European Commission

Natural Water Retention Measures

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Individual NWRM

Crop rotation

Office International de l'Eau

ACTeon environment research & consultancy

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Environment

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I. NWRM Description

Crop rotation is the practice of growing a series of dissimilar/different types of crops in the same area in sequential seasons. Judiciously applied (i.e. selecting a suitable crop) crop rotation can improve soil structure and fertility by alternating deep-rooted and shallow-rooted plants. In turn this can reduce erosion and increase infiltration capacity, thereby reducing downstream flood risk. It gives various benefits to the soil. A traditional element of crop rotation is the replenishment of nitrogen through the use of green manure in sequence with cereals and other crops. Crop rotation also mitigates the build-up of pathogens and pests that often occurs when one species is continuously cropped. However, as crop rotation has been traditionally practiced for agronomic reasons rather than to achieve environmental and water objectives, new practices may be required to ensure water retention benefits can be achieved. Some crops such as potatoes carry greater risks of erosion due to formation of ridges and the greater area of bare soil (see for example: http://publications.naturalengland.org.uk/file/5925127770341376). Crop rotation can be used in combination with other measures when these are compatible with crop choice.

II. Illustration

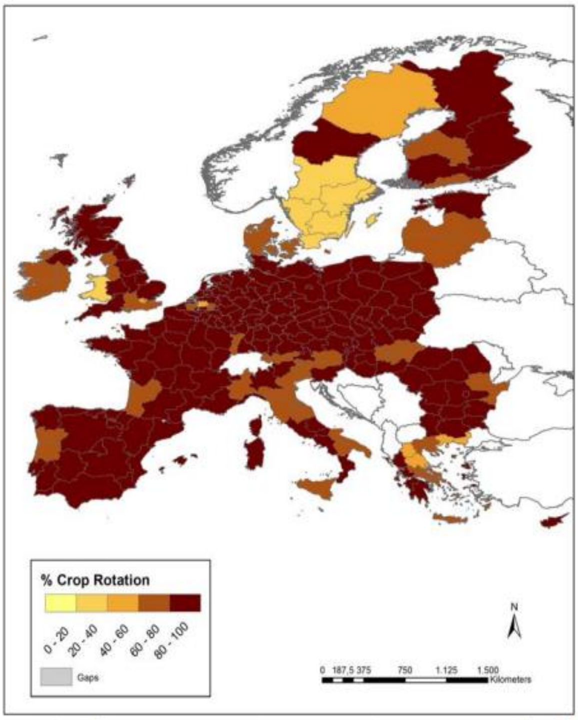
Illustration 1: Example of northern European crop rotation

Source: images (C) SRUC

III. Geographic Applicability

Land Use	Applicability	Evidence
Artificial Surfaces	No	
Agricultural Areas	Yes	Crop rotations involve several crops, mostly cash crops (cereals), legumes, and temporary grasslands (BIO Intelligence Service with support from Hydrologic, 2014). It can include pluri-annual crops.
Forests and Semi-Natural Areas	No	
Wetlands	No	

Region	Applicability	Evidence
Western Europe	Yes	Crop rotation is widely undertaken in most of the EU-27 regions, as the EU-27 average of crop rotation implementation out of total arable land is approximately 86% (BIO Intelligence Service with support from Hydrologic, 2014). Under continental climate (Eastern Germany, Poland, Czech Republic, Hungary, Slovakia, Austria and Romania), crop rotation can include potatoes and beets. Under oceanic climate (Ireland, the UK, the Netherlands, Belgium, Denmark, most of France, western Germany and the oceanic coast of Spain), crop rotation include high yielding varieties (horticultural species and fruits). Under Mediterranean climate (Spain, Italy, South of France, Greece and Cyprus), rotations can include permanent culture (olives, fruits), legumes, beans, alfalfa and maize (BIO Intelligence Service with support from Hydrologic, 2014).
Mediterranean	Yes	
Baltic Sea	Yes	
Eastern Europe and Danube	Yes	



Crop rotation as percentage of arable land in Europe (Berta Sánchez et al, 2013)

IV. Scale

	0-0.1km^2	0.1-1.0km^2	1-10km^2	10-100km^2	100-1000km^2	>1000km^2
Upstream Drainage Area/Catchment Area	✓	✓				
Evidence	Crop rotation is designed and implemented at the farm scale and at each field scale. In terms of drainage, the concerned area is the field itself. In Europe, field size can vary a lot across states and agriculture types in each state; in France (Latruffe, 2013) and Denmark (Levin, 2006) for instance, mean field size is a bit more than 4ha.					

