agronomy

Article

Perception of the Relevance of Soil Compaction and Application of Measures to Prevent It among German Farmers

Sandra Ledermüller [1,*], Johanna Fick [2] and Anna Jacobs [1]

[1] Coordination Unit Soil, Thünen Institute, Bundesallee 49, 38116 Braunschweig, Germany; Anna.Jacobs@thuenen.de
[2] Thünen Institute of Rural Studies, Bundesallee 63, 38116 Braunschweig, Germany; Johann.Fick@thuenen.de
* Correspondence: Sandra.Ledermueller@thuenen.de

Abstract: Intensive field traffic and high axle loads can lead to soil compaction, with ecological and economic consequences. However, the relevance of this issue among practitioners is largely unknown. Therefore, the aim of this study was to determine the relevance of this issue for farmers in Germany, whether and which mitigation measures are applied to avoid it, and what a (non-) application might depend on. We conducted an online survey among farmers in Germany in winter 2017/2018. For the majority of the respondents, soil compaction is a relevant issue on their own farm, and even at higher share rates, this issue is important for Germany as a whole. To prevent or avoid soil compaction, 85% of the participants apply agronomic, 78% tyre/chassis, and 59% planning/management measures. The farm size, tractor power, working in full- or part-time, estimated relevance of soil compaction for Germany, and the estimated yield loss were positively associated with the application of management measures. The insights gained suggested that more effort is needed to encourage farmers' perceptions regarding soil compaction in order to generate demand-oriented and practice-oriented recommendations for action for various target groups and thus promote the application of soil-conserving measures on a broad scale.

Keywords: soil management; farmers' attitudes; yield loss; risk perception; advisory service; formal learning

check for updates

Citation: Ledermüller, S.; Fick, J.; Jacobs, A. Perception of the Relevance of Soil Compaction and Application of Measures to Prevent It among German Farmers. *Agronomy* **2021**, *11*, 969. https://doi.org/10.3390/agronomy11050969

Academic Editors: E. A. C. Costantini and Simone Priori

Received: 23 April 2021
Accepted: 11 May 2021
Published: 13 May 2021

1. Introduction

Background

Soil compaction of arable soils is caused by intensive field traffic on wet soils due to under unfavourable weather conditions [1–4]. Soil compaction leads to decreased porosity and changed pore size distribution and disturbs the water and gas regime of soils [5,6]. It also reduces hydraulic conductivity and increases bulk density, which can cause floods [7], disturbs biological processes in the soil, and promotes nitrous oxide emissions (N_2O) [8–11] or reduces crop growth [12,13]. Soil degradation caused by compaction is receiving increasing attention from policymakers as it is considered as a major soil threat in Europe [14]. Among suggestions for efficient soil management, preventing soil compaction is one of the key objectives for the future Common Agricultural Policy (CAP) [15] and is seen as one lever to achieve the goals of the European Green Deal [16].

Measures to Prevent or Mitigate Soil Compaction

In Germany, crops such as silage maize and sugar beet are especially associated with high machinery loads during harvest in late summer/autumn, when the weather is rainy and soils have a high moisture content and are therefore susceptible to compaction [17]. The area under silage maize and sugar beet regionally accounts for up to 20–34% and 14–24% of arable land in individual districts, respectively [18]. Additionally, a large amount of liquid manure is applied to the fields in spring, when soils can be even wetter than in autumn.

With climate change, drier summers and wetter winters are expected for Germany [19]. This also brings drier soils in the summer, but the regional expression of this is associated with considerable uncertainties [20]. Dry conditions in summer could be beneficial for wetter regions in terms of the number of trafficable days [21]. However, this has not been demonstrated for Germany so far. To prevent or mitigate soil compaction, farmers can choose between a variety of mitigation measures, including agronomic, technical, or management measures [22]. Agronomic measures include, for example, the cultivation of cover crops, direct seeding, or no or no-turn tillage without ploughing. These measures have a rather indirect effect on the prevention of soil compaction by stimulating soil biota, thereby improving aggregate stability and thus the resilience of soils [2,23–25]. As a further side effect, the number of machine passes is reduced and the generation of a so-called "plough sole" is avoided. They are referred to as indirect measures for the purposes of this paper because they are not primarily applied to prevent soil compaction. The technical measures include tyre variations and configurations as wide tyres, twin tyres, or technical options to adopt the tyre inflation pressure and chassis options as rubber tracks or crab steering. These measures increase the contact area or decrease the number of wheelings and thus the associated soil pressure [26]. Information on the functionality, advantages, and disadvantages of these measures in the form of manufacturers' recommendations, practitioner reports, or articles in agricultural journals is widely available (e.g., [27–32]). Separating street and field transport during harvest and manure spreading or the adaption of the machine utilisation scope to the trafficable period of the soil are among the management measures. When separating street and field transport, the tyre pressures of the transport vehicles on the field are adjusted to the respective requirements (low tyre pressure for soil protection). For this measure, an additional transport vehicle is needed, which causes additional operational costs. When adapting the machine utilisation scope, it is generally not expected with 100%. The 100% utilisation scope of a beet harvester, for example, would be 1000 ha per year and 10 years of utilisation. This way, the highest machine efficiency and thus the lowest machine costs per ha are achieved. If it is now planned with a utilisation scope of 70%, farmers can react flexibly to weather conditions and are not under pressure to use the machine under any conditions. In this case, the machine costs per ha will increase. There is much less information available on these measures and it is provided rather by official bodies (e.g., [33,34]).

(Pro-) Soil Conservation Behaviour and Decision Making of Farmers

Thorsøe et al. [35] described subsoil compaction as a "wicked" problem. Contrary to tame problems, wicked problems are "ill-defined, ambiguous and associated with strong moral, political and professional issues. Since they are strongly stakeholder dependent, there is often little consensus about what the problem is, let alone how to deal with it. [. . .] they are sets of complex, interacting issues evolving in a dynamic social context" [36]. In the context of soil compaction, pragmatic trade-offs, technological barriers, knowledge deficit, and responsibility outsourcing are to be mentioned [35]. Furthermore, yield effects and thus the direct economic consequences largely depend on the soil type and soil conditions at the time of wheeling and type of machinery [37]. For decisions on sustainable soil management as made by local actors, knowledge of the local soil properties and management is necessary. Moreover, each player acts in an individual socioeconomic environment, which also needs consideration [38,39].

In the past, exploring what farmers in industrialised countries know about soil compaction, how they perceive it, and what measures they implement to avoid or mitigate it were issues that received little attention from a scientific perspective. However, there are quite a number of studies on different aspects of sustainable land management in developing countries (e.g., [40–44]) but only a few in industrialised regions such as Central Europe. For Central European conditions, Reichardt and Jürgens [45] studied the adoption of precision farming in Germany and found technical challenges (e.g., data handling and interpretation, incompatibility between machines) to be the main barrier for a broad adoption. Caffaro and Cavallo [46] found perceived, not further specified, economic barriers to have a negative effect on the application of smart farming technologies in Italy. Farm size, in contrast, had a positive effect on the implementation. Tamirat et al. [47] showed for Germany and Denmark that farm size, age, and information/demonstration events significantly influence the decision of farmers to adopt precision agriculture. Regarding the acceptance of conservation measures in Germany, Sattler and Nagel [48] observed that associated risk, effectiveness, and the efforts needed to implement a certain measure are equally or even more important than economic considerations. For a change in land management practices in order to avoid soil erosion in UK, Boardman et al. [49] pointed out the importance of financial incentives as a motivator, in addition to socioeconomic influences. According to Barnes et al. [50], farm size and income had an influence on the adoption of precision agriculture technologies, but so did expectations of economic benefits from adoption and personal attitudes towards information and innovation. In the review of Bartkowski and Bartke [51] on decision making concerning soil management, economic considerations and pro-environmental attitude were found to be studied most often, and studies that reported a significant influence of these variables on decision making predominate. Concerning the effect of information and advisory service, Klerkx and Jansen [52] and Baumgart-Getz et al. [53] pointed out the important role of advisory service in terms of capacity and awareness building for sustainable farming and management among farmers. Within the stakeholder groups from practice and policy design and implementation, Prager et al. [54] identified advisory services as impotant players for the promotion of conservation measures. Especially for the case of sustainable soil management, Ingram and Mills [55] suggest for Europe that not all needs of farmers and advisors are met to push forward sustainable soil management.

Aim of This Study

In order to promote measures against soil compaction, e.g., by policy interventions or by information and education, it is of high importance to know how widespread such measures are and on which factors application depends. With this knowledge, certain measures can be promoted in a targeted manner and the promotion can be designed in a target-group-oriented way. Moreover, knowledge on the perceived relevance of the issue by farmers, as the main decision makers, is of strong importance. From this, conclusions may be drawn about the type of interventions that can promote adoption. If the relevance is assessed as being high but adoption is low, suitable measures are probably lacking or are unknown. If the relevance is assessed as being low, it is possible that the relevance is actually low or that the sensitivity to the issue needs sharpening. To the best of our knowledge, no scientifically based information is available on the perception of soil compaction as a relevant problem in Germany. The same applies to the adoption of measures to avoid it in Germany because the technical and management measures described above are not included in any agri-environmental program or agricultural surveys. Thus, the aim of this study was to explore the perception and knowledge of soil compaction, to find out how widespread mitigation measures to avoid soil compaction are, but also to identify possible variables that may determine the adoption of measures preventing soil compaction among German farmers.

2. Materials and Methods

Due to the lack of a complete and accessible contact list of farmers in Germany, we contacted as many farmers as possible to obtain a broad sample. We did this by distributing the invitation to the online survey through numerous channels, including articles in agricultural magazines, press releases of official institutions, interest groups, and magazines and announcements published by farmers' associations. In particular, by contacting agricultural magazines/media and farmers' associations in all Federal States of Germany, we aimed to obtain a regionally balanced sample (see Appendix A, Table A1 for complete list). In addition, we offered non-cash rewards to increase motivation for participation. The survey was active from February to April 2017. To conduct the survey, we used the software LimeSurvey. The questionnaire consisted of 5 sections which addressed variables recognised from the literature to influence pro-environmental behaviour in a broader sense: 1. general information on the farm, 2. crop rotation and soil tillage, 3. perception of and measures applied to prevent soil compaction, 4. technical equipment and process organisation, and 5. use of consulting and information offers. We used five different question types. Single-choice questions were chosen for categories which were mutually exclusive. Multiple-choice questions were asked when a selection of expected answers was known but not mutually exclusive. Open-text/numeric questions were asked when the answers were unperceivable or when a number was required. For personal assessments, a five-point rating scale was chosen. When a specification of categories was desired, the multiple- and single-choice questions were combined with open-text questions. In total, the survey was accessed 285 times, of which 124 respondents dropped out before the questions of interest (Section 3). Of the remaining 161 observations, only those which reported practicing arable farming were included in the evaluation presented here. The remaining 154 observations were included in the further analyses. Not all of them were complete, and, therefore, the number of observations considered for each question varies and is indicated accordingly. To evaluate variables influencing the application of measures, we adopted the scheme of Bartkowski and Bartke [51] and allocated the variables queried to the respective groups (Figure 1).

