Farmers' choices of adopting and coupling strategies of sustainable intensification – Evidence from European farm level data

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Abstract: *Sustainable intensification (SI) covers a broad portfolio of practices and strategies of which farmers apply specific bundles. Understanding farmers' rationales for the uptake of SI practices is crucial for targeted context and objective-oriented policy design and strategy-making. The aim of this study is therefore to (i) detect which SI practices are adopted, (ii) analyse the influence of farmers' characteristics and perceptions as well as farm attributes on adopting SI and (iii) evaluate to what degree the selection of different SI strategies is interdependent and shows complementary effects. We draw on farm survey data from 2017. First, we investigate the occurrence of various region-specific SI practices descriptively. To analyse determinants for the adoption, we use a SI conceptual framework that assigns practices to four fields of action (FoA) from farm to landscape level and land use to structural optimisation. Using multivariate probit modelling, we assess the probability of taking action within a certain FoA, controlling for the fact that the uptake of different fields might be correlated. Results indicate that most farmers apply SI practices as a combined portfolio. Farmers are more prone to apply field-level interventions than SI practices that require regional cooperation and coordination. Farmers' characteristics especially in terms of risk taking and environmental consciousness affect the adoption pattern. Across all FoA there is indication for economies of scale. Coupling SI practices is an important issue, also across spatial scales, showing a tendency for complementarities and path dependencies in SI adoption.*

Keywords: *Sustainable intensification, Farm management strategies, Decision making, Survey data, Multivariate Probit Model*

Introduction

The notion of sustainable intensification (SI) of agriculture has been popularized as an approach to effectively combine agricultural production gains with environmental protection and sustainability goals (Gadanakis et al., 2015). Originally introduced by Pretty (1997), after two decades of research, opinions and understanding still vary on the agricultural and sustainability advancements and their respective extent that SI can and should achieve (Baulcombe et al., 2009; Dile et al., 2013; Godfray et al., 2010). Foci are set on closing yield gaps (Mueller et al., 2012), applying advanced technologies (Foresight, 2011), producing more environmentally sustainable in identified protection areas even though yields might decline (Godfray, 2015), or on the resilience of farming systems (Dile et al., 2013).

As SI does not include a predefined and limited set of farm management or land use practices, analysing the practical implementation of SI is demanding (Franks, 2014; Pretty et al., 2014). However, there is consensus that implementation depends on regional and problem contexts of the farming systems (Godfray et al., 2014; Petersen et al., 2015). In a systematic review of the complete scientific SI literature up to 2016, Weltin et al. (2018) have advanced a conceptual framework consisting of four fields of action (FoA), differentiating SI practices according the spatial scale on which they are applied and to the optimization scope (see Fig.1). All main practices covered in the literature can be assigned to this framework. The discussion on the framing of SI is ongoing also regarding the relation and boundaries to other concepts striving for sustainable agricultural development, such as ecological intensification or agroecology (Wezel et al., 2015). Taking the practices that make up a concept as a starting point, allows also comparing how different concepts overlap or diverge.

