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Linking Farmer Weed Management Behavior with Weed Pressure: More than Just Technology

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Most studies on weed population dynamics in farming systems have focused on the effects of different weed control strategies. Those studies usually assume that farmers, operating within a particular system, have a uniform management style. However, it is likely that weed management decision making also varies between farmers that operate within a system. In this study, the relationship between weed management behavior and the outcome of that behavior within an organic farming system is studied. It is hypothesized that differences in weed pressure between organic farms can be related to differences in farmers' weed management behavior. We explore which weed and general management factors are of main influence on the weed pressure, and investigate the influence of farmer's beliefs and knowledge on weed control techniques and the observed weed pressure. Preventive measures and timing of main soil tillage operation were identified as the weed management factors most influential for weed pressure. With the increasing number of preventive measures applied, weed pressure decreased, with a stale seedbed being the most important preventive measure. The weed pressure increased with the number of days after September 1st on which the main tillage operation was carried out. Because of this postponement of the tillage treatments, the growing season of weeds was extended and more species were able to reproduce before winter, thereby enhancing weed pressure. Field size, rather than weed pressure, determined the number of hand-weeding hours per ha; with increasing field size the amount of hand weeding per surface area was reduced. On farms with lower weed pressures a higher percentage of competitive crops were grown than on farms with higher weed pressures. The farmer's beliefs and knowledge on weed control techniques differed between farmers with different weed pressures. Market-oriented growers had a higher on-farm weed pressure than crop-growth–oriented growers. It was concluded that studies on weed management behavior and the effect of that behavior can lead to a better understanding of farming systems and to more effective weed management in those systems.

Key words: Organic farming system, hand weeding, beliefs, weed density, weed seed production, management behavior.

Agriculture has changed tremendously during the last decades, especially in western European countries such as the Netherlands (Henle et al. 2008; Meerburg et al. 2009). Nowadays European agriculture is characterized by the use of large amounts of external inputs and high outputs (Hersperger and Bürgi 2009; Ten Berge et al. 2000). One of the main factors that enabled the intensification of agriculture was the introduction of herbicides (Bastiaans et al. 2000; Kropff et al. 2008). Before the introduction and availability of herbicides, weed management was one of the major issues determining the design of cropping systems in most agricultural systems in Europe. After the introduction of herbicides, however, weeds came to be regarded as solvable side problems rather than being an important and decisive factor in the design of cropping systems (Bastiaans et al. 2000; Macé et al. 2007). Today, agriculture is economically still strongly dependent on these chemicals to maintain crop yields at a certain level (Pimentel 1997; Wilson and Tisdell 2001). The strong dependency of agriculture on chemical weed control is considered undesirable (e.g., Hyvönen 2007; Liebman 2001; Lotz et al. 2002). First of all, a strong dependence on herbicides implies the extensive use of compounds with a potential negative side effect on the environment (Bastiaans et al. 2000). Second, the risk of the development of herbicide resistance makes herbicide-dependent systems vulnerable (Powles 2008). As a result, organic farming systems have received much attention during the past decades. Much research effort has been focused on the development of alternative, mostly mechanical, weed control technologies (Barberi 2002). Nonchemical control options have progressed a great deal during the past decade for inter- and intrarow weed control. Developed techniques for interrow weeding involve steering systems that differ in their discrimination of their mode of crop row detection, which ranges from detection of the crop row with the human eye to sensing of the crop row mechanically by gliders, camera-based optical sensing of the crop row, and detection of the crop row with satellite navigation (RTK-DGPS) (Weide et al. 2008). Research concerning intrarow weeding has focused on the discrimination between crop and weed plants combined with the ability of tools to get close enough to the crop plant. Successively, the focus has been on harrowing, torsion, and finger weeding and weeding using compressed air (Weide et al. 2007). In spite of this expansion of the scientific knowledge on alternative weed control, the adoption of these alternative control methods is very low and mostly associated with organic farming. On top of that, the percentage of organic farms is still rather low: 3.8% on average in Europe and 2.7% in the Netherlands in 2008 (Centraal Bureau voor de Statistiek [CBS] 2008). Although nonchemical weed control tools can be as effective as herbicides (Riemens et al. 2007b), weed densities in organic systems are usually higher than in conventional herbicide-based systems (Albrecht 2005; Riemens et al. 2007a; Sjursen, 2001; Verschwele and Zwerger 2005). As a result, fear of ineffective weed control with often more expensive non-

