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Catch Crops in Lower Saxony—More Than 30 Years of Action against Water Pollution with Nitrates: All in Vain?

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Abstract: Intensive animal production, vast amounts of biogas plants, and the spreading of manure and digestates, exerts strong pressure on water quality in the German federal state of Lower Saxony. Catch and cover crop (c&c) cultivation is seen as one measure to inhibit nitrate leaching into soils, and to prevent water pollution with nitrates. A document analysis was carried out, covering the time span of 1992 to 2020, and the findings were combined with available quantitative data of the same period, and with GIS analysis. From 1994 to the year 2020, the acreage of subsidized c&cs increased from ca. 10,000 ha to ca. 380,000 ha. In addition, there was an acreage of unsubsidized c&cs of about 100,000 ha declining to 50,000 ha. In comparison, the acreage of arable land remained at approximately 1,880,000 ha. We found that c&cs did not contribute substantially to water protection for the following reasons: the design of the measure, control of farmer's actions, and the antagonistic trend due to the increase in animal numbers and biogas plants. The development of c&cs over time and space reveals that frame conditions and management requirements of cultivating c&cs need to be well designed to be effective and efficient (with regard to N reduction and reduction of costs). It is vital to coordinate all programs and schemes in one region. From our evaluation, we conclude that a measure such as c&c cultivation, which is simple to introduce and easy to control, should be implemented over winter as a mandatory measure in order to achieve a greater uptake. Additionally, result-based measures could complement this scheme, as there is a strong link between subsidy level and the success of the measure.

Keywords: catch crops; cover crops; nitrate; groundwater pollution; fertilization; agri-environmental and climate measures; ecological focus areas; Lower Saxony cooperation model



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1. Introduction

The German federal state of Lower Saxony is characterized by intensive animal production and a large number of biogas plants. The spreading of manure and digestates exerts strong pressure on water quality. Catch and cover crop (c&c) cultivation is one measure to reduce nitrogen leaching and run-off. Since the early 1990s, the cultivation of c&cs was supported by various schemes. Following the long-standing German tradition of cooperative solutions in policy development [1], during the last 30 years, water suppliers and politicians have opted for cooperation and voluntary measures, combined with financial and/or technical support, to increase c&c cultivation and other measures meant to reduce (ground)water pollution.

Between 1998 and 2018, the annual surplus of the farmgate budgets in cooperation areas (water protection and abstraction areas, where water suppliers subsidize farmers to apply measures against (ground)water pollution) decreased from 95 kg N/ha

UAA (utilized agricultural area) to 55 kg N/ha. Purchases of mineral N dropped from 139 kg N/ha UAA to 93 kg N/ha, while manure N application increased from 91 kg N/ha UAA to 101 kg N/ha. Between 2009 and 2018, farmgate budget surplus was reduced by 11 kg N/ha UAA, and the mineral N concentration in soils dropped on average by 12 kg N/ha UAA [2,3].

However, water quality indicators mostly stagnated, despite increasing efforts and costs. In 2018, in 37% of all sampling points in the water abstraction areas for drinking water supply, nitrate concentrations were higher than the limit of 50 mg/L according to the EC Groundwater Directive [4]. Nitrate concentrations in monitoring wells dropped from an average of 68 mg/L in 2000 to 60 mg/L in 2018. This reduction slowed down considerably since 2008, and nitrate concentrations stabilized at the federal state level [2,3], and, in some areas, it even increased [5].

The reasons for this tendency are the high application rates of manure and mineral fertilizers, the turning of grassland, the high percentage of maize in crop rotation, and the high number of biogas plants [6].

With this background, we have a closer look at the implementation of c&cs in Lower Saxony during the last three decades. We estimate the implementation costs and deduce whether, and under which conditions, subsidizing c&cs as a voluntary measure was a cost-efficient strategy to improve drinking water quality.

Furthermore, we assess the implications of the new rules of the German Fertilization Ordinance [7], as a national implementation measure of the EU Nitrates Directive [8] and of the CAP reform in 2023, with respect to conditionality and eco-schemes.

2. Materials and Methods

2.1. Analysis of Documents and Statistics

We conducted a document analysis and combined our findings with available quantitative data. Statistical data on the acreage of c&cs under the different schemes are published at the national and federal state level as tables or as part of reports (Appendix A). We reviewed the legislation and scientific papers, as well as the grey literature and reports, in order to thoroughly evaluate the different programs, such as cooperation between water companies and farmers, agri-environmental and climate measures (AECM), and greening measures in the framework of the common agricultural policy (CAP). We structured all relevant literature according to institutions, date and title of publication, and link to the website, if available (Appendix A).

2.2. GIS Analysis

A GIS analysis was carried out to identify geographical location and extent of overlap of areas where different schemes are offered, respectively, where there are modifications in legislation. The following maps were downloaded:

- A map from the LEA (rural development and promotion on agriculture; Landentwicklung und Agrarförderung) portal on areas with vulnerable groundwater bodies according to Fertilization Ordinance [7], an administrative regulation at a national level [9], and the corresponding Lower Saxony implementing legislation [10]: <https://sla.niedersachsen.de/landentwicklung/LEA/> (accessed on 10 February 2022).
- A map from the Lower Saxony Ministry of Environment, Energy, Construction and Climate Protection (Niedersächsisches Ministerium für Umwelt, Energie, Bauen und Klimaschutz), which shows all areas of the Lower Saxony cooperation model according to [11] and all regions where groundwater bodies are in bad condition according to [12]: <https://urls.niedersachsen.de/2pe2> (accessed on 10 February 2022). QGIS was used to overlay layers (change in colour and transparency).

For quantifying the degree to which cooperation areas and the newly defined vulnerable groundwater bodies, according to the Fertilization Ordinance, overlap, an overlap analysis was conducted (input of intersection as the overlay layer, addition of a new column

to calculate overlapped area (\$area)), finding the percentage of overlap by adding a new column and calculating as follows: $\text{intersection_area}/\text{area of base polygon} \times 100$.

3. Results

A clear definition of c&cs is a precondition for further research on their application as a mitigation measure against groundwater pollution, and the implementation of these measures in legislation and cooperation contracts.

3.1. Definition of c&cs According to Their Agronomic Utilization

There is a clear distinction between catch crops, cover crops, and green manure [13–15]:

- Catch crops are grown with the purpose of preventing nitrogen leaching. Excess nitrogen may derive from the preceding crop, or it may be mineralized during or after harvest (from soil organic matter). Catch crops incorporate soil mineral nitrogen into their plant biomass, and they also counteract leaching due to a reduction in drainage water [16]. Therefore, good agricultural practice for improving groundwater quality implies that catch crops receive no N fertilization, and should not include leguminous crops. There are many field tests that prove that leguminous catch crops or catch crop mixtures with leguminous species, do not reduce the risk of leaching, respectively only reduce this risk to a minor extent [13,14,17,18]. Catch crops are, therefore, preferably cultivated in zones where the precipitation exceeds evapotranspiration, either naturally, as in central Europe, or artificially, as in arid or semiarid conditions under irrigation [17]. While yields under non-leguminous catch crops were not significantly different from those of conventional, bare fallow systems, leaching was reduced by 70% on average [19]. Nitrogen uptake is regularly 30 to 40 kg N/ha [20,21], but may reach more than 100 kg N/ha [22,23].
- Cover crops are grown to protect soils from erosion [24]. They cover the soils during periods where land would otherwise be uncovered and susceptible to losses to water and wind, particularly during the autumn and winter seasons. In the United States, cover crops are used in summer rain regions with arable production (maize, wheat, soybeans), often in close crop rotations. Farmers in these regions appreciate the effect of cover crops against soil erosion, soil organic matter increase, and weed suppression [24,25]. In the case that leaching outside the main vegetation period is not a problem, leguminous cover crops can be used as a component of mixtures or in pure form.
- Green manure consists also of leguminous crops grown to increase plant/soil health, soil fertility, and thus improve the N supply for succeeding crops [15]. Green manure is not grown for water protection purposes (in order to prevent leaching or run-off).

C&cs may be sown in summer/autumn after the main crop is harvested, or they may be undersown in autumn/spring, together with the main crop [26]. Undersowing of catch crops is applicable particularly for northern countries with short vegetation period, where the development of catch crops in autumn is hampered [27], or in case of dry periods after the harvest of the main crop [28]. As with undersown c&cs, tillage after harvest in autumn can be prevented, there is less stimulation of mineralization of soil organic matter, and therefore, less mineral nitrogen in the soil [27]. C&cs that are sown with or after the main crop, and that show their main plant growth in late summer and autumn, are classified as summer c&cs. Main crop utilization occurs in autumn, plants may be destroyed by frost or may remain as winter-hardy crops on site. Winter c&cs, on the other hand, are sown in autumn after the main crop, and use both the autumn and spring as vegetation periods. Characteristically, they consist of winter-hardy species, and there is a harvest of plant biomass in spring [26].

3.2. Historical Development of the Introduction of Different Schemes

In Lower Saxony, institutionalized agricultural water protection measures, in water protection and abstraction zones, started in 1992 as a so-called voluntary cooperation

between water companies and farmers. Procedures were laid down in the Lower Saxony Water Act [11]. In 2016, 74 cooperations in 374 drinking water abstraction areas were organized in the “Lower Saxony cooperation model” [2,3]. Farmers receive advisory service for free, and get financial compensation for the implementation of mitigation measures. Almost unique among German federal states is the establishment of a water abstraction fee, to be paid by water companies and by the industry abstracting groundwater. This fee—the water penny—is used for compensating farmers in cooperation areas for implementing mitigation measures. The coordination unit represents the Lower Saxony Water Management, Coastal Defence and Nature Conservation Agency (NLWKN). Recently, the water abstraction fee was doubled in order to better solve pollution problems [11], last amended in 10 December 2020. Since 2013, the accompanying advisory service is paid for by EU, via the European Agricultural Fund for Rural Development (EAFRD), the so-called CAP pillar 2 support for development of rural areas; previously, the advisory service was paid by the federal state, and later through the water penny. Modes of financial support are assembled in a directive at the federal state level [29].