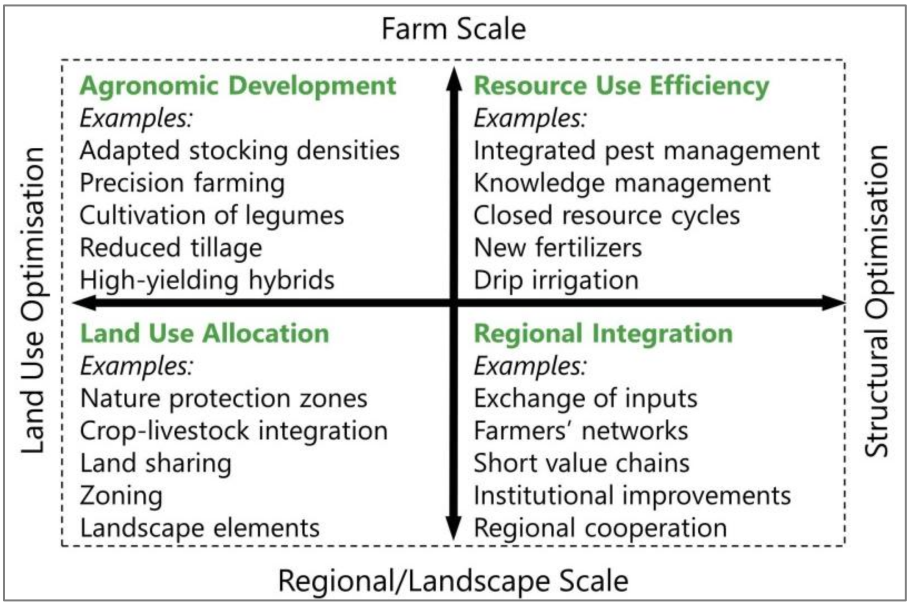

Figure 1. Systematisation of sustainable intensification (SI) practices through fields of action (FoA) (Weltin et al., 2018). Practice examples for each FoA are included.

Discussing the framework in a participatory process in four European case study regions, local stakeholders from the fields of agriculture, environmental protection, local administration and science defined current and future SI solutions for their regional farming system. The solutions in all regions covered all four FoA demonstrating that SI implementation is likely to include a broad portfolio of practices (Weltin et al., 2018). Especially in highly-developed farming systems, the implementation of SI often will not mean the adoption of one new practice but an optimal set of different practices. It can be expected to see complementarity or substitutional effects among different SI practices.

The understanding of the drivers of SI adoption decision is crucial in order to design policies to support more environmentally and socially sustainable farming. Farmers represent a key group of actors to implement SI practices. Although the economic literature on innovation and technology adoption has a long tradition (Griliches, 1957) besides a few applications in developing countries (Kassie et al., 2015a; Kassie et al., 2015b; Shiferaw et al., 1998), studies on how exactly and why farmers adopt SI are lacking. In the innovation adoption literature, the decision of the farmer or farm household to adopt a new practice is modelled as a result of a profit or utility maximisation process, which is determined by farmers' characteristics and social embeddedness, as well as farm and regional context variables (Baerenklau, 2005; Di Falco et al., 2014; Ghadim et al., 1999; Sauer et al., 2012). Modelling the motives for SI adoption, moreover, has to take into account the simultaneity of the decision for a whole bundle of SI practices by the farmer and its context specificity.

Using recent farm survey data, this paper focuses on disentangling the SI agenda of farmers and the determinants of its uptake for the European case of Northern German lowlands. The research questions addressed are: (i) Which bundles of different SI practices are applied? (ii) What are the determinants of SI adoption? (iii) Do complementary or substitutional relationships between adoption decisions exist? We propose a conceptual and methodological procedure that is sensitive to the specific case but also allows the application to different cases by analysing the decision based on the four FoA suggested by Weltin et al. (2018). We analyse the SI practices taken up by farmers descriptively and estimate the drivers of the decision in a multivariate probit model (Kassie et al., 2015a) allowing for correlation of adoption decisions for the different FoA.

Material and Methods

Data and case studies

The data used for analysis was gathered by the European research project VITAL (http://vital.environmentalgeography.nl/) in four European case study regions in 2017/18. Based on the portfolio of possible SI practices identified in (Weltin et al., 2018) and the interviews with stakeholders involved in land use and regional workshop discussions relevant SI practices for each case study region were identified (Kemmis et al., 2014). Subsequent to the selection of SI practices, larger samples of farmers were asked to indicate their applied SI practices, together with other farm and farmer-related variables to be used as drivers of these decisions using closed questionnaires. Data from the case study of Northern Germany were analysed, where we focused on the management of lowland areas with a high share of peatlands. From a SI perspective, these areas are particularly interesting due to their high climate impact potential and the challenge to maintain economic viability.