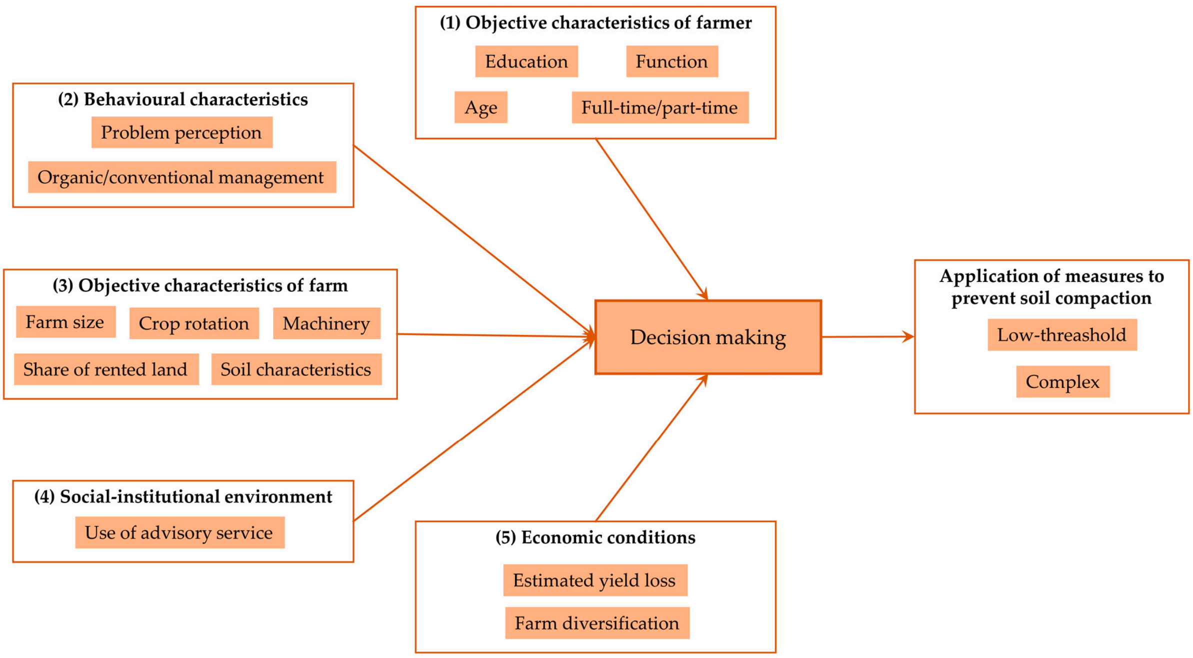

Figure 1. Theoretical framework for the evaluation of variables affecting the application of measures. Modified according to Bartkowski and Bartke [51].

In group (1), we included the variables education, function, age, and full-/part-time occupation. For group (2), we captured the variables problem perception and organic/conventional management as an indicator of environmental attitude. For group (3), we captured the variables farm size, share of rented land, machinery, crop rotation, and soil characteristics. For group (4), we recorded the variables use of advisory service, and for group (5), the variables estimated yield loss by soil compaction and farm diversification. It should be noted that the allocation of variables to the respective groups was partly subjective. For example, the variable full-/part-time occupation was allocated to "characteristics of the farmer" because it can influence focus and prioritisation in terms of how much time and money a farmer invests. Another scientist could assign this variable to the “economic conditions” (see Appendix B, Table A2 for questions, question type, and unit). We distinguished the applied measures, which we asked as multiple-choice questions, into three groups. The first differentiation was made according to the effects on soil compaction into direct and indirect effects. The second differentiation was made according to the type of measure. This resulted in the first group of “agronomic” measures with a more indirect effect in terms of soil compaction. The second group consists of measures with a direct effect on soil compaction of the type “tyre/chassis”, which are associated with a low planning effort (adjusting the internal tyre pressure), are well known (wide tyres), or are partly standard from the manufacturer (rubber tracks). The third group also consists of measures with a direct effect, but of the type “planning/management”, which are associated with a much greater long-term planning effort (adapt machine utilisation scope) or a short-term crop and operation specific management with additional machine capacity requirement (separation of field and street transport) (Table 1).

Table 1. Asked measures and corresponding grouping.

Asked Measure	Effect on Soil Compaction	Type of Measure
direct seeding	indirect	agronomic
cultivation of cover crops	indirect	agronomic
no-turn tillage	indirect	agronomic
adjusting the internal tyre pressure (with tyre inflation system or quick exhaust valves for manual pressure control)	direct	tyre/chassis
soil protecting tyres (e.g., twin tyres, rubber track, wide tyres),	direct	tyre/chassis
crab steering	direct	tyre/chassis
adoption of the machine utilisation scope to trafficable period	direct	planning/management
separation of field and street transport in manure spreading	direct	planning/management
separation of field and street transport at harvest	direct	planning/management

For a deeper evaluation of the variables influencing the application of measures, we focused on the direct measures of the group “planning/management”. We did so because these measures are less promoted and more complex than those of the group “tyre/chassis” and have a kind of innovative character and are therefore subject to special consideration within this analysis.

Statistical data from the survey year (2017) were used to contextualise our dataset, but for some characteristics, the most recent data were taken from the Farm Structure Survey in 2016 (FSS 2016). We used descriptive statistics; additionally, the chi-square test at $p \leq 0.05$ for categorical data was used to evaluate significant differences between observed and expected distributions between the groups “measure applied” and “no measure applied” among the tested variables. For numerical data, the t-test was used to assess whether the differences in the expression of the variables between the group applying direct measures and the group not applying direct measures of type “planning/management” were assumed to be significant at $p \leq 0.05$. The exact p values are provided at the appropriate places.

3. Results and Discussion

3.1. General Description of the Dataset

Out of the 154 observations, the largest proportion of respondents were from Lower Saxony (32%), followed by Bavaria (16%), Baden-Würtemberg (8%), and Northrhine-Westphalia (7%) (Table 2). The remaining federal states were represented with 1–5% of the respondents, except the city states Berlin, Hamburg, Bremen and Saarland, and Rhineland-Palatinate, with no respondents. The location was not specified by 20%. A comparison of the distribution of farms with the real distribution of arable farms in Germany as captured by FSS 2016 indicated that our dataset overrepresented Lower Saxony and underrepresented Bavaria [56]. The remaining federal states were quite well represented.

Table 2. Distribution of participating farmers in our dataset (n = 154) (Germany-wide survey: "Technical soil protection" 2017) and of arable farms captured by the Farm Structural Survey (FSS) 2016 [56] across the federal states of Germany.

Federal State	Our Dataset	Statistics (FSS 2016)
Lower Saxony	32%	15%
Bavaria	16%	35%
Baden-Würtemberg	8%	13%
Northrhine-Westphalia	7%	13%
Hesse	5%	6%
Schleswig Holstein	3%	4%
Thuringia	3%	1%
Saxony	3%	2%
Mecklenburg Western Pomerania	1%	2%
Brandenburg	1%	2%
Saxony-Anhalt	1%	2%

With 86%, the majority of the participants were the farm managers, 7% were family member employees, 1% non-family member employees, and 5% had another function or did not respond to this question. While the official statistics for Germany showed an employment rate of 48% full-time and 52% part-time (FSS 2016, [57]), the majority in our dataset were running the farm full-time (76%) and the smaller share part-time (22%). A small share gave no answer (2%) (Table 3). Thus, the group of full-time farmers was overrepresented in our dataset.

Table 3. Distribution of participating farmers in our dataset (n = 154) (Germany-wide survey: "Technical soil protection" 2017) and official statistics (FSS 2016 [57] and 2017 [58]) according to different features for our dataset.

Feature	Our Dataset	Statistics	Year of Statistics
full-time	76%	48%	2016 (FSS)
part-time	22%	52%	2016 (FSS)
organic	13%	11%	2017
conventional	85%	89%	2017
university degree	35%	9%	2016 (FSS)

The smaller share of participants practiced organic farming, with 13%, and the larger share of 85% practiced conventional farming; 2% gave no information on this. For the year 2017, the official statistics reported that 11% of the farms in Germany practiced organic farming [58], which was quite well-represented in our dataset (Table 3). With 35% of the farm managers having a university degree in our dataset, this group was overrepresented compared to the official statistics for arable farms in Germany, with 9% (FSS 2016, [58]) (Table 3). The majority (68%) of the corresponding farms in our dataset had a total area of arable land between 50 and <500 ha, whereas our dataset slightly underrepresented the farm groups below <50 ha and overrepresented the farms ≥50 ha (Table 4).

Table 4. Distribution of participating farmers in our dataset (Germany-wide survey: "Technical soil protection" 2017) and official statistics [58] according to arable land.

Arable Land	Our Dataset	Statistics 2017
under 5	3%	3%
5–<10	1%	12%
10–<20	5%	19%
20–<50	16%	27%
50–<100	29%	21%
100–<500	39%	16%
≥500	9%	2%

The mean area of cultivated arable land was 314 ha (standard derivation SD = 193 ha) and 45 ha of grassland (SD = 7 ha), the most powerful tractor had a mean power of 182 hp (SD = 76 hp), and the share of rented land was 50% (SD = 30%).

3.2. Perception of Soil Compaction

To investigate the perception of soil compaction, we asked the farmers about the relevance of soil compaction for their own farm (n = 152) and for Germany (n = 153). For Germany, six participants answered "can not judge"; for their own farms, none did so. In general, from "not relevant at all" to "very relevant" on a five-point rating scale, the number of answers increased more strongly for Germany than for participants' own farms (Figure 2).

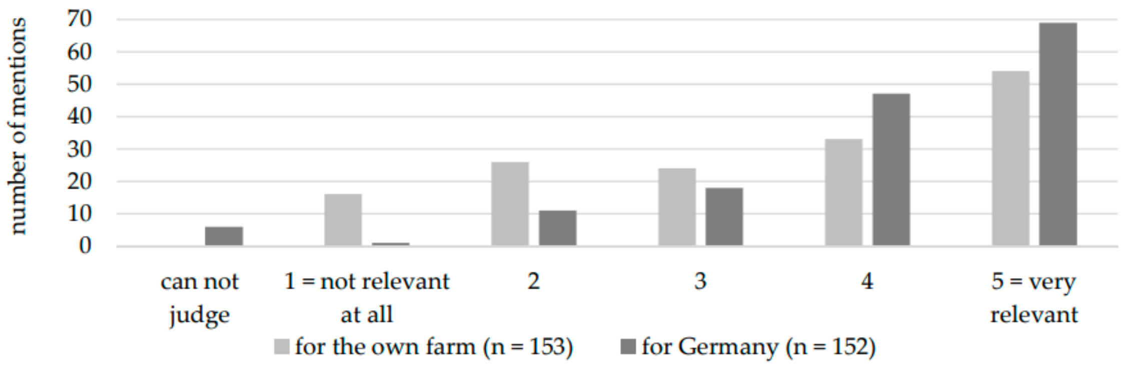

Figure 2. Perception of soil compaction for participants' own farms (n = 152) and for Germany (n = 153). (Germany-wide survey: "Technical soil protection" 2017).

Whereas 76% of the 152 participants who answered this question perceived soil compaction as "relevant" or "very relevant" (point 4 and 5 on the rating scale) for Germany, just 57% did so for their own farm. On the contrary, 8% perceived soil compaction as "not relevant" or "not relevant at all" (point 1 and 2 on the rating scale) for Germany and 27% for their own farm. We cannot exclude the possibility that the stated high relevance and sensitivity to soil compaction issues is a result of the recruiting procedure. Therefore, we assume that "innovators" and "early adaptors" are somewhat overrepresented. Around 60% rated the relevance higher for Germany than for their own farm and around 40% the other way around (Figure 3).

relevance for the own farm	relevance for Germany: 1 = not relevant at all	2	3	4	5 = very relevant	sum
1 = not relevant at all	0	5	3	5	2	15
2	0	5	6	6	7	24
3	0	0	5	9	7	21
4	0	0	3	20	10	33
5 = very relevant	1	1	1	7	42	52
sum	1	11	18	47	68	

Figure 3. Number of estimates of the relevance of soil compaction per scale unit (1–5 rating scale) for participants' own farms and for Germany, dark grey = same relevance estimated for participants' own farms and for Germany; light grey = higher relevance estimated for Germany than for participants' own farm; n = 145. (Germany-wide survey: "Technical soil protection" 2017).

