calcium, manganese) from deeper soil layers and accumulate them in biomass. E.g. secreta of buckwheat root dissolves phosphorus which is not available for plants and returns it back to nutrient cycle. Crops with deep roots raise nutrients from deeper soil layers. Roots of lupine, seradella, and buckwheat dissolve phosphorus and potassium that are in bound compounds which are not available for plants.

In the experiments in Lithuania the largest amounts of nutrients were accumulated in the above-ground biomass of red clover, the lowest – in the biomass of Italian ryegrass (*Figure 2*). Undersown red clover accumulates large quantities of nitrogen. White mustard accumulates a lot of nitrogen only when large above-ground biomass is produced (*Figure 3*).

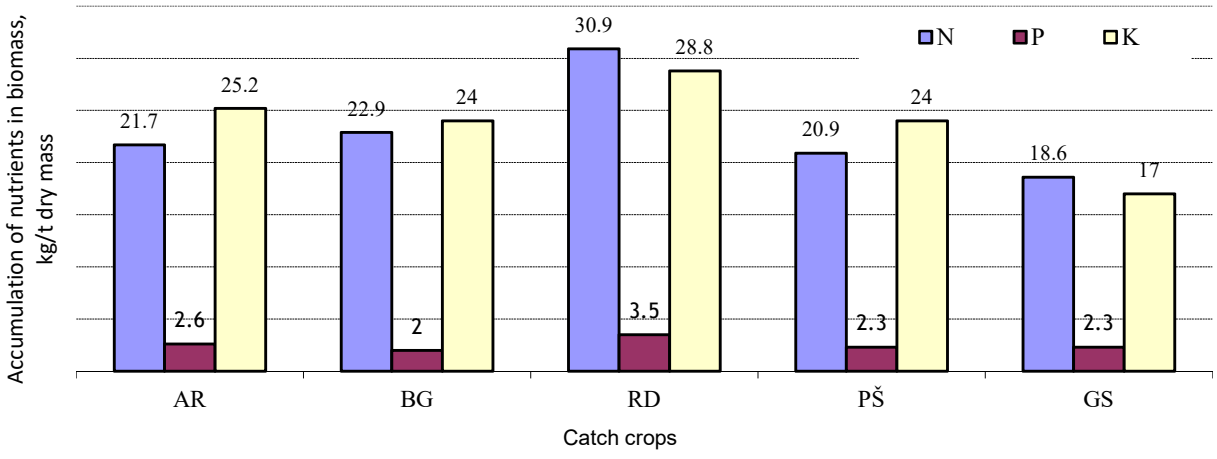


Figure 2. Accumulation of nutrients in above-ground biomass of catch crops kg/t dry mass (experimental data from 2001-2003, LAMMC Joniškėlis experimental station). RD – red clover, BG – white mustard, AR – oil radish, PŠ – cocks' foot, GS – Italian ryegrass.

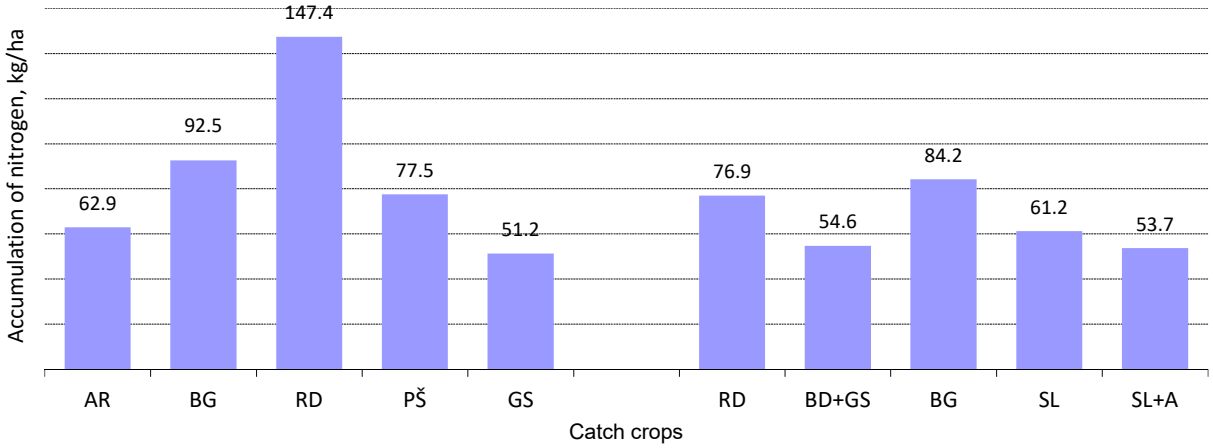


Figure 3. Accumulation of nitrogen in above-ground biomass of catch crops kg/ha (experimental data from 2001-2003 and 2003 - 2006, LAMMC Joniškėlis experimental station). RD – red clover, BD+GS – mixture of white clover and Italian ryegrass, BG – white mustard, SL – blue bitter lupine, SL+A – mixture of blue bitter lupine and oat, AR – oil radish, PŠ – cocks' foot, GS – Italian ryegrass.

It is worth noting that small above-ground biomass of catch crops indicates their poor performance. Soil nitrogen deficit may limit establishment of brassica crops.

Yield benefits

Leguminous which were used as pre-crops to summer crops and rape had a positive effect on the yield of the succeeding crop. It is determined that the yield effect of non-leguminous crops depends on the chemical composition of the biomass, i.e. C/N ratio. The larger is this ratio, the slower is release of mineral N from the biomass. Decomposition of low nitrogen content biomass can cause temporary immobilisation of soil nitrogen in a result of which crop production may decrease.

Experiments in Joniškėlis, Lithuania, have revealed that in comparison with the variant without catch crops, the yield of barley after incorporation of red clover biomass increased by 0,38 – 0,47 t/ha. Positive yield effects after incorporation of white mustard biomass are observed only when enough above-ground biomass of white mustard is produced. Incorporation of other catch crops did not give any yield effect.

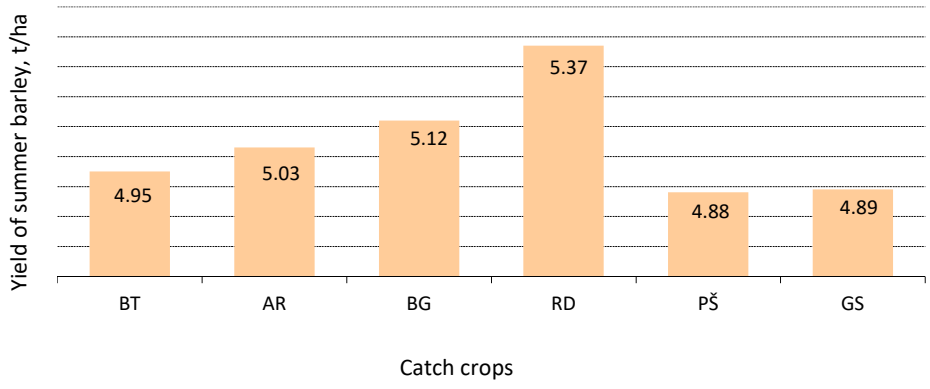


Figure 4. Impact of catch crops on the yield of summer barley (experimental data from LAMMC Joniškėlis experimental station) BT – without catch crops, RD – red clover, BG – white mustard, AR – oil radish, PŠ-cocks foot, GS – Italian ryegrass

Weed control

Soil loosening during sowing of catch crops creates favourable conditions for germination of not only catch crop but also weed seeds. Rapid establishment and development of catch crop biomass effectively suppress germination of weeds. Catch crops suppress development of stubble weeds and ripening of seeds. Crops growing intensively from the begging and rapidly covering soil surface have the largest weed suppression capacity. Those are undersown legume grasses or their mixtures with other grasses, postharvest crops - white mustard and oil radish. Experience shows that dense cover of white mustard in autumn effectively supress couch-grass. Weed control effectiveness can be increased by growing catch crop mixtures. Weed germination and development can be suppressed due to allelopathic properties of catch crops (release of toxins).

Improvement of soil properties

Accumulation of soil organic matter. Catch crops can be used to facilitate the increase in soil organic matter. For this purpose, crops having high biomass C/N ratio are suited best. A good choice is grasses. Impact of incorporated catch crop biomass must be double: not only supply of nutrients to the succeeding crop but also increase in soil organic matter (humus) content. The impact depends on the quality of incorporated green biomass. Humus content of soil can be increased by incorporation of the biomass which C/N ratio is close to 15-20. Most scientists observe that decomposition of organic matter depends on the quantities easily decomposable (glucose, starch) and hardly decomposable (cellulose, lignin) substances in the biomass. Mineralization and humification processes of incorporated biomass depends on the soil humus content and quality, hydro-thermal conditions, soil properties (granulometric, mineral composition), and capacities of microorganisms to utilize organic carbon. Nitrogen and lignin content of many plants roots is favourable for formation of humus, though above-ground biomass mineralizes fast. Catch crops may have no effect on soil humus content, if incorporation of biomass is not timely. Brassicas such as radish, mustard, rape, must be incorporated after flowering, otherwise they will only play the role of green manure (supplying nitrogen for succeeding crops). In order to facilitate humification processes in the soil, legumes must be grown in mixtures with grasses.

Improvement of soil structure. After the harvest of the main crop, catch crops immediately cover soil surface protecting it from direct atmospheric impacts and reducing the risk of erosion and drying. Composing mixtures of crops with different root penetration capacities, facilitates loosening of soil, better mineralization of incorporated organic matter, faster rooting of succeeding crops, better utilization of nutrients, and increase of productivity. Incorporated green catch crop biomass facilitates activity of soil microorganisms and increases the storage of soil organic matter, consequently, soil humus content increases. According the effect on soil structure, main crops can be rated in the following order (starting from the ones having negative effect and finishing with soil improvers): spring legumes < cereals < early potatoes < winter crops < sugar beet < maize <winter rape < late potatoes < forage legume and other grasses.

Soil structure degrades not only because of biological properties of grown crops, but also due to intensive soil cultivation during vegetation, droughts, torrents, and soil compaction during harvesting. Catch crops can facilitate improvement of soil structure. Rapidly establishing above-ground biomass of many catch crops (red clover, oil radish, white mustard, buckwheat, phacelia) protects soil surface from failing and sagging. It takes up the soil moisture and actives soil microorganisms, which decompose plant residues and stick together soil particles into stable aggregates. Deep-rooted crops (legume grasses, lupine, phacelia) loosen soil, increase aeration, intensify nutrient and moisture exchange between topsoil and subsoil. Undersown crops (red clover, cock's foot, Italian ryegrass) have larger effect on soil structure than postharvest crops (white mustard, oil radish).

More detailed analysis of catch crop effects is presented in the Project report *"Environmental effects of catch crops "*.

Catch crops to be grown in Venta and Lielupe RBDs

Lithuanian and Latvian agricultural experts within the scope of this project identified the following crops that can be used as postharvest catch crops in Venta and Lielupė RBDs:

Brassicas:

- White mustard
- Brown mustard
- Spring rape
- Winter rape
- Oil (forage) radish
- Root (tillage) radish
- Turnip

Grasses/cereals:

- Winter rye
- Italian ryegrass
- Perennial ryegrass
- Oat and black oat

Legumes:

- White clover
- Red clover
- White melilot
- Winter vetch
- Pea
- Blue bitter lupine
- Bean

Other:

- Phacelia
- Buckwheat

Detailed description of selected crops is provided in Annex I of this report.

Establishment of catch crops

Selecting of suitable catch crops

Establishment of catch crops requires careful planning taking into account soil and climate conditions, crop rotations and varieties. Choosing the wrong species can result in high establishment costs and still failure in doing the job that the catch crop was grown for.