A mixed mode approach was pursued for data collection. Farmers' were addressed postal and via farmers' associations and had the option to reply either postal or online. To maximise the homogeneity of the sample and responses from peatland farmers, we reduced the spatial scope of the survey to those zip code areas with high shares of peatlands. The map in Fig. 2 shows the regional spread of the collected responses. In total, 465 responses were collected. The response rate from direct address was 13.5% overall. 410 farms recorded their SI uptake.

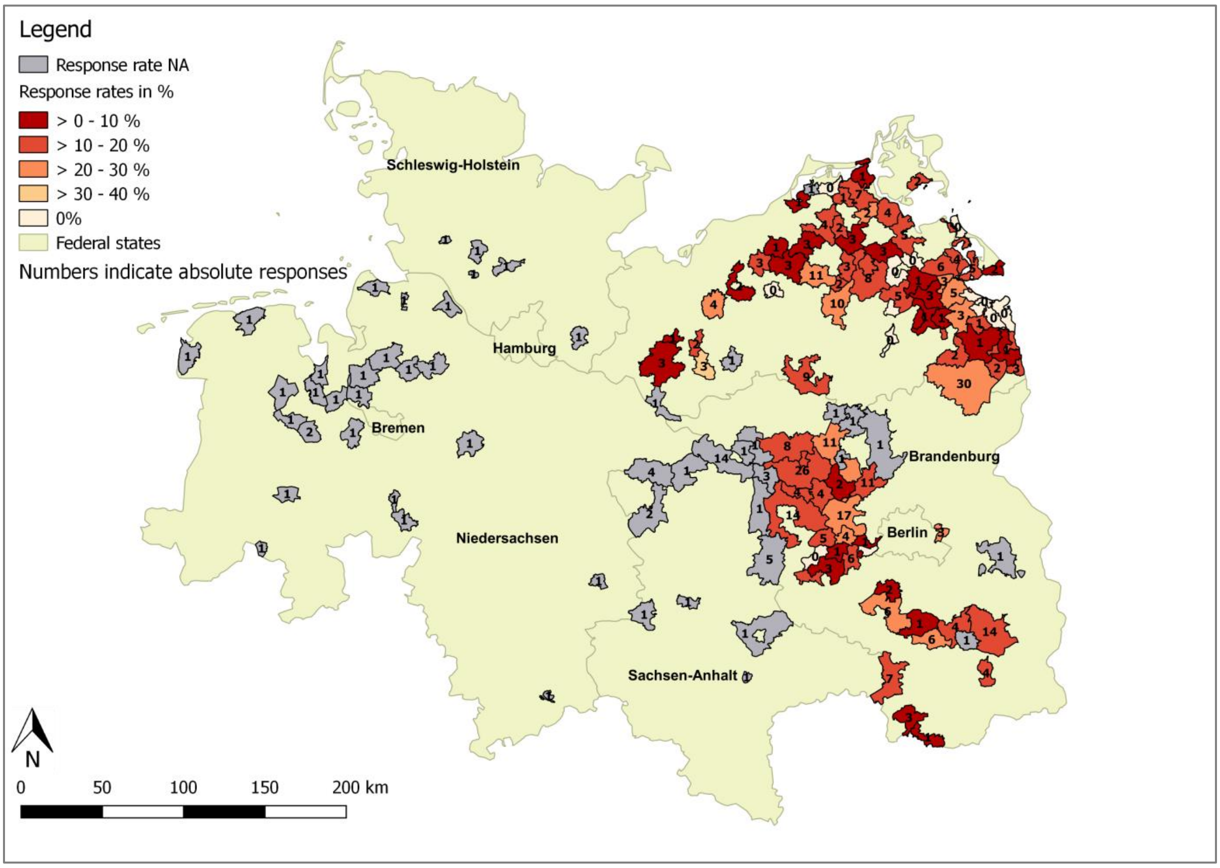

Figure 2. Map of surveyed area including response rates for the ZIP-code areas addressed postal. 32 missing values. Response rates are not available (NA) when the zip code area was only addressed via farmers' associations.

