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The use of conservation tillage in an agro-intensive region: results from a survey of farmers in Scania, Sweden

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Abstract

Conventional agricultural practices can lead to soil erosion and a reduction in soil organic carbon (SOC) content. It has been suggested that less intensive agricultural practices, such as conservation tillage (including no-till and reduced till without soil inversion) may reduce both erosion and loss of SOC. The aim of this study was to determine whether, and why, conservation tillage is used in Scania, which is one of the most agro-intensive regions in Sweden. We also investigated how information on tillage practices is obtained, why one type of tillage may be favored over another, and whether some farmers are more likely to use conservation tillage. The result of this study will benefit policy makers and researchers by pinpointing factors that influence the use of conservation tillage. To collect data, a questionnaire was sent to farmers in Scania in 2016. We found that the majority of the responding farmers used conservation tillage, and that it was more likely to be used if the farmer was highly educated and spent more than 50% of their annual working time on crop production. The use of conservation tillage was also more common if the farm was large and clay soil dominated. Crop rotation was often highlighted as the most important factor influencing the choice of tillage practice, which may be due to crop species requirements. When asked to compare the consequences of reduced tillage and plowing, the perception of farmers using conservation tillage was in general more positive, indicating skepticism toward the practice of reduced tillage until it had been tried. We show that the use of conservation tillage, sometimes in combination with plowing, is widespread in Scania. However, unless changes in, for example, crop rotation and labor requirements occur, the use of conservation tillage will most likely remain the same as today, or only increase slightly in the near future. Farm enlargement may result in an increased conservation tillage use, and so may efforts to educate advisors, increased opportunities for peer-to-peer meetings, and the development of economically viable small farm solutions. Increased conservation tillage may be part of the solution for sustainable crop production, but drawbacks such as increased pesticide use must be addressed further, as well as factors such as crop rotation development and practical knowledge that influence conservation tillage use at the farm level.

Introduction

Agriculture is practiced around the world to produce food, feed, biomass for bioenergy carriers and fiber, leading to varying degrees of soil disturbances depending on the type of tillage. Conservation tillage is commonly defined as non-inversion tillage combined with a soil surface crop residue cover of at least 30% (FAO, 2017). It includes no-till and various reduced till practices (Phillips *et al.*, 1980; Davies and Finney, 2002). These practices can be implemented together with, or as alternatives to, conventional plowing (Prokopy *et al.*, 2008; Freitas and Landers, 2014). Because a number of factors can influence whether conservation tillage is favorable, general guidelines are often not useful as soil and climate conditions, for instance, vary among farms. The rate of adoption of conservation tillage has so far been low in Scandinavia (Carter, 2017), and the reasons for this are not clear. We have surveyed farmers about the use of conservation tillage, and factors that may underpin their decision to adopt conservation tillage, in a region in southern Sweden with high agricultural intensity. Studies of why and how conservation tillage is being used provide knowledge that can be helpful when changing agricultural policies to preserve soil quality, improve farm economy and reduce agricultural ecological foot prints. In this study, we focused on previously identified factors that have been shown to influence the adoption of conservation tillage. These factors were broadly categorized into site-specific factors (e.g., edaphic and crop-related factors), economic factors (e.g., fuel and herbicide costs, the amount of labor required and farm size) and farmer-specific factors (e.g., age, education, attitudes and previous experience).

Conservation tillage was, to a large extent, initially adopted because of its recognized potential to control soil erosion (Montgomery, 2007), although the susceptibility of soil to erosion is not always considered an important factor when deciding on tillage practice (D'Emden *et al.*, 2006). The introduction of broad-spectrum herbicides has facilitated the transition from conventional tillage to conservation tillage (Awada *et al.*, 2014), although concerns related to increased herbicide dependence may have slowed the process (D'Emden *et al.*, 2006; Thomas *et al.*, 2007). Herbicide requirements, under conservation tillage, may be reduced if crop rotation is improved and combined with cover crops and surface crop residue, as this may lessen the extent of weed infestation (Schmitz *et al.*, 2015). Within a crop rotation, crops may have different levels of tolerance to soil compaction, and their performance may vary depending on the root penetration resistance of the soil (Wilhelm and Wortmann, 2004). Rotation tillage, where plowing and conservation tillage are both practiced within a rotation, could therefore be suitable to ensure successful long-term crop production. Occasional plowing to reduce soil compaction also has the advantage of mechanical weed suppression. Conservation tillage can be suitable at sites with moderate weed pressure, whereas plowing has been recommended in high weed pressure areas, in particular where perennial weeds dominate (Gustafsson and Johansson, 2008).

The use of conservation tillage may be good in clay soils since plowing can result in clod formation, thus impeding crop establishment. Moreover, the traction demand is higher in clay soils than sandy soils (Gustafsson and Johansson, 2008), and the use of conservation tillage practices can therefore reduce fuel consumption, thus having positive effects on farm economy (Gustafsson and Johansson, 2008). Reductions in fuel and labor demands, as well as the potential to reduce the negative impact on soil quality and the environment, have been recognized as incentives for the adoption of conservation tillage (Al-Kaisi and Yin, 2005; Knowler and Bradshaw, 2007). Researchers have found that employing no-till or reduced till can reduce the labor demand in corn production by 70 and 15%, respectively, and fuel requirements by 83 and 23%, respectively, compared with plowing (Lithourgidis *et al.*, 2005).