In Germany, agri-environmental and climate measures (AECM) for all federal states are presented and summarized by a coordinated planning committee, and laid down in the framework program as the ‘Improvement of the agricultural structures and coast protection’; the latest plan was published for the period 2020–2023 [30]. Detailed definition and implementation of measures lies within the responsibilities of the federal states. In Lower Saxony, the establishment of c&cs as AECM has been supported since 2008.

From 2015 onwards, c&cs were cultivated in Lower Saxony as one option for ecological focus areas (EFAs) in order to fulfil the new greening rules during the CAP period 2014–2022.

In 2020, the national implementation of the Nitrates Directive [8], and the Fertilization Ordinance [7], was amended. Following Germany-wide common rules [7,9] on the definition of nitrate-polluted groundwater bodies and phosphorus-polluted surface waters, the delimitation of corresponding “red areas” was implemented into Lower Saxony legislation in 2021, together with the specified management restrictions for these red areas [10].

With the new CAP, to be implemented in 2023, the conditionality will be strengthened by a redefinition of the GAEC (good agricultural and environmental conditions) criteria. These basic GAEC standards represent sustainable agriculture, and will have to be followed by all farmers in the EU. The principle of conditionality also implies that farmers only receive subsidies under the condition that the GAEC principles are fulfilled. The recent GAEC 7 definition “minimum soil cover to avoid bare soil in periods that are most sensitive” [31] is not (yet) particularly implemented in German legislation.

The findings above are summarized in the timeline in Figure 1 to visualize the succession of schemes in which c&cs were implemented in Lower Saxony. This timeline also includes present and possible future mandatory legislation at the national and EU level.

3.3. Management Requirements of Different Schemes

In Table 1a–d, the different schemes under which c&cs were cultivated in Lower Saxony in the past, or will be cultivated under in the future, are described, including their requirements for agricultural management. While Table 1a–c contains voluntary schemes, Table 1d lists mandatory programs. Criteria for the characterization of schemes are (1) date of first introduction of the c&c scheme, (2) source of funding, (3) regional scenario, (4) level of subsidy, (5) contract duration, (6) funding rules, (7) whether schemes are mandatory or voluntary, (8) whether schemes are action-based (funds are paid when measures are implemented) or result-based (funds are paid when certain indicators, e.g., N surplus or N_{\min} in soil, are reached) (9), specification of seeds, such as type and number of species, (10) latest sowing date, (11) restrictions for fertilization, (12) restrictions for pesticides, (13) latest turning over date.

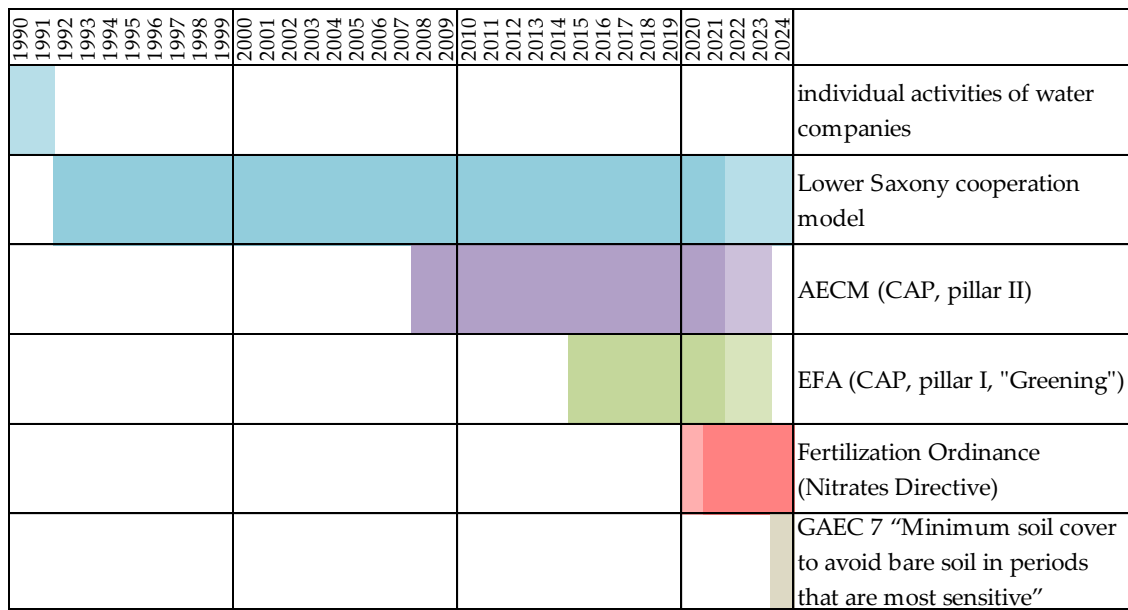


Figure 1. Timeline for different schemes related to c&cs. GAEC, good agricultural and environmental conditions.

Table 1. Different schemes with c&cs in the past, at present, and in future.

(a) Different Schemes with c&cs in the Past, at Present, and in Future			
Program	Lower Saxony Cooperation Model (OOWV)		
Scheme	Cooperation OOWV, Municipalities of Norden and Bad Zwischenahn		
Measure	Volunteer Oilseed Rape	c&c before Summer Crop with Limited N Fertilization	c&c before Summer Crop
Code	IE 511	IE 508, IE 509, IE 510	IE 508, IE 509, IE 510
introduction c&cs	2010	2010	2016
funding	Lower Saxony "water penny"		
regional scenario	Municipalities of Norden and Bad Zwischenahn		
subsidy	40 €/ha	IE 508: 120 €/ha; IE 509: 100 €/ha IE 510: 80 €/ha	IE 508: 120 €/ha; IE 509: 100 €/ha IE 510: 80 €/ha
contract duration	1 year		
funding rules	no combination with AEEM, A7 (=no double funding)	combination with AEEM, ecological farming allowed (double funding, 20 €/ha reduction of subsidy); combination with registration as EFA (Greening) allowed (double funding, 75 €/ha reduction of subsidy)	
mand. or voluntary	voluntary		
result-based	no		
seeds; type and number of species	volunteer oilseed rape	no legumes allowed; no cereals allowed; no harvesting of turnips; seeding after 31 August only with winter-hardy species/mixtures containing ≥30% winter-hardy species	no legumes allowed; no cereals allowed; no harvesting of turnips; seeding after 31 August only with winter-hardy species/mixtures containing ≥30% winter-hardy species

Table 1. Cont.

sowing date	no active sowing; soil cultivation to promote dense growth of volunteer oilseed rape seeds	after harvest of main crop, IE 508: until 20 August IE 509: until 31 August IE 510: until 15 September	after harvest of main crop, IE 508: until 20 August IE 509: until 31 August IE 510: until 15 September
fertilization	No fertilization allowed	no N fertilization after potatoes, maize, oilseed rape IE 508: maximum N fertilization with 60 kg N _{tot} /ha (*) until 20 August; IE 509: maximum N fertilization with 60 kg N _{tot} /ha (*) until 31 August; IE 510: maximum N fertilization (no organic fertilizers) with 30 kg N _{tot} /ha until 15 September;	fertilization according to Fertilization Ordinance and recommendations of Lower Saxony chamber of agriculture: IE 508: maximum N fertilization with 30 kg NH ₄ -N/ha or 60 kg N _{tot} /ha (**) until 20 August; IE 509: maximum N fertilization with 30 kg NH ₄ -N/ha or 60 kg N _{tot} /ha (**) until 31 August; IE 510: maximum N fertilization (no organic fertilizers) with 30 kg N _{tot} /ha until 15 September;
pesticides		no specification	no pesticides; only mechanical destruction of plants
turning over date	in spring 2011	longest 4 weeks before seeding date of the summer crop	longest 4 weeks before seeding of the summer crop; not before 15 February
(b) Different Schemes with c&cs in the Past, at Present, and in Future			
Program	Lower Saxony Cooperation Model		AECM
Scheme	NLWKN Catalogue of Measures		PROFIL (2007–2013)
Measure	Actively Sown Catch Crop or Self-Greening, Legume Free	Groundwater (GW) Protecting Manage-Ment of Arable and Grassland	c&cs and Undersown c&cs, Both Winter-Hardy and Legume Free
Code	IE	III	A7
introduction c&cs	2016	2016	2004 (*)
funding	Lower Saxony “water penny”	Lower Saxony “water penny”	EU-pillar II, Germany, Lower Saxony
regional scenario for funding	water protection and abstraction areas (11% of UAA)		2005, 2009 targeted: GW bodies in bad condition (WFD); after 2010: Lower Saxony-wide; also measure against erosion
subsidy	max. 249 €/ha	max. 588 €/ha	basic funding: up to 70 €/ha
contract duration	variable	variable	5 years
funding rules	no	no	no
mandatory or voluntary	voluntary	voluntary	voluntary
indicator (result-based)	no	autumn N _{min} value ≤ 35 kg N/ha	no
			basic + additional funding: up to 110 €/ha (A7 + 40 €/ha)
			5 years
			no
			voluntary
			no