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chemical weed control methods is often one of the most important obstacles for implementation of these alternative weed management systems (Beveridge and Naylor 1999; De Buck et al. 2001). However, decision support systems and extension work often focus on pure economics (Hammond et al. 2006): It is assumed that farmers will use economic rationality when they evaluate the trade-offs between weed management strategies. We know from previous studies on farmer decision making that farmers' decisions about farming practices are largely influenced by prior values and beliefs, not necessarily by the quality of the information they receive (Eckert and Bell 2005; Wossink et al. 1997). These values and beliefs are developed by trial and error or discovery learning (Eckert and Bell 2006). Another assumption that is made in previous work on weed population dynamics in farming systems is that farmers operating within a system have a uniform management style. However, it has already been shown that farmers who supposedly operate in the same system are known to respond differently to, for instance, the market (Nowak and Cabot 2004) or changes in the availability of farming techniques (Vanclay and Lawrence 1994). It is therefore likely that weed management decision making also varies between farmers that operate within a system. Understanding what and how growers think about weed management and how that affects practice may enlighten us about why outcomes of weed management within organic systems vary. Data on the farmers' weed management beliefs and behavior and the effects of these aspects on the on-farm weed pressure are still lacking (Mertens 2002).

In this article, we study the relationship between weed management behavior and the outcome of that behavior within an organic farming system. We hypothesize that differences in weed pressure between organic farms can be related to differences in farmers' weed management behavior. We explore which weed and general management factors are of main influence on the weed pressure, and investigate the influence of farmer's beliefs and knowledge on weed control techniques and the observed weed pressure.

Materials and Methods

Farms. The research took place at 16 commercial organic farms distributed over four areas in the Netherlands, 2 on clay soils, and 2 on sandy soils. All farms were located between 52°N and 5°E, and 52°N and 10°E. The four farms per region were chosen to represent farms with high and low weed pressures, relevant crop rotations, and the willingness of the farmers to participate in the research.

Farmer Characteristics. Data on the weed management behavior of the farmer were collected via an interview and a registration form. The interview consisted of a set list of questions regarding the effect of cropping practices on weed population dynamics and soil structure, the effect of weed control activities of the farmers such as preventive weed management tools (e.g., stale seedbed, fallowing, sowing density, stubble treatments, crop choice), grower typology, and the priority of weed management compared to other activities such as pest control and fertilization. A part of the interview questions is depicted in Table 1. The interviews were held at the beginning of the project, spring 2003.

Table 1. Part of the survey questions designed to explore factors that influence farmer weed management decision making.

Survey question
How would you describe yourself?
As a market-oriented grower
As a crop-growth–oriented grower
Which of the following measures do you think can prevent weed growth?
Stale seedbed technique
Fallowing
Increased sowing density
Stubble treatments
Crop choice
Other
How often is the risk of soil structural damage a reason not to control weeds?
Never
Sometimes
Often
Which of the following do you consider when selecting crops? Prioritize on a scale from 1 to 5 (5 = highest priority, 1 = lowest priority).
Nematodes
Insects
Weeds
Fungal diseases
Soil nutrients
What do you consider to be the most important causes of an increase of the soil seed bank? Only mark three. Prioritize on a scale from 1 to 3 (3 = highest priority, 1 = lowest priority).
Weather
Labor for control unavailable
Costs of control too high
Other activities of higher importance needed to be done
Import of seeds (from surroundings of the farm)
Other

Furthermore, each farmer was asked to register activities that took place at the farm each year of the survey (2003 through 2005) by filling in a registration form on the amount and timing of activities related to fertilization, cultivation, disease control, weed control, and planting and harvest dates of the crops for each field.