Lee and Stewart (1983) and Morris *et al.* (2010) found that the probability of conservation tillage being adopted is likely to increase with farm size. This is probably due to the fact that the possible savings, e.g., in fuel and labor, are higher for large farms than smaller ones. Also, large farms are more likely to have the economic capacity needed to make larger investments such as purchasing new mechanical equipment for conservation tillage (Gould *et al.*, 1989), and to buffer potential reductions in yield during the transition to conservation tillage practices (Lahmar, 2010). In addition, ownership of the cultivated land may influence the choice to adopt conservation tillage or not (Lee and Stewart, 1983; Soule *et al.*, 2000).

Shifting to conservation tillage not only involves purchasing new equipment, it also involves learning new techniques and translating previous and new experiences of cultivation into successful crop production and soil management strategies. Experience is often positively correlated with age, and it is therefore interesting to study whether age is an important factor in the choice of tillage. Hoover and Wiitala (1980) found that age affected how farmers perceived soil erosion; young farmers tended to identify soil erosion as a problem requiring countermeasures more often than their older colleagues. Mango *et al.* (2017) also found an effect of age, although with increasing age being positively associated with the adoption of soil conservation practices. However, Uri (1997) did not find age to be an important factor in decisions regarding tillage practices, indicating that age may be important in some cases, but not in others.

The existence and nature of off-farm work experience, in particular occupations involving a high degree of decision-making, have been shown to positively influence the adoption of conservation tillage practices (Lexmon and Andersson, 1998). In this case, age may be an indirect explanatory factor when considering the importance of off-farm work experience in tillage adoption. Some decades ago, when plowing was considered the norm, pioneer farmers who did not conform to this norm, e.g., by adopting conservation tillage practices, could find themselves being subjected to social pressure such as isolation and ridicule (Lindwall and Sonntag, 2010). Thus, the early adopters of conservation tillage practices probably based their decisions on experience gained mainly through learning-by-doing, although communication with like-minded farmers may have influenced their choice of farming practices.

The attitude toward a particular tillage practice influences adoption behavior among farmers (van Hulst and Posthumus, 2016). Wauters *et al.* (2010) found that when a farmer had not adopted conservation tillage practices, this was often due to negative attitude toward the new practice, rather than practical difficulties. Increased resistance to soil penetration and reduced soil–seed contact due to surface crop residues are two possible reasons why some farmers may prefer plowing to conservation tillage (Friedrich *et al.*, 2014). Another possible drawback of leaving crop residues on the soil surface is the increased prevalence of slugs and the risk of plant pathogen infections (Friedrich *et al.*, 2014). Refraining from plowing in temperate regions also results in lower soil temperatures as the soil holds more water, which can lead to delayed crop emergence (Riley *et al.*, 2005). Factors such as these may explain why some Scandinavian farmers were described as skeptical to adoption of novel practices, and why the rate of adoption of conservation tillage in Scandinavia is slow (Carter, 1994). Nevertheless, a personal positive attitude toward conservation tillage, and the communication of positive attitudes and results from peers who have already adopted conservation tillage, may influence decisions to adopt the practice (Lexmon and Andersson, 1998; Reimer *et al.*, 2012; Rochecouste *et al.*, 2015). The length of time trusted or neighbor farmers have practiced conservation tillage has also been shown to positively affect the likelihood (D'Emden *et al.*, 2006) and the rate (Rochecouste *et al.*, 2015) of adoption.

Scania is one of the most intensively farmed regions in Sweden, and the potential for a variety of tillage practices is high as the region contains a mosaic of soil types. We have conducted a survey of Scanian farmers to determine whether, and why, different tillage practices are being implemented in the region. We expected the adoption of conservation tillage to be higher among farmers with a higher education, more off-farm experience, larger farms and soils dominated by clays. Net income was also expected to be one of the most important factors influencing the choice of tillage practice. Crop rotation, soil type and recommendations by colleagues were also expected to be highly ranked, based on their possible impact on the success of crop production, and because attitudes have been shown to be of great importance in decision-making. Furthermore, farmers using conservation tillage were expected to have a more positive attitude toward the effects of conservation tillage than farmers who had not adopted the practice. We also expected knowledge transfer through direct contacts (e.g., with peers and consultants) and hands-on information

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sources (e.g., meetings and agricultural fairs) to be valued more highly than written information, based on the results of previous studies showing higher adoption rates among farmers whose attitudes are positive toward conservation tillage.

Materials and methods

Research location

The region of Scania (Skåne) in southern Sweden covers approximately 11,000 km^2, and around 40% of the land is used for crop production (Statistics Sweden, 2010). The proportion of agricultural land on which conservation tillage is practiced (excluding no-till) ranges between 16 and 30%, while the national average is <7.5% (Eurostat, 2013). According to the County Administrative Board of Skåne (2017), there are almost 10,000 registered agricultural holdings in Scania, and in 2014, there were 3088 registered farmers with conventional (i.e., non-organic) crop production. Approximately one-third of the cultivated land is owned by the farmers, and two-thirds are leased. The dominant soils are typically sandy and clay moraines. The soil type throughout the county varies largely in clay and organic matter content, and also peat soils can be found in some areas (Germundsson and Schlyter, 1999).

Inclusion criteria and questionnaire design

For a farmer (respondent) to be able to participate in the study, the following two criteria had to be fulfilled: the respondent had to be working on a farm in Scania, and use some type of tillage practice. The respondent should also preferably be the person deciding which tillage practices to use on the farm.