For catch cropping, crops that differ from the main crops should be selected, e.g. crops of different families, with different vegetation time, root system etc. For example, in short rotations with rape, brassicas should

be avoided. Bad choices of crops may result in spreading of pests and diseases. It is not recommended that two crops having common pests and diseases are grown in succession, e.g. rye and oat, pea and vetch which are susceptible to club root diseases. On the other hand, catch crops can provide benefits to the subsequent crops: leguminous crops provide nitrogen, brassicas reduce spreading of pathogens.

To make the best choice, farmers should consider several factors such as expected catch crop effect, catch crop compatibility with main crops, potential disadvantages, establishment and termination problems.

Irish experts name the following aspects related to different crop species that should be considered when selecting catch crops to be included into crop rotation *(Hacket, 2015)*:

Grass/cereals:

- possess a risk of pest/disease carryover;
- some can have negative effect on succeeding crop (e.g. rye);
- possess a risk of weed problems in succeeding crop;
- some are possibly less suitable for reduced tillage;
- are potential source of forage;

Brassicas:

- are fast growing and relatively cheap;
- possess limited disease/pest risk for cereals (if no volunteers);
- can reduce pests, diseases and weeds;
- can host sclerotinia;
- can be tall – difficult to plough without chopping;

Phacelia:

- relatively expensive seed;
- has small seed - difficult to broadcast;
- establishment requires cultivation;
- different family to crops – good disease break;
- generally good weed suppression;
- can be easier to incorporate than brassicas;

Legumes:

- have potential to fix nitrogen and reduce fertiliser requirement;
- seed can be expensive;
- good from disease/pest risk;
- can be poor for N leaching.

Tables 3 - 6 provide more information about catch crops (role and performance, advantages and disadvantages, compatibility with main crops) that helps farmer to select the best option for his farm and crop rotation.

Table 3. Performance and roles of catch crops (source: SARE, 2012)

	Species	Legume N source	N scavenger	Soil builder	Erosion fighter	Weed fighter	Good grazing	Quick growth	Lasting residue	Length of vegetative stage	Serving as a companion crop
CEREALS	Italian ryegrass		◕	◕	◕	◕	◕	◕	◕	◕	●
	Oat & Black oat		◕	◑	◕	●	◑	●	◑	◔	●
	Winter rye		●	●	●	●	◑	●	●	◕	◕
	Buckwheat		○	◑	◔	●	○	●	○	◔	●
BRASSICAS	White mustard		◑	◕	◕	◕	◑	◕	◔	◑	○
	Brown mustard		◕	◕	◕	◕	◔	◑	◔	◑	○
	Oil (fodder) radish		●	◕	◕	●	◑	◕	◔	◑	◔
	Root (tillage) radish		●	●	◕	◕	◕	◕	◕	◑	●
	Winter rapeseed		◕	◑	◕	◕	◑	◕	◑	◕	○
	Spring rapeseed		◕	◑	◕	◕	◑	◕	◑	◕	○
	Winter turnip rape		●	◕	●	◕	●	●	●	◕	◔
LEGUMES	Red clover	◕	◑	◕	◑	◕	●	◔	◔	◑	●
	White clover	●	◔	◑	◕	◕	●	◔	◔	●	◕
	Berseem clover	●	◕	◕	◕	●	●	●	◑	●	◑
	Persian clover	◕	◑	◕	◕	◕	●	◑	◑	◔	●
	White melilot	●	◔	●	◕	◕	◕	◑	◕	◕	◑
	Phacelia	●	◔	◕	◕	◕	◑	◕	◑	◑	●
	Pea	●	◔	◑	◕	◑	◕	◕	◔	◑	●
	Winter vetch	●	◔	◕	◑	◑	◑	◔	◔	◕	◑

○ *- poor;* ◔ *- fair;* ◑ *- good;* ◕ *- very good;* ● *- excellent*

N Scavenger - ability to take up/store excess nitrogen
Soil Builder - organic matter yield and soil structure improvement
Erosion Fighter - soil-holding ability of roots and total plant
Good Grazing - production, nutritional quality and palatability. Feeding pure legumes can cause bloat
Lasting Residue - rates how long the killed residue remains on the surface

Table 4. Potential advantages of catch crops (source: SARE, 2012)

	Species	Soil impact			Soil ecology				Other		
		subsoiler	free P and K	loosen topsoil	nematodes	disease	allelopathic	choke weeds	attract beneficials	bears traffic	short windows
OTHER	Italian ryegrass	◑	◑	●	◑	◑	◑	●	◔	●	●
	Oat & Black oat	○	◔	◕	○	◑	◕	●	○	◑	●
	Winter rye	◔	◕	●	◑	◕	●	●	◔	◕	●
	Buckwheat	○	●	◕	◔	○	◕	●	●	○	●
BRASSICAS	White mustard	◔	◑	◕	◕	◕	◕	◕	◑	◑	◕
	Brown mustard	◕	◑	◕	◕	●	◕	◕	◑	◑	◕
	Oil (fodder) radish	●	◕	◑	◕	◑	◕	●	◔	◔	◕
	Root (tillage) radish	●	◕	●	◕	◑	◕	◕	◔	◔	◕
	Winter rapeseed	◕	◔	◑	◕	◑	◕	◑	◑	◔	◑
	Spring rapeseed	◑	◔	◑	◕	◑	◕	◕	◑	◔	◑
	Winter turnip rape	◕	◑	◕	◕	◑	◕	◕	◔	◔	◕
LEGUMES	Red clover	●	◕	◑	◔	◔	◑	◑	◕	◑	◑
	White clover	◔	◔	◕	○	○	◑	◕	◑	●	◑
	Berseem clover	◔	◕	◕	○	○	◔	◕	◑	◔	◕
	Persian clover	◔	◑	◑	◔	◑	◔	◑	◕	◔	◑
	White melilot	●	●	●	◔	◔	◔	◑	◕	◑	○
	Phacelia	◔	◑	◕	◕	◕	◑	◕	●	◑	◑
	Pea	◔	◔	◕	◑	◕	◔	◕	◕	◔	◕
	Winter vetch	◑	◑	◕	◔	◑	◑	◕	●	○	○

○ *- poor;* ◔ *- fair;* ◑ *- good;* ◕ *- very good;* ● *- excellent*

Table 5. Potential disadvantages of catch crops (source SARE, 2012)

	Species	Increase pest risks			Management challenges				
		weed potential	insects/ nematodes	crop disease	hinder crops	establishing	killing by tillage	killing by mow	incorporation of mature stand
CEREALS	Italian ryegrass	○	◕	◕	◑	●	●	●	◑
	Oat & Black oat	◕	◑	◕	◑	●	●	◔	◑
	Winter rye	◔	◑	◕	◔	◕	◕	●	○
	Buckwheat	○	◕	●	●	●	●	●	●
BRASSICAS	White mustard	◔	◕	●	◑	●	●	◔	●
	Brown mustard	◔	◕	●	◑	●	●	◔	●
	Oil (fodder) radish	◑	◕	●	●	●	●	●	●
	Root (tillage) radish	◑	◕	●	●	●	●	●	◕
	Winter rapeseed	◔	◔	●	◑	●	◑	◔	◕
	Spring rapeseed	◔	◔	●	◑	●	◑	◔	◕
	Winter turnip rape	◑	●	●	◑	●	◑	◔	◕
LEGUMES	Red clover	◑	◔	◕	●	◕	◑	◔	◕
	White clover	◑	◑	◕	◔	◕	○	◑	◕
	Berseem clover	●	◑	◕	●	●	◔	◔	◕
	Persian clover	◑	○	◕	●	◕	◕	◕	◕
	White melilot	◔	◔	●	◑	●	◑	◕	◔
	Phacelia	◑	●	◕	●	◑	◕	◕	◕
	Pea	●	◑	◔	●	●	●	●	◕
	Winter vetch	◑	◑	●	●	◑	◔	●	◑

○ - problem; ◔ - could be a moderate problem; ◑ - could be a minor problem; ◕ - occasionally a minor problem; ● - not a problem

Table 6. Catch crop suitability in crop rotations (source: SARE, 2012)

	Species	Maize	Cereals	Oilseed rape	Sugar beets	Potatoes	Intensive crops	Legumes
CEREALS	Italian ryegrass	+ +	+	+	+	+	+	+
	Oat & Black oat	+ +	+	+ +	+ +	+ +	+ +	+
	Winter rye	+ +	+	+	+	+	+	+
	Buckwheat	+	+	+		+	+	+
BRASSICAS	White mustard	+ +	+ +		NR			+ +
	Brown mustard	+ +	+ +				+ +	+ +
	Oil (fodder) radish	+ +	+ +	+	NR	+	+	+ +
	Root (tillage) radish	+ +	+ +	+				+ +
	Winter rapeseed	+ +	+ +		+	+		+
	Spring rapeseed	+ +	+ +		+	+		+
	Winter turnip rape	+ +	+ +		+	+		+
LEGUMES	Red clover	+ +	+ +	+	+			
	White clover	+ +	+ +	+	+			
	Berseem clover	+ +	+ +	+	+ +			
	Persian clover	+ +	+ +	+	+			
	White melilot	+ +	+ +	+	+			
	Phacelia	+ +	+ +	+ +	+			+
	Pea	+ +	+ +	+ +	+ +	+	+	
	Winter vetch	+ +	+ +	+ +	+	+	+	

+ suitable; ++ strongly recommended; NR – only nematode-resistant species

Sowing times and methods

According the method of sowing, catch crops are classified as either under-sown or post-harvest.

The advantage of catch crop under-sowing is that it does not require additional soil tillage. It is enough to under-sow catch crops into the main crop and, after the harvest, leave them to grow until the autumn. The crops most commonly used for under-sowing are those that can grow in the shade and after the harvest of the main crop rapidly grow and develop *(Lazauskas, 1992; Marcinkevičienė, 2003)*. This method of sowing can be applied for slowly developing crops – perennial legumes, grasses, or their mixtures. In spring, they are under-sown in winter or spring cereals, or in short vegetation forage crops. For sowing in winter cereals, stubble-seeder, seeder with shares, or seeder combined with harrows can be used. When planning under-sowing of catch crops, it is important to use suitable herbicides, reduce crop seeding and fertilisation rates.

The success of catch crop growing depends not only on the choice of the main crop but also on the competitive power of under-sown crops. According to *N. Lütke Entrup (1993)*, red clover and Italian ryegrass are suitable for being under-sown in wheat. *I. Rydberg (1998)* has found that out of 39 plant species tested the ones that could be successfully grown in a barley crop are cocksfoot, red fescue, common bentgrass, white clover, and bird's foot trefoil.

Under-sown catch crops grow well only in well-cultivated, fertile soils. In dry, infertile soils they grow poorly and produce low fresh biomass yield.

Under-sowing of catch crops has to be done in spring. Catch crops have to be sown 1 – 3 days after sowing of the main spring crop or sown in winter crops as soon as the soil is dry enough. Plant sowing is successful only when the soil is of optimal humidity *(Lazauskas, 1992)*.

Seeding rate of under-sown crops is selected in such a way that the yield of the main crop is not reduced, and after the harvest of the main crop under-sown catch crops grow well and produce high fresh biomass yield. Under-sown catch crops do not require any special care. It is important that the main crop is harvested as early as possible and removed from the field *(Lazauskas, 1992)*.

Post-harvest catch crops are sown after the harvest of the main crop. Growth of post-harvest catch crops should correspond to the length of the postharvest period. Under Lithuanian conditions, cereals are usually harvested in the first decade of August or later. For successful germination and production of large biomass, catch crops should be sown immediately after the harvest of the main crop so that they could use the remaining soil moisture. When sown immediately, post-harvest crops germinate in 8-10 days.