In their study, Thorsøe et al. [35] detected similar patterns for Denmark, as 77% of the respondents regarded soil compaction as a "high" or "considerable" risk for Danish farming, and 39% for their own farm. There seems to be a gap between the individual and the overarching, collective concern. Since soil compaction is a difficult topic with complex underlying processes ("wicked problem" as described by Thorsøe et al. [35]), one explanation could be that individuals underestimate their exposure as a kind of moral exclusion. Opotow et al. [59] described moral exclusion as a way to avoid the complexity and ambiguity of environmental problems. This moral exclusion leads to an underestimation of environmental threats to one's own land [60,61]. However, the results of our survey may have further explanations. Using the argumentation of Dessart et al. [61], perception is influenced by what others do or say—in other words, by the social system. Consequently, the increased perception of soil compaction as a problem for Germany compared to participants' own farms can be seen as a result of social norms and expectations. This may in turn be reinforced by the increased media coverage of the issue of soil compaction in agriculture.

As a second indicator for the perception of soil compaction, we asked about the estimated yield loss due to and the area affected by soil compaction. This question was only posed to participants who rated the relevance of soil compaction for their own farm as 3 or higher (n = 106). The mean area affected was estimated to be 17% (median 10%) and the correspondent yield loss (n = 105) on the affected area to be 22% (median 20%) (Figure 4).

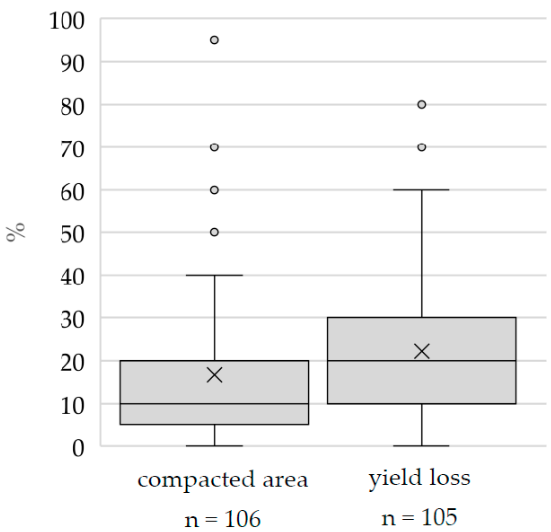

Figure 4. Estimated area affected by, and yield loss due to, soil compaction in percent (Box: 25–75% quantile; line in box: median (50% quantile), cross: mean, lower whisker: Q1–1.5 * inter-quartile range (IQR), upper whisker: Q3 + 1.5 * IQR, points: outlier). (Germany-wide survey: "Technical soil protection" 2017).

Above the 75% quantile, the mean area affected was 44%, with a higher mean estimated yield loss than the total mean of 26%. Below the 25% quantile, values were 1% and 17%, respectively. When multiplying the share of affected compacted area with the corresponding yield loss, the mean estimated "effective" yield loss was 3% (max. = 36%; min. = 0%). The results are in line with findings from Schleswig-Holstein, where farmers estimated 10% of their land to be affected by soil compaction, but the estimated yield loss was higher, ranging from 5 to 9% [62]. Scientific research to estimate yield effects of soil compaction is diverse in terms of investigated soils, crops, weather conditions, and machine configurations and varies on a wide range along these factors. Keller et al. [7] and Chamen et al. [37] gave an overview of numerous individual studies in their reviews and reported yield effects due to soil compaction between −2.5 and −27% (mean = −11%, number of studies cited = 15) and between +12 and −47% (mean = −16%, number of studies cited = 35), respectively.

To gain an insight into how farmers perceive soil compaction, we asked how they recognised that their fields may be affected. Out of 154 participants, 94 perceived soil compaction based on different indicators, which they were asked to name in a free-text question; multiple answers were possible. Of these, 50 participants named one indicator, 35 mentioned two, eight mentioned three, and one mentioned four indicators. Visual compaction phenomena were most often referred to (44 times) (Figure 5). The major statements in this indicator category were *waterlogging on the field* and *visible traffic lanes in the field*. Plant physiological indicators such as *growth depressions* or *restricted root growth* were mentioned 42 times, followed by other indicators which could not be clearly assigned to one of the other categories, such as *plough sole* or *compaction* with 31 mentions. Economic indicators such as *yield decrease* or *yield loss* were mentioned 25 times. In the category pests and diseases, with two mentions, *increased abundance of field horsetail* and *fungal infection* were specified. For soil biological indicators, with also two mentions, *improvement of the soil life* and *less earthworms* were mentioned.

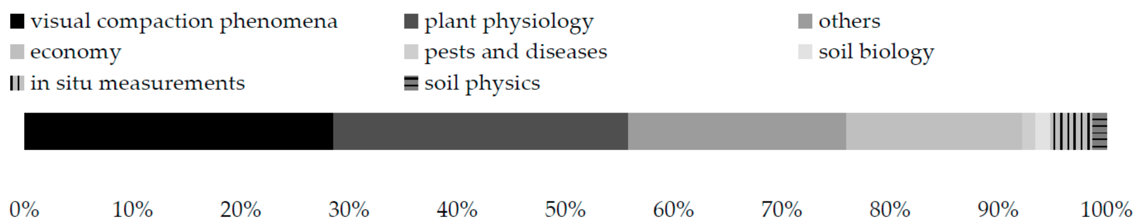

Figure 5. Percentage of perceived indicators for soil compaction, summarised in categories (n = 154). (Germany-wide survey: "Technical soil protection" 2017).

Indicators can be distinguished into primary ones, which indicate directly the compaction itself, and secondary ones, which rather indicate the indirect effects. The indicators listed up to this point, except the category others, describe the possible secondary effects of soil compaction. Generally, secondary effects are easier to detect and more visible than primary effects [63,64]. The soil physical indicators such as *water storage* or *formation of clods*, with two mentions, and in situ measurements such as *spade, penetrologger, or soil penetrometer diagnosis*, with six mentions, describe the primary effects of soil compaction (with hatching in Figure 5). Such in situ measurements can detect changes in bulk density, soil structure, and soil strength as a direct result of the process of soil compaction [63,65,66]. While these indicators are clearly measurable and scientifically based, the previously mentioned indicators of secondary effects are based more on perception and experience. Since this was a free-text question, the assignment of the answers to the respective categories, especially for the secondary effects, is subjective. Nevertheless, these indicators were observed clearly more frequently than those of the primary effects. We conclude that farmers either rely more on their perceptions and experience to identify soil compaction, or that easily applicable and comprehensible methods to verify these perceptions are lacking in practice or not known.

3.3. Applied Measures

The participants were asked what kind of measures they apply to prevent soil compaction. Multiple answers were possible and 154 participants answered the question. As for the indirect, "agronomic" measures, 85% reported using at least one of them. In total, 94% of the farmers applied at least one direct measure to prevent soil compaction, 78% applied at least one measure of the group "tyre/chassis", and 59% applied at least one measure of the group "planning/management" (Figure 6; for grouping, see Table 1).

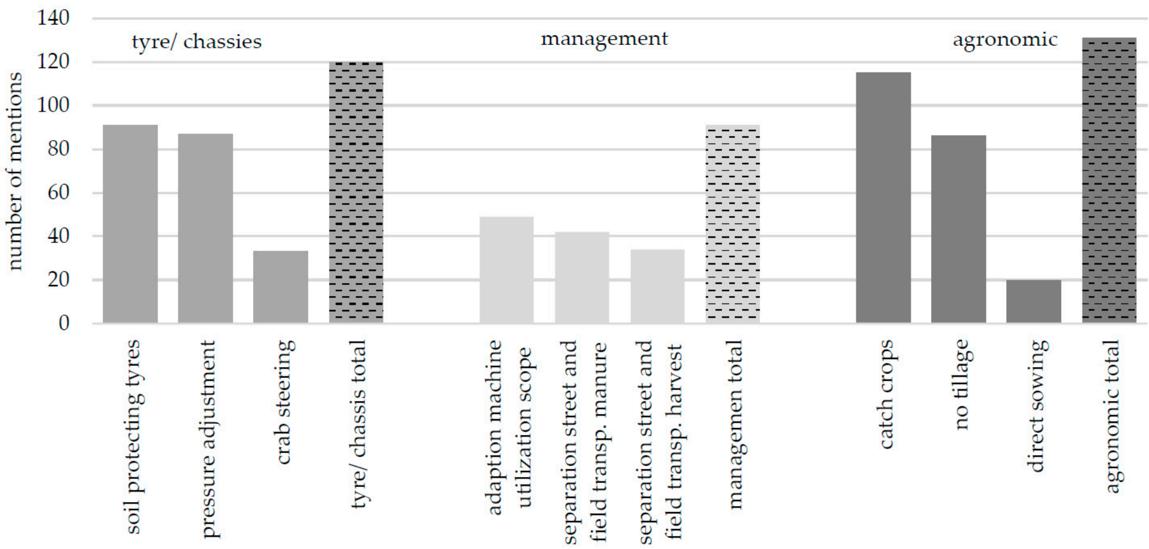

Figure 6. Applied measures, grouped by "tyre/chassis", "planning/management", and "agronomic measures" (n = 154). (Germany-wide survey: "Technical soil protection" 2017).

Cultivation of cover crops was most frequently mentioned within the group of "agronomic" measures (75%). Within "tyre/chassis" measures, soil-protecting tyres were most often named (78%). Adjustment of internal tyre pressure (pressure adjustment with tyre inflation system or quick exhaust valves for manual pressure control) was stated to be applied by 56% of the participants. As the only available approximate estimate, Volk [30] estimated the number of users of tyre inflation systems at 10,000 in 2018 for Germany. With 275,392 arable farms in 2016 (FSS [58]), this corresponds to a share of 4%. The adoption rate of quick exhaust valves, which we asked in the same answer option, is probably a lot higher, as they are easier to upgrade on the tyre and cheaper. However, no information on this is available. Therefore, we cannot make a statement regarding the representativeness of our sample in this respect. Within "planning/management" measures, adaption of machine utilisation scope was most often mentioned (32%), followed by separation of street and field transport during manure application (27%) and during harvest (22%). The last mentioned measures of the "planning/management" group are addressed when talking about measures in the following chapters of this paper. In the evaluations, we focused on the comparison between the group that has applied these "planning/management" measures ("measures applied", 59%) and the group that has not applied them ("no measure applied", 41%).

3.4. Factors Influencing the Application of Measures

3.4.1. Objective Characteristics of the Farm

Within the objective characteristics of the farm, we considered the variables total arable land, the power of the most powerful tractor, the share of rented land, the share of different crop-groups within the crop rotation, the area share of different soil textures (light soils = predominantly sandy substrate; medium soils = predominantly silty/loamy substrate; heavy soils = predominantly clayey substrate), and the number of operations outsourced to contractors. The group of farmers "measure applied" cultivated 233 ha of arable land and the most powerful tractor had a mean power of 204 hp (Figure 7a,b). In the group of farmers named "no measure applied", these were 134 ha and 158 hp, respectively. The differences between the two groups of farmers were significant for these two variables (ha arable land $p = 0.02$; hp most powerful tractor $p = 0.0001$). In the literature, the influence of farm size, here indicated by the area of arable land, on farmers' participation in environmental measures was reported to be contradictory [67]. Wuepper et al. [68], for example, concluded that small family farms are not principally more sustainably oriented. Van Vliet et al. [69] stated that environmentally sustainable practices cannot be associated directly with farm size, and Novelli [70] supposed that farm size plays an important role in the decision making of farmers because it affects the emerging opportunity costs of a certain measure. It can be argued that larger farms have greater capacity in terms of machines and manpower to implement complex "planning/management" measures.