An online questionnaire was used to collect data, as this was a low-cost method which also enabled us to gather information from a large number of farmers with less environmental impact compared with using regular mail. In addition, using an online questionnaire was more time-effective to spread the questionnaire as the link to the questionnaire could easily be shared among farmers. The questionnaire consisted of 19 questions (Q1–19) (a translated version of the complete questionnaire is provided in online Supplementary material A). Questions 1 and 2 were used as filter questions to ensure that the respondent fulfilled the inclusion criteria. If the tillage criterion was not fulfilled (i.e., the respondent did not use any tillage at all), the survey ended. Respondents who did not fulfill the criterion of working on a Scanian farm were allowed to complete the survey, but the responses were not used in the study. The definitions of tillage practices in Q12 (online Supplementary material A) were taken from Gustafsson and Johansson (2008), and were provided to minimize the risk of misinterpretation. Depending on whether the respondent stated that some type of conservation tillage was practiced on the farm or not, the respondent was either allowed to continue to Q13, or was forwarded to Q17. Respondents using conservation tillage practices are henceforth referred to as users and those who do not use conservation tillage practices (i.e., they only use conventional deep plowing) are referred to as non-users. All respondents were asked to respond to Q17–Q19.

Distribution of the questionnaire

In order to distribute the online questionnaire and ensure that results were representative of the whole region, e-mail addresses of farmers throughout Scania were needed. A majority of the farmers in Sweden are members in the Federation of Swedish farmers (LRF), and in Scania, they are organized in 140 local groups. We contacted the chair or secretary of all local groups via e-mail in April 2016, asking if they would participate and/or distribute our questionnaire within their local group. A reminder to reply was sent 3 weeks after the initial e-mail. On May 25 and 26, 2016, we e-mailed 53 farmers, both LRF members (including interested chairs or secretary), and others who had announced their interest in participating in our study. The e-mail contained background information, contact information, instructions on how to distribute the questionnaire and a link to the online questionnaire.

The responses were anonymous, but we were able to obtain an idea of the geographical coverage of Scania based on the location of the LRF contacts who participated. When the link to the questionnaire was sent out in May, most parts of Scania were represented, covering at least the areas known to be used for crop production, and thus some form of tillage practice. Answers were collected from May 25 to August 19, 2016. To increase the number of respondents, the link to the questionnaire was also distributed to farmers visiting the agricultural fair at Borgeby (Borgeby Fältdagar) on June 29 and 30, 2016. In addition, the Scanian branch of the LRF included the web link to the questionnaire and information about our project in their weekly newsletter from June to August, 2016.

Data analysis

Frequency data were collected and compiled for the answers on questions Q3–Q5, Q10, Q11 and Q13–Q15. Frequency analysis was also used on the multiple choice question (Q19) and when the respondent had ranked two or more factors as equally important (Q8 and Q16). Pearson's χ^2 test was used to test for differences between users and non-users in regard to their level of education, prevalence of off-farm experience, farm size (based on the area used for crop production), most common soil type and sources of information. When assumptions for Pearson's χ^2 test were not met, Fischer's exact test was used (Agresti, 1990; Dytham, 2011). Strength of the association was tested following Dytham (2011). Qualitative data (i.e., respondent comments) directly related to the tillage practice, off-farm experience and source of information were summarized and presented together with the related quantitative data.

The Mann–Whitney *U* test was used to test for differences in how users and non-users perceived the effects of reduced tillage compared with plowing (Q17). The test was conducted with 10,000 Monte Carlo permutations and with the respondent category as the grouping variable. Differences were considered statistically significant when $P < 0.05$. We excluded the 'don't know' option from the analysis because our main interest was in studying those who made a ranked choice.

Linear regression models were used to determine whether any of seven factors (Table 1) were associated with the use of conservation tillage practices. Some categories, within each factor, were combined to ensure sufficient number of responses for each category, and data on the original number of categories and respondents are given as Appendix 1. Multivariate regression model building was performed with the inclusion criterion of $P < 0.05$ in the first step and $P < 0.1$ in the following steps. The association of each factor with the use of conservation tillage was first evaluated for each factor separately. The variable with the lowest

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Table 1. The factors and their categories used in the multivariate regression analysis

Factor	Categories
Age (years)	<40, 40–50, 51–60 and >60
Highest completed education	Basic, secondary and tertiary
Proportion of owned land (%)	0–50 and 51–100
Farm size (ha)	0–50, 51–100, 101–200 and >200
Off-farm work experience	Yes or no
Dominating soil type	Sandy-silty soils (grain sizes 0.002–6 mm), clay soils (grain sizes <0.002 mm) and other soils (organic, no type was dominating or other type dominated)
Proportion of yearly work time spent on crop production (%)	0–50, 51–100

P-value (if <0.05) was retained and the other factors were tentatively added one at a time. Then, the two variables with the lowest *P*-values were retained (if $P < 0.1$) and other factors were added one at a time. This procedure was continued as long as the included factors had *P*-values <0.1.