V. Biophysical Impacts

Biophysical Impacts		Rating	Evidence
Slowing & Storing Runoff	Store Runoff	None	
	Slow Runoff	Medium	Carefully designed crop rotations can reduce the period of time that soil is left bare or fallow. This may lead to increased infiltration and runoff reduction (BIO Intelligence Service, 2014)

<table>
<tr><td rowspan="2"></td><td>Store River Water</td><td>None</td><td></td></tr>
<tr><td>Slow River Water</td><td>None</td><td></td></tr>
<tr><td rowspan="3">Reducing Runoff</td><td>Increase Evapotranspiration</td><td>None</td><td></td></tr>
<tr><td>Increase Infiltration and/or groundwater recharge</td><td>Medium</td><td>Carefully designed crop rotations can reduce the period of time that soil is left bare or fallow. This lead to increased infiltration and runoff reduction.</td></tr>
<tr><td>Increase soil water retention</td><td>Medium</td><td>Crop rotations play a role in soil water retention by maintaining soil cover, improving soil structure and increasing soil organic matter, which insures better water absorption and holding capacity (BIO Intelligence Service, 2014).</td></tr>
<tr><td rowspan="2">Reducing Pollution</td><td>Reduce pollutant sources</td><td>Medium</td><td>Crop rotation can improve fertilization efficiency by several means: making mineral elements available for following crops, increasing humus rate in the soil, increasing organic concentration in the soil etc.
A study conducted by Arvalis and GNIS (Cavaillès, 2009) in France showed that introducing a different crop before wheat could lead to decreased Nitrate inputs (or N losses) in wheat production for the same yield objective:
From wheat-wheat to:
• wheat-legume -20 to -40 kgN/ha
• rapeseed-wheat: -20 to -40kgN/ha
• sunflower-wheat: 0 to +30kgN/ha
• alfalfa-wheat: -25 to -40 kgN/ha first year, -45 to -60 kgN/ha second year
• purple clover-wheat: -20 to -40 kgN/ha first year, -60 to -90 kgN/ha second year
Crop rotation is also efficient in managing grass cover. By limiting adventitious flora, it can lead to decrease pesticides use.</td></tr>
<tr><td>Intercept pollution pathways</td><td>High</td><td>Compared to monocultures or land left fallow, crops catch nutrients brought for the current and previous crop and prevent them from being lost to the soil and groundwater. Regarding the succession, nutrients inputs and use by crops can lead to different levels of nitrate losses.
A study led by Besnard and Rio (2006) showed that nitrate losses in rotations following pastures could reach:
• 165 (reduced tillage) to 240 (tillage) kg/N/ha/year in pastures</td></tr>
</table>

			• 250 to 270 kg/N/ha/year in rotations including rapeseed and wheat • 505 to 550 kg/N/ha/year on bare soil
Soil Conservation	Reduce erosion and/or sediment delivery	Low	Carefully designed crop rotations can reduce the period of time that soil is left bare. This leads to increased infiltration and runoff reduction, and contributes to reduce soil erosion. A study conducted by Gooday et al (2014) showed that crop rotation could decrease sediments loss by 0.9 to 3.3% in Wales.
	Improve soils	High	Crop rotation may have a positive impact on pore morphology and connectivity and on aggregate stability. The development of earthworms benefits to the continuity of soil porosity. These beneficial impacts depend on the choice of crops and of the rotation scheme, and on the associated practices.
Creating Habitat	Create aquatic habitat	None	
	Create riparian habitat	None	
	Create terrestrial habitat	None	
Climate Alteration	Enhance precipitation	None	
	Reduce peak temperature	None	
	Absorb and/or retain CO_2	Medium	Introducing specific crops in rotations, such as legumes, can improve carbon sequestration compared to bare soil or other crops. Cavaillès (2009) showed that increasing legume part in rotations by 4 to 7% could lead to 11 to 16% reduction of GES emissions.