On-Farm Weed Pressure. Several parameters were recorded at each of the farms to obtain the on farm annual weed pressure: the weed species, the average density per species (number of plants m^{-2}), and the average number of viable seeds produced per plant (number of seeds per plant). Weed density was monitored in 15 quadrats arranged along a diagonal transect in each field (Mertens 2002). Each quadrat had an area of 1 m^2; however, different shapes were used in order to maintain the same proportion of crop row to interrow space found in the field as a whole. The quadrats were placed approximately 10 m apart. Transects were approximately located at the same sites in the fields each year. If weeds were present in two or more of the quadrats, 10 individual plants were taken from the field for seed production measures. Those plants were harvested outside the quadrats. These recordings were done each year (2003 through 2005), on each farm, on every field, 3 wk prior to crop harvest. This implies that every field was monitored at least once a year, and in some cases several times a year, due to different succeeding crops in one season. The weed density per species and the number of seeds produced per plant were used to calculate the total weed density (total number of plants m^{-2}) and the total seed production (total number of seeds m^{-2}). As a result of measuring at the end of the growing season, the measured weed density and weed seed production were the result of weeds emerging from the viable soil seed banks present in a field (the potential density) and the weeds surviving subsequent weed control during the season.

Data Analysis. The approach to the analysis was first to identify general patterns in the weed density, weed seed production, and number of weed species between farms by means of the summary statistics menu in the Statistical program GenStat (Payne et al. 2008). Second, the relationships between various factors (farm size, crop, soil tillage, weed management) and the weed pressure were investigated with the use of linear regression analysis. Finally it was investigated whether farmers with different self-reported beliefs and behaviors on weed management also differed in weed pressure and factors that had an important effect on the weed pressure. These analyses are described in detail in the following sections.

General Patterns in Weed Pressure and Weed Abundance. The weed density per species was used to calculate the total weed density (total number of plants m^{-2}) per farm averaged over all years and fields. To investigate which species were most abundant, the weed densities and seed production per species were averaged over 3 yr, on farms and in fields.

Screening of Factors Influencing the Weed Pressure. Two measures were used to represent the on-farm weed pressure: the weed density (number of plants m^{-2}), and the weed seed production (number of seeds m^{-2}). The relationship between the two measures for weed pressure were analyzed by fitting a linear regression model in the Statistical program GenStat (Payne et al. 2008) of the seed production vs. the weed density. Prior to fitting the model, the data on weed density and weed seed production were log transformed to meet terms of normality.

Factors influencing the weed pressure were investigated by fitting all possible linear regression models in the Statistical program GenStat (Payne et al. 2008) of all a priori selected factors that could be influencing the weed pressure (weed density and weed seed production). These factors were hand-weeding effort (h ha^{-1}), timing of main soil tillage (number of days after September 1st), number of applied preventive weed control measures, field size, and soil type. Prior to fitting the models, data were log transformed to meet terms of normality whenever required. The fitted models were compared according to the highest adjusted R-square value and the lowest Mallow's C_p (Mallows 1973; Ronchetti and Staudte 1994). In this way the best regression model containing only the most important factors was selected for the average weed density and the average weed seed production.

Investigating the Effects of Factor Levels. After the most suitable models were found, the effects of the factors on the weed pressure were investigated by examining the coefficients of the models.

For the factors not included in the models, it was investigated why these were not as influential as was expected. These factors were hand-weeding hours, field size, and soil type. Because hand-weeding hours and field size were correlated, the number of hand-weeding hours averaged over the 3 yr (h ha^{-1}) was plotted against the average field size (ha). A logarithmic function was fitted with the statistical program (Payne et al. 2008).