Sowing of postharvest catch crops by the mid of August is recommended. Some species (such as buckwheat) should be sown even earlier as they are sensitive to low temperatures and shortening of days. Oilseed rape, oil radish and turnip rape have to be sown until August 15. White mustard is less sensitive to the sowing time *(Stancevičius, 1992)*. However, in order to obtain a higher biomass yield, mustard should be sown not later than August 10. It then reaches the flowering stage before the end of vegetation. If to some reasons harvest of the main crop is delayed, possibilities of late sown catch crops to produce sufficient biomass significantly decrease.

The success of post-harvest catch crop cultivation depends on the sowing time and agroclimatic conditions during the second half of the summer and autumn. After cereal harvesting, vegetation season of post-harvest crop should be not shorter than 50 – 60 days, average daily air temperature not lower than 9^{o}C, precipitation amount not less than 160 – 200 mm. Hence, for post-harvest catch cropping plant species with a short vegetation period should be chosen *(Kerschberger, 1995)*.

Potential niches for post-harvest catch cropping as estimated by the project experts are presented in *Table 7*. Based on the agroclimatic data from south-eastern part of Lithuania, it was found that after annual forage crops harvested for forage, and after harvesting of early potatoes in the middle of July, or after harvesting of cereals, there are still 74 – 77 days when air temperature is above 10^{o}C. The sum of the active temperatures above 10^{o}C reaches 1100^{o}C and precipitation is about 150 – 170 mm. During this period, fast growing *Brassicaceae* plants – white mustard, spring oilseed rape and oil radish produce enough fresh biomass *(Nedzinskas, Nedzinskienė, 1999)*.

White mustard, oilseed rape and oil radish are the crops most commonly grown for green manure in Lithuania and its neighbouring countries. Under favourable conditions, seeds of these plants emerge rapidly, seedlings grow fast and fresh biomass accumulates a lot of nutrients. They are suitable to be grown after annual forage grasses harvested for forage, early potatoes, winter and spring cereals, oilseed rape and are not suitable for being grown after sugar and fodder beets, maize, potatoes, soy, buckwheat, peas.

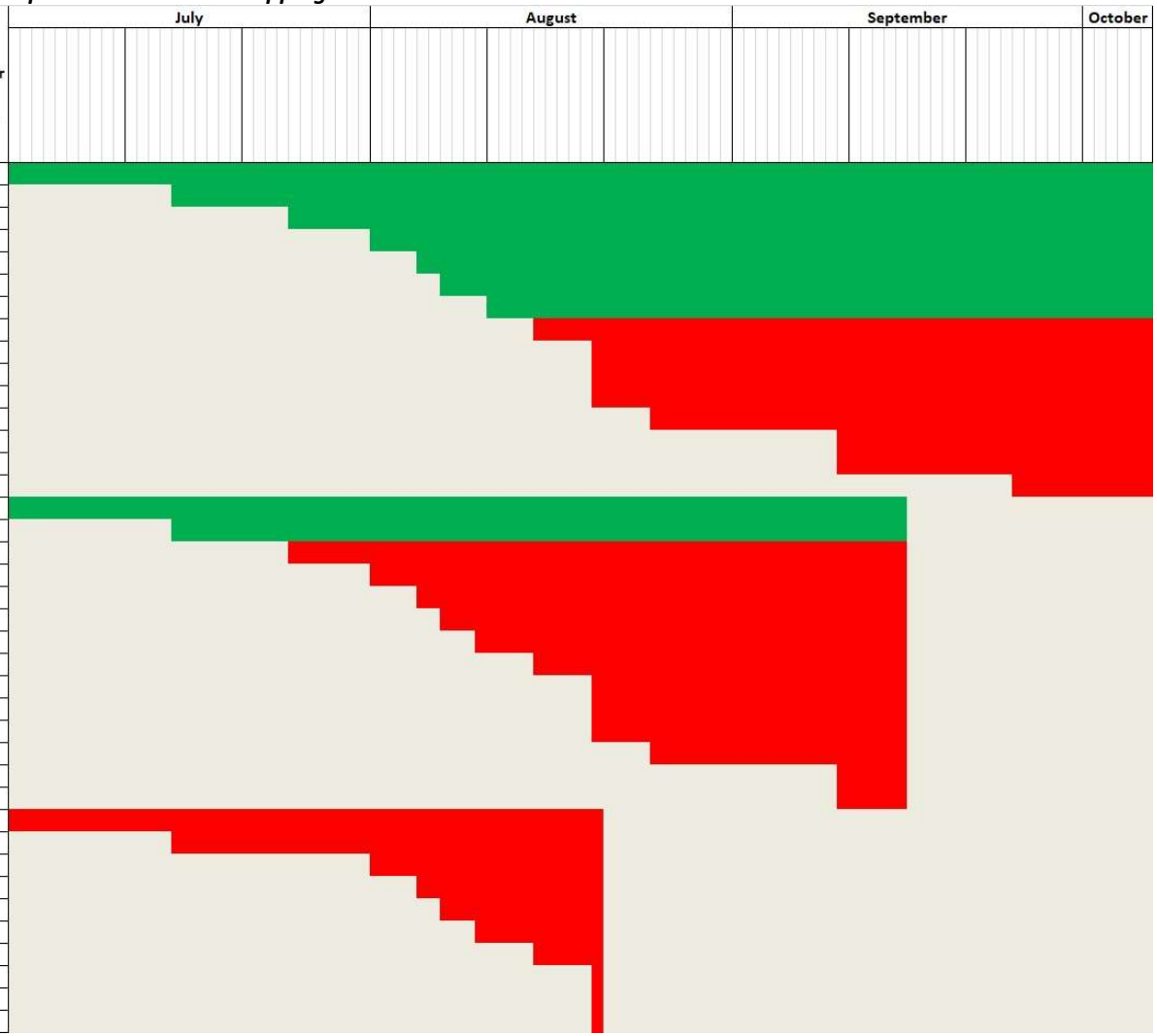
For sowing of post-harvest catch crops, the same machinery as for under-sowing can be used, also, a seeder combined with shallow stubble cultivation. With a double sowing rate, post-harvest catch crops can be sown by broadcasting when cereals are in the stage of early milk maturity. The following crops are recommended as post-harvest catch crops: oil radish, white mustard, rape, phacelia, buckwheat, lupine, peas and other fast-growing crops and their mixtures.

Seeding rate of post-harvest catch crops is several times higher compared with that of crops grown as the main crop. Seeding rate of post-harvest catch crops is determined by the sowing time. The later the crop is sown, the higher the seed rate is needed (*Diercks, Heitefuss, 1990*). Recommended seeding rate is 15–25 kg/ha.

In Lithuanian climatic conditions, under-sown catch crops produce larger biomass that post-harvest crops. When the main crop is harvested, under-sown catch crops have already undergone first stages of their development, and that increase the possibility of producing good soil cover and biomass.

Table 7. Time intervals between main crops suitable for post-harvest catch cropping

Preceding crop	Succeeding crop	Harvest time of the main crop	End of period for catch cropping*	Time interval suitable for catch cropping, days
Early potatoes	Spring crops or fallow	1-Jul	6-Oct	97
Winter barley	Spring crops or fallow	15-Jul	6-Oct	83
Winter rape	Spring crops or fallow	25-Jul	6-Oct	73
Winter wheat	Spring crops or fallow	1-Aug	6-Oct	66
Winter rye	Spring crops or fallow	5-Aug	6-Oct	62
Pea	Spring crops or fallow	7-Aug	6-Oct	60
Winter triticale**	Spring crops or fallow	10-Aug	6-Oct	57
Spring barley**	Spring crops or fallow	15-Aug	6-Oct	52
Spring wheat**	Spring crops or fallow	20-Aug	6-Oct	47
Oat	Spring crops or fallow	20-Aug	6-Oct	47
Spring triticale	Spring crops or fallow	20-Aug	6-Oct	47
Spring rape	Spring crops or fallow	25-Aug	6-Oct	42
Late potatoes	Spring crops or fallow	10-Sep	6-Oct	26
Faba beans	Spring crops or fallow	10-Sep	6-Oct	26
Buckwheat	Spring crops or fallow	25-Sep	6-Oct	11
Early potatoes	Winter cereals	1-Jul	15-Sep	76
Winter barley	Winter cereals	15-Jul	15-Sep	62
Winter rape	Winter cereals	25-Jul	15-Sep	52
Winter wheat	Winter cereals	1-Aug	15-Sep	45
Winter rye	Winter cereals	5-Aug	15-Sep	41
Pea	Winter cereals	7-Aug	15-Sep	39
Winter triticale	Winter cereals	10-Aug	15-Sep	36
Spring barley	Winter cereals	15-Aug	15-Sep	31
Spring wheat	Winter cereals	20-Aug	15-Sep	26
Oat	Winter cereals	20-Aug	15-Sep	26
Spring triticale	Winter cereals	20-Aug	15-Sep	26
Spring rape	Winter cereals	25-Aug	15-Sep	21
Late potatoes	Winter cereals	10-Sep	15-Sep	5
Faba beans	Winter cereals	10-Sep	15-Sep	5
Early potatoes	Winter rape	1-Jul	20-Aug	50
Winter barley	Winter rape	15-Jul	20-Aug	36
Winter wheat	Winter rape	1-Aug	20-Aug	19
Winter rye	Winter rape	5-Aug	20-Aug	15
Pea	Winter rape	7-Aug	20-Aug	13
Winter triticale	Winter rape	10-Aug	20-Aug	10
Spring barley	Winter rape	15-Aug	20-Aug	5
Spring wheat	Winter rape	20-Aug	20-Aug	0
Oat	Winter rape	20-Aug	20-Aug	0
Spring triticale	Winter rape	20-Aug	20-Aug	0



** - average daily air temperature not lower than 9 °C (till 6th of October), or before next main crop sowing*

*** - mustards or spring rape seeds can be broadcasted before winter triticale, spring barley or spring wheat harvest but not later 5th of August*

Soil properties

Development of every sown field crop greatly depends on soil quality. Different crops need different type of soils, different types and amounts of nutrients, and different amount of water (*Passioura, 2002*). The amount of water required by the plant also depends on the growing season and the climate where it is grown. Most of crops prefer well drained medium textured soils with optimum physical properties and neutral pH (*Ruza, 2013*). Since the availability of both water and plant nutrients is largely controlled by the physico-chemical and microenvironment of soils, the success and failure of any plant species, in a particular area is largely determined by these factors.

Sandy soils are referred to as coarse-textured and have the tendency to drain quickly after rainfall. Because they drain faster than other soil textures, they are subject to nutrient losses through leaching, and they also warm faster in spring. Sandy soils tend to have a low pH and very little buffering capacity; hence, are often acidic. Sandy soils have large particles and gaps between them. This allows water and nutrients to drain away freely, making sandy soils less fertile than heavier soils. Sandy soils also tend to dry out in summer. But they warm up quickly in spring and they are much easier to dig than clay-based soils. If soil is sandy, farmer may struggle with nutrient-hungry brassicas (such as rape, mustard, radish). Also, plants with shallow roots are prone to drying out as sandy soils lose moisture faster than heavier soils. **For sandy soils farmers can choose winter vetch and/or winter rye, buckwheat.**

Clay and silt soils – 'heavier soils' – have small particles. This means water is less likely to drain away, but the soil is more likely to become waterlogged. Heavier soils are fertile but take longer to warm up in spring and are harder to dig. **If it is clay soil, farmer should find that brassicas grow well, but some other crops are likely to struggle as they have to push through the heavy, often compacted soil.**

Soil's chemical composition has important implications on plant growth, in particular pH, or degree of acidity of the soil, that often is a symptom of some disorder in the chemical condition of the soil as it relates to plant nutrition. *(Allaway, 1957)*. Crops that grow well in high-pH soil may perform poorly in low-pH soil and vice-versa. The most favourable range of pH is between 5.8 -6.5 for most of crops. **For acid soils farmers can choose buckwheat.**

Although factors mentioned play an important role in catch crop choice, they are specific to a locality and should be studied and evaluated for each site.