Results

Respondent characteristics

In total, 119 farmers completed the questionnaire, one of whom was excluded due to not fulfilling the criterion of working at a Scanian farm. The age distribution was skewed, as the majority of the respondents were older than 50 yr (Fig. 1a). However, approximately 90% of the respondents planned to continue farming for the next 10 yr. Most respondents were well educated, and even though ten respondents stated that they had only completed basic education, the majority had completed secondary education ($n = 42$) or tertiary education ($n = 64$). There was a moderately strong significant association between level of education and use of conservation tillage practices (Pearson's $\chi^2 = 6.8_{\text{df }2}$, $P = 0.034$, Cramer's $V = 0.24$), and a higher proportion of users had completed secondary and tertiary education than non-users.

Conservation tillage practices were common among the responding Scanian farmers; 74% of them regarded themselves to be users, while 26% stated that they were non-users. The length of time the respondents had been using conservation tillage practices varied, ranging from just having adopted the practice (0 yr) to having used some form of conservation tillage practice for 40 yr and all but two respondents were involved in the decision regarding which tillage practice should be used. Off-farm working experience (Q5) was common; out of 117 responses, 78% had off-farm experience. The high frequency of off-farm work was suggested by some farmers to be due to the low profitability of agricultural production. Thus, combining agriculture with an additional occupation was an economic necessity for some. The proportion of farmers with off-farm experience was higher among non-users than among users (Fig. 1b and c). However, no significant association was found between respondent category and off-farm experience (Pearson's $\chi^2 = 1.8_{\text{df }1}$, $P = 0.18$). When asked to specify what type of off-farm occupation they had, the most frequent responses were accounting, agricultural consulting, truck driving and technical/mechanical support and operation.

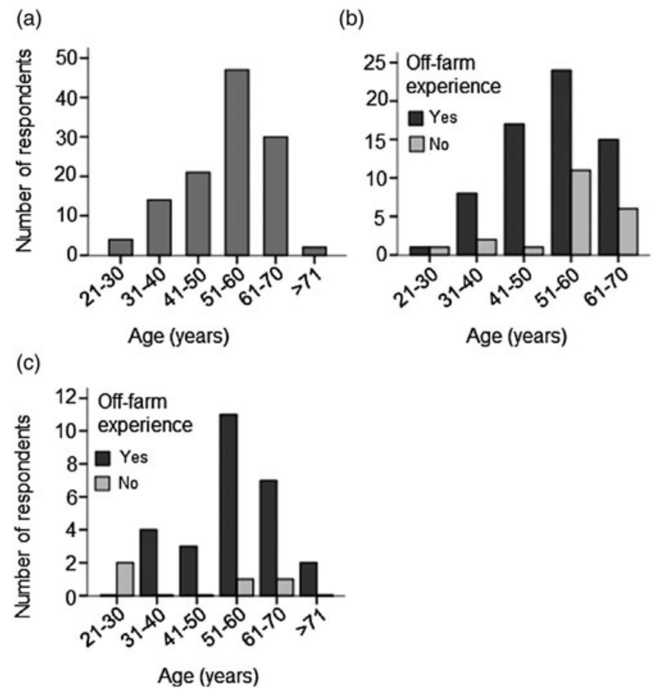

Fig. 1. Distribution of age and off-farm experience. (a) Age distribution of all respondents ($n = 118$), (b) off-farm experience among users ($n = 86$) and (c) off-farm experience among non-users ($n = 31$).

Approximately half of the users ($n = 42$) spent more than 50% of their annual working time on crop production, whereas only 24% ($n = 7$) of the non-users spent more than 50% of their annual working time on crop production. The remaining time could be used for off-farm work or livestock keeping. Regarding land ownership and tenancy (Q7), both users and non-users completely or almost completely owned the land they cultivated (Fig. 2).

Farm characteristics

Farm size was a factor that differed between users and non-users, and we found that only users were represented at farms with more than 200 ha used for crop production (Fig. 3). This difference was also confirmed statistically, as we found a significant, strong association between type of tillage user (user or non-user) and farm size (likelihood ratio $= 33_{\text{df }5}$, $P < 0.001$, Cramer's $V = 0.47$).

Most respondents (74 users and 28 non-users) ranked one soil type as dominating, and some (14) ranked more than one as dominating, which indicates that the farmers had good knowledge on soil types. Field heterogeneity is a possible explanation for why a few ranked more than one soil type as dominating. Among the 102 respondents who ranked one soil type as dominant, we found a significant association between soil type and type of tillage practice (likelihood ratio $= 26_{\text{df }14}$, $P = 0.024$). Among users, the soil type most frequently ranked as dominating was fine clay (with 25–40% clay content), which was chosen in 42% of the responses. Coarse clay (with 15–25% clay content) and clay till were also frequently ranked as the dominating soil type, and represented 20 and 16% of the responses, respectively. Clay soils were also most frequently defined as dominating among non-users, and coarse clay, fine clay and clay till corresponded to 20, 14 and 14% of the responses. All soil type options were ranked as dominating at least once among non-users but not

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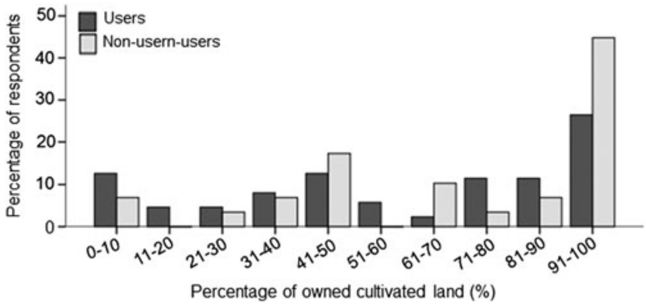

Fig. 2. Proportion of cultivated land owned by the farmer, according to tillage practice (users and non-users). Ownership of cultivated land ranged from full tenancy (0% ownership) to complete ownership (100%), for both users ($n = 87$) and non-users ($n = 29$).