Investigating which Crops Allow High Weed Pressures. Hierarchical cluster analysis (HCA) was used to analyze the seed production and weed density in the crops. HCA is a tool designed to reveal natural groupings within a data set. We used the agglomerative method, which starts with individual objects (crops) that are combined into groups by collection of objects or groups into larger groups. Grouping is based on similarity between objects/groups. Crops are placed in a multidimensional space (number of dimensions = number of crops). Position of crops in the space is based on the weed pressure (weed density and weed seed production) in the various crop species. Distance between crops is the measure for dissimilarity: Euclidean distance (ED). Crops were only included in the analysis if they were grown at least three times by different farmers.

Linking Farmers' Self-Reported Beliefs on Weed Management with Weed Pressure. Because of the relatively small sample size (n = 16), it was not possible to reduce the number of variables from the questionnaire and perform a PCA (principal-component analysis). Therefore descriptive analysis was used to detect differences in the farmers' beliefs on weed management. At several times during the interview each farmer was asked to tell about his or her interests. Based on their response during the interview, farmers were categorized as either crop-growth or market oriented. This and other variables that were significantly different between farmers were used for comparison with the weed pressure data. For each of those questionnaire variables, the average weed density and weed seed production were calculated. Differences in weed pressure were evaluated with Fisher's LSD test.

Results and Discussion

Over the survey period of 3 yr a total of 20 weed seed producing species were observed (Table 2). *Stellaria media* was the most abundant species on each farm and had an average density of 29 plants m^{-2}. Other abundant species were *Chenopodium album*, *Polygonum convolvulus*, *Poa annua*, and *Polygonum persicaria*, although they were not, like *S. media*, observed at each farm. *Galinsoga parviflora* had the highest average density (36 plants m^{-2}), but was detected on farms less frequently than *S. media*.

The average weed density on the farms ranged from almost 1 weed plant m^{-2} on farm 1 to 26 weed plants m^{-2} on farm 8 (Table 3). The average weed density on sandy soil was, for most farms, higher than on a clay soil. Results in Table 2 are the average densities of species present in the fields, and average densities in Table 3 also include data of fields at which no species were present.

Factors Influencing Weed Pressure. The two parameters used to represent weed pressure, the average weed density per farm (plants m^{-2}) and the weed seed production per farm (plants m^{-2}), were linearly related when averaged over all years and fields (Figure 1). Similar linear relationships were found for the weed seed production and weed density per farm per year (data not shown).

Table 2. Mean density of the individual weed species and the standard error of the mean (SEM), and the mean number of weed seeds produced per species and the SEM, averaged over all years, farms, and fields.

Weed species	Weed density (no. m^{-2})	SEM	Weed seeds (no. m^{-2})	SEM
Amaranthus retroflexus L.	2.0	–	569	–
Apera spica venti (L.) Beauv.	15.5	7.50	0	–
Capsella bursa pastoris (L.) Medk	11.2	2.56	2,217	839
Chenopodium album L.	25.2	2.81	15,018	3,790
Echinogloa crus galli (L.) Beauv.	9.0	1.54	1,005	204
Elymus repens (L.) Gould.	12.5	4.01	0	–
Galinsoga parviflora Cav.	36.1	6.88	7,076	2,034
Lamium purpureum L.	10.4	3.70	143	43
Matricaria chamomilla L.	6.0	1.19	2,329	720
Poa annua L.	9.8	3.23	5	2
Polygonum aviculare L.	8.0	2.18	5	2
Polygonum convolvulus L.	11.2	1.54	182	28
Polygonum persicaria L.	17.1	4.30	1,137	520
Raphanistrum raphanistrum L.	3.3	1.86	381	212
Senecio vulgaris L.	8.8	4.12	409	115
Solanum nigrum L.	10.7	2.34	4,138	3,052
Sonchus oleraceus L.	7.3	5.92	228	131
Stellaria media (L.) Vill.	29.1	2.71	2,204	487
Urtica urens L.	12.4	5.90	2,001	1,341
Veronica filiformis Sm.	12.0	5.86	3,942	257