Table 1. Cont.

seeds; type and number of species	no legumes allowed (in ecofarming legumes limited according to water protection needs)	no specification	actively sown, no self-greening allowed	actively sown, no self-greening, no legumes (ecofarming: legumes allowed mixed with non-legumes), seed mixtures in winter-hardy species \geq 30% of weight share
sowing date	latest 1 October	no specification	latest 15 September	latest 15 September
fertilization	no specification	no specification	no specification	no N fertilization: 1 June–31 May and after potatoes, maize, oilseed rape
pesticides	not allowed	no specification	no specification	no specification
turning over date	not before 15 February, only mechanical destruction of plant biomass	no specification	not before 15 February	not before 15 March
(c) Different Schemes with c&cs in the Past, at Present, and in Future				
Program	AECM			CAP (2014–2022)
Scheme	PFEIL (2014–2022)			EFA (2015–2022)
Measure	Winter-Hardy Catch Crops for Guest Birds from the North	c&cs and Undersown c&cs	c&cs, Undersown c&cs, Both Winter-Hardy & Legume-Free	c&cs and Undersown c&cs
Code	NG1	AL21	AL22	ÖVF 052
introduction c&cs	2014	2014	2014	2014
funding	EU pillar II, Germany, Lower Saxony			EU-pillar I
regional scenario for funding	targeted: EU protection zones 1 and 2	Lower Saxony-wide, not in those water protection areas where c&c cultivation is mandatory	targeted: at least 25% of the farm or 10 ha of GW bodies in bad condition (WFD), not areas with mandatory c&c; max. 5% of arable UAA of farm	5% of arable UAA of farm, farms > 15 ha;
subsidy	zone 1: 450 €, zone 2: 330 €	basic funding: 75 €/ha, ecological farms 55 €/ha	basic + additional funding: up to 120 €/ha (A7 + 45 €/ha), ecological farms 100 €/ha;	75 €/ha for total farmland (in 2015 85 €/ha) related to basic payment of 173 €/ha total farmland (in 2015 175 €/ha)
funding rules	no double funding of (pillar I and II) measures: reduction for counting of AL21/AL22 simultaneously as EFA-area: 75 €/ha			
contract duration	5 years	5 years	5 years	1 year
mandatory or voluntary	voluntary	voluntary	voluntary	voluntary
indicator (result-based)	no	no	no	no

Table 1. Cont.

seeds; type and number of species	cultivation of winter cereals, winter oilseed rape or grass seeds: no bird control techniques	actively sown no self-greening allowed	actively sown no self-greening (in ecofarming legumes mixed with non-legumes accepted)	> 2 species out of a list; one variety not more than 60%, grass seeds not more than 60%
sowing date	latest 15 October	latest 1 October	latest 1 October	15 July–30 September
fertilization	no specification	no fertilization (except initial fertilization)	N fertilization after potatoes, maize, oilseed rape and legumes, not before 1 March	no mineral N fertilization (but manure accepted according to Fertilization Ordinance (**))
pesticides	no specification	no pesticides; only mechanical destruction of plants		only mechanical destruction of plants; herbicides allowed (**) after 15 February
turning over date	1 November–31 March: no crop management activities	not before 15 February	not before 1 March	not before 15 February (exception on federal state level 15 January)
(d) Different Schemes with c&cs in the Past, at Present, and in Future				
Program	Fertilization Ordinance	Lower Saxony Implementation Ordinance		CAP (2023–2027)
Scheme	DüV (2020)	NDüngGewNPVO (2021)		GAEC 7
Measure	Mandatory c&c Cultivation in Red Areas	Mandatory c&c Cultivation in Red Areas	Minimum Soil cover To Avoid Bare Soils in Periods that Are Most Sensitive	
Code	-	-	-	
introduction c&cs	2021	2021	2023	
funding	-	-	-	
regional scenario for funding	nitrate-polluted “red areas” according to § 13a DüV, in case subsequent summer crop is to be fertilized after 1 February; exceptions: the preceding crop is harvested after 1 October or longterm mean precipitation < 550 mm		EU-wide, national specification possible	
subsidy	no subsidy	no subsidy	no subsidy; “conditionality”	
funding rules	mandatory		no funding	
duration of validity	as long as zones are classified as polluted		at least until 2027	
mandatory or voluntary	mandatory	mandatory	mandatory	
indicator (result-based)	concentration of nitrate in GW body		no specification yet	
seeds; type and number of species	no specification	no specification	no specification yet	
sowing date	in autumn of preceding year		no specification yet	

Table 1. Cont.

	outside red areas: ≤ 60 kg N/ha or ≤ 30 kg NH ₃ -N/ha until 1 October		
fertilization	in red areas: c&cs utilized as fodder may be fertilized; c&cs not grown as fodder may be fertilized with solid manure or compost up to 120 kg N _{tot} /ha		no specification yet
pesticides	no specification	no specification	no specification yet
turning over date	no specification	no specification	no specification yet

(a) (*) 10–15 m³ liquid beef manure or ca. 10 m³/ha liquid pig manure. (**) 14–17 m³ liquid beef manure or ca. 10 m³/ha liquid pig manure; 120 kg N_{tot}/ha solid manure. (b) (*) Subsidizing c&c within the framework of AECMs started in 2004 with the program PROLAND. (c) (*) Since 2020 rules of Fertilization Ordinance were tightened: c&cs not grown as fodder may be fertilized with solid manure or compost up to 120 kg N_{tot}/ha; only c&cs utilized as fodder may be fertilized. (**) amendment after 2017 to be applied from 2018 onwards.

- Lower Saxony cooperation model—differentiation within a particular cooperation**
 An overview of how the basic measure “IE” was designed and differentiated in 2010 and 2016 by the contractors OOWV and the municipalities of Norden and Bad Zwischenahn, can be seen in Table 1a. In each offered variant of the measure IE, subsidies are lower than the maximum amount calculated by the standard technical agricultural data [32] for the basic measure (see Table 1b); they range from 40 €/ha to 120 €/ha. However, the measures defined by the water suppliers are in some aspects more restrictive than the basic measure, e.g., with respect to winter-hardy species to be sown after 31 August, and N fertilization. Between 2010 and 2015, volunteer oilseed rape “IE 511” was also offered as c&c measure.
- Lower Saxony cooperation model—basic measures** Two recent measures (IE, III) were taken from the NLWKN catalogue [33] (Table 1b), in which the measures are described, and maximum subsidies are calculated by the Lower Saxony Chamber of Agriculture on the basis of standard calculation data [32]. Within this framework, subsidies are a matter of negotiation between individual companies and farmers, and can be modified in the cooperation arrangements. For the basic measure IE, maximum subsidy is calculated as almost 250 €/ha. Although N-fixing legumes were not allowed as a component of the seed mixture, there were no restrictions with respect to fertilization. In 2016, a result-based program “III” was also established. In order to prevent the distortion of competition, this subsidy program was formally notified by the European Commission as part of the water protection measures financed by the water abstraction fee. The full contracted fund will be paid in the case where N_{min} values of the plot remain below, or equal to, the limit value of 35 kg NH₄ N/ha. While acceptance of this program among farmers at first was limited, there has since been an increasing number opting for it [34].
- AECM programs in Lower Saxony** Subsidizing c&c within the framework of AECMs in Lower Saxony started in 2004 with the program PROLAND, and continued with the last two programs, PROFIL (2007–2013) and PFEIL (2014–2022). The contract duration with farmers typically is five years, but can be prolonged according to the length of the program. In the first few years of PROFIL, subsidized cultivation of c&cs was targeted, meaning that it was only offered in defined, limited scenarios; however, from 2010 onwards, measure “A7” was open to farmers all over Lower Saxony. In addition, from 2011, farmers situated in areas where groundwater is in bad condition, according to the Water Framework Directive (WFD) criteria—according to [35] 60% of Lower Saxony territory—could opt for a special measure, particularly aiming at water protection (“W2”). After the CAP reform in 2014, new c&c measures were designed within the AECM scheme PFEIL, as well as in view of the new option to grow c&c as a greening measure. Although quantitatively, from 2015 onwards, most c&c were cultivated within the greening scheme, qualitatively, the updated AECM schemes “AL21” and “AL22” were soon merged into one scheme focussing on winter-hardy,

legume-free catch crops with restricted fertilization. From 2016 onwards (to be realized in 2017), “AL21/AL22” were offered only for farms with at least 25% of the farmland, or 10 ha of groundwater bodies, in bad condition according to the WFD.

- **Greening measures within the CAP** From 2015 onwards, in Lower Saxony, c&cs played a major role as an option to fulfil the new greening rules of the CAP period 2014–2022 (Figure 2). During this period, the total share of c&cs of all EFA options in this federal state varied between 86% and nearly 89%, in most of the cases sown after the main crop, not as an undersown crop. Between 2015 and 2020, the share of undersown c&cs slightly decreased from 12% to close to 8%.

