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# The Effect of Tillage on the Weed Control: An Adaptive Approach

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## Abstract

The tillage systems and performance of the operations have an important impact on the weed control. The primary goal for the tillage is to establish the best possible conditions for the crop establishment and growth under the given conditions as soil texture, moisture and so on. In addition, the tillage system also strongly influences the weed pressure and conditions for weed control. As tillage requires a substantial amount of fuel, and affects the leak of nitrogen and CO<sub>2</sub> from the soil, there is a big motivation in optimizing the tillage operations due to the local conditions in the field. A big challenge is how to sense the local conditions and information that are needed to optimize the tillage system for local treatment and intensity. This chapter focuses on how to optimize the tillage operations in a local adaptive approach aiming at the best possible weed control.

**Keywords:** tillage, weed control, adaptive, soil fertility

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## 1. Introduction

This chapter describes how the tillage operations contribute to the weed control. It is important to understand that the weed pressure, both perennials and annual germinating species, depends on the common conditions controlled by the cropping system, involving the crop rotation, the soil fertility, nutrient strategy, tillage, and direct control methods as weed harrowing and hoeing. The different actions that contribute to weed control can be considered like filters that favor some plant traits and filter out others. The challenge then is to design the growing system like a system of filters such that all weed species are controlled such that they do not grow unrestrained [1, 2]. By all means, diversity is important in the growing system. As a part of this, it is important that the crop rotation includes different crops, seeded in both

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spring and autumn. It is important to have in mind that fast-germinating and established crops are highly competitive and contribute substantially to weed control [3]. Another specific element is the benefit of cutting perennial forage grass in the rotation three times or more per year to control quack grass and other root-emerging weeds. With respect to the direct control methods, it is important that the crop rotation allows for space to perform dedicated quack grass control after harvest. The presence of row crops allows one to perform the control by hoeing during the growing season. This potentially gives a good weed control but can also cause substantial problems if the operation fails.

The tillage operations are, in general, divided to be part of the primary tillage or the preparation of the seedbed. The primary tillage is aimed to obtain a good turnover of the plant residuals and to maintain a healthy soil structure. In this multi-oriented context, the demands for the tillage operations can be different if it is related to optimizing the soil fertility or the weed control. An example here is the performance of the moldboard plowing. Aiming for an effective control of perennial weeds demands that the plants are covered deep in the soil or that they are dried out in a starvation strategy. Whereas the requirements related to the soil fertility can with good conditions be fulfilled by more superficial treatments. In fact, an unnecessary intensive tillage strategy will cause harm to the soil fertility [4, 5]. Therefore, in the operative planning, it is very important to be aware of the actual field conditions for the specific year, and thereby also the infield variations.

The performance of the operations for seedbed preparation and seeding also affect the weed germination and the weed control. The goal of this operation is to do the final leveling of the soil surface and to establish the right structure for the soil aggregates to form the best possible conditions for the seeds to germinate and establish growth. If the time schedule allows, it can be beneficial to perform a weed harrowing prior to the seeding to reduce the density of the first generation of germinating weeds. In the seeding operation, it is of course important to establish the best possible conditions for the seed. A quick and fast germination and establishment of the crop is important to optimize the competitiveness against the weed. In addition, a uniform seeding depth is important for the subsequent weed control, in a way that this enables room for weed harrowing prior to the crop seeds that break through the soil surface [6, 7]. A uniform seeding depth causes a uniform germination and propagation of the crop plants, and thereby the best possible conditions for the following weed control by weed harrowing or hoeing.

All this together makes good sense to involve the principles of precision agriculture, also to support the effectiveness of the contribution to the weed control. This can be site-specific primary tillage, site-specific seedbed preparation, fixed tracking and controlled traffic, implement control in general, and row control of the hoeing process.