In total, 18 different SI practices were investigated. Farmers also had the option to state whether they use other practices. In a first step, the frequency of the uptake was captured to identify, which SI practices are more prominent and how choices for different practices are combined. Doing so, we were able to investigate the likelihood that farmers apply SI practices jointly.

Empirical model

We modelled the decision of the farmers in a multivariate probit model (Kassie et al., 2015a) that allows for M binary dependent variables, capturing the adoption decisions. We reduce the complexity of the model and derive a procedure that is applicable beyond our specific case, drawing on the framework conceptualising the four FoA for SI (Weltin et al., 2018). Each of the practices of the survey can be assigned to one specific FoA. When a farmer applies at least one practice (s)he is considered as being active in the respective FoA. This yields four binary yes-no-decisions for each farmer, which we expected to be interrelated. Correlation between adoption decisions arises when the same unobserved variables drive the decision or the adoption of practices in one FoA is conditional on another FoA (Belderbos et al., 2004; Kassie et al., 2015a). As they do not take the correlation of the error terms of the adoption decisions into account, univariate binary models would be inefficient in this case (Belderbos et al., 2004).

Farmers choose the utility maximising number of SI practices and thus the respective FoA. For four FoA, there are 2^4=16 possible outcome combinations. This utility or willingness to adopt at least one practice belonging to a FoA j of farmer i is a non-observable latent variable y_{ij}^*. Only the outcomes of the utility maximisation process of the farmers y_{ij} are observed – either adoption or non-adoption – implying that the latent utility has crossed a certain threshold which can be set to 0. The system of latent adoption equations is represented by

$$y_{ij}^* = \boldsymbol{x_i}\boldsymbol{\beta_j} + \varepsilon_{ij}, \qquad j = 1 \dots 4$$

where $\boldsymbol{x_i}$ is a vector of observed exogenous variables driving the decision, $\boldsymbol{\beta_j}$ is a vector of coefficients and ε_{ij} is the error term. The observed outcome is given by

$$y_{ij} = \begin{cases} 1 \; if \; y_{ij}^* > 0 \\ 0 \; otherwise \end{cases}, \; j = 1 \dots 4.$$

The error terms of the adoption decisions are assumed to be jointly multivariate normal distributed with

$$\boldsymbol{\varepsilon} = [\boldsymbol{\varepsilon_1} \dots \boldsymbol{\varepsilon_4}] \sim N[0, \boldsymbol{R}].$$

The correlation matrix $\boldsymbol{R}$ is given by $\boldsymbol{R} = \begin{bmatrix} 1 & \rho_{12} & \rho_{13} & \rho_{14} \\ \rho_{12} & 1 & \rho_{23} & \rho_{24} \\ \rho_{13} & \rho_{23} & 1 & \rho_{34} \\ \rho_{14} & \rho_{24} & \rho_{34} & 1 \end{bmatrix}$.

ρ_{jk} represents the pairwise correlation coefficient between two choices. Thus the multivariate probit model allows simultaneously estimating the determinants of adoption and the correlation structure between the adoption decisions in order to assess complementarities or substitutes between FoA. The model was estimated using simulated maximum likelihood estimation with a number of 250 draws for the simulated likelihood calculated by the Geweke-Hajivassiliou-Keane simulator (Cappellari et al., 2003). All estimations were performed using Stata14 software.