VI. Ecosystem Services Benefits

Ecosystem Services		Rating	Evidence
Provisioning	Food production	Low	Crop rotations require consideration of yields at a pluri-annual scale and for different crops (compared to monoculture). Comparison is difficult since crops are not equally valued and do not serve the same functions. Conclusion on food production is thus difficult to address. A field experiment led by Arvalis (2008) in France gives some results about yields in wheat monoculture and crop pea-wheat-barley rotations: • with tillage: 89q/ha wheat + 54q/ha pea + 75 q/ha barley // 3 X 82 q/ha wheat • reduced tillage: 92 q/ha wheat + 53 q/ha pea + 73 q/ha barley // 3 X 75 q/ha wheat • no tillage: 96 q/ha wheat + 52 q/ha pea + 75 q/ha barley // 3 X 81 q/ha wheat
	Water Storage	None	
	Fish stocks and recruiting	None	
	Natural biomass production	None	
Regulatory and Maintenance	Biodiversity preservation	Low	Bio Intelligence Service (2010) note that the impact of crop rotation on biodiversity (soil and above ground) is complex and relies on the choice of crops used and management actions. Harmful inputs may be reduced, but field operations and soil disturbance may be damaging. Maintaining a heterogeneous habitat may be beneficial.
	Climate change adaptation and mitigation	None	
	Groundwater / aquifer recharge	Medium	By enhancing infiltration, crop rotation contributes to groundwater recharge.
	Flood risk reduction	Low	By slowing down runoff and enhancing infiltration, crop rotation contributes to flood risk reduction.
	Erosion / sediment control	Low	Crop rotation may reduce the period of bare or fallow soil. Together with soil structure improvements this leads to increased infiltration and runoff reduction, and contributes to reduce soil erosion. A study conducted by Gooday et al (2014) showed that crop rotation could decrease sediments loss by 0.9 to 3.3% in Wales.

	Filtration of pollutants	Medium	Well-designed crop rotations can reduce the overall quantity of pollutants by optimising nutrient use, reducing losses at critical times and reducing disease burden (BIO Intelligence Services, 2010). The sequence of crop in the rotation, nutrients inputs and use by crops can lead to different levels of nitrate losses. Besnard and Rio (2006) showed that nitrate losses in rotations following pastures could reach: • 165 (reduced tillage) to 240 (tillage) kg/N/ha/year in pastures • 250 to 270 kg/N/ha/year in rotations including rapeseed and wheat • 505 to 550 kg/N/ha/year on bare soil
Cultural	Recreational opportunities	None	
	Aesthetic / cultural value	Medium	Crop rotation contributes to landscape heterogeneity.
Abiotic	Navigation	None	
	Geological resources	None	
	Energy production	None	

VII. Policy Objectives

Policy Objective		Rating	Evidence
Water Framework Directive			
Achieve Good	Improving status of biological quality elements	None	

	Improving status of physic-chemical quality elements	Medium	Crop rotation can help improving status of physicochemical quality elements by two mechanisms: - improving soil fertility and thus reducing the need for nitrate inputs - enhancing nutrient catching by crops and thus reducing nutrients losses. These two mechanisms highly rely on an efficient reasoning of crop rotations and crops management. The type of crop and their succession impact the effects on soil fertility and nutrient catching. A study conducted by Arvalis and GNIS (Cavaillès, 2009) in France showed that introducing a different crop before wheat could lead to decrease Nitrate inputs needed in wheat production for the same yield objective: From wheat-wheat to: • wheat-legume -20 to -40 kgN/ha • rapeseed-wheat: -20 to -40kgN/ha • sunflower-wheat: 0 to +30kgN/ha • alfalfa-wheat: -25 to -40 kgN/ha first year, -45 to -60 kgN/ha second year • purple clover-wheat: -20 to -40 kgN/ha first year, -60 to -90 kgN/ha second year Crop rotation is also efficient in managing grass cover. By limiting adventitious flora, it can lead to decrease pesticides use. A study led by Besnard and Rio (2006) showed that nitrate losses in rotations following pastures could reach: • 165 (reduced tillage) to 240 (tillage) kg/N/ha/year in pastures • 250 to 270 kg/N/ha/year in rotations including rapeseed and wheat • 505 to 550 kg/N/ha/year on bare soil Crop rotation is also one of the measures which can be combined at field scales in cultivated areas to improve water status, subject to the rotation design and crop selection.
	Improving status of hydromorphological quality elements	None	
	Improving chemical status and priority substances	Low	Bio Intelligence Service (2010) note that diverse crop rotations as part of integrated pest management can reduce disease and pest impacts reducing the need for pesticide inputs. In turn this will reduce the quantities of these substances reaching water bodies.

Achieve Good GW Status	Improved quantitative status	None	By enhancing infiltration, crop rotation contributes to groundwater recharge.
	Improved chemical status	None	Based on the same principles as the ones leading to improve status of physicochemical quality elements (see above), crop rotation can also contribute to prevent ground water status deterioration in cultivated areas.
Prevent Deterioration	Prevent surface water status deterioration	Medium	Based on the same principles as the ones leading to improve status of physicochemical quality elements (see above), crop rotation can also contribute to prevent surface water status deterioration in cultivated areas.
	Prevent groundwater status deterioration	None	Based on the same principles as the ones leading to improve status of physicochemical quality elements (see above), crop rotation can also contribute to prevent ground water status deterioration in cultivated areas.
Floods Directive			
Take adequate and co-ordinated measures to reduce flood risks		Low	Crop rotation can be one of the measures taken in rural areas in order to reduce flood risks. Indeed, by slowing down runoff and enhancing infiltration, crop rotation contributes to flood risk reduction. These benefits would be dependent on the choice of crops and rotation sequence.
Habitats and Birds Directives			
Protection of Important Habitats		None	
2020 Biodiversity Strategy			
Better protection for ecosystems and more use of Green Infrastructure		Medium	
More sustainable agriculture and forestry		Medium	Crop rotation is part of the measures increasing agriculture sustainability. Compared to monoculture, crop rotation enables to maintain good conditions for further cropping, mostly through soil fertility preservation. Crop rotation is also an effective mean to fight pests and grass and prevent (by alternating of crops and pesticides) from pests adaptation to pesticides.
Better management of fish stocks		None	
Prevention of biodiversity loss		None	