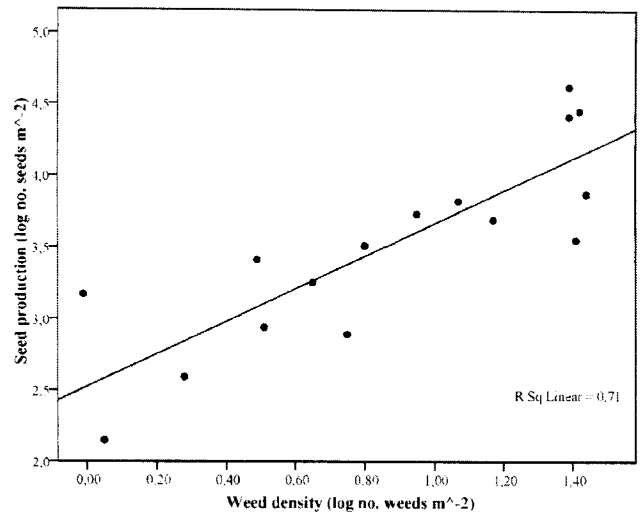

Figure 1. Relationship between the log-transformed average weed seed production and average weed density, measured at the end of a growing season, 3 wk prior to crop harvest. $R^2 = 71.0$. $Y = 2.52 + 1.14 \times X$, with Y = log(weed seed production), and X = log(weed density).

The variation in weed seed production and weed density was best explained by a model with two factors: timing of the main soil tillage treatment (x_1) and the number of applied preventive measures (x_2): $Y = c + a \times x_1 - b \times x_2$, in which a, b, and c are constants and Y is either the log(seed production) or the log(weed density). With increasing number of applied preventive measures, the number of weed seeds being produced and the weed density decrease (Table 4). Applied preventive measures were the use of a stale seedbed, a high sowing density, adjusted row distance, stubble treatment, and crop and variety choice. The most influential preventive measure applied was the stale seedbed. A stale seedbed followed by control of the emerging seedlings prior to planting or seeding a crop can reduce the number of weeds during crop growth, compared to a weed control system without a stale seedbed, by 80% or more under experimental conditions (Riemens et al. 2007a). The current results show that the application of a stale seedbed has a positive influence on the reduction of the weed pressure at the farm level as well.

The timing of the main soil tillage operation influenced the weed density and the number of weed seeds on the fields in the season followed by the operation. The most common form of soil tillage in the Netherlands in general, and also on the farms in our study, is moldboard plowing. The number of produced weed seeds and the weed density significantly increased with the number of days after September 1st on which the main tillage operation was carried out. On fields where the main soil tillage operation was carried out in autumn, the seed production and density were lower than on fields tilled in spring. The average timing of the main soil tillage operation on a clay soil did not significantly differ from the average timing on a sandy soil (P = 0.672).

Table 3. Mean density of the total weed species and the standard error of the mean (SEM) averaged over all years, weed species, and fields.

Farm	Soil type	Weed density (no. m^{-2})	SEM
1	Clay	1.0	0.27
2	Clay	3.3	1.04
3	Clay	1.9	0.20
4	Clay	3.1	0.978
5	Sand	24.4	4.95
6	Sand	1.1	0.83
7	Sand	17.3	2.63
8	Sand	26.4	10.18
9	Sand	14.7	3.80
10	Sand	15.8	2.37
11	Sand	14.8	5.99
12	Sand	8.9	1.77
13	Clay	11.6	3.97
14	Clay	4.5	0.45
15	Clay	6.4	1.49
16	Clay	5.6	1.09

Vleeshouwers and Kropff (2000) also observed that late soil cultivation (large number of days after September 1st) results in higher weed densities than early soil cultivation. Three factors influence the differences in seedling numbers after soil cultivation at different dates: the degree of dormancy of the seeds, soil temperature after cultivation, and soil penetration resistance after cultivation (Vleeshouwers and Kropff 2000). In the present study, *S. media* was the most abundant species, occurring at high densities (Table 2). Weed management practices affecting *S. media* will therefore have a large effect on the total on farm weed pressure. Under favorable conditions, *S. media* can germinate and emerge all year round in the Netherlands (Sobey 1981). Seeds of this species emerging in late summer and early autumn, after crop harvest, will be controlled by the main soil tillage operation. When this control takes place in spring, these late-emerging plants are able to grow during winter and produce seeds before the tillage operation takes place in early spring. However, when a treatment is already performed in the autumn, those late-emerging plants will be controlled and will not contribute to