Healthy, high-quality soil has:

- Good soil tilth
- Sufficient depth
- Sufficient, but not excessive, nutrient supply
- Small population of plant pathogens and insect pests
- Good soil drainage
- Large population of beneficial organisms
- Low weed pressure
- No chemicals or toxins that may harm the crop.

Table 8. Suitability of catch crops for different soil types

Soil	Suitable catch crops	Not suitable catch crops
Sand	Winter vetch, winter rye	Brassicas, catch crops with shallow roots (eg. pea, Italian ryegrass)
Loam	White mustard, winter rye, phacelia, buckwheat, winter vetch, pea, cock's foot, spring rape, forage radish	
Clay	Perenial ryegrass, cock's foot, brown mustard, oil radish, root radish, forage radish, turnip, white clover, red clover, white melilot, italian ryegrass, oat, black oat.	Winter turnip rape, rye, buckwheat, lupine

Climatic conditions

Catch crops have different tolerances to heat, drought shade, flood, soil fertility. If moisture requirements are not satisfied or low air temperature prevail – growing of catch crops can be restricted. Early frosts can negatively affect catch crops also. Buckwheat is most sensitive catch crop to early frosts (*Table 9*).

Table 9. Cultural traits of catch crops (adopted from SARE, 2012)

	Species	Type of catch crop[1]	Cold-frost resistance	Tolerances					Minimum germination temperature, ºC
				heat	drought	shade	flood	low fertility	
NON-LEGUMES	Italian ryegrass	U	◔	◔	◔	◕	◕	◔	4,4
	Oat & Black oat	Ph	○	◔	◔	◔	◑	◑	3,3
	Winter rye	Ph	●	◑	◕	◕	◑	●	1,1
	Buckwheat	Ph	NFT[2]	◑	○	◔	◔	◔	10,0
BRASSICAS	White mustard	Ph	○	◑	◕	◑	◔	◔	4,4
	Brown mustard	Ph	○	◕	●	◑	◔	◔	
	Oil (fodder) radish	Ph	◑	◑	◔	◑	◔	◔	7,2
	Root (tillage) radish	Ph	◔	◑	◑	◑	◔	◔	
	Winter rapeseed	Ph	●	◔	◑	◑	◔	◔	5,0
	Spring rapeseed	Ph	◔	◔	◑	◑	◔	◕	
	Winter turnip rape	Ph	◑	◔	◔	◑	◔	◔	
LEGUMES	Red clover	U	●	◔	◔	◕	◑	◔	5,0
	White clover	U	●	◑	◑	◕	◕	◑	4,4
	Berseem clover	U	◑	◕	◑	◕	◑	◑	5,6
	Persian clover	U	◔	◑	◔	◕	◔	◑	
	White melilot	U	●	◕	●	◔	◔	●	5,6
	Phacelia	U	○	◑	●	◕	◕	●	
	Pea	Ph	○	◔	◑	◔	◔	◔	5,0
	Winter vetch	Ph	●	◔	◑	◑	◔	◔	15,6

[1] U – undresown; Ph – post-harvest. [2] NFT – not frost tolerant.

○ - poor; ◔ - fair; ◑ - good; ◕ - very good; ● - excellent.

The success of catch crop cultivation depends on the sowing time and weather conditions during the second half of summer and autumn. Germination and emergence of crops are driven by soil temperature and water content, seedbed structure, size of aggregates and crust formation. Thus, stand establishment can vary depending on the way species respond to environmental conditions, especially soil water content and temperature. Good seed beds will obviously produce better crops than poor ones and helps to overcome unfavourable weather conditions. Cover crops are seeded either by broadcasting the seed onto the surface

of a prepared seedbed, using a conventional seed drill, minimum tillage drill or no till drill. Drilling places seeds directly into the soil providing better planting depth control and enhancing seed to soil contact. Good seed to soil contact helps protect the seeds from constant wetting and drying cycles that may hinder germination.

Catch crop mixes can be useful to overcome unfavourable weather or soil conditions to compare with stand of sole catch crop. Each crop in the mix may respond differently to soil, pest and weather conditions. Combining shallow and deep-rooted species in a mix allows the plants to use a greater portion of the soil profile for water and nutrient resources. Advantage of species mixtures is their different response to dry or wet soil conditions, ability to address multiple objectives at the same time. Mixes are also better for weed suppression. They shade the soil surface and compete with weeds for light, nutrients and moisture.

Preparation of soil

Under-sowing of grasses does not require additional preparation of soil, while for post-harvest crops more intensive soil preparation is needed. Research results demonstrate that in the fields with straw, germination of catch crops is better when they are sown with shallow stubble cultivation. By shallow stubble cultivation not only plant residues are incorporated for the primary mineralisation but also moisture from deeper soil layers is preserved, additionally, soil microorganisms which faster release nitrogen for initial plant growth get activated. Germination and development of catch crops depend on the amount of plant residues and the level of their incorporation in the soil. At the time of plant residue mineralisation and germination of catch crops, microorganisms and plants compete for nitrogen, therefore, an initial norm of nitrogen fertilizers (N 30 kg/ha) is recommended to be provided. Larger seeds (of peas, vetch, lupine) germinate only when incorporated at the depth of 3-4 cm and well covered with soil layer. For this reason, first stubbles are cultivated and afterwards seeding with a simple seeder is done. Seeds can also be broadcasted by using fertilizer spreaders and incorporated during stubble cultivation.

Timing and methods for incorporation

Many researches observe, that catch crops is a good source of nitrogen, however, due to low C/N ratio, mineralization of organic nitrogen compounds takes place during decomposition of the catch crop biomass, constituting a risk of nutrient leaching. Under warm and wet conditions, mineralization of incorporated catch crop biomass starts already in autumn. Leguminous crops decompose most rapidly, hence it is recommended to grow them in mixtures with grasses and brassicas. Catch crop biomass should be incorporated at the flowering stage. In light soils with good aeration, mineralisation of organic matter is especially intensive and mobile nutrients can be lost late in autumn or in winter. Therefore, it is recommended to grow winter crops or incorporate biomass of summer crops in spring. This way a positive effect of catch crops on physical properties of the soil is extended and established soil cover prevents leaching of nutrients over the winter. At the same time, frozen crop residues perform a function of mulch and protect soil surface from negative atmospheric impacts and preserve soil moisture for spring crops. Moreover, the later is incorporation of catch crops, the later mineralization starts and losses of mineralised nutrients decrease. Decomposition of organic nutrient compounds is determined by their chemical composition – proportion of easily degradable compounds and content of lignin.

Catch crop growing potentials in Venta and Lielupe RBDs

Catch crops can fit well into many different crop rotations during periods between two main crops when the soil would otherwise be bare for a long time (for instance, after wheat harvest and before sowing spring crops such as corn, sugar beet or potato). Often the main limiting factor for establishing catch crops is too short vegetation period left after the late harvested main crops. To grow sufficient biomass, even the latest seeding time having brassica species must by sown till 10-15th of August when the most of main crops are still on the field. Niches between the main cash crops generally determine catch crop growing potentials in Venta and Lielupe RBDs.

In Lithuania and Latvia winter wheat is usually succeeded by winter rapeseed. After good preceding crop, winter wheat is used to be reseeded for one year. For wheat stubble with perennial weeds chemical or mechanical weed control should be used. In some cases, perennial grasses can be under-sown in winter wheat in spring, however after the harvest, if winter wheat is followed by winter crops or perennial grasses, there is no possibility for catch cropping. Only in case when winter wheat is succeeded by spring crops (cereals, rape, row crops, etc.) there is good possibility for post-harvest or under-sown catch crops in between. Considering the current crop structure, today only approx. 30 percent of the area covered with winter wheat can be used for catch crop establishment (*Table 10*).

Winter rye can be grown in less productive, poor, sandy soil, even with low pH ≤ 5.5. Such soil conditions usually are not favourable for catch cropping. In more productive soils winter rye is preferred as preceding crop for winter rapeseed as well as other winter cereals. In such cases, there is no sufficient niche for catch crops in between the main crops. Only if winter rye is followed by spring cereals or other spring crops there is an opportunity for catch crops. Hence, only about 10 percent of area after winter rye can usually be used for catch crops.

Harvest time for winter triticale is about 7–10 days later than for winter wheat or winter rye. In comparison with other winter cereals, winter triticale is more susceptible for weed spreading and laying of crop stand. These are the main limiting factors for undersown catch crops. Post-harvest catch cropping is possible if winter triticale is succeeded by spring crops. Considering the above, only about 20 percent of area with winter triticale is potentially suitable for catch crop establishment.

In Lithuania winter barley is usually used as preceding crop for winter rapeseed. As there is no niche for catch cropping between these two crops, it is assumed that there is no potential for catch cropping after winter barley in Lithuania. In Latvia, winter barley is sometimes succeeded by spring crops, so experts estimate that some 10% of the area can be used for catch crops.

Spring barley in the farms with livestock can be undersown with perennial grasses and in such a case there is no possibility for catch cropping. Only minor part of spring barley area can be harvested before 10-15th of August, but some catch crops can be undersown in spring. Also catch crops (especially white mustard and spring rape) can be seeded before crop harvest, usually by broadcasting. Thus, approx. 30 percent of spring barley area can potentially be covered with catch crops.

Spring wheat is a late harvest crop, with a high stand. Therefore, this crop is not suitable for either undersown or post-harvest catch cropping. Catch crop (especially brassica) seeds can only be broadcasted before the harvest of spring wheat. Potential area for catch cropping is approx. 20 percent.

Early potatoes can be harvested even at end of June or beginning of July. Therefore, after early potatoes there are very good opportunities for growing long vegetation period legume and nonlegume catch crops. On the contrary, there are no possibilities for catch cropping after the late harvest potatoes. Depending on the potato's variety, potential area for catch crops is approx. 30 percent.

Depending on weather conditions, harvest time for pea is first and second decade of August. Pea is good preceding crop for winter rapeseed or winter wheat. Such circumstances define that only about 50 percent of the area after pea can be used for catch crop.

Winter rape is the main preceding crop for winter wheat in Lithuania, while Latvian farmers sometimes use it a preceding crop for spring crops. There is only very short niche of about 50 days between winter rape and winter wheat which is not sufficient for catch cropping, so experts assume that there are no possibilities for catch crops after winter rape in Lithuania. In Latvia, 10 % of the winter rape area is considered to be available for catch crops.

Harvest time of spring rape is too late for establishment of catch crops. It is considered as good preceding crop for winter wheat, so there is no sufficient niche for catch cropping after spring rape.

Establishment of catch crops after perennial grasses, bare land or fallow is not reasonable.

Sugar beet, corn, soya, fava bean, oat, spring triticale are harvested too late to leave a niche for establishment of catch crops.

Main crops after the harvest of which establishment of catch crops is possible and available niches for catch crops are summarised in *Table 10*.

Considering the current crop structure, project experts estimated catch crop growing potentials in Venta and Lielupe RBDs. For the assessment field declaration data for 2016 was used.

Calculation results demonstrate that on average 20 percent of arable land can be used for catch cropping. The potential is higher in counties where prevailing crop rotations include more crops with early harvest time leaving sufficient time for catch crops. Under current crop rotations, the potential is mainly determined by the areas of winter wheat and summer barley. Additionally, there are counties having significant areas with peas which are also favourable for establishment of catch crops.

Calculated catch crop growing potentials are presented in *Figure 5*. The potential is expressed as a percentage of arable land in each county which potentially can be used for the establishment of catch crops. The estimated potential represents the maximum area available for successful establishment of catch crops under the current crop rotations.