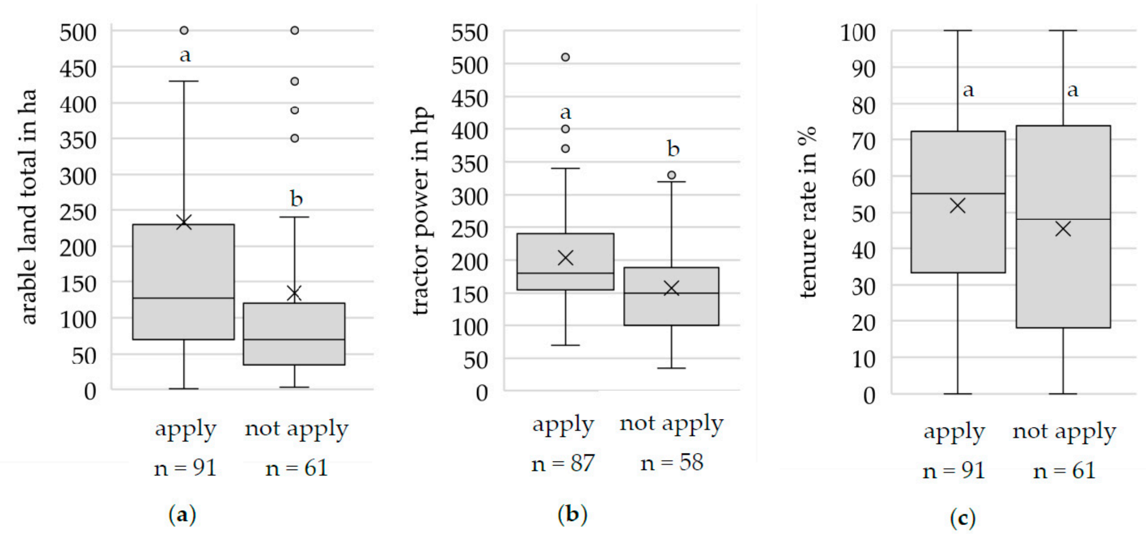

Figure 7. Influence of the variables (**a**) arable land, (**b**) tractor power, and (**c**) share of rented land per group "measure applied" and "no measure applied" (Box: 25–75% quantile; line in box: median (50% quantile), cross: mean, lower whisker: Q1–1.5 * IQR, upper whisker: Q3 + 1.5 * IQR, points: outlier); different letters indicate statistically significant differences (*t*-test, $p \leq 0.05$). (Germany-wide survey: "Technical soil protection" 2017).

The share of rented land in percent was slightly, but not significantly ($p = 0.12$), higher for the group "measure applied" (Figure 7c). Caswell et al. [71] argued that farmers who lease fields for long periods feel responsible to the landlord or are afraid of being held responsible for possible damages. Therefore, renters act the same as or similarly to landowners with regard to soil protection. A similar conclusion was drawn by Leonhardt et al. [72] for Austria, where tenure is seen as a long-term choice and therefore the land is treated equally in terms of soil protection.

For the variables area share of soil textures and share of crops, the difference between the groups of farmers "measure applied" and "no measure applied" was small and not significant, except for the share of forage grass (area share of soil textures $p = 0.47$ (light soils), 0.26 (medium soils), 0.19 (heavy soils); share of crops $p = 0.36$ (root crops), 0.25 (grains), 0.29 (maize), 0.05 (forage grass)), between 0 and 4% for soils and 0 and 5% for crops (Figure 8a,b).

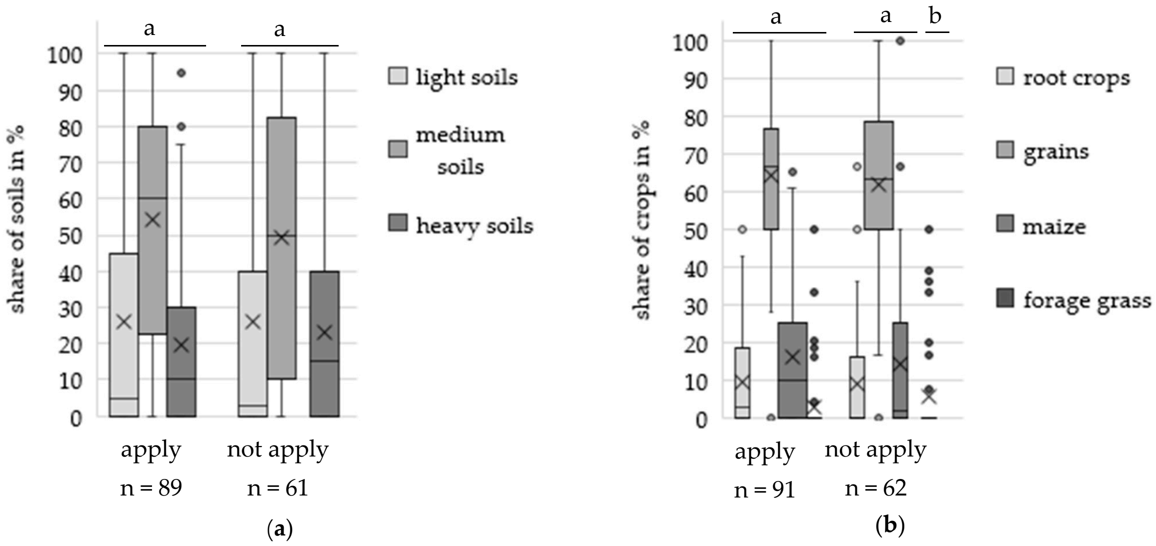

Figure 8. Influence of the variables (**a**) area share of soil texture (light soils = predominantly sandy substrate; medium soils = predominantly silty/loamy substrate; heavy soils = predominantly clayey substrate) and (**b**) share of crops per group "measure applied" and "no measure applied" (Box: 25–75% quantile; line in box: median (50% quantile), cross: mean, lower whisker: Q1–1.5 * IQR, upper whisker: Q3 + 1.5 * IQR, points: outlier); different letters indicate statistically significant differences (*t*-test, $p \leq 0.05$). (Germany-wide survey: "Technical soil protection" 2017).

As soil texture is one of the most relevant factors (besides soil moisture at the time of wheeling and loads applied) influencing the risk of soil compaction [73–77], we expected differentiation in the application of measures according to the area share of light, medium, and heavy soil textures. However, we cannot confirm an effect of the dominant soil structure. In particular, root crops (sugar beet or potato) and (silage) maize harvests involve heavy machinery with harvest dates in late summer/fall. In Germany, considerable rainfall often occurs at this time of year, making the soils susceptible to compaction. Therefore, we expected an impact on the grown crops but could not confirm any association.

In total, 130 participants answered the question regarding whether they engage agricultural contractors and 80% of them do so. For specifications of operations outsourced, multiple answers were possible. Among those who engage agricultural contractors, most often, harvest was mentioned to be outsourced (73%), followed by the application of liquid manure (56%), seeding (21%), others (18%, e.g., mulching or application of solid manure), tilling (10%), pest control (6%), and mineral fertilisation (4%). There was no influence of the number of outsourced operations on the application of measures to prevent soil compaction. The outsourcing of operations is a crucial factor for soil compaction risk on arable land, since "farmers partly lost control" [35,78] concerning the timing of fieldwork and the machine used and its configuration (e.g., internal tyre pressure). Von Buttlar et al. [62] reported that 91% of the farmers participating in a survey used agricultural contractors or machinery cooperations, of which 43% state that soil-protecting technology is "used" or "mostly used"; in 25% of the cases, it is "partly used", and in 33%, no such technology is used or it is not known. Besides this study, no information is available on the use of soil-protecting technologies among agricultural contractors. Since agricultural contractors play such a substantial role in minimising soil compaction on arable land, we suggest investigating in more detail how the topic is integrated in these companies in order to engage these stakeholders in soil conservation as well.

3.4.2. Objective Characteristics of the Farmers

To capture the objective characteristics of the farmers, we queried the highest level of agrarian education, age, their own function on the farm, and whether they run the farm full- or part-time. Within the group "measures applied" (n = 77), 44% were agricultural engineers/Master's degree holders, and within the group "no measures applied" (n = 55), this figure was 27% (Figure 9).

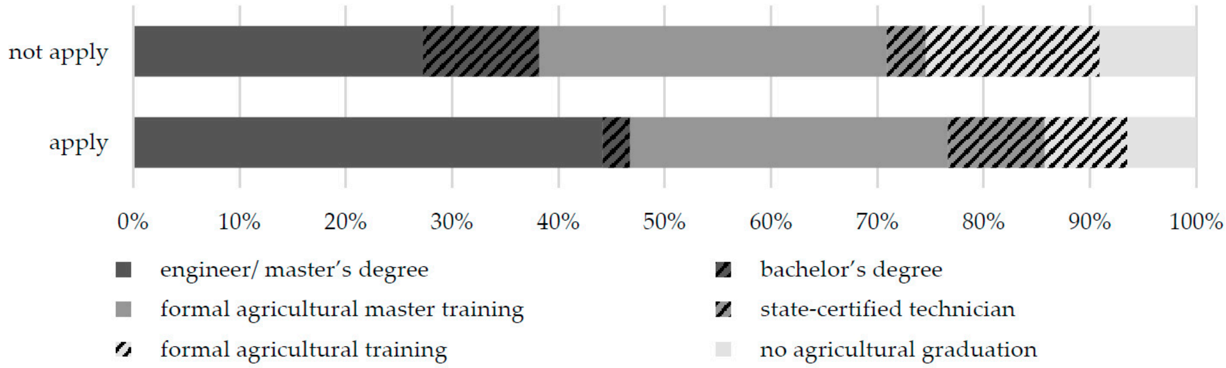

Figure 9. Percentage of agrarian education type by the groups "measure applied" and "no measure applied" (n = 77) and "no measure applied" (n = 55). (Germany-wide survey: "Technical soil protection" 2017).

The share of master training (in German, "Meisterabschluss") of all education types was 30 and 33% for the groups "measures applied" and "no measures applied", respectively. The share of farmers who were state-certified technicians was 9 and 4% and the share who had formal agricultural training was 8 and 16% in the group "measures applied" and in the other group, respectively. The chi-square test indicated no significance ($p = 0.08$) for the distribution of the degrees, even when aggregating university degrees and non-university degrees before statistical evaluation. However, other studies found the level of education to be a critical variable influencing pro-environmental behaviour among farmers [79–81] and scientists are calling for more education, especially in the field of soil protection [82,83]. We suggest that our results do not follow this general recommendation since an agricultural degree can be obtained in different ways in Germany: there is the possibility of studying agriculture at university, where (presumably) rather theoretical expertise is taught, or the option to follow a formal vocational training, which is more focused on practical knowledge. Moreover, informal education in the sense of social learning has been reported to play a significant role in strengthening sustainable agriculture [84,85], as sharing information and learning in a group of peers can shift social norms [60]. To date, there are no studies on how the topic of soil compaction is included in the curricula of different types of study and training in Germany. We consider that this open question needs illumination first in order to strengthen formal education in terms of soil compaction.

We asked the age by ranges (n = 133), with the result that the shares of the respondents within the respective ranges were only slightly shifted between the group "measures applied" and "no measures applied". No significant ($p = 0.82$) difference was found for this characteristic, although younger people displayed a higher level of environmental awareness [86]. On the other hand, it could be argued that older farmers apply more soil-conserving measures due to the experience and knowledge gained in their working life [87]. While Knowler and Bradshaw [88] explored in the wider field of conservation agriculture both positive and insignificant correlations between adoption and experience, we found no significant connection here, assuming that age equals experience.