Table 4. Coefficients of the model $Y = c + a \times x_1 - b \times x_2$, with Y: either the log(seed production) or the log(weed density), x_1: timing of the main soil tillage treatment, and x_2: the number of applied preventive measures.

Y	a	b	c	R^2
log(weed density)	0.72 ± 0.323	0.21 ± 0.069	0.24 ± 0.076	55.8
log(weed seed production)	1.18 ± 0.398	0.22 ± 0.085	1.98 ± 0.935	58.2

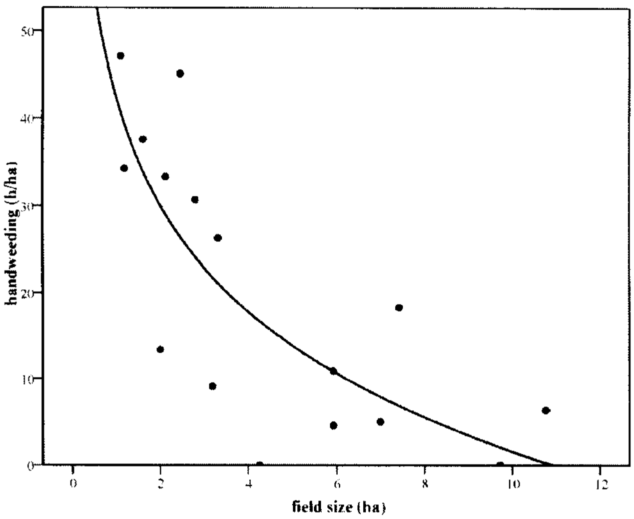

Figure 2. Relationship between manual weed control effort (hand-weeding hours per ha) and the average field size (ha). $R^2=79.2$. $Y = 42.41 - 17.74 \times \log(x)$ with Y = manual weed control effort (hours per ha), and x = field size (ha).

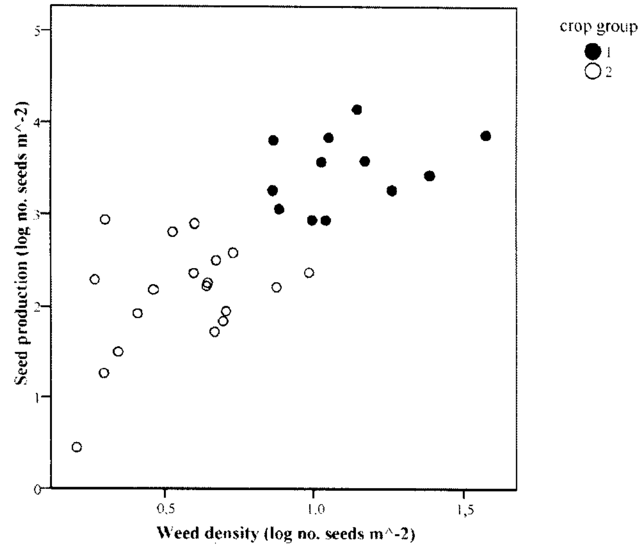

Figure 3. Grouping of crops with HCA (hierarchical cluster analysis) based on weed density and seed production. Group 1 contains noncompetitive crops allowing high weed densities and weed seed productions; Group 2 contains competitive crops that allow lower weed densities and weed seed production.

the weed pressure in the following season. The weeds emerging during winter after the soil tillage will have a reduced growth and seed production, thereby contributing less to the weed pressure in the following growing season than the weeds emerging in autumn. Other summer annuals with germination and emergence characteristics similar to those of *S. media* will probably respond in a similar way.