Table 10. Catch cropping potentials after the harvest of the main crops

Main crops after the harvest of which establishment of catch crops is possible	Main crops after the harvest of which establishment of catch crops is not possible
Winter wheat – 30 % of the area	Winter rape (in LT)
Winter rye (depending on soil conditions) – 10 % of the area	Spring rape
Winter triticale – 20 % of the area	Winter barley (in LT)
Spring barley – 30 % of the area	Perennial grasses (red clover, timothy, …)
Spring wheat – 20 % of the area	Bare land or fallow
Potatoes – 30 % of the area	Sugar beet
Pea and mixtures with pea– 50 % of the area	Corn
Winter barley – 10 % of the area (in LV)	Soya
Winter rape – 10 % of the area (in LV)	Fava bean
	Oat
	Spring triticale

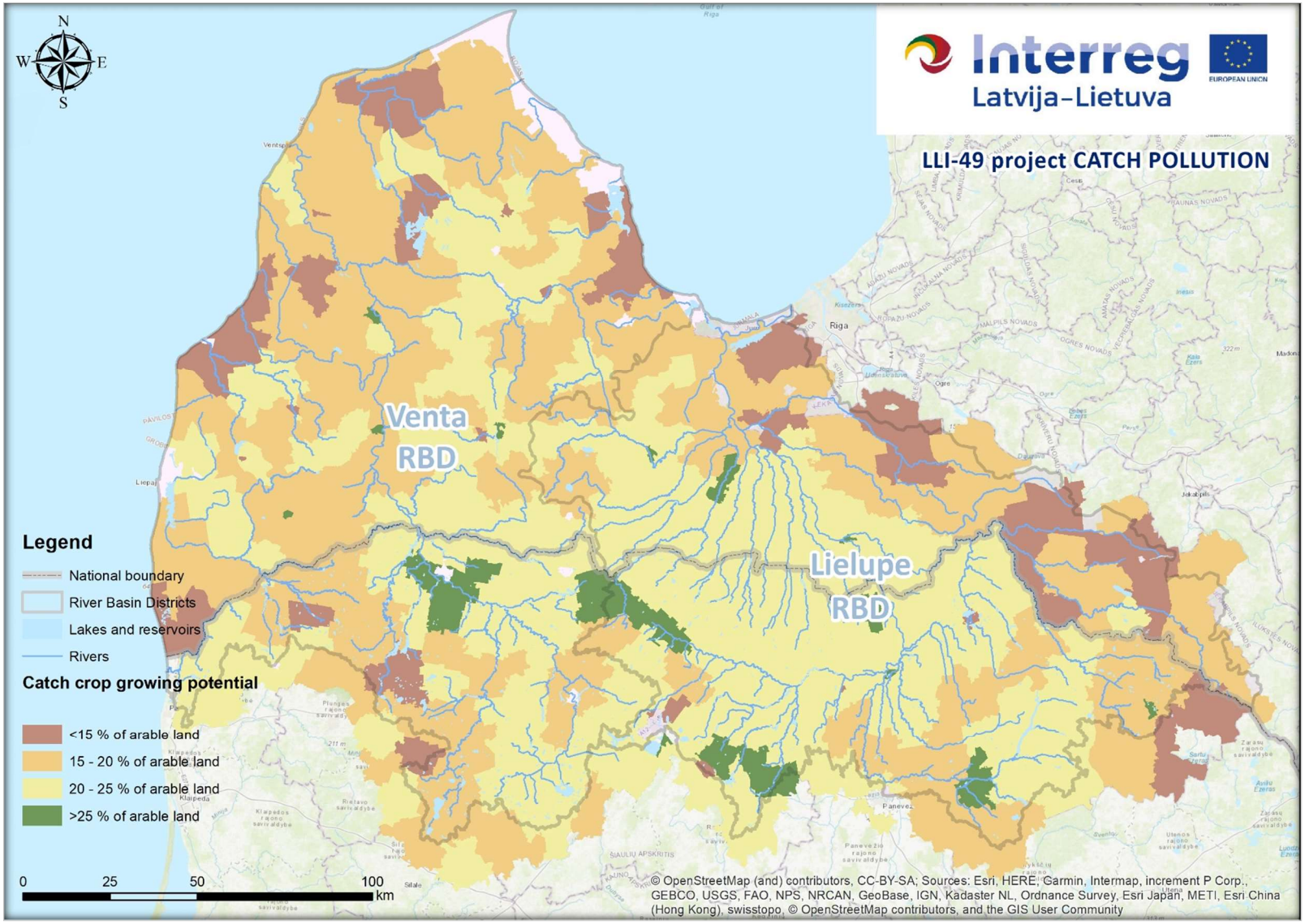
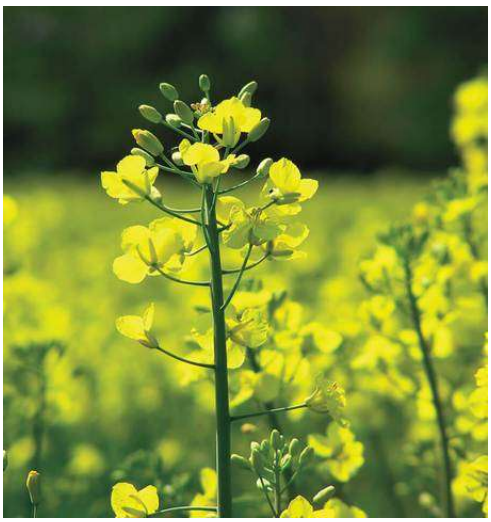


Figure 5. Catch crop growing potential in Venta and Lielupe RBDs (estimated by the project experts)

ANNEX I. Description of catch crops

Brassicas

White Mustard / *Sinapis alba*



Family: *Brassicaceae* (Cruciferae)
Growing form: Annual herb.

- Height: 30–60 cm. Stem branched, bristly, usually clearly coarsely hairy.
- Flower: Corolla regular (actinomorphic), yellow, approx. 1.5 cm across; petals four, 7–10 mm long. Sepals 4, spreading. Stamens 6, of which 4 long and 2 short. Gynoecium fused, a single carpel. Inflorescence an elongating raceme in fruiting stage.
- Leaves: Alternate, stalked. Blade coarsely hairy, irregularly pinnately lobed, terminal leaflet large. Uppermost stem leaves clearly lobed.

Cultivation

White mustard or Brassica alba has a preference for a light soil having a proper drainage. The best quality white mustard can be grown on a soil rich in nutrients and also having high amounts of nitrogen. Nevertheless, this species may also be cultivated on an assortment of soils ranging from light to heavy (clay) and even on soils that are comparatively heavy, but sandy and loamy. It is important to note that white mustard plants do not grow well in soils that are very damp. It has been found that white mustard plants thrive most excellently in places receiving average annual rainfall between 35 cm and 179 cm, the yearly temperature varies between 5.6°C and 24.9°C and the pH of the soil ranges between 4.5 and 8.2. White mustard is an annual species that grows quickly when the days are longer and has a preference for temperate climatic conditions having some amount of humidity in the atmosphere. The seeds take less than a week to germinate.

Sowing as catch crop

- **Should be sown after the cereal harvest from July through to the mid of August.**
- **Minimal seed bed preparation is required, but the good seed beds will obviously produce better crops than poor ones. Seed should be sown to a depth of 1-2 cm at 20-25 kg ha^{-1} depending variety.**
- **Mustard can be used in mixtures with legumes (e.g., clover, vetch) or grasses.**

Brown mustard / *Brassica juncea (L.) Czern.*

- Family: *Brassicaceae* (or *Cruciferae*)
- Growing form: annual plant

- Height: 90-200 cm. Stem is strait, at least lower leaves and lower part of stem are more or less hairy.
- Flower: yellow, approximately 1.5 cm across, petals four, 7–10 mm long, sepals 4, spreading. Stamens 6, of which 4 long and 2 short. Gynoecium fused, a single carpel. Inflorescence an elongating raceme in fruiting stage.
- Leaves: are not dilated at the base and clasping as in the case of rape, but are stalked and broad.
- Fruit: (pods) are slender and only 2.0-6.5 cm long strongly ascending with short and stout beaks. The color of seed is brown or dark brown. Seed coat is rough. Mustard is self-pollinated, but cross-pollination also takes place to some extent.

Cultivation

Well grown in full sun in most well-drained moisture-retentive fertile soils. Prefers a heavy soil and some shaded places. Dislikes very hot weather. Plants tolerate high rainfall and, although fairly deep rooted, are not very drought resistant. Tolerates pH in the range of 4.3 - 8.3. Plants take from 2 - 5 months from sowing to maturity, depending on the season and the cultivar. They prefer a fairly high stable temperature and are well adapted to short day length. Plants have a rooting depth is between 90-120 cm.

Sowing as catch crop:

- **Brown mustard is used as rotational cover crop in cropping systems as well as in row crop production. It has the potential to prevent erosion, alleviate soil compaction, and suppress weeds and soil-borne pests.**
- **The disperse of pest and diseases are generally not a problem in mustard but clubroot could become an issue if brassicas are used as a cover crop over many years.**
- **Brown mustard has rapid fall growth with high biomass production (on average from 1.2 to >4.0 t DM ha^{-1}) and nutrient scavenging ability (reduce nitrogen leaching by accumulating nitrogen in approximately by 70 kg N ha^{-1}).**
- **Seeding date: June - July; sowing rate: 10 - 15 kg ha^{-1}.**
- **Mustard can be used in mixtures with legumes (e.g., clover, vetch) or grasses.**

Oilseed (spring) Rape /*B. napus var. Oleifera*

- Subspecies, varieties and synonyms: Rape, Oilseed Rape, Rapa, Rappi, Cole, Canola (B. napus var. oleifera, B. napus ssp. oleifera), Swedish Turnip, Swede, Yellow Turnip, Rutabaga (B. napus var. rapifera, B. napus var. napobrassica, B. napus ssp. rapifera)
- Family: *Brassicaceae* (Cruciferae)
- Growing form: Annual or biennial herb.

- Height: 100–150 cm. Stem branched, glabrous.
- Flower: Corolla regular (actinomorphic), yellow, approx. 1–1.5 cm across; petals four, 10–15 mm long. Sepals 4. Stamens 6, of which 4 long and 2 short. Gynoecium fused, a single carpel. Inflorescence an elongating raceme in fruiting stage. Flowers fairly level with buds.
- Leaves: Alternate, lowest stalked, upper stalkless, amplexicaul. Blade glabrous, bluish green, basal leaves shallow-lobed, upper leaves entire, lanceolate.
- Fruit: Many-seeded, opens lengthwise, usually 5–8 cm long, spreading–quite erect siliqua, terminated by a terete, 1–2 cm long, seedless beak.

Cultivation

Oilseed rape will grow on a wide range of soils but, similar to white mustard, has a preference for a soil having a proper drainage. Growth is often restricted by:

- poor drainage
- soil compaction
- soil pH of less than 5.5

Oilseed rape is more sensitive to soil compaction than cereals. Soil compaction restricts rooting, which can reduce nutrient and water uptake. It is important to check problem areas in fields by digging inspection pits and correct using cultivations at the appropriate depth to alleviate compaction.