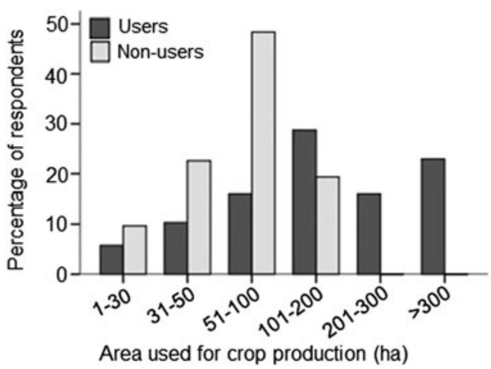

Fig. 3. Proportion of respondents in each farm size category, depending on tillage practice for users ($n = 87$) and non-users ($n = 31$). The area used for crop production was used as a proxy for farm size.

among users, suggesting that with a wide range of soils, plowing may be more suitable. One respondent also commented that plowing of light clay was required in the fall to break up clods and aggregates, and to ensure a good seedbed in the spring.

Table 2. Ranking of factors influencing respondents' choice of tillage practice

Factors	Ranking: First	Second	Third	Number of times selected
Crop rotation	40	15	7	62
Soil type	19	18	15	52
Labor requirement	23	12	11	46
Net income	21	14	5	40
Soil structure	19	8	12	39
Weed pressure	10	21	7	38
Machine park	10	13	7	30
Prevalence of stones	6	9	15	30
Concern for earthworms	12	9	6	27
Cost of fuel	11	12	3	26
Concern for microorganisms	12	6	6	24
Environmental impact	11	7	6	24
Organic matter content	7	9	7	23
Season	11	7	4	22
Farm size	7	6	7	20
Cost of herbicide	4	8	8	20
Laws and regulations	3	2	15	20
Tradition	3	1	16	20
Number of employees	6	2	11	19
Recommendation by neighbors	1	7	11	19
Other	8	2	4	14

The combined rankings from respondents selecting only one alternative per rank (1–3), and from those who selected multiple alternatives per rank are listed here. The factors are sorted based on the total number of times they were selected by the respondents.

Current and future tillage practice and influential factors

Compared with the number of responses on the other questions, fewer users chose to answer which and to what extent they used different tillage practices (Q13 and Q14). As a result, the degree of participation was too low to make a statistical analysis of the extent to which each tillage practice was used by the respondents. However, we found that shallow non-inversion tillage and deep plowing were most common in the spring (44 and 37%, respectively). In the fall, the most common practices were deep non-inversion tillage, deep plowing, shallow non-inversion tillage and shallow plowing (72, 70, 64 and 38%, respectively). One respondent commented that deep tillage was only applied on fields that were to be left undisturbed over the winter. Furthermore, judging from our respondents, a small (14%) reduction in plowing in favor of increased (16%) use of reduced tillage practices is to be expected during the coming 8 yr. The use of direct seeding, on the other hand, may remain the same.

Multiple factors were found to influence the choice of tillage practice (Table 2). When only one factor was ranked as being the most important, 41% of the respondents selected crop rotation. Soil type, net income and labor requirement were among the other frequently selected factors, and were each ranked as most important by approximately 10% of the respondents. When the respondents selected more than one factor as being equally important, the most frequently selected factors were labor requirement ($n = 13$), crop rotation ($n = 11$) and soil structure ($n = 11$). The possibility of combining plowing with conservation tillage within a crop rotation was mentioned by one respondent, who used conservation tillage for 3 yr and then plowed in the fourth year. Other comments indicated that some crops, such as peas (*Pisum* sp. L.) and particularly oilseed rape (*Brassica napus* L.), were perceived as suitable for conservation tillage practices, as plowing after harvest was not necessary. Conservation tillage practices were also stated to work well in rotations where wheat (*Triticum aestivum* L.) followed oilseed rape or sugar beets (*Beta vulgaris* L.), but plowing was often deemed necessary after cereals. From the respondents' comments, we also learned that the weather, general economic status, intentions to reduce the use of pesticides and labor requirement per ha influenced the decision regarding tillage. The results from the multivariate regression model indicated that the use of conservation tillage was significantly associated with both the farmer's level of education and the proportion of the annual working time (i.e., labor)

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that was spent on crop production ($P < 0.1$). Typically, farmers using conservation tillage were more highly educated and spent more than half of their annual working time on crop production.

Perception of the effects of tillage and sources of information

We found significant differences between users and non-users regarding their perception on the effects of reduced till as a replacement for plowing, on the occurrence of weeds, labor requirements, fungicide requirements, net income, soil compaction, soil erosion and soil organic matter (Fig. 4). Users had a more positive perception of the consequences of reduced tillage than non-users. For instance, the increase in infestation of root-dispersed weeds was perceived to be lower by the users, who also perceived that fuel use decreased to a greater extent and that the profit tended to be the same between the tillage practices. There was also a tendency toward a difference in how users and non-users perceived the importance of the preceding crop, although this was not significant (Mann–Whitney $U = 630$, $P = 0.051$). A larger proportion of non-users than users appeared to think that the importance of the preceding crop would increase considerably when using reduced till (Fig. 4).