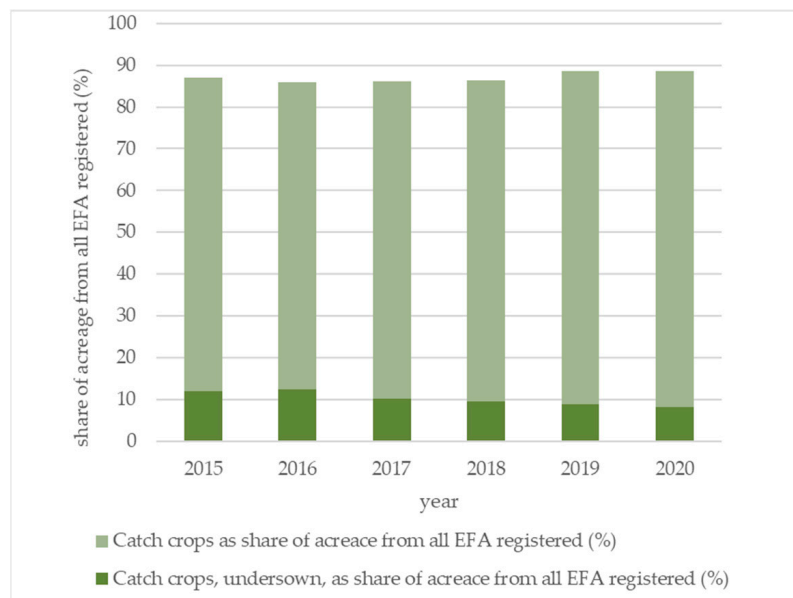


Figure 2. Share of c&cs from all EFA options registered in Lower Saxony between 2015 and 2020 [36–38].

3.4. Target Areas for the Different Schemes and Acreage for c&cs

Figure 3 shows a map of Lower Saxony, with a total area of 4,771,000 ha, a UAA of 2,571,300 ha, and total arable acreage of 1,880,000 ha [39]). The map shows different target areas for some of the schemes described in Table 1. These are the water abstraction areas (turquoise; since 1992), groundwater bodies in bad condition according to WFD [12] (grey; since 2010), and nitrate-polluted groundwater bodies according to the Fertilization Ordinance and Nitrates Directive [7,8] (red; since 2021).

In 2016, the Lower Saxony cooperations covered 293,000 ha land with agricultural use—which equals 11% of the total UAA—and 239,000 ha of wooded land. The cooperation area in total is larger than the actual the water protection zones, also including registered drinking water abstraction zones with 152,610 ha [2].

A total of 11 regions with groundwater bodies in bad condition according to WFD were defined in 2010. The regions were later partly subdivided to 14 regions, with an acreage after subtracting the cooperation area mentioned above of approximately 880,000 ha [40]. In these regions, different agencies were assigned to offer farm advice in order to reduce nitrate leaching to groundwater. From 2016, these farm advice measures were cofinanced by EU-means (pillar II) [41].

Germany as a whole (100% of the UAA) is subject to the Nitrates Directive Action Program. In addition, in 2021, due to a tightening of the implementation of the Nitrates Directive [8], “red areas”, with nitrate-polluted groundwater bodies, were defined by national [7,9] and Lower Saxony [10] legislation. These areas sum up to 685,000 ha, respectively 24.5% of the total UAA of Lower Saxony.

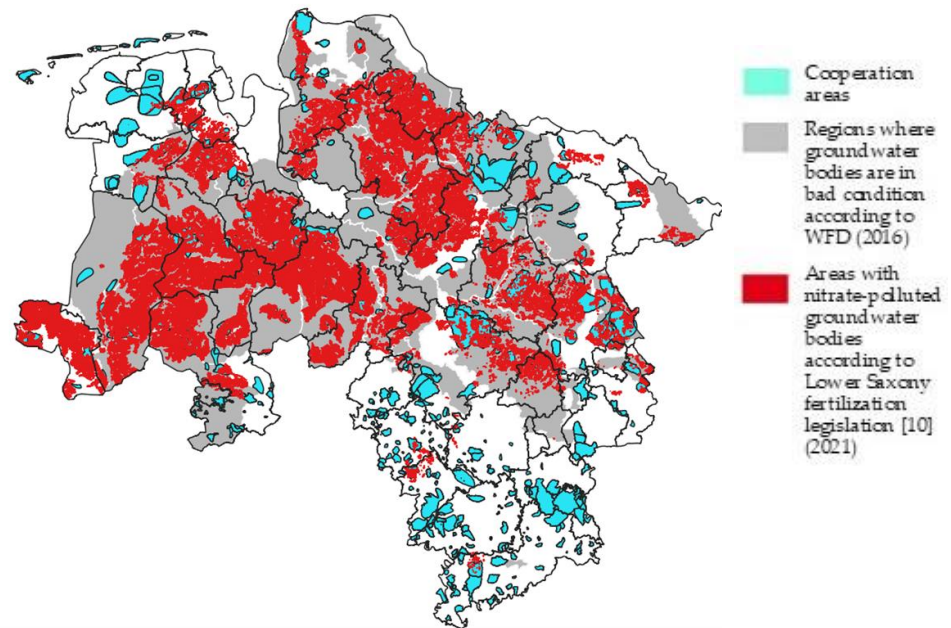


Figure 3. Target areas of different schemes for groundwater protection in Lower Saxony (© Richu Mary Shelly, Team Geoinformatics, Thuenen Institute, Braunschweig).

In these red areas, c&c cultivation is, under certain circumstances, mandatory. This implies, that in these areas, plots cultivated with c&c cannot be counted as EFA for the greening.

It further implies, that in the future, in cooperation areas, the (simple) establishment of c&cs is no more a measure which can be subsidized by the water suppliers. Figure 3 shows, that water abstraction areas and red areas are hardly congruent: while in central Lower Saxony, many cooperation areas are strongly affected by the new fertilization legislation, this is not much the case in the southern parts of the federal state (Figure 4). In Appendix B, for each water protection area the percentage of UAA in the red area is listed.

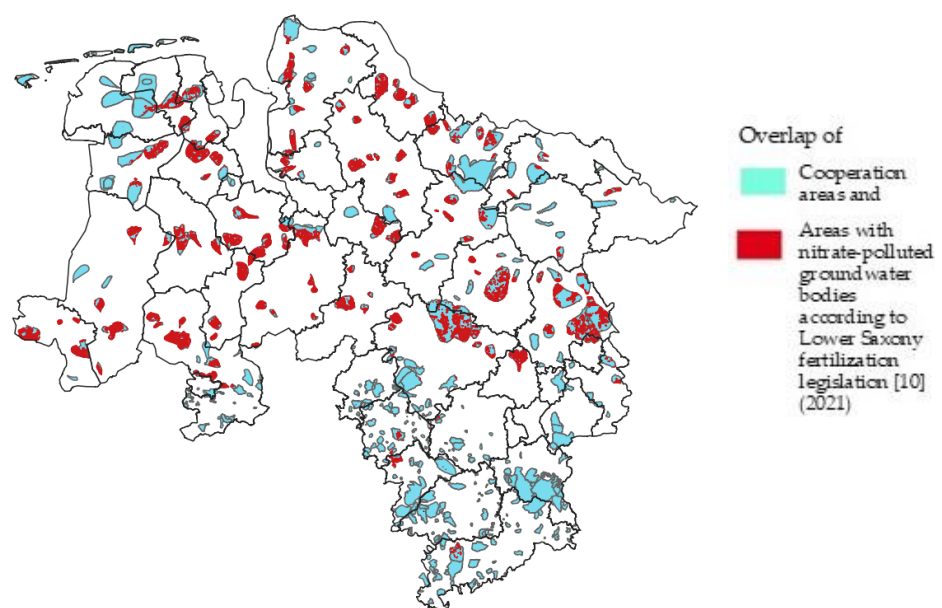


Figure 4. Cooperation areas in Lower Saxony (turquoise) and their affection by the recent definition of red areas defined by [10] (© Richu Mary Shelly, Team Geoinformatics, Thuenen Institute, Braunschweig).

3.5. Acreage of Different Schemes

In Figure 5, the acreage of c&cs related to the different schemes are shown, from the early 1990s to the present. The figure combines data from different sources; for some years, there were no data available. The black bars show the total acreage of c&cs in selected years, while the coloured bars are related to the different schemes in which c&c cultivation was offered.

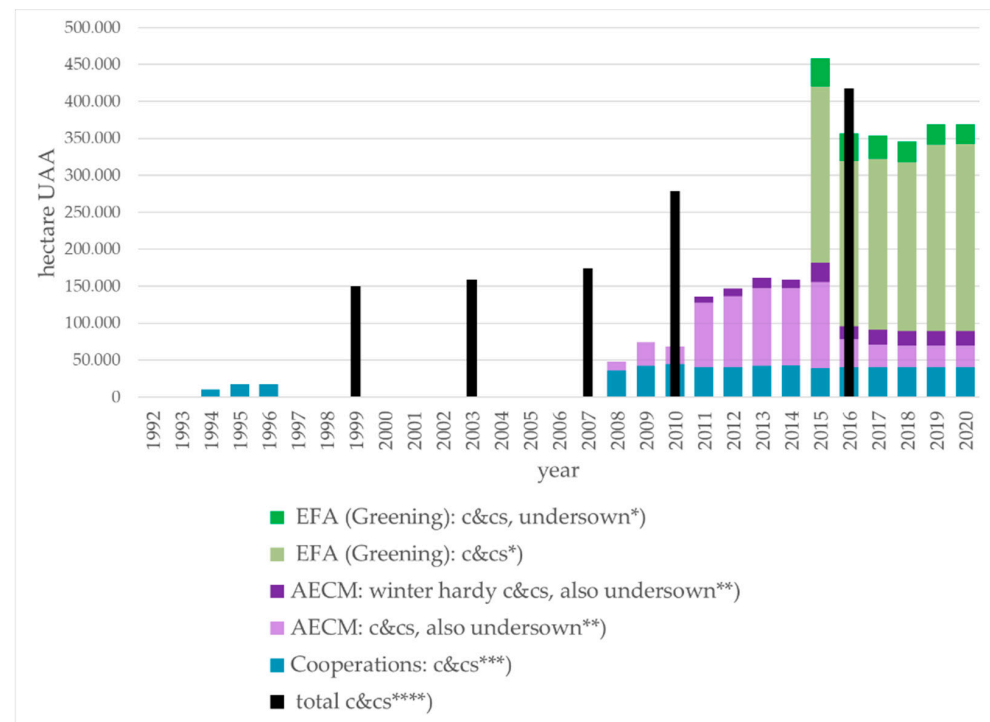


Figure 5. Acreage of c&cs under different schemes in Lower Saxony. Appendix A, Table A1, Index *_****.