Sowing as catch crop:

- **Should be sown after the cereal harvest from June through to the mid of August.**
- **Minimal seed bed preparation is required, but the good seed beds will obviously produce better crops than poor ones. Seed should be sown to a depth of 1-2.5 cm being sown at 10-20 kg ha^{-1} depending variety.**
- **Can be used in mixtures with legumes (e.g., vetch, pea, fava bean) or grasses (ryegrass).**

Winter rape / *Brassica napus L.*

- Family: *Brassicaceae* (or *Cruciferae*)
- Growing form: annual or biennial plant

- Height: the stems is straight, simple to freely branched, glabrous or sparsely hairy and can grow up to 1.5 m tall. The seedlings grow to form a rosette of 5–6 leaves with the older leaves at the base and the smaller younger leaves in the center of the rosette. The basal rosette leaves are short-petiolate, toothed, glaucous, ovate to elongate and entire to lobed with 1 to 5 pairs of small lateral lobes and a large terminal lobe. In autumn, early sowing and a high nitrogen regime can accelerate plant development and elongate stem length resulting in increased susceptibility to frost damage.
- Flower: flowering begins at the base of the raceme and the buds form above the open flowers. The pale-yellow flowers have 4 sepals and 4 diagonally opposite obovate petals arranged in the form of a cross when viewed from above.
- Leaves: leaves are waxy with a glabrous underside and often have an enlarged base that partially clasps the stem. Leaves are hairless, smooth, fleshy and bluish-green in color.

Cultivation

Winter rape can be grown in mean summer temperatures ranges from 13.0°C to 16.0°C and mean winter temperatures that range from -14.5°C to -8.0°C and mean annual precipitation of up to 700 mm. The cultivation of winter rape is not suitable in soils with pH less than 5.5 or more than 8.3, in waterlogged soils. The optimal temperature for winter rape germination is 20°C. Unfavorable environmental conditions (e.g. temperature fluctuations, low soil moisture, prolonged darkness) may induce secondary dormancy in seeds.

Sowing as catch crop:

- **Winter rape has the potential to prevent erosion, alleviate soil compaction, and suppress weeds and soil-borne pests.**
- **The disperse of pests and diseases are generally not a problem in rape but clubroot could become an issue if brassicas are used as a cover crop over many years.**
- **Winter rape has rapid biomass growing ability (average yield in 4–6 t DM ha^{-1}) with good winter hardiness. The ability to reduce nitrogen leaching is higher on winter rape root weight basis than for many other *Brassicaceae* cultivars.**
- **Seeding date: June - August; sowing rate: 8.0 -20.0 kg ha^{-1}.**
- **Can be used in mixtures with legumes (e.g., vetch, pea, fava bean) or grasses (ryegrass).**

Oil radish / *Raphanus sativus L. var. oleiformis Pers.*

Family: *Brassicaceae* (Cruciferae)
Syn.: *Raphanus sativus* L. var. *oleiferus* Stokes

- Height: 90–130 cm. Stem branched, glabrous.
- Flower: Corolla regular (actinomorphic), white, petals and sepals- four.

Cultivation

Grow rapidly when planted in late summer and can provide full canopy closure in about three weeks. This canopy intercepts rain drops minimizing surface impact and detachment of soil particles. Even after radishes are killed by a hard freeze, a layer of decomposing residue remains on the soil surface throughout the winter and into the early spring providing erosion control. In addition, runoff and sediment transport are reduced because of the rapid infiltration facilitated by open root holes. For more complete protection against erosion, radish can be mixed with other cover crops that are winter hardy (e.g., cereal rye) or winter kill but leave more persistent residue cover (e.g., oats).

Radishes germinate rapidly, emerging within 3–4 days when environmental conditions are favourable. Seed broadcast on the surface can establish well if seeding is followed by a timely rain. Radishes have little tolerance of wet soils, so sowing in fields that collect standing water or are prone to prolonged wetness should be avoided. Radishes are very responsive to N, and N deficiency limits their ability to compete with weeds, grow through compacted soil, and perform other potential functions.

Sowing as catch crop:

- **Should be sown directly before or after the cereal harvest from June through to the mid of August.**
- **Minimal seed bed preparation is required, but the good seed beds will obviously produce better crops than poor ones. Seed should be sown to a depth of 1-2cm being sown at 15-25 kg ha^{-1} depending variety.**
- **Can be used in mixtures with legumes.**

Forage radish and root ***radish***/ *Raphanus sativus L.*

- Family: *Brassicaceae* (or *Cruciferae*)
- Growing form: annual plant

- Germination: radish usually emerges within just three days if the soil is warm and not too dry. Radish has a very flexible and aggressive growth habit and will spread out in a rosette to fill the space it is given.
- Development: forage and root radish develops via the succulent taproot reaching the depth in soil of 15 cm.
- Leaves: radish above ground growth consists of wide leaves that are soft, moist, and fast growing. The foliage reaches more than 50 cm in height in a semi-straight stature. Leaf stems easily break from the main root.

Cultivation

Radish is of cool season cover crop, best suited for early fall growth and develops within more than 60 days. Radish establishes quickly if soil moisture is adequate. Plants are not tolerant of shade, standing water or severely nitrogen-deficient soils. Radish plants tolerate soils with pH values of 6.0-7.5. While planting in intensively fertilized plots do not typically need additional fertilization. Plants cannot survive freezing temperatures of -7^{o}C or below.

Planting depth should be not less 1.5 cm. Drilling yields more successful stands, but seed can also be broadcast at a higher rate. Follow broadcast seeding with a light disking. Aerial/surface seeding can also be done on standing crops when the crops reach physiological maturity.

Sowing as catch crop:

- **Lower planting rates (4-5 kg ha^{-1}) produce larger taproots, which may prevent soil compaction; higher planting rates (15-20 kg ha^{-1}) produce smaller taproots and weaker plants. More root surface area may help trap more nematodes or assist with soil-borne pest suppression. Deep rooting plant extracts nutrients from deep in the profile and helps opening channels in the soil for subsequent crops, improves water movement and drainage and increases airflow through soil.**
- **The disperse of pests and diseases is generally not a problem in radish but clubroot could become an issue if brassicas are used as a cover crop over many years.**
- **Planted in spring, or late summer radish grows quickly and produces a large amount of biomass in a relatively short time. Total biomass generally exceeds 2 t DM ha^{-1}. Most cultivars produce more shoot than root biomass.**
- **Radish was shown to recycle more than 70 kg N ha^{-1} even in two months.**
- **Seeding date: July; sowing rate: 6.0 – 8.0 kg ha^{-1}.**
- **To enhance growth, can be used in mixtures with legumes.**

Turnip / *Brassica rapa L.*

- Common name - stubble, fall, white or Dutch turnip
- Family: *Brassicaceae* (or *Cruciferae*)
- Growing form: annual or biennial non-legume broadleaf. Turnip is a member of the mustard family and is therefore related to cabbage and cauliflower.

- Development: turnips are short-season root brassicas that provide roots, stem and leaf growth. Turnip is a biennial which generally forms seed the second year or even late in the fall in the first year if planted early in the spring.
- Leaves / storage root: leaves are usually light green, thin and sparsely pubescent (hairy). White-fleshed, large global or tapered root develops at the base of the leaf petioles. The storage root varies in size but usually is 15 cm and about 17 cm in long. The storage mot generally has little or no neck and a distinct taproot. The storage root can overwinter in areas of mild winter or with adequate snow cover for insulation and produce 8 to 10 leaves from the crown in a broad, low-spreading growth habit the following spring.

Cultivation

Turnip is cold-hardy and drought-tolerant. They can be planted late as a second crop and provide high-quality biomass late in the fall. Turnip planted in July will be biomass productive from September to November. The most vigorous root growth takes place during periods of low temperature in the fall. Turnips are a fast growing and high yielding crop. The leaves maintain nutritional quality even after repeated exposure of frosts.

Turnip grows best in a moderately deep loam, fertile and slightly acid soil. Turnip does not grow well in soils that are of high clay texture, wet or poorly drained. For good root growth turnip needs a loose, well aerated soil.

Sowing as catch crop:

- **Yields of turnip biomass ranges between 3–5 t DM ha^{-1}, even about 90 days after planting. Their deep rooting improves soil condition and relocate nutrients from the sub-soil to the top. Will also help reduce nitrogen leaching.**
- **The disperse of pest and diseases are generally not a problem in turnip but clubroot could become an issue if brassicas are used as a cover crop over many years. Turnip cannot be used in rotation with other *brassicaceae*.**
- **Seeding date: from June to the mid of August; sowing rate: 10.0–16.0 kg ha^{-1}.**
- **Can be planted as single-species catch crop or in a mixture with a legume (e.g., vetch, pea).**

Cereals/ grasses

Rye /*Secale cereale*

- Family: *Poaceae*
- Growing form: winter annual

- Height: 70-140 cm. Stem long, flexible, hollow, rod-shaped with structural nodes (6-7).
- Flowers: hermaphrodite and consist of three stamens Lodicules 2; ciliate. Anthers 3; 7 mm long. Ovary with a fleshy appendage below style insertion; pubescent on apex.
- Leaves: narrow, lanceolate or glabrous, grow alternately on the steam.
- Fruit: Caryopsis with adherent pericarp; obovoid; sulcate on hilar side; 8-10 mm long. Embryo 0.33 length of caryopsis. Hilum linear.

Cultivation

Rye is the best cool-season cereal cover for absorbing unused soil N. It has no taproot, but rye's quick-growing, fibrous root system can take up and hold a lot of N until spring. Rye is one of the best cool season cover crops for outcompeting weeds, especially small-seeded, light-sensitive annuals such as lambsquarters, redroot pigweed, velvetleaf, chickweed and foxtail. Rye also suppresses many weeds allelopathically (as a natural herbicide), and has been shown to inhibit germination of some triazine-resistant weeds.

Rye prefers light loams or sandy soils and will germinate even in fairly dry soil. It also will grow in heavy clays and poorly drained soils, and many cultivars tolerate waterlogging. Rye can establish in very cool weather. Because cereal rye matures earlier than other small grains, strict harvest and grazing management procedures are important to prevent it from becoming a weed.

Sowing as catch crop:

- **Results are best if rye is planted by the mid of August. It can be drilled or broadcast after main crop harvest, with or without cultivation. It can be seeded also before main crop harvest, usually by broadcasting.**
- **Soil moisture availability is crucial to, either for germination of the cover crop or to avoid competition for water with the main crop.**
- **Sowing rate: 110 – 140 kg/ha.**
- **Can be used in mixtures with legumes (e.g., pea, vetch, fava bean).**

Italian ryegrass */Lolium multiflorum*

- Annual ryegrass, also called Italian ryegrass
- Latin name: *Lolium multiflorum*
- Family: Poaceae
- Growing form: annual/biennial

- Height: 30–65 cm.
- Flower: consists of a flowering culm with alternate leaves about 1-3' tall.
- Leaves: the leaf sheaths are pale green to pale reddish green, hairless, and longitudinally veined.
- Fruit: At the apex of the culm, there develops a floral spike about 6-10" long, consisting of alternate spikelets along the rachis (flowering stalk).

Cultivation

Italian Ryegrass is a turf grass with a dense, shallow root system. The extensive root system of this cover crop tolerates compacted soils and makes it an effective catch crop for excess nitrogen. It offers many benefits, including erosion control, improvement of aggregate stability, and minimization soil compaction, which is useful in high traffic areas. It can also be used as a nurse crop with fall-planted legumes such as clover. Annual ryegrass grows vigorously enough to out-compete late summer annuals as well as winter annuals that start in the fall. Ryegrass will tolerate a wide range of soils but performs best on loam soils with high fertility. Rapid, dense growth will suppress weeds in 4-6 weeks and will provide winter cover. These many attributes make annual ryegrass an effective management tool in vegetable crop rotations.

It thrives on all kinds of soil and is mainly used for conservation in short duration leys, often in mixtures with Red Clover, helps to protect the soil from erosion especially during winter. Italian Ryegrass is often combined with Red Clover as clover is brilliant at collecting nitrogen but when dug in it rapidly decomposes & quickly releases the nitrogen.