We cannot say if the farmers' perceptions on the effects of the tillage practice are based on personal experience, or if they are a result of external sources of information, or a combination of both. We can, however, say that the respondents used several types of information sources, and that some sources were more popular than others. A majority (75%) of the respondents stated that they extracted information on tillage practices by reading specialized journals and/or information material that were mailed to them. Around 70% of the respondents also learned about tillage practices from field trips, agricultural fairs and contact with their colleagues and peers. In particular, the users seemed to benefit from contact with colleagues, as indicated by an association between colleagues as an information source and respondent category (user and non-user) (Pearson's $\chi^2 = 9.0_{\text{df }1}$, $P = 0.003$, $\phi = 0.28$). No association was found between respondent category and the other information sources. In contrast to knowledge transfer between peers, learning about tillage practices by communicating with scientists was not common (<10%). Some respondents commented that personal experience was important and that they followed the development of conservation tillage abroad. In line with the latter, another respondent claimed that involving foreign consultants could be particularly useful, as some Swedish consultants lack the qualifications needed to give the best advice regarding conservation tillage.

Discussion

Among the countries within the European Union, the proportion of cultivated arable land under conservation tillage and no tillage in 2010 ranged between 0 and 63%. However, in most of the countries, the proportion varied between 10 and 30%, and in Sweden, it was around 20% (including no tillage) (Eurostat, 2013). Thus, the use of these practices in Sweden could be considered average on a European level. Our study does not provide any estimate of the proportion of land under conservation tillage, but it shows an interest and use of a range of conservation tillage practices in the region. Some of the farmers in our study can be regarded as pioneers for conservation tillage use in Sweden, because of their early adoption of the practice, approximately 40 yr ago.

Farmers changing from one tillage practice to another may face a range of challenges (Lahmar, 2010), such as insufficient knowledge of the new practice. A higher level of education is often found to be correlated with the adoption of conservation tillage and soil conservation practices (Soule, 2001; Bielders *et al.*, 2003), which was also the case in our study. Thus, knowledge of conservation tillage gained through education may facilitate a shift in tillage practice. Investing significant amounts of time in crop production was also associated with the use of conservation tillage in our study, which is in line with the previous findings that learning the practice of conservation tillage takes time, requires more practical experience and day-to-day monitoring of the fields than conventional plowing (Uri, 1999; Ingram, 2010). Judging when the weather is suitable for tillage, or when crop residues were sufficiently incorporated, is considered important practical experience for farmers using conservation tillage in England (Ingram, 2010). Learning about a practice from others may increase the learning speed, and the fact that specialized journals, mail, agricultural fairs and field trips, and colleagues were regularly used when searching for information, in part confirms our expectation of the importance of a direct information flow. The association between users and knowledge transfer between colleagues is also in accordance with the previous studies highlighting the importance of learning from someone with experience (Reimer *et al.*, 2012; Rochecouste *et al.*, 2015). Qualitative comments in the survey indicate that the Internet's role in providing relatively easy access to information from other countries where conservation tillage practices may be more commonly used, such as Germany, Brazil, USA and Canada (Holland, 2004; Freitas and Landers, 2014; Schmitz *et al.*, 2015), may facilitate knowledge sharing. Thus, the number and accessibility of farmers with 'know-how' regarding conservation tillage has increased, benefitting those who favor learning directly from their peers, which may influence the spread of the use of the practice in the longer term.

Interaction with peers with positive experiences and a willingness to share their knowledge has been shown to promote adoption of conservation tillage (Reimer *et al.*, 2012; Rochecouste *et al.*, 2015). However, when the farmers in our study were asked to rank the three most important factors influencing their decision on tillage practice, recommendations by colleagues were rarely included in the top three. Instead, crop rotation was the most frequently selected factor. Possible explanations of this may be the influence of crop rotation on soil quality (Taghizadeh-Toosi *et al.*, 2014), or that the various species used in crop rotation are not equally successful in suppressing weeds (McLaughlin and Mineau, 1995; Liebman and Davies, 2000). Couch grass (*Elytrigia repens* L.), black grass (*Alopecurus myosuroides* Huds.), and goosefoot (*Chenopodium album* L.) are weeds that can become a problem in conservation-tilled fields (Semb Tørresen and Skuterud, 2002). According to our respondents, the prevalence of both seed- and root-dispersed weeds was perceived to be higher under reduced tilling than with plowing. One explanation of this could be that plowing usually results in deep burial of weed seeds, whereas the accumulation of weed seeds is often observed in the topsoil in conservation-tilled soil, thus increasing the risk of germination (Chauhan and Opeña, 2012). The need for herbicides was also perceived to be higher under reduced tillage, although weed pressure was not among the most frequently selected factors influencing the choice of tillage. Another possible explanation for the importance of crop rotation on the choice of tilling practice is related to fungal pest