From the black bars, it can be deduced that c&cs were grown in the 1990s to an extent of approximately 150,000 ha, an acreage which increased almost three-fold until the year 2016. In the 1990s, however, the share of subsidized c&c cultivation in comparison was very small, and referred only to the cooperation areas. Annual c&c cultivation started with 10,500 ha in 1994, and increased to almost 35,500 ha in 2008. Since that time, c&c cultivation in cooperation areas quantitatively stabilized.

In 2004, c&c cultivation was added to the portfolio of AECMs, financed by funds of the second pillar of the CAP. At first, the schemes were targeted, and c&c cultivation as AECM remained around 80,000 ha; however, the AECM A7 of the program “PROFIL” was opened in 2010 on a Lower Saxony-wide scale. As a consequence, c&c cultivation as AECM sharply increased, and by 2015 reached almost 105,000 ha per annum. Regularly, the program was “oversubscribed”; for example, in 2012 there were applications for 120,000 ha, but only the financial means for 96,000 ha [42]. Winter-hardy c&cs were introduced as measure W7 in 2011. From an agricultural point of view, this measure was more demanding, as the seeding date, as well as the seedbed preparation for the succeeding crop, is affected. Scheme W7 focussed on sustaining groundwater quality, and included further measures (e.g., additional support of ecological farming, no soil conservation after maize). However, it remained targeted to farms in regions with poor water quality according to the WFD, and the increase in acreage of this measure remained limited to below 14,000 ha.

In the following CAP period (2014–2022), AECM measure A7 of the program “PROFIL” was transferred to measure A21 of the program “PFEIL”, and measure W7 was transferred to measure A22. In 2015, the acreage of the Lower Saxony-wide measure A21 further

increased to almost 117,000 ha per annum, as well as the targeted winter-hardy c&c measure A22, which reached almost 27,000 ha per annum.

In the same year, 2015, with the revised CAP rules (2014–2022), c&c cultivation sharply increased to a total acreage of more than 450,000 ha. A large share of this development was due to the introduction of greening by the CAP. Catch and cover crops became the most popular measure within the options for EFAs. Almost 238,000 ha were cultivated as regular c&cs, and an additional 39,000 ha as undersown c&c. In 2020, the figure for regular c&c cultivation increased slightly to 253,000 ha, while the undersown option was only cultivated over 26,000 ha.

As a reaction to the great popularity of c&cs as an EFA measure, the Lower Saxony Ministry of Agriculture cancelled the basic measure “AL21” in 2015. Only the agronomically more demanding combined measure “AL21/AL22” was offered to farmers in defined scenarios.

At present, c&c cultivation in Lower Saxony amounts to approximately 400,000 ha UAA per annum (some recent data are estimations), with a strong share as EFA measures on the expense of the AECM schemes. Figure 4 shows that there was, before the implementation of c&cs as an EFA measure within the greening of the CAP, quite a large area, more than 100,000 ha per annum, on which c&cs were grown without subsidies (difference between black bars and coloured bars). In 2016, the share of c&cs cultivated without subsidy diminished to approximately 50,000 ha per annum.

Figure 6 specifies the agronomic purposes for which c&cs were grown, i.e., as feedstuff, as an energy crop, or as green manure. For both cultivation forms, as summer or as winter c&c, the main agronomic purpose, as specified by the farmer, was “green manure”. There are, however, contradictions to the definition in [26], where winter c&cs generally consist of winter-hardy plant species and the plant biomass of winter c&cs is usually harvested in spring.

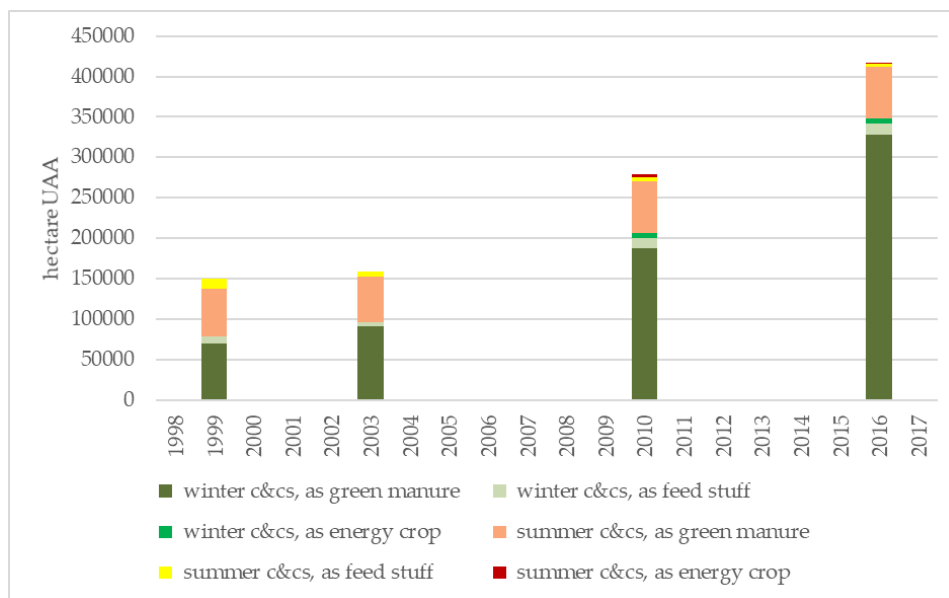


Figure 6. Different agronomic purposes for which c&cs were cultivated in selected years from 1999 to 2016 in Lower Saxony. Appendix A, Table A1, Index ****.

3.6. Cost of c&c Implementation

Each year in the cooperation areas, the Lower Saxony Chamber of Agriculture calculates the subsidies for cultivation of c&cs on the basis of different assumptions that take into account additional costs for the farmer when cultivating c&cs, e.g., costs of seeds, machines, work force. The positive and/or negative effects on the yield of the following crop; savings on operating material, machines, and work force; and the advantages and/or

disadvantages of use as c&cs are occupying the field, are also considered [33,43]. The calculations serve as an orientation; in each cooperation area, an individual contract is negotiated between water suppliers and farmers.

As AECMs, the costs of c&cs are calculated at a national level by a coordinated planning committee [30]; in addition, there are calculations at the federal state level.

The subsidy level for implementing greening measures is a result, first of negotiations at the EU level (Commission, Parliament, and Council), and second at a national level, as the proportion of financial means paid as a subsidy for pillar I (cross compliance) and pillar II (greening) measures were agreed upon in both the German parliament and federal assembly. Implementation costs are calculated, except for the cooperations, in relation to the area covered, with 7 €/ha (comparable to measures such as the extensification of grassland or the diversification of crop rotations) [44].

Table 2 gives an estimation of the costs of implementation and subsidies for the years 2015 and 2016, respectively. The costs in the framework of Lower Saxony cooperations are cited from an official report [2].

Table 2. Estimated costs of implementation and subsidies of c&cs within different schemes in Lower Saxony in 2015/16.

Year	Scheme Specification	Cooperations		AECM		EFA (Greening)	
		C&cs	C&cs, Also Undersown	Winter-Hardy c&cs, Also Undersown	C&cs	Undersown c&cs	
2015	area (ha)	(no data)	116,608	26,529	237,714	38,649	
	implementation (€)	(no data)	816,256	185,703	1,663,998	270,543	
	subsidy (€)	(no data)	8,745,600	3,183,480	123,916,275	19,826,604	
	total (€)	(no data)	11,929,080		143,742,879		
	total costs per ha (€/ha)	(no data)	83		520		
2016	area (ha)	40,634	37,080	17,964	223,774	37,559	
	implementation (€)	(included)	259,560	125,748	1,566,418	262,913	
	subsidy (€)	(included)	2,781,000	2,155,680	120,886,013	20,366,665	
	total (€)	4,048,615	5,321,988		143,082,009		
	total costs per ha (€/ha)	100	97		548		
financed by	water abstraction fee	EU, pillar II		EU, pillar I			
Lower Saxony	100%	10%					
German government		15%					
EU		75%		100%			
duration contract (year)	5 (*)	5		1			

(*) but plots within the scheme may change from year to year.

The yearly total costs of c&c implementation amounted to around 4 mio € within the framework of cooperations, to 5.3 million € as AECM and to 143 million € as a Greening measure. The high amount with respect to the Greening explains by two factors: (1) the majority of Lower Saxony farmers, 87% in 2015 and 86% in 2016, chose c&cs out of the portfolio of greening options in Germany [36,37]; (2) the high total subsidy amount is

explained by the mode of payment of the greening fee, which refers to the total UAA of the farm in cases where the greening conditions are fulfilled. The strong increase in c&c acreage after the introduction of the greening can be explained with the principle that one hectare cultivated as c&c counts for 1/3 of a hectare used as a greening measure.

While total costs for c&cs are around 100 €/ha, which is about the same as for measures in cooperations or as AECMs, c&cs in the framework of the greening amounted to more than 500 €/ha.