Hand-weeding hours, average field size, and soil type were not included in the models that gave the best fit for one of the weed pressure parameters. The hand-weeding effort (that is, the average number of hand-weeding h ha^{-1}) of the farmers was determined by the average field size (ha). The larger the field, the lower the number of hand-weeding hours per ha (Figure 2). The number of hand-weeding hours did not significantly differ between farms on a sandy soil and farms on a clay soil ($P = 0.129$). Earlier studies with multiyear experiments by Weide et al. (2008) and Melander and Rasmussen (2001) showed that the amount of hand weeding (h ha^{-1}) was positively related to the weed density (plants m^{-2}). The difference between those previous studies and the present study can be explained by the farmers' behavior. The previous studies were carried out on experimental farms and had the objective to manage the weed populations according to best available weed management practices. In contrast, manual weed control on the 16 farms in this study was related to field size. With increasing field size, the average hand-weeding hours per ha decreased. This result suggests that farmers can only dedicate a certain amount of time to manual weed control, independent of the weed densities on the fields.

The results further imply that the adoption of preventive weed control measures may provide farmers with an effective way of reducing the weed pressure on their farms. It is well known from previous studies that the use of preventive measures such as the stale-seedbed technique (Riemens et al. 2007a) and the use of a high cropping density (Kropff et al. 1993) can significantly reduce weed densities. This is the first study in which the importance of preventive weed control measures for weed pressure is shown in an exploratory study on commercial farms.

Results should be interpreted carefully, because investigated factors were intertwined. An example is the correlation between the applied preventive weed control measures and the soil type. On farms with a sandy soil type the average number of applied preventive weed control measures was 2.88 per farm, which was significantly ($P = 0.012$) lower than the average of 4.63 per farm on a clay soil. Because of this correlation, soil type and the number of preventive measures could not be included in one model. The model that best fitted the weed pressure data was the model with the preventive measures, thereby excluding soil type from the model. Soil type did influence a factor that was included in the models—the number of applied preventive measures on a farm.

Crops Allowing High Weed Pressures. The hierarchical cluster analysis showed that crops could be grouped into two groups (Figure 3); group 1 containing the noncompetitive crops allowing high weed pressure (that is, with high weed density and weed seed production) and group 2 containing the competitive crops with lower weed pressure. The noncompetitive crops (group 1) were bulb crops (tulip), lettuces (lettuce, endive), onion-like crops (e.g., onions, carrots, leek, fennel), sunflower, and vegetable crops (courgette, pumpkin). The more competitive crops (group 2) were cabbages (e.g., brussel sprouts, cauliflower, broccoli, Chinese cabbage), potatoes, celeriac, cereals (e.g., oat, winter and summer barley, winter and summer wheat, rye), grass, and legumes (peas, fresh beans). For each farm we calculated which percentage of the crops that were grown belonged to group 1 (noncompetitive). Crops with high weed pressures are crops with low competitive abilities to weeds. Apparently, this factor has more effect on these farms than the mechanical control possibilities that these crops offer compared to more competitive crops such as cereals. Again results need to be interpreted with care; the farms located on a sandy soil differed from farms on a clay soil in the percentage of noncompetitive crops grown as well. The percentage of noncompetitive crops grown on sandy soils was on average

Table 5. Farmers' self-reported grower typology in relation to the observed weed pressure (weed density and weed seed production). Different letters indicate significant differences between grower typologies within columns at the 5% level.

	Weed pressure (mean ± SEM)	
Type of grower	Weed density (plants/m^2)	Weed seed production (seeds/m^2)
Crop-growth oriented	5 ± 1.8^a	1,728 ± 624.2^a
Market oriented	18 ± 3.3^b	13,592 ± 4,815.9^b

42%, on clay soils it was on average 11% ($P < 0.001$). Because soil type determines to some extent the crop types that can be grown, and the crop determines for a large part the management options, factors are intertwined.