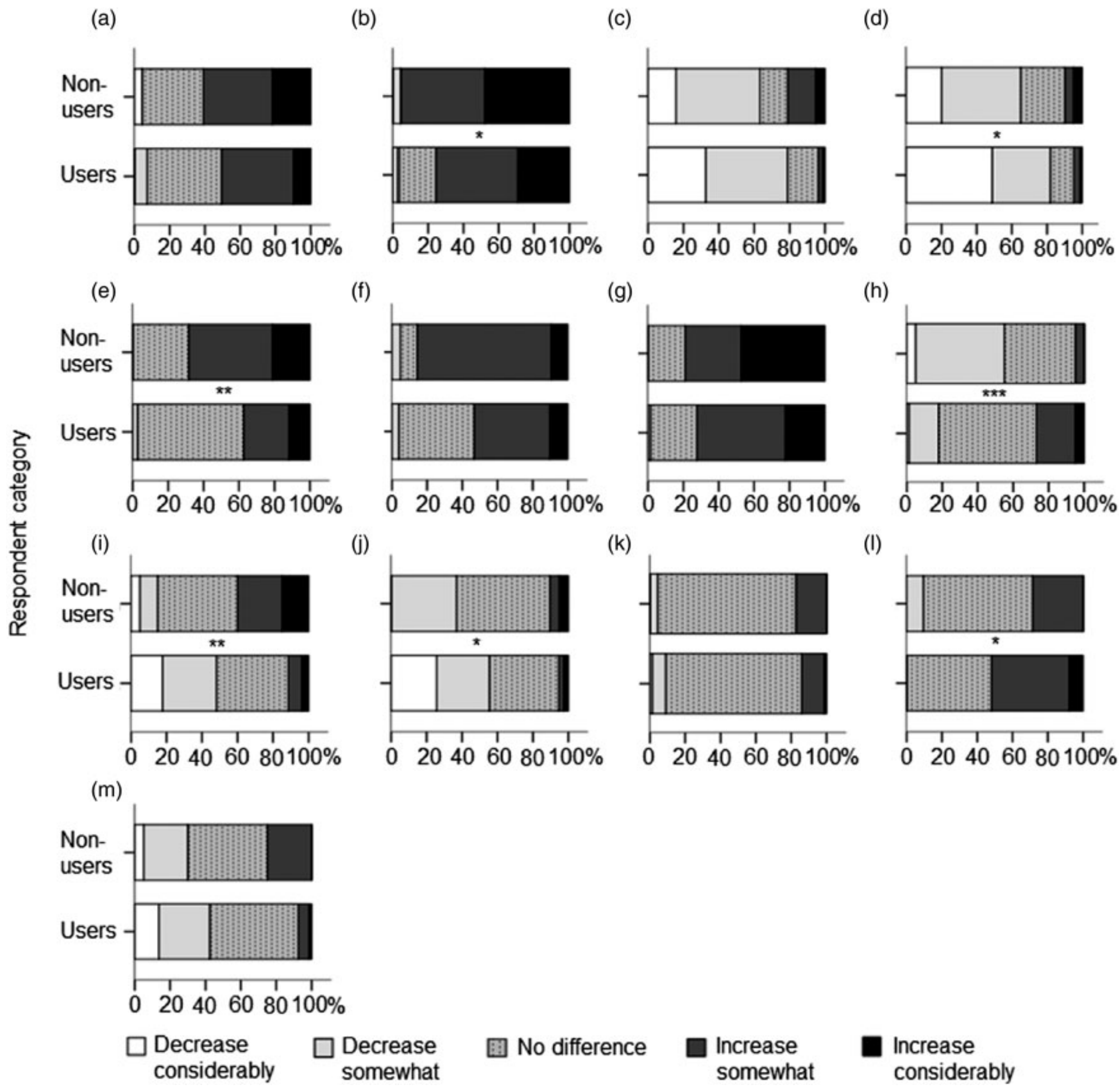

Fig. 4. Summary of how respondents perceive the change in 13 factors (A–M) when using reduced till rather than plowing, for users and non-users. For each factor, the number of respondents who provided a ranking is given as a subscript. Factor A_{106} = seed-dispersed weeds, B_{105} = root-dispersed weeds, C_{99} = fuel requirement, D_{102} = labor requirement, E_{94} = fungicide requirement, F_{98} = herbicide requirement, G_{95} = importance of preceding crop, H_{98} = profit, I_{99} = soil compaction, J_{93} = soil erosion, K_{101} = fertilization requirement, L_{98} = organic matter content, M_{86} = nutrient leakage. *$P < 0.05$, **$P < 0.01$ and ***$P < 0.001$.

control. By choosing to rotate crops not susceptible to the same fungal pests, producers may reduce the spread of infection. Once infected, plowing can be used to mechanically control fungi in fields (Roger-Estrade *et al.*, 2010), or the farmer may use fungicides. Most of the non-users in this study answered that the need for fungicides would increase under reduced tillage, whereas users were less prone to foresee an increased use.

Soil type and structure were considered important factors influencing the choice of tillage, although these were not selected as frequently as crop rotation. Clay soils were the dominating soil types at many user farms, which is consistent with the findings of Lexmon and Andersson (1998), indicating that clay soils are associated with reduced tillage adoption. This association could be explained by the fact that conservation tillage provides greater benefits on clay soil compared with sandy soils, due to differences in their need for loosening. Although clay soils were common at non-user farms, soil types less suitable for conservation tillage were also present, and may have discouraged the use of non-plow-based tillage. In addition, more non-users compared with users thought that reduced tillage would increase soil compaction. For the non-users, the cost of conservation tillage may therefore be perceived as larger than potential benefits, which promotes plowing even with clay soils. Differences in soil type may further influence other factors such as the labor requirement and net income, which were important in the farmers' decisions regarding tillage practice. The possibility of economic benefits through reduced labor and fuel requirements with conservation tillage, as reported by Knowler and Bradshaw (2007) and Lithourgidis *et al.* (2005), may promote the use of conservation tillage, at least for some soil types.