VIII. Design Guidance

Design Parameters	Evidence
Dimensions	
Space required	
Location	
Site and slope stability	
Soils and groundwater	
Pre-treatment requirements	
Synergies with Other Measures	Crop rotation can be combined with a range of other agriculture measures provided that these are compatible with crop selection. These include: no tillage, conservation tillage, green cover, early sowing, controlled traffic farming and mulching.

IX. Cost

Cost Category	Cost Range	Evidence
Land Acquisition		
Investigations & Studies		
Capital Costs	32€/ha	In the report Green Infrastructure Implementation and Efficiency (Tucker, 2011), an average cost of 32€/ha is calculated for changing crop rotations and increasing fallow index in crop rotations. Introducing a greater diversity of crop types may require investment in specialised machinery (or incur contractor costs) for those crops.

Cost Category	Cost Range	Evidence
Maintenance Costs	400€/ha	The ongoing costs of crop rotations will depend on the interaction of crop selection and sequence on nutrient requirements and pest pressures; in turn this will affect input costs. Specific costs are likely to be context specific Arvalis (2008) give a French example of input costs for pea-wheat-barley rotation compared to wheat monoculture: • with tillage: 387€/ha (22€/ha more than wheat monoculture) • reduced tillage: 407€/ha (38€/ha less than wheat monoculture) • no tillage: 408€/ha (40€/ha less than wheat monoculture)
Additional Costs	128€/ha	Subsidies for supporting crop rotation development have been estimated to 128€/ha/year in Europe (Stella Consulting, 2012).

X. Governance and Implementation

Requirement	Evidence
Farmers involvement	Crop rotation is implemented on private areas (fields). Even considering regulation (in the implementation), farmers' buy-in to environmentally beneficial crop rotation implementation and management is necessary to guarantee positive biophysical impacts. In the case of crop rotation, impacts on soil fertility and nutrient loss are highly dependent on crop and succession management.
Europe and/or state and/or local communities financial support and/or regulation	Crop rotation can imply implementation costs for farmers and decreased benefits, at least in the first years of the implementation. Without support or compensation from public stakeholders and/or regulation, environmentally beneficial crop rotation is not likely to develop. The CAP, through the 1st and 2nd pillar, allows that support.
Research and experimentation and technical support	Crop rotation can be more or less efficient regarding its environmental impacts and its food production level, depending on the way the succession is thought through and managed. Such management is quite complex and benefits from research and experimentation (field tests) and exchanges between farmers. Indeed, technical aspects of crop rotation design and management need to be discussed and learnt by farmers to enable crop rotation applicability. Stakeholders involved in farming technical support have an important role to play on providing support and knowledge exchange networks, see for example http://www.inspia-europe.eu/. Research also plays and important role, for example: http://www.hutton.ac.uk/about/facilities/centre-sustainable-cropping

Coordination and animation	In order to be efficient in reaching policy objectives, crop rotation should be part of a wider program of measures and be considered at a sufficient scale. If implemented only at individual field scale, the measure will not be sufficient to impact on water quality or flood control. Coordination of measures at a relevant scale (watershed) can make the implementation of the measure more effective. Local authorities, local water or agricultural stakeholders (consular chambers, watershed agencies...) have a role to play.

XI. Incentives supporting the financing of the NWRM

Type	Evidence
Subsidies	Agri-environmental measures are strengthened in the new CAP under the 'greening' regulations; specifically crop rotations are considered equivalent measures with respect to the requirement for crop diversification. In the previous CAP, agri-environmental measures were implemented up to 2013 in member states, partly financed by European funds (EAFRD) and partly by national funds. In France, the so-called Rotation Agro-environmental measure supported crop rotation implementation (3 crops or 2 crops plus a grassland, excepting green cover) by providing 32€/ha payment under contract (per year).
CAP Pillar II: agri-environment-climate measures, organic farming	Crop rotations are potential agri-environment and climate measures under article 28 of Regulation 1305/2013. They may also be encouraged under article 29 on organic farming.

XII. References

Reference
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