3.7. Recent Developments and Future Perspectives

The new rules of the Fertilization Ordinance in 2020 [7] required the redefinition of red areas for nitrate-polluted groundwater bodies, stricter limitation on fertilization, and further measures to prevent surplus nitrogen from leaching.

As summarized in Table 1d, in these red areas, c&c cultivation is mandatory, under the condition that it is intended to fertilize the following summer crop, unless the preceding crop is harvested after 1 October or the area receives less than 550 mm of precipitation (see Figure 3).

Moreover, with the revised CAP to be implemented in 2023, an enhanced conditionality includes “GAEC 7”, i.e., the requirement of “minimum soil cover to avoid bare soils in periods that are most sensitive”. This conditionality could entail an increase in c&c surface, in the case that this principle is implemented into national legislation. The Member States, however, are not obliged to do this [31]. At present, it is not apparent that, in Germany, GAEC 7 will be transferred into national legislation. Nevertheless, this tendency could change come the new legislation period. The other main element of the new CAP, the eco-schemes, do not include c&cs.

4. Discussion

4.1. C&c Cultivation and Rules on Fertilization and Nutrient Management

In Lower Saxony, until 2021, all the c&c schemes offered—whether within the framework of cooperations, as AECMs or as EFAs—were voluntary; farmers, when opting for them, would receive funds. A general rule could be described as follows: the further the regular farming practices for c&cs were restricted (fertilization, pesticides, obligate winter-hardy or undersown cultivation), the higher the subsidies would be (Figure 7, straight red line). Higher subsidy levels were, in general, targeted to defined scenarios (Table 1a–c).

Concerning fertilization, the basic standard was, and still is, defined by the German Fertilization Ordinance [7] and the corresponding Lower Saxony Implementation Ordinance [10]. Until 2016, the German Fertilization Ordinance allowed up to 80 kg N/ha for the fertilization of c&cs in autumn [45]. With the amendment of the Fertilization Ordinance in 2016, this value was reduced to 60 kg N/ha [46]. In the latest amendment of the Ordinance in 2020 [7], this value was novated for plots above groundwater bodies in good condition. In the red areas above nitrate-polluted groundwater bodies, since 2020, fertilization in autumn is generally prohibited, unless there is a utilization of the plant biomass as feedstuff, or only solid manure or compost is applied in quantities equivalent to 120 kg N/ha [7].

To date, general rules for fertilization planning and budgeting with respect to c&cs are unclear and imprecise. Minimum amounts of N captured in the plant biomass of c&cs are to be taken into account for a fertilization planning range between 0 and 40 kg N/ha [7]; the highest amount of 40 kg N/ha refers to leguminous c&cs, not frozen, and not incorporated into the soil during winter.

Generally, there is no duty to analyze mineral soil N in spring prior to fertilization; instead, values published by the Lower Saxony Chamber of Agriculture [47] can be used to calculate the amount of mineral N in the soil ready for plant uptake in spring. An exception has now been introduced for the red areas, according to the latest amendment of the Fertilization Ordinance [7] and its Lower Saxony implementation [10], where on-site sampling and laboratory analysis of N_{\min} in spring is compulsory.

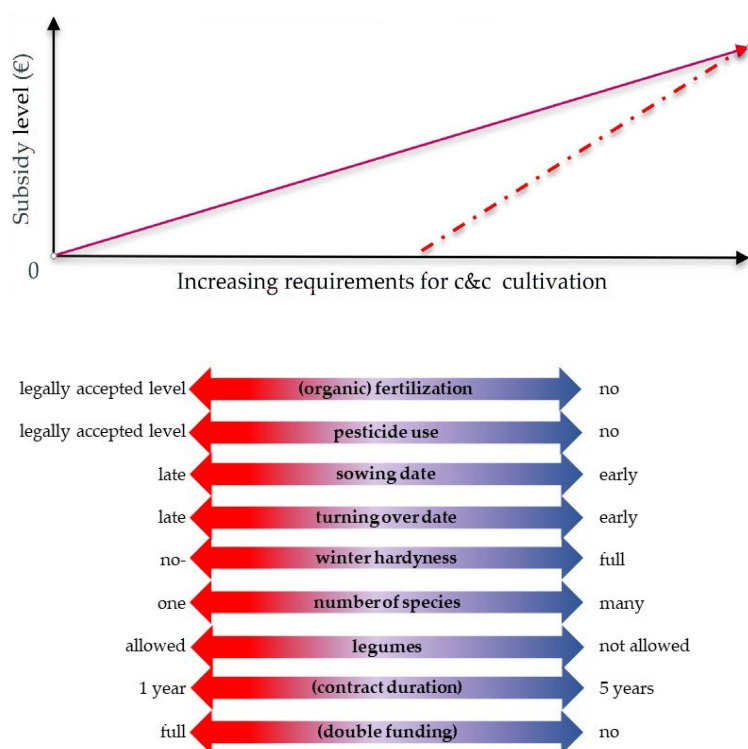


Figure 7. Top: general relation of subsidy level and management requirements for different voluntary schemes of c&c cultivation (straight red line) and general impact of new mandatory schemes (as recent implementation of Nitrates Directive (ND), dotted red line). Bottom: examples of requirements for c&cs cultivation.

4.2. Expert Opinion on the Management of c&cs

While legislation still allows N fertilization of c&cs, even—under certain circumstances—in red areas, experts see the necessity to refrain from fertilization of real catch crops in, for example, AECM schemes, in order to fully profit from the reduction potential of this measure on water pollution with nitrates [41,48,49]. A study from the federal state Hesse revealed that farmers are expected to save between 5 and 20 kg N/ha due to c&c cultivation, whereas a comparison of N surplus values from farms growing c&cs and those that did not, only showed a difference of 10 kg N/ha [50]. These last findings might be due to the standard values typically applied to calculate N budgets. However, the situation has been changing recently (see 4.4).

While N captured in the biomass of c&cs only has to be included in fertilization planning up 40 kg N/ha, in reality, the amount of N stored in the above-ground biomass can make up to 100 kg N per ha (and more); a fertilizing potential that will be partially available in the following growing season [22,51].

As AECMs, c&cs were introduced in 2004, not only to prevent the leaching of nitrogen, but also to inhibit erosion [41]. There was no distinct differentiation between catch and cover crop, and (also in cooperation areas) initial fertilization with mineral or organic fertilizers was allowed to establish the crop.

In 2012, c&cs were subsidized on 12,391 ha of arable land, which is, according to the categorization of the State Office for Mining, Energy and Geology (LBEG), susceptible to soil erosion [41]. This was only around 13% of the Lower Saxony-wide subsidized area for c&cs as AECMs under the “A7” scheme. Only for this share of the total AECM acreage would it possibly have made sense to allow fertilization in autumn, in order to establish a strong plant canopy before winter.

The data in Table 1b,c show, with respect to the design of schemes, that the agronomic requirements of schemes offered by the government (AECM and EFA) were not very

demanding. This is the case for the number of species in a c&c mixture, and for the winter hardiness of at least some of the components of a mixture. The disadvantage can be seen in the widespread windfall effect [41], whereas the advantage is the possibility of topping up with measures in cooperation areas (Table 1a). In fact, in the majority of cases, single crops are grown as c&cs, mostly mustard and sweet grasses (in the period 2001–2018) [52].

4.3. Impact of CAP 2015–2022

With the new AECM program PFEIL in 2014, a large number of farmers contracted for c&c, also undersown (“AL21”), and also more contracts for winter-hardy c&cs were signed (“AL22”). However, with the new CAP rules becoming effective in the same year, 2015, new obligations had to be fulfilled. Many farmers stepped back from their AECM contracts, and instead registered their plots in order to fulfil Greening obligations with c&cs as EFAs [53]. While fertilization was further limited within the AECM scheme “AL21” to an undefined starter fertilization [54] for the cultivation of c&cs as EFAs within the greening obligations, the above-explained, generous rules of the Fertilization Ordinance were in place. Therefore, the reason why farmers in Lower Saxony so frequently opted for c&cs as a greening measure may not only be connected to how easy they could be integrated into traditional cropping patterns [55], but also because a considerable amount of manure and/or biogas residue could be applied in autumn [36].

With respect to c&cs as AECMs under the program PROFIL, Reiter et al. diagnosed a considerable windfall effect for this measure [41]. Regarding the urgent disposal problems for manure, choosing c&cs within a rotation might be a strategy to legally dispose of manure.

Another factor, why c&cs were so successful as a Greening measure in Lower Saxony during the current CAP period, is that, for the farmer, the cultivation was quite profitable, as shown in Table 2. However, regarding the administration, c&cs as a measure to improve groundwater quality was not efficient. With costs of approximately 100 €/ha and 15 €/kg N, Reiter et al. [41] diagnosed a low cost-efficiency for c&cs as AECMs under the framework of PROFIL. Looking at the cost development of c&cs within the last CAP period, the cost-efficiency is most likely to be far worse.

4.4. Impact of the New Requirements for Implementation of Nitrates Directive (ND)

Section 3.2 revealed that the newly defined red areas, with mandatory measures for c&c implementation, are often not congruent with the cooperation areas; this further implies that, in the future, the (simple) establishment of c&cs in cooperation areas will no longer be a measure which can be subsidized by the water suppliers.