Explanatory variables and summary statistics

We selected variables explaining the choice of SI practices based on previous theoretical and empirical studies that deal with farm household decisions regarding the uptake of environmental practices such as agro-environmental schemes (Chabé-Ferret et al., 2013) or the combined economic-environmental outcomes of a farm (Gómez-Limón et al., 2012; Urdiales et al., 2016). Evidence suggests that decisions are driven by farmer and farm household characteristics, such as household size or the age and education of the principal farmer. As profit maximisation is not the only motive, especially for environment-related decisions, a broader set of motivations was taken into account, such as environmental consciousness or the propensity to take risk. We further selected key characteristics of the farm that are likely to influence the decision to take action in different fields of SI. The final set of explanatory variables, including a summary statistics is presented in Table 1, as well as SI practice adoption per FoA

Table 1. Summary statistics of variables included for analysis

Variable	Explanation / coding	Obs.	Mean	Std. Dev.	Min.	Max.
Household size	Number of members living in household	386	3.04	1.47	1	8
Age of farm manager	In years	390	53.28	11.61	21	88
Succession secured	1 “yes”; 0 “no”	396	0.32	0.47	0	1
Highest level of education of farm manager	1 “lower secondary degree or below”, 2 “intermediate secondary degree; 3 “high school degree”; 4 “ university degree”	397	3.23	0.99	1	4
Legal status: single enterprise	1 “yes”; 0 “no”	408	0.65	0.48	0	1
Propensity to take risk	Self-assessment of 10-point scale	392	5.91	2.56	1	10
Feeling of environmental responsibility	Self-assessment of 10-point scale	389	7.12	2.64	1	10
Total area of agricultural land (ha)	Applied in natural logarithms	410	4.55	1.97	0	8.43
Share of grassland	In % of total agricultural land	410	0.45	0.39	0	1
Organic farm	1 “yes”; 0 “no”	402	0.20	0.40	0	1
FoA I ‘Agronomic development’	1 “adopted”; 0 “not adopted”	410	0.92	0.28	0	1
FoA II ‘Resource use efficiency’	1 “adopted”; 0 “not adopted”	410	0.54	0.50	0	1
FoA III ‘Land use allocation’	1 “adopted”; 0 “not adopted”	410	0.55	0.50	0	1
FoA IV ‘Regional integration’	1 “adopted”; 0 “not adopted”	410	0.48	0.50	0	1

Sample is based on the 410 farms that provide information on SI adoption.

Whereas the uptake in the FoA of ‘Agronomic development’ is very high with over 90%, the adoption in the other three FoA is with around 50% of the farms less likely. Due to missing values, the final model was based on a sample size of 357 observations. The multivariate probit model allows including different variables for each adoption equation. However, as little primary results on SI adoption exist, we used the same set of variables for all adoption decisions.

Results

Coupling SI practices

Farms adopt up to 17 different sustainable intensification (SI) practices. There are only 20 farms in the sample (4.9%) that do not adopt any practices at all. Also only 17.3% of sampled farms apply SI as an isolated practice. All other farms tend to connect different SI practices to pursue a more diversified SI agenda. Figure 3 provides an overview on the frequency of adopted practices and how often they are connected with other SI practices.