Further, we compared the groups "measure applied" and "no measure applied" among different the functions (manager, not the farm manager) of those running the farm. The largest share in our dataset (88%) were the farm manager. Among the farm managers, a larger proportion applied measures than not. Non-farm managers showed the reverse trend, without significance ($p = 0.16$) for this variable (Table 5).

Table 5. Distribution between the groups "measure applied" and "no measure applied" according to participants' own functions within the farm (n = 151) and whether the farm is run full-time or part-time (n = 151).

	Apply	Not Apply
not the farm manager (n = 18)	44% (8) [a]	56% (10) [a]
farm manager (n = 133)	62% (82) [a]	38% (51) [a]
farm run in full-time (n = 117)	65% (76) [a]	35% (41) [b]
farm run in part-time (n = 34)	41% (14) [a]	59% (20) [b]

Different letters indicate statistically significant differences (chi-square test, $p \leq 0.05$); absolute values given in brackets. (Germany-wide survey: "Technical soil protection" 2017).

A significant ($p = 0.01$) association between the groups "measure applied" and "no measure applied" and whether the farm is run full- or part-time was found (Table 5). Those who run the farm full-time were more likely to apply measures than those running the farm part-time. Of the 151 participants who answered the two previous questions, around half (48%) were farm managers who run the farm full-time. Murphy et al. [89] found that the more working time farmers spend on the farm, the more likely they are to participate in the Rural Environment Protection Program.

3.4.3. Behavioural Characteristics

Behavioural characteristics describe, among others, the influence of the perceptions and attitudes of a farmer on decision making [61]. As an indicator for perception, we referred to the estimated relevance of soil compaction in Germany and in the participants' own farms (Figure 2). Those participants who estimated soil compaction as not relevant for Germany (point 1 and 2 on the rating scale) all belonged to the group "measure applied" (Table 6). Of those respondents who rated soil compaction for Germany as relevant (point 4 and 5 on the rating scale), around half applied the measures. The chi-square test suggested a significant ($p = 0.001$) association between the estimated relevance of soil compaction for Germany and the application of measures. Since the subsample not relevant for Germany was relatively small, this result should not be overinterpreted.

Table 6. Distribution between the groups "measure applied" and "no measure applied" according to the perception of soil compaction (sc) for participants' own farms, for Germany, and according to management.

	Apply	Not Apply
sc for Germany not relevant (n = 12)	100% (12) [a]	0% (0) [b]
sc for Germany relevant (n = 116)	52% (60) [a]	48% (56) [b]
sc for own farm not relevant (n = 42)	67% (28) [a]	33% (14) [a]
sc for own farm relevant (n = 87)	59% (51) [a]	41% (36) [a]
conventional (n = 131)	63% (82) [a]	37% (49) [a]
organic (n = 20)	40% (8) [a]	60% (12) [a]

Different letters indicate statistically significant differences (chi-square test, $p \leq 0.05$); absolute values given in brackets. (Germany-wide survey: "Technical soil protection" 2017).

In both groups for which soil compaction for participants' own farms is estimated as relevant or not relevant, the majority of participants applied measures (59 and 67%), and the difference was not significant ($p = 0.38$). Even if the perception of environmental risks can influence the application of measures to prevent them [61], there was no unambiguous direction in our evaluation. Moreover, those participants who rated soil compaction to be not relevant did rather apply measures to prevent it than the others. There are studies reporting positive effects of individual risk perception on the pro-environmental behaviour of farmers (e.g., [90,91]), no significant effect [92], and even a mismatch between risk perception and risk management strategies [93]. The expression of a perception involves a prominent psychological component and other studies already described similar discrepancies between perception and action [94] as we found here.

As an indicator for the environmentally friendly attitude, we referred to whether the farm is managed conventionally or organically, assuming that organic farmers are more environmentally aware. However, among the conventional farmers, more participants applied measures (63%), and among the organic farmers, who were clearly a smaller subsample here, the majority of participants did not apply measures (60%), but this figure was not significant ($p = 0.06$) (Table 6). This is in line with the study of McCan et al. [94], who found no clear indication that organic farmers have a higher environmental awareness, as they previously hypothesised. Michel-Guillou and Moser [95] concluded that social variables had a greater influence on pro-environmental behaviour than environmental awareness. In fact, it is difficult to imply that organic farmers are less environmentally friendly based on the results that they apply fewer of the measures considered. As McCann et al. [94] noted in their study, organic farmers achieve higher sustainability through a variety of measures in the areas of fertilisation, winter cover crops, and diversity of crop rotations.

3.4.4. Social–Institutional Characteristics

Around 35% (n = 54) of the participants claimed to use advisory services, 51% (n = 79) did not, and 14% (n = 21) did not answer this question. In the group "measure applied", more participants use advisory services; in the group "no measure applied", it is the other way around (Table 7). The differences in the distributions are not significant ($p = 0.18$).

Table 7. Number of participants who use or do not use advisory services in general and corresponding numbers within the groups "measure applied" and "no measure applied".

	Apply	Not Apply
Use of advisory services (n = 54)	65% (35) [a]	35% (19) [a]
No use of advisory services (n = 79)	53% (42) [a]	47% (37) [a]

Different letters indicate statistically significant differences (chi-square test, $p \leq 0.05$); absolute values given in brackets. (Germany-wide survey: "Technical soil protection" 2017).

The type of advisory service used was also asked and multiple answers were possible. Professional associations were mentioned 37 times (Figure 10).

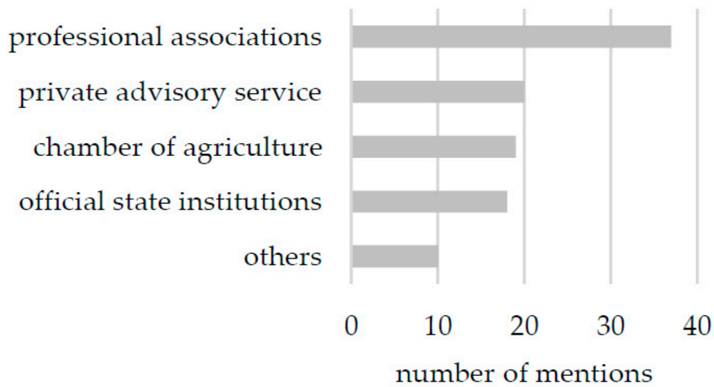

Figure 10. Use of advisory service by type of service (n = 54). (Germany-wide survey: "Technical soil protection" 2017).

Germany-specific professional associations such as GKB e. V. (society for conservation tillage), Bioland e.V. (association for organic farming in Germany), or DLG (German Agricultural Society) were mentioned most often, namely 37 times. This is followed by private advisory services, with 20 mentions; the chamber of agriculture, with 19 mentions; public authorities ("Offizialberatung" in German), with 18 mentions, and others, with 10 mentions. Within the category "others", the Swiss online tool Terranimo [96] was mentioned, as well as agricultural magazines. Marx and Jacobs [97] concluded in their overview of official recommendations for action and advisory material concerning soil compaction in Germany that some of the existing recommendations on national and federal state level are partly difficult to access or out of date. Therefore, they advocated for easier access to recommendations and advisory tools and for more target-group-orientated presentation and modern design. In our study, the professional associations were mentioned twice as often as the official state institutions. An alternative explanation is that organisations with an agricultural background are more likely to be seen as a reliable peer group and are therefore used more often [60]. However, it should also be noted that the advisory structure in Germany varies from region to region. In Southern Germany, advice is mainly provided by official state institutions; in the north-west, it is mainly by chambers of agriculture; and in the east, private advisory services dominate [98].

3.4.5. Economic Conditions

In our survey, economic conditions were captured by estimated yield loss and farm diversification. In total, 106 and 105 participants estimated the affected area by and yield loss due to soil compaction (see Section 3.2). For comparison purposes, the surveyed yield loss and the affected area were multiplied because, otherwise, for example, an estimated yield loss of 50% on a corresponding area of 1% could not be compared to the same yield loss on an estimated area of 20%. There was a significant difference in the estimated "effective" yield loss (estimated yield loss multiplied by the estimated share of affected compacted area) between the group "measures applied" and the group "no measures applied", with a mean of 3% and 6% yield loss, respectively. Therefore, we assume that the greater the estimated yield loss—hence, the level of one's own risk—the more likely farmers are to apply complex "planning/management" measures. The prerequisite for an appropriate reaction on a perceived risk is understanding and knowledge about possible interventions.

In order to characterise the diversity of the farms, we asked if there was any other farm activity besides arable farming. Business diversification can broaden the income base and enhance the viability of a business [99]. Income dependency on arable products can be reduced, highlighting the compelling need to maintain a productive soil through soil conservation measures. In all four groups of farming sectors, a higher percentage applied measures than did not, and there was no significant (p = 0.39) link between farm diversification and the application of measures (Table 8).

Table 8. Number of participants within each farming sector and corresponding numbers within the groups "measure applied" and "no measure applied" (n = 154).

	Apply	Not Apply
sector arable (n = 67)	57% (38) [a]	43% (29) [a]
sector arable + livestock (n = 20)	75% (15) [a]	25% (5) [a]
sector arable + grassland (n = 17)	65% (11) [a]	35% (6) [a]
sector arable + grassland + livestock (n = 50)	54% (27) [a]	46% (23) [a]

Different letters indicate statistically significant differences (chi-square test, $p \leq 0.05$); absolute values given in brackets. (Germany-wide survey: "Technical soil protection" 2017).

Farm size is also an economic constraint. An increased farm size, where we observed a higher rate of the application of management measures (Figure 7a), may increase the farm income and also the capability of risk management [100]. Higher income, greater machinery, and human resources on larger farms allow financial and organisational flexibilities that are needed for the "planning/management" measures under consideration. They also require a certain amount of strategic thinking, as they are more organisational in nature and less based on technical solutions that are already more established (e.g., wide tyres).

An increasing farm size can foster innovation, whereas running the farm part-time, where we observed a lower rate of application of management measures (Table 5), can hold back innovations [101].

3.5. Recommendations and Options for Action

From our results, we derived various options for action that will support and promote soil conservation. They are: (1) an objective assessment of the relevance of soil compaction for farmers, (2) research and development activities to identify soil damage using non-invasive methods, and (3) recommendations for soil protection in agricultural practice. Measures in these three areas support different objectives, address different target groups, and can thus be used in the sense of a modular system.

(1) We recommend the development of methods that allow farmers to conduct a "soil compaction" survey for their soils using low-threshold offers. Regional soil characteristics and crops grown, but also the use of already existing data, e.g., from field documentation, need to be considered. There are already some methods in place, such as the "Simple soil structure assessment for the farmer" [102] or the "BASIS TERRA BOX" [103] with materials and a method manual for the analysis and evaluation of soil conditions. These are to be refined and communicated more effectively (3, iii). The overall aim is to achieve a better self-assessment of the risk of soil compaction by farmers and thereby to promote the need of application of soil protection measures (3).

(2) Activities to identify soil damage with non-invasive methods are currently in early research stage using close-range remote sensing via drones and remote sensing with satellite data. While close-up sensing allows short-term and event-related interventions, the analyses with remote sensing data are rather an evaluation of time series and images taken cannot be influenced by the researcher. Once these methods are applicable on a large scale, they can support the proposed actions (3), e.g., by identifying areas that are particularly threatened by or vulnerable to soil compaction and therefore deserve support.