Sowing as catch crop:

- **Prepare the soil by roughly digging it over and removing any weeds.**
- **Lightly tread the soil, and then sow the seeds by broadcast sowing (i.e. scattering evenly) for good coverage.**
- **Rows can be sown but are not as good for weed suppression.**
- **Rake the soil well.**
- **Seeding date: June; sowing rate: 35.0–45.0 kg ha^{-1}.**
- **Mixtures with legume catch crops can alleviate the N-immobilization effect.**

Perennial ryegrass */Lolium perenne*

- Perennial ryegrass or English ryegrass
- Latin name: *Lolium perenne*
- Family: *Poaceae*

- Height: ~90 cm.
- Leaves: The leaf blades are 2-5 mm. across and up to 6" long; they are medium to dark green, hairless, and ascending to widely spreading. The leaf blades are furrowed above and keeled below; they have whitened auricles (ear-like basal lobes) at their bases that clasp the culms. The leaf sheaths wrap tightly around their culms; they are medium green, hairless, and open.
- Flower: The blooming period typically occurs during early summer, although this may be delayed by disturbance. The florets are cross-pollinated by the wind. Afterwards, the florets of fertile lemmas are replaced by grains. At maturity, these grains are 3-5.5 mm. long, narrowly oblongoid in shape, narrowly grooved along one side, and light tan.

Cultivation

Optimum on normally drained to cool soils. Dry or wet soils are not suitable. Optimum on nutrient-rich or very rich soils and slightly acid to neutral. Quite indifferent to soil texture. Loams and clays are nevertheless more suitable. Sands can be suitable if the water supply (irrigation or water table close to the surface) and the nutrient availability are sufficient. Rarer on peat soils.

The roots are densely fasciculate. They can reach 1 - 1.5 m deep though the great majority of roots can be found in the first 15 centimetres of the soil. Root growth starts early in spring, almost 1 to 2 months before the leaves grow. It slows down in summer and restarts in autumn.

Under-sowing of perennial ryegrass doing in April-May with spring cereals or in a winter crop. The method is inexpensive, the establishment is reliable and the catch crop is ready to grow immediately after harvesting the main crop. Harvest problems might be a disadvantage.

Sowing as catch crop:

- **Lightly tread the soil, and then sow the seeds by broadcast sowing (i.e. scattering evenly) for good coverage. Rake the soil well.**
- **Should be seeded in June. Sowing rate 20-25 kg ha^{-1}.**
- **Mixtures with legume catch crops can alleviate the N-immobilization effect.**

Cock's foot / *Dactylis glomerata L.*

- Common name - cocksfoot grasses, orchard grasses
- Family: *Gramineae* (or *Poaceae)*
- Growing form: perennial plant

- Height: cock's-foot plants are 50-120 cm in tall.
- Leaves: 2-8 mm wide, and 20-30 cm long, v-shaped near the base tapering to a narrow tip with a prominent mid-nerve on the lower surface. The sheath is closed, auricles absent and the ligule is membranous and often split, merging with the throat margins.
- Development: cock's-foot is one of the earliest grasses to initiate growth in the spring with intensive growth during cool conditions. It produces an extensive root system with rooting depths to 60 cm.

Cultivation

Cock's-foot is adapted to moderate and to well-drained and acidic soils (pH 5.8-7.5) on textures ranging from clay to gravelly loams and shallow to deep soils. It does not grow well in saline soils and areas with high water tables within the rooting zone.

Cock's-foot performs in areas that receive 460 mm annual precipitation or on irrigated sites but will establish and persist in areas that receive less than 400 mm of annual precipitation. It will not tolerate soils that are saturated with water for extended periods of time. It will tolerate cold winters if snow insulates the ground during the coldest weather and it has good tolerance to high summertime temperatures and humidity. Cock's-foot is well-adapted to shady areas.

Sowing as catch crop:

- **Cock's-foot is a source of carbon and organic matter, it makes cover as a crop for fall or early spring. Left to grow without management after the cover cropping, cock's-foot can reach a height of 140 cm. It is long-lived and fast growing, producing faster re-growth in summer. The plant can be grown for biomass, annual productivity ranges from 2 to 37 t DM ha^{-1}. If soil fertility is low, a large portion of the total production occurs in the spring, but if the soil is highly fertile, production is well distributed throughout the growing season.**
- **Having a deep root system, the cock's-foot is useful for protection of soil erosion.**
- **Autumn to early winter is the preferred time for sowing a cock's-foot, as this will enable plants to develop a stronger root system. Spring sowing may be an option in higher altitude areas, or areas with more reliable rainfall over late spring and summer.**
- **Cock's-foot should be sown at rates of 1–3 kg ha^{-1}, in combination with annual or perennial legumes.**
- **As cock's-foot seed is very small, it should be sown no deeper than 10 mm.**

Oat and black oat */ Avena strigosa Schreb*

- Family: *Gramineae* (or *Poaceae)*
- Growing form: annual grass plant

- Height: oat and black oat is a tufted grass and grow to a height of 0.8-1.5 m, depending on growing conditions.
- Leaves: leaf blades are linear, flat, rough and numerous. The inflorescence is a loose open panicle. The panicle is drooping and bears pendulous, pedicellated spikelets. The inferior lemma is awned, straight and black (hence the name black oat), 1.5-3 cm long, somewhat lopsided (hence the name oat). *Avena strigosa* has morphological differences from the common oat (*Avena sativa*): it is leafier with side panicles (instead of equilateral), plump kernels (instead of narrow), and smaller seeds.
- Development: unlike common oats, black oat has excellent tillering potential to get the ground covered quicker. It has a dense root system. Oat roots are described as not being very effective at breaking up compacted soils into the depth.

Cultivation

Oat and black oat grow best in cool, moist environments, with soils that are moderately fertile. Plants have the potential to be grown on a wide range of soils and can tolerate a wider pH. Hot, dry weather conditions can really cause oat to struggle. Plants are not highly shade tolerant but can tolerate drought.

Black oat is one of the most sensitive cover crop species to residual herbicide damage. Black oat is highly resistant to barley yellow dwarf virus but is moderately susceptible to crown and stem rusts. Be sure to wait at least two weeks after termination before planting a cash crop after oats to minimize any negative effects from allelopathy chemicals that are excreted during decomposition. Oats have poor winter tolerance.

Sowing as catch crop:

- **Black oat biomass yield potential is much higher than traditional oats, respectively, 8 and 3 t DM ha^{-1}. Though the biomass C:N ratio tend to be 20-30:1, a little lower in comparison with traditional oats 30-60:1.**
- **Oats are excellent at breaking disease cycles and also has been shown to resist root-knot nematode. Allelopathic chemicals from plant decomposition have proven effect against broadleaf weed species.**
- **Black oat produces more mineral nitrogen than other cover crops. Especially, black oat is efficient at translocating soil phosphorus.**
- **Sow in late summer to grow a cover crop that forms its own mulch when it is winterkilled, or when using oats as a companion crop for slower-growing legumes. Oats also can be grown as a spring cover crop to increase soil organic matter.**
- **Oats can be sown alone or in mixtures with vetch, pea, or fava bean, etc.; sowing rate may vary from 180 to 230 kg ha^{-1}.**

Leguminous

White Clover /*Trifolium repens*

- Name also: Dutch Clover
- Family: *Fabaceae* (Leguminosae)
- Growing form: Perennial herb.

- Height: 10–30 cm. Stem creeping, rooting from joints, glabrous.
- Flower: Corolla zygomorphic, white (sometimes slightly reddish), later brownish, 8–10 mm long, fused at base. Petals 5; the upstanding the 'standard', the lateral two the 'wings', the lower two united to form the 'keel', overall shape of corolla being butterfly-like. Calyx 5-lobed, glabrous. Stamens 10. A single carpel. Inflorescence a long-stalked, densely globose head, flowers fragrant.
- Leaves: Alternate, long-stalked, stipulate. Blade with 3 leaflets; leaflets obovate–obcordate, with finely toothed margins, often with white patterning. Stipules mainly united with stalks.
- Fruit: Indehiscent pod, remains inside calyx.

Cultivation

White clover is long-lived and a low-growing perennial, tolerant of shade and slightly acid soil. White clover grows on a wide range of soils but grows better on clays and loams than on sandy soils. The soil pH range for white clover is between 5.5 and 7.0. White clover grows best where annual rainfall is close to 800 mm and conditions are cool and moist. The plant has some tolerance of shade, heat, flooding, and drought.

Sowing as catch crop:

- **To prepare land conventional tillage can be used, important is to maintain a firm seedbed. After seeding it is useful to roll the ground to improve seed-to-soil contact but do not break up soil aggregates.**
- **Seeding date: June. Seeding rate: 8 - 10 kg ha^{-1}.**
- **Can be used in mixtures with mustard or rye.**

Red Clover / *Trifolium pratense*

- Family: *Fabaceae*
- Growing form: Perennial herb.

- Height: 15–50 cm. Stem ascending–erect, often with many stems, runnerless.
- Flower: Corolla zygomorphic, violet-red (sometimes light red–white), 12–18 mm long, fused at base. Petals 5; the upstanding the 'standard', the lateral two the 'wings', the lower two united to form the 'keel' (overall shape of corolla being butterfly-like). Calyx 5-lobed, hairy all over, lowest lobe longer than others. Stamens 10. A single carpel. Inflorescence stalkless–short-stalked, dense, almost spherical, often 2 almost united.
- Leaves: Alternate, stalked, stipulate. Blade with 3 leaflets, leaflets lanceolate–elliptic, with entire–finely toothed margins, usually with white blotches. Stipules ovate, terminated by a short bristle, mainly united with stalks.
- Fruit: Indehiscent pod, remains inside calyx.

Cultivation

Red clover grows 20 to 60 cm height. Growth is best in moist, cool conditions. Usually flowers within 65 days of planting - will continue to flower every 30 to 35 days after harvest once established. Will grow on a wide variety of soil conditions - including slightly acidic pH. Shade tolerant. Best growth with soil pH 6.0 to 7.0. Slow growing at the beginning. It is most common cover crop. Its' easy establishment and shade tolerance make it useful in several cropping sequences.

Sowing as catch crop:

- **As catch crop can be used after potato harvest.**
- **To prepare land conventional tillage can be used, important is to maintain a firm seedbed.**
- **Drill or broadcast at 8-10 kg ha^{-1}.**
- **After seeding it is useful to roll the ground to improve seed-to-soil contact but do not break up soil aggregates.**
- **Seeding date: June.**
- **Can be used in mixtures with grains (e.g., oat, ryegrass).**

White Melilot / *Melilotus albus*

- Latin name also: *Melilotus alba*
- Name also: White Sweet Clover, Honey Clover
- Family: *Fabaceae* (Leguminosae)
- Growing form: Biennial herb.

- Height: 30–150 cm. Stem ascending–erect, branched, bristly, almost glabrous.
- Flower: Corolla irregular (zygomorphic), white, 4–5 mm long, fused at base. Petals 5; the upstanding the 'standard', the lateral two the 'wings', the lower two united to form the 'keel', overall shape of corolla being butterfly-like. Calyx 5-lobed. Stamens 10. A single carpel. Inflorescence an axillary, long raceme; flowers nodding.
- Leaves: Alternate, stalked, stipulate. Blade with 3 leaflets, terminal leaflet stalked. Leaflets elliptic–lanceolate, with toothed margins. Stipules entire.
- Fruit: 3–5 mm long, tapered, wrinkled surface, glabrous, when ripe dark brown, 1–2-seeded, indehiscent pod.

Cultivation

A well-cultivated, uniform and firm seed bed is required for good results. Seed is usually drilled or broadcast directly after conventional seedbed cultivations, but can also be sown under a cereal cover crop. Optimum seed depth is 2.0–3.0 cm, with a firm soil cover. Although usually sown in spring, it can also be sown in summer. Seed is normally scarified before sowing. Seed rates are 9–12 kg ha^{-1} for scarified seed when pure sowing, but reduced to 4–5 kg ha^{-1} if sown in mixture with grasses such as perennial ryegrass (*Lolium perenne*). Responds to high fertility, particularly of P and K. Optimum pH range is 6.5-7.5. White sweet clover is small seeded and rather slow to establish, and problems with weeds should be expected. Sweet clovers may benefit from being sown along with a small grain as companion crop.