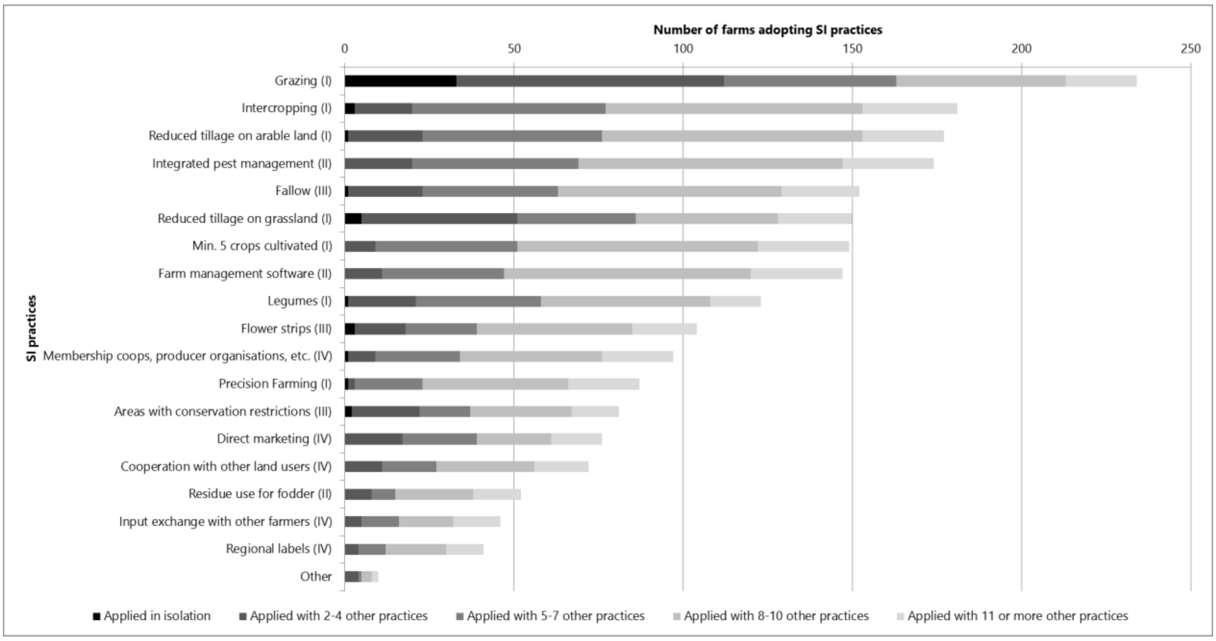

Figure 3. Application of SI practices by sampled farms (N=410). For each practice the respective field of action is indicated in parentheses referring to FoA I 'Agronomic development', FoA II 'Resource use efficiency', FoA III 'Land use allocation', FoA IV 'Regional integration'.

Farm-level practices either belong to the FoA I 'Agronomic development' such as pasture grazing, intercropping or reduced tillage, or to the FoA II 'Resource use efficiency' such as integrated pest management. The most frequently adopted practices on the landscape level are flower strips and fallow contributing to land sharing on regional scale in the FoA III 'Land use allocation'. All practices of FoA IV 'Regional integration' are adopted by less than a quarter of farms. The most prominent is the membership in cooperatives, producer organisation or machine exchange rings. Almost all practices in this field are applied in connection to several other practices. The same can be observed for the practices in the remaining structural optimisation-related FoA of 'Resource use efficiency'. Across all FoA, pasture grazing – also due to its frequent application – represents the only practice, which a larger share of farms applies in isolation.

Modelling SI adoption

In the second step of the analysis, each practice was assigned to a respective FoA according to Weltin et al. (2018). Assignment is indicated in Fig. 3. The determinants of the adoption and the correlation between different fields were estimated in a multivariate probit model. The estimation results in Table 2 include estimates for the four adoption outcomes and the estimated correlation matrix between the four FoA.

The size of the household is not important for the uptake of SI practices. The age of the farmer, and thus the experience of farming, has a statistically negative impact on the two FoA, which are associated to land use optimisation. A higher level of education however significantly increases the likelihood to apply SI in the FoA of 'Agronomic development'. Farms that are single enterprises have a negative influence on SI adoption compared to legal entities. Effects are statistically significant for the two FoA which are structural optimisation-related, also showing rather high coefficients. Having a higher propensity to take business risks and feeling responsible for the environment in the region are important variables to determine SI adoption. Coefficients are comparably high for FoA I 'Agronomic development' and IV 'Regional integration'. There is a strong and statistically significant effect that the likelihood that farms apply SI increases with land size across all fields, an indication for economies of scale. A higher grassland share makes farms less likely to apply SI. The effect for organic farms is high and significantly negative for the FoA II 'Resource use efficiency'.