In those cooperation areas largely influenced by the new legislation, a reorganization of subsidy schemes is necessary, as present funding requirements may be less demanding than those of the new fertilization legislation [7,8,10]. Instead of action-based contracts that subsidise the implementation of certain measures, such as c&cs, in the future, an innovative contract design could be result-based, and could include collective implementation [56,57]. This strategy would allow the complementary support for farms with management in favour of water quality. Instead of framing measures corresponding to the changing legal requirements, funds are granted more independently from legislation on fertilization and water quality.

While action-based schemes are reported to lack effectiveness, the result-based approach is reported to be one of the most promising substitutes due to its direct connection with environmental results and the price paid for them [57]. Collective implementation can help widen the diffusion of schemes and reduce transaction costs [57]. However, the crux of the matter may be the availability of applicable indicators for good management practice, including fertilization, and correlating with high (ground)water quality [58].

4.5. Impact of CAP 2023–2027

In the next CAP, there will be a new architecture; Greening will be abandoned, and part of it will be transformed into conditionalities. For example, it is defined as good agricultural

and environmental condition to maintain “minimum soil cover to avoid bare soil in periods that are most sensitive” (GAEC 7). At present, there is no national legislation to implement the GAEC 7 more strongly. Furthermore, c&cs are not part of the newly installed Eco-schemes. Therefore, it is likely that c&cs will be implemented as AECMs. However, a lesson learnt from the past CAP period is that funding rules for c&cs should be more demanding with respect to fertilization, composition of mixtures, and cultivation period.

5. Conclusions

C&cs are promoted often as a measure for water quality protection in agriculture; however, the results from this paper show that, in Lower Saxony, they did not substantially contribute to water protection, due to various reasons: (i) the design of the measure, (ii) the control of farmer’s actions; and (iii) antagonistic trends over time (e.g., due to increase in animal numbers and biogas plants).

We thus conclude that frame conditions and management requirements of cultivating c&cs need to be well designed to be effective and efficient (with regard to N reduction and cost reduction). It is vital to coordinate all programs and schemes in one region, otherwise success in one scheme can be negated by other competing schemes. Coordination includes the aim of the scheme, the target area, management requirements, subsidy level, and the flanking mandatory measures. From our evaluation, we conclude that a measure such as c&c cultivation over winter, which is simple to introduce and easy to control, should be implemented as a mandatory measure in order to achieve a greater uptake. In addition, result-based measures could supersede this scheme, e.g., in the framework of the cooperation areas, there is a strong link between subsidy level and the success of the measure. However, further research is necessary to increase the reliability of indicators for the result-based approach.

Overall, we could point out in this paper that the original approach in the 1990s, to compensate farmers for the reduction in fertilizers, is now increasingly replaced by a new strategy in Lower Saxony, again putting more emphasis on mandatory, full-coverage measures, and, through this, approaching the WFD principle “polluter pays all”.

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Institutional Review Board Statement: Not applicable for studies not involving humans or animals.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data from the two public accessible maps were used: (1) <https://sla.niedersachsen.de/landentwicklung/LEA/> (accessed on 10 February 2022) and (2): <https://urls.niedersachsen.de/2pe2> (accessed on 10 February 2022).

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Statistics and documents used for analysis on c&cs in Lower Saxony.

Index	Institution/Author	Year	Title	Website
***	Niedersächsisches Umweltministerium	1997	Das Niedersächsische Kooperationsmodell zum Trinkwasserschutz—ein Beitrag zur Agenda 21 in Niedersachsen, 24 p. Agrarstrukturerhebung 2003 Fachserie 3/Reihe 3.1.9 Landwirtschaftliche	
****	Statistisches Bundesamt, BMEL	2004	Bodennutzung—Anbau von landwirtschaftlichen Zwischenfrüchten	
*	Dahl, S.	2015	Bereitstellung ökologischer Vorrangflächen in der Landwirtschaft. Statistische Monatshefte Niedersachsen, 69. Jahrgang. Heft 8 August 2015, pp. 437–443	
*	Dahl, S.	2016	Ökologische Vorrangflächen in der Landwirtschaft 2016. Statistische Monatshefte Niedersachsen 9/2016, pp. 518–522	
*	Landesamt für Statistik Niedersachsen	2017	Dezernat 42—Landwirtschaft. InVeKos 2017; Tabelle 3.2E (MIT GH) Antragstellende Betriebe und Flächen insgesamt 2017 nach Art der ÖVF	(personal communication)
*	Landesamt für Statistik Niedersachsen	2018	Dezernat 42—Landwirtschaft. InVeKos 2018; Tabelle 3.2E (MIT GH) Antragstellende Betriebe und Flächen insgesamt 2019 nach Art der ÖVF	(personal communication)
*	Landesamt für Statistik Niedersachsen	2019	Dezernat 42—Landwirtschaft. InVeKos 2019; Tabelle 3.2E (MIT GH) Antragstellende Betriebe und Flächen insgesamt 2019 nach Art der ÖVF	(personal communication)
*	Landesamt für Statistik Niedersachsen	2020	Dezernat 42—Landwirtschaft. InVeKos 2020; Tabelle 3.2E (MIT GH) Antragstellende Betriebe und Flächen insgesamt 2020 nach Art der ÖVF	(personal communication)
****	Landesbetrieb für Statistik und Kommunikationstechnologie Niedersachsen	2012	Landwirtschaftszählung 2010 Heft 03 Bodennutzung, Rechtsform der Betriebe, Ökologischer Landbau, Zwischenfruchtanbau, Bewässerung—C IV 9.3—j/10	www.statistik.niedersachsen.de/downloads (accessed 10 February 2022)
****	Landesbetrieb für Statistik und Kommunikationstechnologie Niedersachsen	2004	Bodennutzung und Ernte 2003 _ CI 1, C II 1, C II 2, C II 3, j/2003	https://www.statistischebibliothek.de/mir/servlets/MCRFileNodeServlet/NIHeft_derivate_00000294/CI1_CII1_CII2_CII3_2003_pdfa.pdf ;jsessionid=4C40835F4BA21019DB6CC33D8FCFB113 (accessed 10 February 2022)

Table A1. Cont.

Index	Institution/Author	Year	Title	Website
****	Landesbetrieb für Statistik und Kommunikationstechnologie Niedersachsen	2008	Statistische Berichte Niedersachsen; C I 1, C II 1, C II 2, C II 3, Bodennutzung und Ernte 2007	https://www.statistischebibliothek.de/mir/servlets/MCRFileNodeServlet/NIHeft_derivate_00000298/CI1_CII1_CII2_CII3_2007_pdfa.pdf;jsessionid=3E525CB04226DD8B409230A51CD591ED (accessed 10 February 2022)
***	NLWKN	2020	Schutzgebiete Trinkwasser—STATISTIK 20 January 2020	https://www.nlwkn.niedersachsen.de/startseite/wasserwirtschaft/grundwasser/wasserversorgung/wasserschutzgebiete/wasserschutzgebiete-44035.html (accessed 10 February 2022)
***	Quirin, M.	2011	Trinkwasserschutzkooperationen in Niedersachsen Grundlagen des Kooperationsmodells und Darstellung der Ergebnisse NLWKN, Grundwasser Band 13, pp. 1-33	https://www.nlwkn.niedersachsen.de/startseite/service/veroeffentlichungen_webshop/schriften_zum_downloaden/downloads_grundwasser_trinkwasser/veroeffentlichungen-zum-thema-grundwassertrinkwasser-zum-downloaden-44047.html (accessed 10 February 2022)
***	Quirin, M., Hoetmer, M.	2019	Trinkwasserschutzkooperationen in Niedersachsen—Grundlagen des Kooperationsmodells und Darstellung der Ergebnisse. NLWKN, Grundwasser Band 34, pp. 1–56	https://www.nlwkn.niedersachsen.de/startseite/service/veroeffentlichungen_webshop/schriften_zum_downloaden/downloads_grundwasser_trinkwasser/veroeffentlichungen-zum-thema-grundwassertrinkwasser-zum-downloaden-44047.html (accessed 10 February 2022)
****	Statistisches Bundesamt, BMEL	2010	Fachserie 3, Reihe 2.1.2., Bodennutzung der Betriebe einschließlich Zwischenfruchtanbau Landwirtschaftszählung / Agrarstrukturerhebung	https://www.destatis.de/T1\guilsinglright2030212109005_korr (accessed 18 March 2022)
****	Statistisches Bundesamt, BMEL	2016	Statistischer Monatsbericht des Bundesministeriums für Landwirtschaft und Ernährung, Kapitel A.: Zwischenfruchtanbau in Deutschland 2015/2016 Landwirtschaft	https://www.bmel-statistik.de/landwirtschaft/statistischer-monatsbericht-des-bmel-kapitel-a-landwirtschaft/ (accessed 10 February 2022)

Table A1. Cont.

Index	Institution/Author	Year	Title	Website
**	Fährmann, B.; Bergschmidt, A.; Bathke, M.; Eberhardt, W.; Ebers, H.; Fengler, B.; Flint, L.; Forstner, B.; Grajewski, R.; Pollermann, K.; Reiter, K.; Roggendorf, W.; Sander, A.	2018	PFEIL—Programm zur Förderung im ländlichen Raum 2014 bis 2020 in Niedersachsen und Bremen: Analyse der Inanspruchnahme und Umsetzung. Braunschweig, Hannover: Thünen-Institut für Ländliche Räume; entera, 355 p., 5 Länder Eval 2018/8, DOI:10.3220/5LE1543226002000	
**	Grajewski, R.; Bathke, M.; Bergschmidt, A.; Eberhardt, W.; Ebers, H.; Fengler, B.; Forstner, B.; Franz, K.; Gröner, C.; Peter, H.; Pollermann, K.; Pufahl, A.; Raue, P.; Reiter, K.; Sander, A.; Roggendorf, W.	2019	Ergebnisse der laufenden Bewertung von PFEIL: Beitrag zu Kapitel 7 des erweiterten Durchführungsberichts 2018. Braunschweig: Thünen-Institut für Ländliche Räume, 5 Länder Eval 2019/13, 207 p., DOI:10.3220/5LE1567668169000	
**	Reiter, K.; Roggendorf, W.; Sander, A.; Liebersbach, H.; Techen, A.-K.	2016	Ex-post-Bewertung PROFIL 2007 bis 2013: Modulbe-richt 6.4_MB Agrarumweltmaßnahmen (ELER-Code 214). Braunschweig: Thünen-Institut, XII, 215 p.	