Sowing as catch crop:

- **Different soil management practices can be used: mouldboard plough, rotavator, tandem disc, offset disc, and heavy duty cultivator for incorporating sweet clover prior to spring cereals planting.**
- **Seeding date: June. White sweet clover should be seeded at 17 up to 25 kg ha^{-1}.**
- **Can be grown in mixtures with oats.**

Winter vetch, common and hairy vetch/ *Vicia sativa* L. and *Vicia villosa* L.

- Family: *Fabaceae*
- Growing form: winter-hardy species plant

- Plant characteristics: is a slender, winter annual with compound leaves and narrow leaflets. Vetches have pinnate leaves, meaning that they alternate on opposite sides of a main petiole. Vetch has tendrils that terminate the leaves which are used to attach itself to other plants and for support. It usually has two purple flowers in axil of leaves on very short pedicels. Leaves alternate, compound, ending in a tendril, with 5–10 pairs of narrowly oblong leaflets, typically hairy.
- Distribution: vetch is a branching, spreading annual that forms a dense ground cover. Flowers in 10 cm long racemes on long peduncles arising from leaf axils, with 10–30 flowers of the pea type all turned to one side of stalk, in varying colors: rich lavender, purple, violet, or white.
- Rooting: below ground vetch roots is forming nitrogen nodules.

Cultivation

It can be grown in diverse soil types, from shallow duplex soil to heavy clays, and in soils with pH levels from 4.5 to 8.0, with the exception of saline soils and those prone to surface sealing. Low to medium rainfall zones (<325–450 mm) are considered to provide the best growth conditions for the winter vetch. Winter vetch is somewhat shade-tolerant.

Winter vetch seed remains viable for 5 years or longer. It is well-adapted to moderately to well-drained, fertile soils. It is a self-reseeding species and rapidly colonizes low fertility, open spaces. When vetches are seeded following a cultivated crop, little seedbed preparation is needed.

Sowing as catch crop:

- **Winter vetch an excellent crop for fixing nitrogen and competing against weeds. This is probably the most suitable legume for sowing as a cover crop due to its ability to fix nitrogen at lower temperatures than many other legumes.**
- **Winter vetch biomass yield potential is reaching 5.0 t DM ha^{-1}. While, aboveground biomass nitrogen accumulation may increase by 90-120 kg N ha^{-1}.**
- **One other benefit of cover cropping is that soil borne pests, particularly those associated with cereals and grasses have their life cycles disrupted and are generally less troublesome in subsequent crops. H6wever, diseases of vetches include anthracnose, leaf spot and downy mildew, several stem and root rots, and rust. Many of the insects of forage legumes attack vetches. Hairy vetch is susceptible to root-knot nematodes and soybean cyst nematodes.**
- **Seeding date: from June to the mid of August; sowing rate: 80–160 kg ha^{-1}.**
- **Can be used in mixtures with cereal grains, such as rye, oat.**

Pea / *Pisum sativum* L.

- Family: *Fabaceae*
- Growing form: annual plant

- Plant characteristics: pea plants are low growing (less than 0.75 meters) or vining. The vining grow thin tendrils from leaves that coil around any available support and can climb to be 1–2 m high. Field pea is a cool-season crop; planting can take place from winter to early summer depending on location. The stem is hollow, and the taller cultivars cannot climb without support. Leaves are alternate, pinnately compound, and consist of two large leaf like stipules, one to several pairs of oval leaflets, and terminal tendrils.
- Rooting: below ground field pea roots is forming nitrogen nodules.

Cultivation

Peas are adapted to many soil types, but grow best on fertile, light-textured, well-drained soils. Peas are sensitive to soil salinity and extreme acidity. The most proper soil pH for pea growth is 5.5 to 7.0. Peas grow well with 400 mm annual precipitation. Uncovered pea plants may tolerate temperatures to -10°C, and if covered with snow, may tolerate temperatures as low as -10°C. Peas are more tolerant of cold if they are a winter-hardy cultivar, planted early to ensure adequate growth before the soil freezes, and planted into a rough seedbed or grain stubble where they have a protected environment.

Sowing as catch crop:

- **Peas are grown as green manures and cover crops because they grow quickly and contribute nitrogen to the soil. Pea roots have nodules, formed by the bacteria *Rhizobium leguminosarum*, which convert atmospheric nitrogen (N2) to ammonia (NH3). Peas also produce an abundance of succulent vines that breakdown quickly and provide nitrogen.**
- **Field pea biomass yield potential is 8-10 t DM ha^{-1}.**
- **Peas and other legumes are desirable in crop rotations because they break up disease and pest cycles, provide nitrogen, improve soil microbe diversity and activity, improve soil aggregation, conserve soil water.**
- **Seeding date: from June to the mid of August; sowing rate: 200 - 250 kg ha^{-1}.**
- **Can be used in mixtures with cereal grains, such as rye, oat.**

Fava bean / *Vicia faba*

- Family: *Fabaceae*
- Growing form: annual plant

- *Vicia faba* is an upright annual forage legume that can grow to a height of 1.5-2 m
- It has a taproot and many fibrous lateral roots that explore up to 90 cm of the soil area
- The stems are coarse, hollow, and unbranched
- Fava bean has tillers that grow from the basal nodes

Cultivation

Beans can grow and thrive in cool wet soils, and are one of the highest nitrogen-fixing grain legumes. Well grows in clay and loamy soils. Tolerate a wide pH range (from 4.5 to 8.3) but prefers neutral, low acidity soils with pH ranging from 6.5 to 7. Does not tolerate drought and water logging. Beans are susceptible to weed competition during early development. Large seeds—tricky to sow and compose mixtures.

Sowing as catch crop:

- **Should be sown in a depth of 6-10 cm. In dry conditions depth should be increased. Sowing rate has to be high enough. Row sowing highly recommended. After seeding it is recommended to roll the ground.**
- **Seeding date: from June to the mid of August; sowing rate: 220 - 260 kg ha^{-1}.**
- **Can be used in mixtures with grains (e.g. oat), other legumes (e.g. vetch) or brassicas (e.g. rapeseed).**

Blue bitter lupine / *Lupinus angustifolius*

- Family: *Fabaceae*
- Growing form: annual plant

- *Lupinus angustifolius* is a short-hairy annual 20-150 cm tall
- Leaves: digitate, sparsely hairy
- Flowers: clusters
- Root: white, deep, strong taproot with nodules
- Very strong, extensive root system

Cultivation

Lupin is a legume crop that is well known for adding nitrogen to the soil. Blue lupin is tolerant of sand, and is adapted to neutral to moderately-acid sandy loams or loamy sands. It is fairly efficient at extracting phosphorous from the soil. It produces very tiny roots and they produce citric acid that buffers the immediate environment on the roots and they actually raise the pH and make phosphorus available. They also have a deep taproot that mines for subsoil potash. Bad fertility does not hurt this crop. Requires lots of water to trigger germination - only germinates in the right weather conditions. Sensitive to dry conditions in late summer. Dies off at temperatures below -4 to -6 °C.

Sowing as catch crop:

- **Roots penetrate soil deeply.**
- **Nitrogen-fixing.**
- **Plenty of green manure mass that dies off in winter.**
- **Roots improve soil both biologically and mechanically.**
- **Roots penetrate compacted soil layers.**
- **In light soils should be sown at the depth of 3-4 cm, in heavier soils – at the depth of 2 – 3 cm.**
- **Seeding date: June; sowing rate: 150 - 200 kg ha^{-1}.**
- **Can be used in mixtures with oat.**

Other

Buckwheat / *Fagopyrum esculentum Moench.*

- Family: *Polygonaceae*
- Growing form: annual self/cross pollinated plant

- Height: buckwheat plant is a broad leaved, straight with a single main stem and a branching plant. The main stem is grooved, succulent and smooth except at the nodes. Plants generally grow to 0.6-1.3 m in tall. The stems are hollow and subjected to breakage by high winds. Prior to maturity, the stems and branches vary from green to red. They become reddish brown at maturity.
- Leaves: buckwheat has leaves that vary in size, arrangement and shape, but the leaf stalk is always surrounded by a membranous or chaffy sheath at the base.
- Flowering: lowers are often grouped in clusters that are showy owing to the color of the sepals or bracts, for there are no petals.
- Rooting: plants have a short taproot and fine lateral roots producing a root system that is about 3-4 percent of weight of the total plant. The plants can suffer from extreme drought conditions which usually results in delayed maturity.

Cultivation

Buckwheat grows best in soils with light to medium texture and good drainage and tolerate moderately acidic soils (to pH 5). It will not grow well in compacted, saturated, or coarse soils and is not tolerant of frost, flooding, soil crusting or extreme drought. Buckwheat is better adapted to low-fertile soils than most other crops and often the residual nutrients from preceding crops are enough for adequate growth.

Sowing as catch crop:

- **Buckwheat can be grown as a cover crop to prevent erosion, improve soil aggregate stability, scavenge nutrients such as phosphorus and calcium, and mineralize rock phosphate. When buckwheat residue is incorporated into the soil, it rapidly breaks down and releases nutrients for uptake by the subsequent crop. Buckwheat has the potential to suppress root pathogens.**
- **High soil pH is the major limiting factor affecting buckwheat growth. The plant can be grown for biomass but will produce it in extent of 0.5-0.7 t DM ha^{-1}.**
- **Buckwheat forms symbiosis with arbuscular mycorrhizal fungi; buckwheat root colonization ranges from low to medium.**
- **Buckwheat has the potential to fit into many rotations. Sowing rate may vary from with ratio 80-100 kg ha^{-1}. Recommended sowing date: June-July.**
- **Can be planted in mixtures with mustard and legumes.**

Phacelia/ *Phacelia tanacetifolia*

- Other common names Fiddleneck, Scorpion Flower
- Latin name*: Phacelia tanacetifolia*
- Family: *Boraginaceae*
- Growing form: can be annuals, biennials or perennials

- Height: 20-120 cm.
- Leaves: pinnately divided.
- Flower: racemes or panicles of tubular or bell-shaped blue, white or yellow (in LV mostly using blue).

Cultivation

Phacelia germinates at low temperatures, is tolerant of cold temperatures and is suited to most soils. The fast-growing foliage will help suppress weeds, producing lots of organic matter while making an attractive groundcover. If left to flower it is beneficial for bees and insects and is quite simply a beautiful flower.

Phacelia produces a fibrous root system where root mass is very effective at catching excess nitrates in the soil before they can leach into the groundwater.

Phacelia flowers from 6 to 8 weeks from sowing for around a period of 6 to 8 weeks. Phacelia is a long-day plant and requires a minimum of 13 hours of daylight to initiate flowering. Easy to grow, if you do not want the plants to set seed, remove the spent flowers as they fade. Phacelia does self-seed very easily so if it is used as a green manure dig in before flowering or cut down and compost the foliage. Small patches can be left to flower, especially near to vegetables to attract pollinating insects to the area.

Better grow in fertile, well-drained soil in full sun.

Phacelia is a prolific self-seeder but never gets invasive as the seedlings are easy to pull out or hoe off. The plant can also cope with dry soil once established.

Sowing as catch crop:

- **Prepare the soil. Phacelia seed should be broadcast on a finely prepared seedbed. Remove weeds especially perennials and rake the surface of the soil.**
- **Scatter the seed thinly. Cover to a depth of about 1cm.**
- **Should be seeded from June to the mid of August.**
- **Sowing rate 10-12 kg ha$^{-1.}$**
- **Can be used in mixtures with buckwheat.**

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