Table 2. Estimation results of multivariate probit model for the adoption of SI per FoA

	FoA I	FoA II	FoA III	FoA IV
Household size	-0.086 (0.089)	0.029 (0.061)	-0.039 (0.054)	0.008 (0.049)
Age	-0.024** (0.011)	0.003 (0.008)	-0.017** (0.007)	-0.001 (0.006)
Succession secured	-0.454* (0.263)	0.343* (0.189)	0.137 (0.166)	0.100 (0.153)
Level of education	0.251** (0.121)	-0.021 (0.089)	-0.001 (0.079)	-0.054 (0.076)
Legal status: single enterprise	-0.385 (0.371)	-0.511** (0.204)	-0.055 (0.180)	-0.337** (0.167)
Risk taking	0.115** (0.047)	0.059* (0.034)	-0.038 (0.030)	0.120*** (0.030)
Environmental responsibility	0.100** (0.046)	-0.016 (0.032)	-0.016 (0.029)	0.051* (0.028)
Total land in ha (log)	0.277*** (0.089)	0.345*** (0.062)	0.290*** (0.055)	0.088* (0.051)
Share of grassland	-0.007 (0.339)	-1.025*** (0.248)	-0.629*** (0.230)	-0.217 (0.226)
Organic farm	0.064 (0.328)	-0.688*** (0.210)	-0.147 (0.186)	0.361** (0.184)
Constant	0.415 (1.070)	-0.976 (0.767)	0.540 (0.669)	-1.136 (0.078)
Correlation coefficients	FoA I	FoA II	FoA III	FoA IV
FOA I 'Agronomic development'	1			
FOA II 'Resource use efficiency'	0.729*** (0.176)	1		
FOA III 'Land use allocation'	0.112 (0.146)	0.252** (0.102)	1	
FOA IV 'Regional integration'	0.546*** (0.156)	0.465*** (0.090)	0.134 (0.096)	1

Standard errors in parentheses. '*** p<0.01'; '**p<0.05'; '*p<0.1'.

The estimation results allow testing whether the uptake in different FoA is correlated, indicating complementary effects in case of positive correlation and substitution effects for a negative correlation coefficient. The correlation between the two FoA at the farm level is the highest (0.73). There is also statistically significant correlation between these two and 'Regional integration'. Correlation coefficients are with around 0.5 both high. There is also significant correlation but to a smaller extent between the FoA II and III. There is no statistical significant relation between the two FoA on the regional level. A chi-squared test

($chi^2(6)=44.4005$, $p=0.000$) rejected the null hypotheses that all correlation coefficients are jointly equal to zero. That means that the estimates of univariate probit models would be inefficient. Overall, we find that complementarities in SI adoption exist and that the decision rationales for SI differ across FoA.

Discussion and outlook

With this study, we aim to contribute to the debate on sustainable intensification (SI) in highly-developed farming systems (Barnes et al., 2014; Firbank et al., 2013). We especially want to shed light on practice implementation and its drivers. Against this backdrop, we follow a broad understanding of SI (Buckwell et al., 2014; Godfray, 2015) and address it as an optimal portfolio of interventions at different scales, going also beyond the level of the single farm, and with different optimisation targets. We find complementarities between four different fields of action (FoA) for SI. Farmers make decisions for practices across these FoA conditional on each other. This was also found for a much more limited set of farm-scale practices by Kassie et al. (2015a).

Reasons for the interdependence of practices could be that farms that adopt SI practices are on a distinct innovation path, for example due to higher propensity to take risks (Ghadim et al., 1999; Sauer et al., 2012) or that non-adopters are waiting due to unsecure outcomes (Chhetri et al., 2010). Path dependencies could play a role when existing development paths are reinforced, e.g. by learning that certain practices show their positive economic or environmental effects only in combination (Arthur, 1989; Chhetri et al., 2010). As a limitation of our cross-sectional data, we cannot investigate the dynamics of the adoption decision. However, our study takes into account and confirms empirically that SI needs to be addressed as a complex innovation agenda rather than a set of isolated adoption decisions.