(3) In soil protection, three types of support can be distinguished: (i) investment support for technical measures, such as tyre pressure control systems, (ii) area-related support in the context of agri-environmental measures for the application of soil conservation practices, and (iii) expansion of knowledge transfer to prevent soil compaction and disseminate soil conservation measures. (i) Investment support for the establishment of technical measures aims to increase equipment for the application of technical soil conservation measures by the farmer or the contractor. Advantageously, such funding is easy to administer. Disadvantages are the risk that investment supports may be taken up even though investments in soil conservation measures would also take place without it and the limited possibility to control application of technical measures. (ii) In the context of agri-environmental measures, the application of specific measures can be made more attractive through area-related support. The aim is to promote the use of soil-conserving measures specifically for critical works such as manure spreading in spring or sugar beet harvest. (iii) The expansion of knowledge transfer on soil conservation is aimed at professional farmers and contractors as well as those in training or education. In addition to traditional knowledge transfer activities, peer-to-peer formats should also be promoted. Particularly for education and training, it is important to examine how soil protection is currently addressed and which improvements are conceivable. The expansion of knowledge transfer can in turn promote the appropriate application of soil condition assessment methods by farmers (1) and the acceptance and uptake of possible funding options (i, ii).

Regarding possible target groups, we see a need for action in addressing contractors, farmers in training and further education, as well as part-time farmers. For these target groups, it is necessary to create suitable information opportunities that address the specific needs (e.g., little timeframe for new impulses, narrow time windows for crop management).

4. Conclusions

Our study is the first record of the adoption of mitigation measures to avoid or reduce soil compaction in Germany, although we assume that a follow-up study with a larger and more representative sample size is needed. Farmers sometimes need to take contradictory requirements into account within their decisions (economics, market demands, delivery dates, arable restrictions), of which the avoidance of soil compaction is only one aspect [35]. Thus, the application of mitigation measures to prevent soil compaction seems rather to be seen as an add-on within the management when the farm is large enough to give economic flexibilities for voluntary measures. We found few significant differences between the group of farmers who apply measures and those who do not. However, it is important to keep in mind that a correlation is not a causality and that no single factor can be used to explain the application or non-application of soil conservation measures alone and that there might be socio-psychological components in addition to what a quantitative survey can cover [81,104]. Thus, we suggest qualitative follow-up in-depth surveys and interviews on variables which drive farmers during decisions pro or contra a measure. Against the background of supporting a transition of agricultural practices towards soil conservation, more educational work is needed. This concerns formal education as well as informal and advisory service since they shape the socio-psychological background of farmers.

Author Contributions: Conceptualisation, S.L. and J.F.; Formal analysis, S.L.; Investigation, S.L. and J.F.; Project administration, A.J.; Writing—original draft, S.L.; Writing—review and editing, S.L., J.F. and A.J. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Federal Ministry of Education and Research—BMBF of Germany, grant number 031A563A (first phase) and 031B0684A (second phase).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Detailed primary data and the full questionnaire in German and English are stored and published in the BonaRes Repository and are available online at: https://doi.org/10.20387/bonares-k85p-tr5n (Ledermueller, S. & Fick, J. 2020).

Acknowledgments: We thank all the farmers participating in our survey and the associations and professional magazines that made our survey public. Furthermore, we would like to thank Nele Gnutzmann, Kirstin Marx and Bernhard Osterburg for the preliminary work in the project and the review of the questionnaire. Additionally, we thank Norbert Röder for the consultation in the evaluation of the results.

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

Appendix A

Table A1. Overview of the used information channels to distribute the invitation to participate in the online survey. (Germany-wide survey: "Technical soil protection" 2017).

Institutional Type	Institution	Information Channel
farmers' association	farmers' association of all 16 Federal States	direct approach by phone and/or (e-)mail
	Chamber of agriculture of Lower Saxony	direct approach by phone and/or (e-)mail
	Bioland regional associations	press release/newsletter
	Naturland	press release/newsletter
	Arbeitsgemeinschaft bäuerliche Landwirtschaft e. V.	press release/newsletter
	Bauernbund	press release/newsletter
editorial offices of professional media channels	AgrarEurope	press release
	Agrarheute.com	press release
	Agrartechnik	press release
	Agrarticker	press release
	Agrartotal	press release
	Agrarzeitung	press release
	Bauernblatt Schleswig-Holstein	press release
	Bauernzeitung	press release
	BW Agrar	press release/newsletter
	DG Verlag (Newsletter Volks- und Raiffeisenbanken)	newsletter
	DLG-Agrarticker	press release
	Dlz Agrarmagazin	press release
	Hessenbauer	press release
	Land+Forst	press release and journal article
	LZ Rheinland	press release
	Proplanta.de	press release
	Rheinische Bauernzeitung	press release
	Sparkassenmagazin Agrar	press release
	Top agrar	press release
	Wochenblatt Landwirtschaft & Landleben	press release
associations/communities of interest	Stiftung Ökologie und Landbau	press release/newsletter
	Gesellschaft für konservierende Bodenbearbeitung	press release/newsletter
	Rationalisierungs-Kuratorium	press release/newsletter
	eilbote	short article
	bonnerblogs.de	press release/newsletter
scientific institutions or groups	Thünen Institute	press release, website, twitter
	Project team SOILAssist	website
	BONARES-Centre	website

Appendix B

Table A2. Overview of the analysed groups, underlying variables, applied questions, and question (translated in English from the original questionnaire) types to investigate technical soil protection. For original version of the questionnaire, see "Data Availability Statement". (Germany-wide survey: "Technical soil protection" 2017).

Group	Variable	Question	Question Type
Objective characteristics of farm	Farm size	How much arable land (in ha) is currently farmed? Total?	Open numeric
	Share of rented land	How much arable land (in ha) is currently farmed? Of which rented?	Open numeric
	Machinery	Please indicate which tractors you use for field work on your farm (excluding contractors)—tractor 1: power (in PS)	Open numeric
	Crop rotation	How many crop rotations are cultivated on your farm?	Open numeric
		Please indicate the crop rotation members (max. six members each rotation)	Single-choice
		What percentage of arable land do you cultivate with each crop rotation?	Open numeric
	Soil Characteristics	Please state the predominant soil types in percent: light soil (sand), medium soil (silty/loamy), heavy soil (clay)	Open numeric
Objective characteristics of farmer	Education	What is your highest agricultural qualification?	Single-choice
	Function	In which function are you active on the farm?	Single-choice
	Age	Please indicate your age	Single-choice
	Occupation	How is your occupation? Full-time or part-time?	Single-choice
Behavioural characteristics	Problem perception	In your opinion, is the topic of soil compaction relevant for Germany? Do you consider the topic of soil compaction to be relevant for your business?	5 point rating scale
	Farming system	How is the farm managed?	Single-choice
Social–institutional environment	Use of advisory service	Which advisory services do you use?	Multiple-choice
Economic constraints	Yield loss	How high do you estimate the proportion of compacted arable land on your farm (in%)? How high do you estimate the average yield loss on compacted land on your farm (in%)?	Open numeric
	Farm diversification	Which branches of business are there on your farm? Arable farming, grassland, livestock	Multiple-choice
Application of measures to prevent soil compaction	Low-threshold, complex	Which of the following measures do you apply?	Multiple-choice

References

1. Défossez, P.; Richard, G.; Boizard, H.; O'Sullivan, M.F. Modeling change in soil compaction due to agricultural traffic as function of soil water content. *Geoderma* **2003**, *116*, 89–105. [CrossRef]
2. Pöhlitz, J.; Rücknagel, J.; Schlüter, S.; Vogel, H.-J.; Christen, O. Estimation of critical stress ranges to preserve soil functions for differently textured soils. *Soil Tillage Res.* **2020**, *200*, 104637. [CrossRef]
3. de Lima, R.P.; da Silva, A.P.; Giarola, N.F.B.; da Silva, A.R.; Rolim, M.M. Changes in soil compaction indicators in response to agricultural field traffic. *Biosyst. Eng.* **2017**, *162*, 1–10. [CrossRef]
4. Lamandé, M.; Schjønning, P. Soil mechanical stresses in high wheel load agricultural field traffic: A case study. *Soil Res.* **2018**, *56*, 129–135. [CrossRef]
5. Fu, Y.; Tian, Z.; Amoozegar, A.; Heitman, J. Measuring dynamic changes of soil porosity during compaction. *Soil Tillage Res.* **2019**, *193*, 114–121. [CrossRef]