Appendix B

Table A2. Share of water protection areas (in % UAA) in red areas.

Water Protection Area	Region	%
Sülze	LK Celle	82
Bergen	LK Celle	77
Sulingen	LK Diepholz	74
Kirchdorf	LK Diepholz	70
Delmsen	LK Heidekreis	68
Vörden	LK Vechta	68
Osterwald	LK Grafschaft Bentheim	67
Wildeshausen Fassung A–C	LK Oldenburg	67
Hehlen und Hohe Brökeln	LK Holzminden	65
Hagen/Neustadt	Region Hannover	65
Wehnsen	LK Peine	60
Füchtenfeld	LK Grafschaft Bentheim	59
St. Hülfe	LK Diepholz	58
Plaggenschale	LK Osnabrück	58
Vechta-Holzhausen	LK Vechta	57
Plaggenschale	LK Osnabrück	56
Liebenau II/Blockhaus	LK Nienburg (Weser)	55
Jeggen	LK Osnabrück	54
Harpstedt, Fassung A	LK Oldenburg	52
Holßel	LK Cuxhaven	51
Wehnsen	LK Peine	49
Sulingen	LK Diepholz	49
Zeven Großes Holz	LK Rotenburg (Wümme)	48
Wettmar	Region Hannover	47
Wildeshausen Fassung A–C	LK Oldenburg	47

Table A2. Cont.

Water Protection Area	Region	%
Lühnsche Lieth	LK Holzminden	47
Getelo, Itterbeck	LK Grafschaft Bentheim	47
Groß Meckelsen	LK Rotenburg (Wümme)	46
Belm, Nettetal	LK Osnabrück	46
Buxtehude	LK Stade	46
Schwaförden	LK Diepholz	46
Heinbockel	LK Stade	45
Rotenburg, Stadt	LK Rotenburg (Wümme)	45
Grumsmuehlen	Stadt Lingen	45
Schatteburg	LK Leer	45
Stade Süd	LK Stade	44
Moisburg	LK Harburg	44
Wildeshausen Fassung D	LK Oldenburg	44
Ahlde	LK Emsland	44
Thiene	LK Osnabrück	43
Ottenstein, Hehlen und Hohe Brökeln	LK Holzminden	43
Tarmstedt	LK Rotenburg (Wümme)	43
Walsrode	LK Heidekreis	43
Liebenau II/Blockhaus	LK Nienburg (Weser)	42
Holdorf	LK Vechta	42
Panzenberg	LK Verden	41
Surwold	LK Emsland	41
Soltau, Schüttenbusch	LK Heidekreis	40
Ohrte	LK Osnabrück	40
Großenkneten	LK Oldenburg	39
Mundersum	Stadt Lingen	39
Altenwalde	Stadt Cuxhaven	38
Getelo, Itterbeck	LK Grafschaft Bentheim	37
Thülsfelde	LK Cloppenburg	37
Geeste, Varloh	LK Emsland	37
Jeggen	LK Osnabrück	37
Rotenburg-Süd	LK Rotenburg (Wümme)	36
Kührstedt	LK Cuxhaven	36
Elstorf	LK Harburg	36
Hesepe, Klausheide	LK Grafschaft Bentheim	35
Minstedt	LK Rotenburg (Wümme)	35
Ottenstein	LK Holzminden	34
Altes Amt Lemförde	LK Diepholz	32
Nethen	LK Ammerland	32
Ahausen, Sitter	LK Osnabrück	32
Häsebusch	LK Cuxhaven	31
Himmelpforten	LK Stade	31
Westerstede	LK Ammerland	31
Dollern	LK Stade	30
Klein Horsten	LK Wittmund	29
Heinschenwalde	LK Rotenburg (Wümme)	29
Schneverdingen	LK Heidekreis	28
Lechtingen	LK Osnabrück	28
Rotenburg-Nord	LK Rotenburg (Wümme)	28
Sandkrug	LK Oldenburg	27
Langenberg	LK Verden	27
Hoya	LK Nienburg (Weser)	27
Eischott	LK Gifhorn	27
Ristedt	LK Diepholz	27
Ramlingen	Hannover	26
Meyenburg	LK Osterholz	26
Brackstedt/Weyhausen	LK Gifhorn	26

Table A2. Cont.

Water Protection Area	Region	%
Hesel, Hasselt	LK Leer	25
Ristedt	LK Diepholz	25
Hoya	LK Nienburg (Weser)	25
Amelinghausen	LK Lüneburg	24
Engter und Engter, Niewedde	LK Osnabrück	24
Kähmen	LK Lüchow-Dannenberg	24
Fuerstenau	LK Osnabrück	24
Pye-Hollage	LK Osnabrück	22
Langenberg	LK Verden	22
Varel	LK Ammerland	22
Langen/Leherheide	LK Cuxhaven	22
Duengel	LK Osterholz	22
Rühen	NLWKN	22
Garßen	Stadt Celle	22
Zeven Wasserwerk	LK Rotenburg (Wümme)	21
Rotenburg-Stadt	LK Rotenburg (Wümme)	21
Harpstedt, Fassung B	LK Oldenburg	21
Stade Hohenwedel	LK Stade	20
Vrees/Neuvrees	LK Emsland	20
Gifhorn	LK Gifhorn	20
Westerbeck	LK Gifhorn	20
Bexhövede	LK Cuxhaven	19
Wietendorf	LK Heidekreis	18
Holdorf	LK Vechta	18
Burgdorfer Holz	Hannover	18
Bad Zwischenahn	LK Ammerland	18
Schneeren	Hannover	18
Dollern	LK Stade	18
Blumenthal	LK Osterholz	18
Börry Nord	LK Hameln-Pyrmont	17
Schönewörde	LK Gifhorn	17
Fuhrberger Feld	Hannover	17
Lüsche	LK Gifhorn	17
Belm, Nettetal	LK Osnabrück	16
Mariental	LK Helmstedt	16
Maschen	LK Harburg	16
Kirchdorf	LK Diepholz	16
Häsebusch	LK Cuxhaven	15
Annenheide	LK Oldenburg	15
Nienburg	LK Nienburg (Weser)	15
Sandelermöns	LK Wittmund	14
Lenglern	LK Göttingen	14
Eschede-Scharnhorst	LK Celle	14
Stadt Burgdorf	Hannover	14
Hunteburger Weg	Stadt Osnabrück	14
Garstedt	LK Harburg	14
Ramlingen	Region Hannover	14
Winsen/Stelle/Ashausen	LK Harburg	13
Hameln, Süd	Stadt Hameln	13
Feldhausen	LK Friesland	13
Schledehausen	LK Osnabrück	12
St. Hülfe	LK Diepholz	12
Adendorf	LK Lüneburg	11
Hankensbüttel	LK Gifhorn	11
Buchholz	LK Harburg	11
Wingst	LK Cuxhaven	11
Drakenburg	LK Nienburg (Weser)	11
Wittingen	LK Gifhorn	10
Stroot	Stadt Lingen	10

Table A2. Cont.

Water Protection Area	Region	%
Wagenfeld	LK Diepholz	9
Grohnde Süd I	LK Hameln-Pyrmont	9
Verden	LK Verden	8
Hohenholz	Hannover	8
Klein Horsten	LK Wittmund	6
Himmelpforten	LK Stade	6
Stadensen II	LK Uelzen	5
Munster	LK Heidekreis	5
Poppenburg	LK Hildesheim	5
Gronespring	Stadt Göttingen	5
Feldhausen	LK Friesland	4
Aurich, Egels	LK Aurich	4
Hohenholz	Hannover	3
Ritterhude	LK Osterholz	3
Rümmer	LK Helmstedt	3
Woxdorf	LK Harburg	3
Altenwalde	LK Cuxhaven	2
Collinghorst	LK Leer	2
Altes Amt Lemförde	LK Diepholz	2
Lüneburg	Stadt Lüneburg	2
Aurich, Egels	LK Aurich	2
Weesen	LK Celle	1
Nordheide	LK Harburg	1
Leer, Heisfelde	LK Leer	1
Grasdorf	Hannover	1
Harlingerland	LK Wittmund	1
Benstorf	LK Hameln-Pyrmont	1
Stade Hohenwedel	LK Stade	1
Elze	LK Hildesheim	1
Bodenwerder/Rühle	LK Holzminden	0
Börry Nord	LK Hameln-Pyrmont	0
Heinbockel	LK Stade	0
Eckerde	Hannover	0
Alexandersfeld	Stadt Oldenburg (Oldenburg)	0
Winsen	LK Celle	0
Kirchohsen	LK Hameln-Pyrmont	0
Haarbach	LK Hameln-Pyrmont	0
Belm, Schinkel	LK Osnabrück	0
Dueshorner Heide	LK Heidekreis	0
Glessequelle	LK Holzminden	0

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