SI practices do not only consist of recently developed technologies but also include well-known practices such as the cultivation of legumes. It explains why we see high uptake especially in the FoA I 'Agronomic development'. Farms are less active on the regional level, especially regarding the FoA IV 'Regional integration'. Action is more complex to undertake as implementing changes here often requires collective action and coordination among actors (Ostrom, 2010). Farmers cannot act as single decision-makers. They neither control the outcome of the intervention on their own nor the relation to other involved actors when engaging e.g. in input exchange or regional marketing (Wilkinson et al., 2002). Some of the more prominent practices in the FoA III 'Land use allocation' such as flower and buffer strips or fallow are supported by the Common Agricultural Policy (CAP) of the European Union which externally incentivises the uptake. In the model, we do not find a statistical significant relation between the two landscape level FoA, an indication that the subsumed practices differ for the investigated case. A starting point for further research lies in the result that the FoA IV 'Regional integration' is systematically related to both FoA on the farm level. Finding the trigger practices for this connection and support them, e.g. by regionally tailored policies, could help to unfold the full potential of SI.

The proposed method disentangles the adoption decision in several conceptual FoA. The different influence of determinants across all FoA suggests that we cannot investigate SI as a binary decision. A broader set of motivations and attitudes beyond profit maximisation is relevant for the farmer's decision, such as the feeling of environmental responsibility, similar to previous findings (Urdiales et al., 2016). Finding structured methods to assess the underlying preferences of decision-makers is therefore important (Menapace et al., 2012). SI is also dependent on the farm type (Firbank et al., 2013). Economies of scale could be attributed to the fact that SI is very knowledge intensive (Buckwell et al., 2014) and requires substantial monitoring capacities especially when many practices are combined. With negative model coefficients throughout all FoA, the management of grassland seems to inhibit SI adoption. This can also be attributed to the fact that the discussion on SI is still much oriented towards arable farming (Weltin et al., 2018). However, our results highlight the need to investigate the specific decision-rationales and mechanism of livestock farms and to consider SI approaches particularly tailored to them. Even less obvious is the inverse relationship between organic farming and the adoption of FoA II. In fact a number of practices subsumed there, such as close nutrient cycles or integrated pest management are similar to organic farming principles. In theory, positive effects could be expected. A plausible reason could be the low capital intensity of organic farming (especially for extensive grassland management) – a factor, which has not been included in the model – and the investment needs for SI practice adoption.

The feasible and optimal set of SI practices depends on regional and problem contexts (Godfray et al., 2014) which already need to be taken into account when designing the questionnaires to collect primary data. Beyond in-depth analysis of case studies (Wittman et al., 2016), it is important to enable comparisons of drivers for the adoption of SI, especially in Europe where a common set of baseline policies is applied to the agricultural sector through the CAP. Understanding common and diverging rationales of decisions and practices that work in regions that face similar problems could enable inter-regional learning. Regional knowledge and innovation networks differ across Europe but still share common characteristics and challenges, e.g. the need of better knowledge management in an increasingly complex environment (Bellini et al., 2007). The suggested procedure to assess the SI uptake on the conceptual level of four FoA provides a way to facilitate comparison as it is applicable independent of the regional case, although, through the aggregation information will be lost. It can be easily transferred to assess decision making within related concepts such as agroecology that also address new farming arrangements at multiple scales but would imply different sets of practices.

The final VITAL data will provide a baseline for a comparison of SI adoption, allow further testing of the assessment of SI at the level of FoA, and shed more light on the debate of SI implementation. It provides detailed information on SI practices in three more case study regions, namely Kromme Rijn (The Netherlands), Utiel-Requena (Spain) and Vaucluse (France). Understanding the rationales for the uptake is also an important step to assess whether and how SI practices finally result in more economically and environmentally sustainable outcomes.

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