6. Berisso, F.E.; Schjønning, P.; Keller, T.; Lamandé, M.; Etana, A.; de Jonge, L.W.; Iversen, B.V.; Arvidsson, J.; Forkman, J. Persistent effects of subsoil compaction on pore size distribution and gas transport in a loamy soil. *Soil Tillage Res.* **2012**, *122*, 42–51. [CrossRef]
7. Keller, T.; Sandin, M.; Colombi, T.; Horn, R.; Or, D. Historical increase in agricultural machinery weights enhanced soil stress levels and adversely affected soil functioning. *Soil Tillage Res.* **2019**, *194*, 104293. [CrossRef]
8. Liu, Q.; Liu, B.; Zhang, Y.; Lin, Z.; Zhu, T.; Sun, R.; Wang, X.; Ma, J.; Bei, Q.; Liu, G.; et al. Can biochar alleviate soil compaction stress on wheat growth and mitigate soil N_2O emissions? *Soil Biol. Biochem.* **2017**, *104*, 8–17. [CrossRef]
9. Beylich, A.; Oberholzer, H.-R.; Schrader, S.; Höper, H.; Wilke, B.-M. Evaluation of soil compaction effects on soil biota and soil biological processes in soils. *Soil Tillage Res.* **2010**, *109*, 133–143. [CrossRef]
10. Sitaula, B.K.; Hansen, S.; Sitaula, J.I.B.; Bakken, L.R. Effects of soil compaction on N_2O emission in agricultural soil. *Chemosphere Glob. Chang. Sci.* **2000**, *2*, 367–371. [CrossRef]
11. Antille, D.L.; Chamen, W.C.T.; Tullberg, J.N.; Lal, R. The potential of controlled traffic farming to mitigate greenhouse gas emissions and enhance carbon sequestration in arable land: A critical review. *Trans. ASABE* **2015**, *58*, 707–731.
12. Arvidsson, J. Subsoil compaction caused by heavy sugarbeet harvesters in southern Sweden: I. Soil physical properties and crop yield in six field experiments. *Soil Tillage Res.* **2001**, *60*, 67–78. [CrossRef]
13. Colombi, T.; Keller, T. Developing strategies to recover crop productivity after soil compaction—A plant eco-physiological perspective. *Soil Tillage Res.* **2019**, *191*, 156–161. [CrossRef]
14. EEA. *The European Environment—State and Outlook 2020: Knowledge and Transition to a Sustainable Europe*; European Environment Agenc: Luxembourg, 2019; ISBN 9789294800909. [CrossRef]
15. EC. Key Policy Objectives of the Future CAP: CAP Specific Objective: Efficient Soil Management. Available online: https://ec.europa.eu/info/sites/info/files/food-farming-fisheries/key_policies/documents/cap-specific-objectives-brief-5-soil_en.pdf (accessed on 16 September 2020).
16. Montanarella, L.; Panagos, P. The relevance of sustainable soil management within the European Green Deal. *Land Use Policy* **2021**, *100*, 104950. [CrossRef]
17. Arvidsson, J.; Sjöberg, E.; van den Akker, J.J. Subsoil compaction by heavy sugarbeet harvesters in southern Sweden: III. Risk assessment using a soil water model. *Soil Tillage Res.* **2003**, *73*, 77–87. [CrossRef]
18. Gocht, A.; Röder, N. Thünen Atlas: Landwirtschaftliche Nutzung Version 2014: Konsistent: Kreisdaten zur Landwirtschaft. Available online: https://www.thuenen.de/de/infrastruktur/thuenen-atlas-und-geoinformation/thuenen-atlas/konsistent-kreisdaten-zur-landwirtschaft/ (accessed on 5 February 2021).
19. MacDonald, A.M.; Matthews, K.B.; Paterson, E.; Aspinall, R.J. The impact of climate change on the soil/moisture regime of Scottish mineral soils. *Environ. Pollut.* **1994**, *83*, 245–250. [CrossRef]
20. van der Linden, E.C.; Haarsma, R.J.; van der Schrier, G. Impact of climate model resolution on soil moisture projections in central-western Europe. *Hydrol. Earth Syst. Sci.* **2019**, *23*, 191–206. [CrossRef]
21. Bormann, H. Analysis of possible impacts of climate change on the hydrological regimes of different regions in Germany. *Adv. Geosci.* **2009**, *21*, 3–11. [CrossRef]
22. Brunotte, J.; Brandhuber, R.; Vorderbrügge, T.; Schrader, S. Vorsorge gegen Bodenverdichtung. *Gute Fachliche Praxis—Bodenbewirtschaftung und Bodenschutz* **2015**, *2*, 21–73.
23. Harasim, E.; Antonkiewicz, J.; Kwiatkowski, C.A. The Effects of Catch Crops and Tillage Systems on Selected Physical Properties and Enzymatic Activity of Loess Soil in a Spring Wheat Monoculture. *Agronomy* **2020**, *10*, 334. [CrossRef]
24. Lal, R. Restoring Soil Quality to Mitigate Soil Degradation. *Sustainability* **2015**, *7*, 5875–5895. [CrossRef]
25. Wanic, M.; Zuk-Golaszewska, K.; Orzech, K. Catch crops and the soil environment—A review of the literature. *J. Elem.* **2018**, *24*. [CrossRef]
26. ten Damme, L.; Stettler, M.; Pinet, F.; Vervaet, P.; Keller, T.; Munkholm, L.J.; Lamandé, M. The contribution of tyre evolution to the reduction of soil compaction risks. *Soil Tillage Res.* **2019**, *194*, 104283. [CrossRef]
27. Gerdes, J.T. Erträge Steigern, Kosten Senken: Reifendruck und Regelanlagen als Erfolgsfaktoren im Landwirtschaftlichen Betrieb. Available online: https://firstclaasrental.claas.com/de/blog/ertrage-steigern-kosten-senken-reifendruck-und-regelanlagen-als-erfolgsfaktoren-im-landwirtschaftlichen-betrieb/ (accessed on 4 January 2021).
28. Deter, A. Alles Rund um Agrarreifen/Landwirtschaftsreifen. Available online: https://www.topagrar.com/technik/news/technik-technikwissen-alles-rund-um-reifen-9376481.html?test=direktbuchung (accessed on 4 January 2021).
29. Deter, A. Bodenschonung Durch Neues Fliegl Hundegang-Güllefass. Available online: https://www.topagrar.com/technik/news/extreme-bodenschonung-durch-neuste-fliegl-hundegangtechnik-11932567.html (accessed on 4 January 2021).
30. Volk, L. Reifendruckanlagen mit Drehdurchführungen (DD) und Fahrer-Assistenz: Variabler Reifenfülldruck Ist Eine Richtige Entwicklung zu Mehr Bodenschutz, Bessere Dieseleffizienz, Mehr Fahrkomfort, Mehr Klimaschutz und Mehr Verkehrssicherheit. Available online: https://www4.fh-swf.de/media/downloads/fbaw_1/reifenregler/pdfs/RDAEntwicklungMaerz2018.pdf (accessed on 4 January 2021).
31. Blunk. Hier gibt es 'was auf die Ohren: Bodenschonung und Reifendruck. Available online: https://www.blunk-gmbh.de/technik/bodenschonung-reifendruck/ (accessed on 4 January 2021).
32. Uppenkamp, N. Reifenwahl—Was Bringen Moderne Reifenkonzepte? Available online: https://www.landwirtschaftskammer.de/landwirtschaft/technik/aussenwirtschaft/reifen.htm (accessed on 4 January 2021).

33. Brandhuber, R.; Demmel, M.; Koch, H.-J.; Brunotte, J. Bodenschonender Einsatz von Landmaschinen: Empfehlungen für die Praxis. DLG-Merkblatt 344, Frankfurt am Main. 2008. Available online: https://www.lfl.bayern.de/mam/cms07/iab/dateien/boden_dlg_merkblatt.pdf (accessed on 4 January 2021).
34. UBA. Verdichtung. Available online: https://www.umweltbundesamt.de/themen/boden-landwirtschaft/bodenbelastungen/verdichtung#bodenverdichtung-ein-problem (accessed on 4 January 2021).
35. Thorsøe, M.H.; Noe, E.B.; Lamandé, M.; Frelih-Larsen, A.; Kjeldsen, C.; Zandersen, M.; Schjønning, P. Sustainable soil management—Farmers' perspectives on subsoil compaction and the opportunities and barriers for intervention. *Land Use Policy* **2019**, *86*, 427–437. [CrossRef]
36. Ritchey, T. Wicked Problems: Modelling Social Messes with Morphological Analysis. *Acta Morphologica Generalis* **2013**, *2*.
37. Chamen, T.W.C.; Moxey, A.P.; Towers, W.; Balana, B.; Hallett, P.D. Mitigating arable soil compaction—A review and analysis of available cost and benefit data. *Soil Tillage Res.* **2015**, *146*, 10–25. [CrossRef]
38. Huynh, H.T.N.; Lobry de Bruyn, L.A.; Wilson, B.R.; Knox, O.G.G. Insights, implications and challenges of studying local soil knowledge for sustainable land use: A critical review. *Soil Res.* **2020**, *58*, 219. [CrossRef]
39. Montanarella, L.; Pennock, D.J.; McKenzie, N.; Badraoui, M.; Chude, V.; Baptista, I.; Mamo, T.; Yemefack, M.; Singh Aulakh, M.; Yagi, K.; et al. World's soils are under threat. *SOIL* **2016**, *2*, 79–82. [CrossRef]
40. Odendo, M.; Obare, G.; Salasya, B. Farmers' perceptions and knowledge of soil fertility degradation in two contrasting sites in western Kenya. *Land Degrad. Dev.* **2010**, *21*, 557–564. [CrossRef]
41. Yusuf, M.B.; Mustafa, F.B.; Salleh, K.O. Farmer perception of soil erosion and investment in soil conservation measures: Emerging evidence from northern Taraba State, Nigeria. *Soil Use Manag.* **2017**, *33*, 163–173. [CrossRef]
42. Tesfahunegn, G.B. Farmers' perception on land degradation in northern Ethiopia: Implication for developing sustainable land management. *Soc. Sci. J.* **2019**, *56*, 268–287. [CrossRef]
43. Faridi, A.A.; Kavoosi-Kalashami, M.; Bilali, H.E. Attitude components affecting adoption of soil and water conservation measures by paddy farmers in Rasht County, Northern Iran. *Land Use Policy* **2020**, *99*, 104885. [CrossRef]
44. Sileshi, M.; Kadigi, R.; Mutabazi, K.; Sieber, S. Determinants for adoption of physical soil and water conservation measures by smallholder farmers in Ethiopia. *Int. Soil Water Conserv. Res.* **2019**, *7*, 354–361. [CrossRef]
45. Reichardt, M.; Jürgens, C. Adoption and future perspective of precision farming in Germany: Results of several surveys among different agricultural target groups. *Precis. Agric.* **2009**, *10*, 73–94. [CrossRef]
46. Caffaro, F.; Cavallo, E. The Effects of Individual Variables, Farming System Characteristics and Perceived Barriers on Actual Use of Smart Farming Technologies: Evidence from the Piedmont Region, Northwestern Italy. *Agriculture* **2019**, *9*, 111. [CrossRef]
47. Tamirat, T.W.; Pedersen, S.M.; Lind, K.M. Farm and operator characteristics affecting adoption of precision agriculture in Denmark and Germany. *Acta Agric. Scand. Sect. B Soil Plant Sci.* **2018**, *68*, 349–357. [CrossRef]
48. Sattler, C.; Nagel, U.J. Factors affecting farmers' acceptance of conservation measures—A case study from north-eastern Germany. *Land Use Policy* **2010**, *27*, 70–77. [CrossRef]
49. Boardman, J.; Bateman, S.; Seymour, S. Understanding the influence of farmer motivations on changes to soil erosion risk on sites of former serious erosion in the South Downs National Park, UK. *Land Use Policy* **2017**, *60*, 298–312. [CrossRef]
50. Barnes, A.P.; Soto, I.; Eory, V.; Beck, B.; Balafoutis, A.; Sánchez, B.; Vangeyte, J.; Fountas, S.; van der Wal, T.; Gómez-Barbero, M. Exploring the adoption of precision agricultural technologies: A cross regional study of EU farmers. *Land Use Policy* **2019**, *80*, 163–174. [CrossRef]
51. Bartkowski, B.; Bartke, S. Leverage Points for Governing Agricultural Soils: A Review of Empirical Studies of European Farmers' Decision-Making. *Sustainability* **2018**, *10*, 3179. [CrossRef]
52. Klerkx, L.; Jansen, J. Building knowledge systems for sustainable agriculture: Supporting private advisors to adequately address sustainable farm management in regular service contacts. *Int. J. Agric. Sustain.* **2010**, *8*, 148–163. [CrossRef]
53. Baumgart-Getz, A.; Prokopy, L.S.; Floress, K. Why farmers adopt best management practice in the United States: A meta-analysis of the adoption literature. *J. Environ. Manag.* **2012**, *96*, 17–25. [CrossRef]
54. Prager, K.; Schuler, J.; Helming, K.; Zander, P.; Ratinger, T.; Hagedorn, K. Soil degradation, farming practices, institutions and policy responses: An analytical framework. *Land Degrad. Dev.* **2011**, *22*, 32–46. [CrossRef]
55. Ingram, J.; Mills, J. Are advisory services "fit for purpose" to support sustainable soil management? An assessment of advice in Europe. *Soil Use Manag.* **2019**, *35*, 21–31. [CrossRef]
56. 5DESTATIS. Landwirtschaftliche Betriebe, Fläche: Bundesländer, Jahre, Bodennutzungsarten: Landwirtschaftszählung: Haupterhebung 2016. 2021. Available online: https://www-genesis.destatis.de/genesis//online?operation=table&code=41141-0016&bypass=true&levelindex=1&levelid=1614328105781#abreadcrumb (accessed on 25 February 2021).
57. DESTATIS. Landwirtschaftliche Betriebe: Deutschland, Jahre, Größenklassen des Standardoutputs, Rechtsformen, Betriebswirtschaftliche Ausrichtung: Landwirtschaftszählung: Haupterhebung 2016. 2021. Available online: https://www-genesis.destatis.de/genesis//online?operation=table&code=41141-0014&bypass=true&levelindex=1&levelid=1614236837782#abreadcrumb (accessed on 25 February 2021).
58. BMEL. Statistisches Jahrbuch Über Ernährung, Landwirtschaft und Forsten der Bundesrepublik Deutschland 2018. 2019. Available online: https://www.bmel-statistik.de/fileadmin/SITE_MASTER/content/Jahrbuch/Agrarstatistisches-Jahrbuch-2018.pdf (accessed on 11 December 2020).