Linking Farmers' Self-Reported Beliefs on Weed Management with Weed Pressure. Grower typology (crop growth or market oriented), beliefs about soil structural damage caused by mechanical weed control, and awareness of the influence of crop choice on weed growth were questionnaire variables in which farmers significantly differed.

Farmers that regarded themselves more market-oriented growers had a higher average on-farm weed pressure (Table 5). The mean weed density on farms managed by market-oriented farmers was 17.6 plants m^{-2}, whereas the mean weed density on farms managed by crop growth oriented farmers was 4.6 plants m^{-2}. A similar pattern was found for the mean weed seed production; on farms managed by market oriented farmers the average weed seed production was 13,592 weed seeds m^{-2}, whereas the mean weed seed production on farms managed by crop-growth–oriented farmers was 1,728 weed seeds m^{-2}.

Farmers that were aware of the influence of crop choice on weed growth and took the farm weed situation into account during crop choice significantly ($P = 0.03$) chose less noncompetitive crops (group 1) than farmers who did not take the weed situation into account (37% vs. 16%).

Those farmers that believe that soil structural damage can occur when weeds are mechanically controlled and do not often control weeds mechanically to avoid soil structural damage had a significantly higher average weed density than farmers that never or sometimes avoid mechanical weed control to prevent structural damage (Table 6). The same trend emerged for the weed seed production, although differences between farmers that often avoid and farmers that never or rarely avoid mechanical weed control were not significant.

Conclusions and Considerations for Future Research. In this study we investigated the relationship between weed management behavior and the outcome of that behavior, the weed pressure, on commercial, organic farms. In addition, we investigated the possibility of using a questionnaire to identify beliefs of farmers regarding their weed management and weed pressure. Differences between organic farms in weed pressure were influenced by differences in farmers' management behavior. Preventive measures and timing of main soil tillage operation were identified as the most influential weed management factors for weed pressure. The farmer's beliefs and knowledge on weed control techniques differed for farmers with different weed pressures. The sample size we eventually chose ($n = 16$) was a compromise between a

Table 6. Farmers' risk perception of soil structural damage as a reason not to control weeds mechanically, in relation to the observed weed pressure (weed density and weed seed production). Different letters indicate significant differences within the farmers' risk perception of soil structural damage within columns at the 5% level.

	Weed pressure (mean ± SEM)	
	Weed density (plants/m^2)	Weed seed production (seeds/m^2)
How often is the risk of soil structural damage a reason not to control weeds?		
Never	5 ± 1.0^a	2,197 ± 730.0^a
Sometimes	8 ± 3.2^b	5,511 ± 3,299.1^a
Often	22 ± 3.4^c	16,749 ± 7,406.2^b

minimization of the number of fields for determination of the weed pressure on one hand, and a maximization for the questionnaire variables on the other hand. In future studies, a better view on farmers' beliefs and perceptions on weed management behavior can be obtained by increasing the number of farmers and reducing the number of fields for weed pressure monitoring. Despite the fact that our sample size was relatively small and only consisted of farmers that were willing to cooperate, the results will probably be representative of the larger group of organic farms. According to Luschei et al. (2009), so-called convenience samples can be a good representative of the more general class of farms. They compared the response of a subgroup of 18 farmers with that of the larger group of 187 farmers to a survey on weed management behavior and attitudes. Results of the smaller group were linked to the results of the larger group.

Qualitative aspects, such as the perception a farmer has concerning weeds, the strategy the farmer uses to achieve certain goals, the awareness of certain processes in weed biology, and the reasons for the use of certain techniques, are much more difficult to quantify than the quantitative aspects such as hand-weeding hours. Wilson et al. (2008) presented the mental model approach to identify the motivational and cognitive processes underlying farmer decision making. In future research, the combined incorporation of the human dimension, in terms of farmers' beliefs, attitudes, and behavior, and the underlying processes with the mental model approach and the effect of that behavior, in terms of weed pressure, can lead to a better understanding of the (organic) farming systems and to more effective weed management in those systems.

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