Whether farming is the sole occupation of the farmer may influence the use of conservation tillage. Having off-farm experience was expected to be associated with the use of conservation tillage. However, we did not find any significant relation between off-farm experience and tillage practice, although such a relationship has been found among Swedish farmers earlier (Lexmon and Andersson, 1998). The different result may be linked to a different profitability of farming today, compared with 20 yr ago. Several of

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the participants in our study explained that they worked off-farm because of low profitability in farming. It is also possible that off-farm work can increase available capital that can be used for investments. However, trying to estimate the use of conservation tillage in Scania from the data on off-farm work is not likely to give accurate numbers. Farm size on the other hand may provide a more accurate estimate, at least on large farms with more than 200 ha, because all farms larger than 200 ha in this study were managed by users. Users were also associated with spending more time on crop production than non-users, suggesting that this is their main production orientation. These findings indicate that for large farms focused on crop production, the use of conservation tillage is the most used option at present.

A potential weakness of the present study is the small number of participants (3.8%) compared with the total number of registered farmers with conventional crop production in Scania. The low number of participants could be the result of the methodology we used, but without a list of e-mail addresses for all the relevant farmers, the distribution option we used was considered the best. The timing of the survey, during the spring–summer, which is a highly productive time of year, could also have influenced the number of participants, but we tried to reduce this problem by using a short questionnaire. It is also possible that a larger proportion of users than non-users were willing to participate, which could give a biased picture of tillage use. However, because of the unwillingness, among some of the LRF contacts, to reply to our e-mails, we did not perform a follow-up study with non-respondents to confirm if there was a bias or not. However, despite these weaknesses, we believe that our study provides a representative picture of the range of practices among Scanian farmers as the collected data have a good geographical coverage of the region, represent farmers of different ages and farm sizes, and with different soil types on their farms.

Conclusion

To conclude, by studying farmers in an agro-intensive region, we identified whether, why and by whom conservation tillage is used, and how information on tillage is gathered. This study illustrates a diverse and flexible use of conservation tillage practices that is influenced by factors such as opinions of what is the best practice, soil type, farm size, education, weather and crop rotation. The need to maintain soil quality and to reduce the climate impact of agricultural may lead to the development of rigid regulations promoting the use conservation tillage. However, although reduced greenhouse gas emissions are needed, such regulations may have negative impact on the farmer, and potentially the environment, if flexibility to choose the most suitable practice in relation to soil type, crop rotation and maybe also farm size is not taken into consideration when framing new policies. Alternative ways to increase conservation tillage use may include additional education of agricultural advisors and maybe also formalization of peer-to-peer exchange of practical experience. Crop rotation development in addition to research on how to make conservation tillage economically viable also on small farms, by for instance introducing machine-sharing systems, may also promote conservation tillage. Without changes in factors such as crop rotation and labor requirements, or special efforts to increase a particular practice, the use of conservation tillage of Scanian soils 8 yr from now will probably resemble that of today or be slightly increased, according to the findings of this study. The optimistic perception on conservation tillage by the users may also positively impact future adoptions through knowledge transfer.

Supplementary material. The supplementary material for this article can be found at https://doi.org/10.1017/S174217051800025X.

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Appendix 1

Original data for all categories within each factor evaluated in the multivariate logistic regression, with the exception of dominating soil type, for which data are not given here. Values are given as numbers with percentages in brackets, for users and non-users. The total number of respondents for each factor (*N*) is given in italics. Categories with no responses are indicated by (nr).

Factor	Categories	Users	Non-users
Age (years)	21–30	2 (2.3)	2 (6.5)
	31–40	10 (11.5)	4 (12.9)
	41–50	18 (20.7)	3 (9.7)
	51–60	35 (40.2)	12 (38.7)
	61–70	22 (25.3)	8 (25.8)
	>71	0 (0)	2(6.5)
	N	*87*	*31*
Education	Basic (1–9th grade)	5 (5.8)	5 (16.7)
	Secondary	28 (32.6)	14 (46.7)
	Tertiary	53 (61.6)	11 (36.7)
	N	*86*	*30*
Off-farm work experience	Have experience	65 (75.6)	27 (87.1)
	Do not have experience	21 (24.4)	4 (12.9)
	N	*87*	*31*
Farm size (ha)	1–30	5 (5.7)	3 (9.7)
	31–50	9 (10.3)	7 (22.6)
	51–100	14 (16.1)	15 (48.4)
	101–200	25 (28.7)	6 (19.4)
	201–300	14 (16.1)	nr
	>300	20 (23.0)	nr
	N	*87*	*31*
Proportion of owned land	0–10	11 (12.6)	2 (6.9)
	11–20	4 (4.6)	nr
	21–30	4 (4.6)	1 (3.4)
	31–40	7 (8.0)	2 (6.9)
	41–50	11 (12.6)	5 (17.2)
	51–60	5 (5.7)	nr
	61–70	2 (2.3)	3 (10.3)
	71–80	10 (11.5)	1 (3.4)
	81–90	10 (11.5)	2 (6.9)
	91–100	23 (26.4)	13 (44.8)
	N	*87*	*29*
Crop production (% annual working hours)	0–25	17 (19.8)	11 (37.9)
	26–50	27 (31.4)	11 (37.9)
	51–75	21 (24.4)	4 (13.8)
	76–100	21 (24.4)	3 (10.3)
	N	*86*	*29*

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