59. Opotow, S.; Weiss, L. New Ways of Thinking about Environmentalism: Denial and the Process of Moral Exclusion in Environmental Conflict. *J. Soc. Issues* **2000**, *56*, 475–490. [CrossRef]
60. Mills, J.; Gaskell, P.; Ingram, J.; Dwyer, J.; Reed, M.; Short, C. Engaging farmers in environmental management through a better understanding of behaviour. *Agric. Hum. Values* **2017**, *34*, 283–299. [CrossRef]
61. Dessart, F.J.; Barreiro-Hurlé, J.; van Bavel, R. Behavioural factors affecting the adoption of sustainable farming practices: A policy-oriented review. *Eur. Rev. Agric. Econ.* **2019**, *46*, 417–471. [CrossRef]
62. von Buttlar, C.; Müller-Thomsen, U.; Schlüter, H. *Erweiterte Befragung von Beratern, Lohnunternehmern und Praktikern zur Betroffenheit landwirtschaftlich genutzter Flächen von Bodenverdichtungen unter Berücksichtigung regionaler Schwerpunkte und Problemlagen*; Ingenieurgesellschaft für Landwirtschaft und Umwelt: Göttingen, Germany, 2017.
63. Batey, T.; McKenzie, D.C. Soil compaction: Identification directly in the field. *Soil Use Manag.* **2006**, *22*, 123–131. [CrossRef]
64. Wolkowski, R.; Lowery, B. *Soil Compaction: Causes, Concerns, and Cures*; Cooperative Extension Publishing (A3367); University of Wisconsin: Madison, WI, USA, 2008.
65. Håkansson, I.; Lipiec, J. A review of the usefulness of relative bulk density values in studies of soil structure and compaction. *Soil Tillage Res.* **2000**, *53*, 71–85. [CrossRef]
66. Alaoui, A.; Diserens, E. Mapping soil compaction—A review. *Curr. Opin. Environ. Sci. Health* **2018**, *5*, 60–66. [CrossRef]
67. Defrancesco, E.; Gatto, P.; Runge, F.; Trestini, S. Factors Affecting Farmers' Participation in Agri-environmental Measures: A Northern Italian Perspective. *J. Agric. Econ.* **2008**, *59*, 114–131. [CrossRef]
68. Wuepper, D.; Wimmer, S.; Sauer, J. Is small family farming more environmentally sustainable? Evidence from a spatial regression discontinuity design in Germany. *Land Use Policy* **2019**, *90*, 104360. [CrossRef]
69. van Vliet, J.A.; Schut, A.G.T.; Reidsma, P.; Descheemaeker, K.; Slingerland, M.; van de Ven, G.W.J.; Giller, K.E. De-mystifying family farming: Features, diversity and trends across the globe. *Glob. Food Secur.* **2015**, *5*, 11–18. [CrossRef]
70. Novelli, S. Determinants of environmentally-friendly farming. *Qual. Access Success* **2018**, *19*, 340–346.
71. Caswell, M.; Fuglie, K.; Ingram, C.; Jans, S.; Kascak, C. *Adoption of Agricultural Production Practices: Lessons Learned from the U.S. Department of Agriculture Area Studies Project*; U.S. Department of Agriculture: Washington, DC, USA, 2001.
72. Leonhardt, H.; Penker, M.; Salhofer, K. Do farmers care about rented land? A multi-method study on land tenure and soil conservation. *Land Use Policy* **2019**, *82*, 228–239. [CrossRef]
73. Imhoff, S.; Da Silva, A.P.; Fallow, D. Susceptibility to compaction, load support capacity, and soil compressibility of Hapludox. *Soil Sci. Soc. Am. J.* **2004**, *68*, 17–24. [CrossRef]
74. Ledermüller, S.; Brunotte, J.; Lorenz, M.; Osterburg, B. *Arbeitsbericht: Verbesserung des physikalischen Bodenschutzes bei der Wirtschaftsdüngerausbringung im Frühjahr—Herausforderungen und Lösungsansätze*; BonaRes Series: Halle, Germany, 2020. [CrossRef]
75. Lorenz, M.; Brunotte, J.; Vorderbrügge, T.; Brandhuber, R.; Koch, H.-J.; Senger, M.; Fröba, N.; Löpmeier, F.-J. Anpassung der Lasteinträge landwirtschaftlicher Maschinen an die Verdichtungsempfindlichkeit des Bodens—Grundlagen für ein bodenschonendes Befahren von Ackerland. *Landbauforschung* **2016**, *66*, 101–144. [CrossRef]
76. Saffih-Hdadi, K.; Défossez, P.; Richard, G.; Cui, Y.J.; Tang, A.M.; Chaplain, V. A method for predicting soil susceptibility to the compaction of surface layers as a function of water content and bulk density. *Soil Tillage Res.* **2009**, *105*, 96–103. [CrossRef]
77. Jones, R.J.A.; Spoor, G.; Thomasson, A.J. Vulnerability of subsoils in Europe to compaction: A preliminary analysis. *Soil Tillage Res.* **2003**, *73*, 131–143. [CrossRef]
78. Schjønning, P.; Lamandé, M.; Thorsøe, M.H.; Frelih-Larsen, A. Policy Brief: Subsoil Compaction—A Threat to Sustainable Food Production and Soil Ecosystem Services. Available online: https://www.ecologic.eu/sites/files/publication/2018/2730_recare_subsoil-compaction_web.pdf (accessed on 5 January 2021).
79. Rezaei-Moghaddam, K.; Vatankhah, N.; Ajili, A. Adoption of pro-environmental behaviors among farmers: Application of Value–Belief–Norm theory. *Chem. Biol. Technol. Agric.* **2020**, *7*. [CrossRef]
80. Hilimire, K.; Greenberg, K. Water conservation behaviors among beginning farmers in the western United States. *J. Soil Water Conserv.* **2019**, *74*, 138–144. [CrossRef]
81. Delaroche, M. Adoption of conservation practices: What have we learned from two decades of social-psychological approaches? *Curr. Opin. Environ. Sustain.* **2020**, *45*, 25–35. [CrossRef]
82. Salhi, A.; Benabdelouahab, T.; Martin-Vide, J.; Okacha, A.; El Hasnaoui, Y.; El Mousaoui, M.; El Morabit, A.; Himi, M.; Benabdelouahab, S.; Lebrini, Y.; et al. Bridging the gap of perception is the only way to align soil protection actions. *Sci. Total Environ.* **2020**, *718*, 137421. [CrossRef] [PubMed]
83. Bampa, F.; O'Sullivan, L.; Madena, K.; Sandén, T.; Spiegel, H.; Henriksen, C.B.; Ghaley, B.B.; Jones, A.; Staes, J.; Sturel, S.; et al. Harvesting European knowledge on soil functions and land management using multi-criteria decision analysis. *Soil Use Manag.* **2019**, *35*, 6–20. [CrossRef]
84. Schneider, F.; Ledermann, T.; Fry, P.; Rist, S. Soil conservation in Swiss agriculture—Approaching abstract and symbolic meanings in farmers' life-worlds. *Land Use Policy* **2010**, *27*, 332–339. [CrossRef]
85. Schneider, F.; Fry, P.; Ledermann, T.; Rist, S. Social Learning Processes in Swiss Soil Protection—The 'From Farmer—To Farmer' Project. *Hum. Ecol.* **2009**, *37*, 475–489. [CrossRef]
86. Diamantopoulos, A.; Schlegelmilch, B.B.; Sinkovics, R.R.; Bohlen, G.M. Can socio-demographics still play a role in profiling green consumers? A review of the evidence and an empirical investigation. *J. Bus. Res.* **2003**, *56*, 465–480. [CrossRef]

87. Ahnström, J.; Höckert, J.; Bergeå, H.L.; Francis, C.A.; Skelton, P.; Hallgren, L. Farmers and nature conservation: What is known about attitudes, context factors and actions affecting conservation? *Renew. Agric. Food Syst.* **2009**, *24*, 38–47. [CrossRef]
88. Knowler, D.; Bradshaw, B. Farmers' adoption of conservation agriculture: A review and synthesis of recent research. *Food Policy* **2007**, *32*, 25–48. [CrossRef]
89. Murphy, G.; Hynes, S.; Murphy, E.; O'Donoghue, C. An investigation into the type of farmer who chose to participate in Rural Environment Protection Scheme (REPS) and the role of institutional change in influencing scheme effectiveness. *Land Use Policy* **2014**, *39*, 199–210. [CrossRef]
90. Toma, L.; Mathijs, E. Environmental risk perception, environmental concern and propensity to participate in organic farming programmes. *J. Environ. Manag.* **2007**, *83*, 145–157. [CrossRef]
91. Zhou, Z.; Liu, J.; Zeng, H.; Zhang, T.; Chen, X. How does soil pollution risk perception affect farmers' pro-environmental behavior? The role of income level. *J. Environ. Manag.* **2020**, *270*, 110806. [CrossRef] [PubMed]
92. van Winsen, F.; de Mey, Y.; Lauwers, L.; van Passel, S.; Vancauteren, M.; Wauters, E. Determinants of risk behaviour: Effects of perceived risks and risk attitude on farmer's adoption of risk management strategies. *J. Risk Res.* **2016**, *19*, 56–78. [CrossRef]
93. Duong, T.T.; Brewer, T.; Luck, J.; Zander, K. A Global Review of Farmers' Perceptions of Agricultural Risks and Risk Management Strategies. *Agriculture* **2019**, *9*, 10. [CrossRef]
94. McCann, E.; Sullivan, S.; Erickson, D.; de Young, R. Environmental Awareness, Economic Orientation, and Farming Practices: A Comparison of Organic and Conventional Farmers. *Environ. Manag.* **1997**, *21*, 747–758. [CrossRef]
95. Michel-Guillou, E.; Moser, G. Commitment of farmers to environmental protection: From social pressure to environmental conscience. *J. Environ. Psychol.* **2006**, *26*, 227–235. [CrossRef]
96. Stettler, M.; LKeller, T.; Weisskopf, P.; Lamandé, M.; Lassen, P.; Schjønning, P. Terranimo®—ein webbasiertes Modell zur Abschätzung des Bodenverdichtungsrisikos. *Landtechnik* **2014**, *69*, 132–138.
97. Marx, K.; Jacobs, A. SOILAssist-Teilprojekt ‚Akzeptanz und Implementierung': Analyse behördlicher Handlungsempfehlungen zur Vermeidung von Bodenverdichtung auf Ackerböden, 160th ed.; Braunschweig/Germany. 2020. Available online: https://www.thuenen.de/media/publikationen/thuenen-workingpaper/ThuenenWorkingPaper_160.pdf (accessed on 27 January 2021).
98. Thomas, A. Landwirtschaftliche Beratung in der Bundesrepublik Deutschland—eine Übersicht. 2007. Available online: http://www2.komm-agrar.de/cms/sites/komm-agrar.de/files/bub_2007_02_thomas_lw_beratung_in_dtl.pdf (accessed on 26 February 2021).
99. Turner, M.; Whitehead, I.; Millard, N. *The Effects of Public Funding on Farmers' Attitudes to Farm Diversification*; Centre for Rural Research, University of Exeter: Yasit, UK, 2006; ISBN 1870558936.
100. Poon, K.; Weersink, A. Factors affecting variability in farm and off-farm income. *Agric. Financ. Rev.* **2011**, *71*, 379–397. [CrossRef]
101. Läpple, D.; Renwick, A.; Thorne, F. Measuring and understanding the drivers of agricultural innovation: Evidence from Ireland. *Food Policy* **2015**, *51*, 1–8. [CrossRef]
102. *Simple Soil Structure Assessment for the Farmer*, 3rd ed.; Thünen-Institut, Gesellschaft für konservierende Bodenbearbeitung e.V. (GKB): Neuenhagen, Germany, 2012.
103. Bodenzustandserfassung Landwirtschaftlich Genutzter Böden. Available online: https://www.schleswig-holstein.de/DE/Fachinhalte/B/boden/landwGenutzteBoeden.html#docbe206fff-4ccf-4934-a29c-24fcfe303ca3bodyText2 (accessed on 1 January 2021).
104. Burton, R.J.F. The influence of farmer demographic characteristics on environmental behaviour: A review. *J. Environ. Manag.* **2014**, *135*, 19–26. [CrossRef]