## 2. Primary tillage

The primary tillage aims at maintaining or improving the soil structure and soil fertility. In addition, the strategy and operational execution of tillage greatly affect the weed. The soil structures enable the drainage and water absorption. The porosity for drainage and the water

capacity of the upper soil layer is controlled by the microbes and the content of organic matter. This is maintained by the incorporation of fresh organic matter with smooth tillage operations. At the same time, at stable conditions, the planning and performance of the primary tillage must ensure that no increase in the occurrence of the root-emerging weeds occurs. To control root-emerging weeds, the plant must be covered in the soil layer the deeper the better. Normally a depth of approx. 20 cm is recommended. This conflicts with the preferred conditions for the turnover of plant residuals and is supported by the presence of a smooth mix into the soil having access to the oxygen from the air and soil moisture getting into contact with the soil fungal and fauna that catalyze the process. Jacobs et al. [8] test has shown that the best conditions for the turnover of plant residuals are placements in the upper soil layer—0–5 cm. In practical the working depth of approx. 20 cm for the primary tillage is used. The experience is that this gives a good balanced result, just that the operator must be aware, that the working depth must be as shallow as possible. Deeper working depth increases the effect due to weed control but reduces the access to oxygen. Tillage operations may not be overdone in intensity as the operations are highly energy consuming. Also, that the tillage is not only positive. Unnecessary tillage damages the soil structure, this both due to the workability in the seed bed preparation, and the porosity. The challenge for the tillage operations is to support the dynamics of the growing system, not the operation itself.

If it occurs from the monitoring of the fields, that it is necessary to apply a dedicated treatment to reduce the occurrence of root emerging weeds this can be done in more ways. One obvious method is to increase the working depth for the primary tillage operation, and to make sure, that all the residuals are effectively covered deeply under the soil layer. Another more dedicated method is to make space in the crop rotation; this allows for a series of operations in the period after harvest. Here there are in principal two different methods: “drying” and “starving”. Convenient conditions allow additionally to cultivate just prior to a period with temperatures below 0°C.

## **2.1. The type of operation**

In Scandinavian countries, as in many other countries, the primary implements used for the primary tillage has been the moldboard plow and the stubble cultivator. Often, the stubble cultivator is used for a shallow operation immediately after harvest to stop the growth and cut the roots of weed plants and to catalyze the contact from the microbiological life to the residues. Hereafter, the strategy is different and highly dependent on the crop rotation and local conditions. If there is a need for a dedicated treatment to reduce the occurrence of perennial weeds, it is generally after harvest that a series of repeated stubble cultivations can be performed [4]. Danish tests show that repeated stubble cultivations in the autumn can reduce the density of perennial weeds up to 90%. Similar results can be seen in a test in Norway and Germany [9, 10]. Under wet conditions in Norway, it has been observed that the best results are obtained by applying the treatment in spring prior to moldboard plowing and seeding. By this method, the time for seeding becomes too late and too costly in yield reduction. In the autumn, as the temperatures are getting lower, the plowing operation is performed. Here, the growth is stopped, and the turnover of the residuals are continued, now integrated into the soil and sowed in some depth.

In areas having problems with erosion and where the farmers want to perform a strategy that is highly focused on soil fertility, deeper cultivation with chisel plows are used instead of the moldboard plowing. Under nonchemical conditions, success rate for this strategy to work is hard to come by. One major challenge is keeping a check on the development of the weed species in a way that it damages the yield and growth conditions for the crops. Although more tests have shown that the most important factor in weed control is the soil fertility and the composition of the crop rotation [11–13], It is shown that when the crops are healthy and the yield is high, it can be acceptable that there is some presence of weed the tests also shows that it is possible to control the weed not to develop uncontrolled. Although the earlier mentioned tests have shown that tillage, especially stubble cultivation or hoeing can be helpful in practical use to control the weed.

## **2.2. Data and precision agriculture in primary tillage**

The system of precision agriculture has been developed during the last three decades. The focus has primarily been on fertilizing and pesticide applications. There has been limited focus on the tillage no matter that there are big potentials both due to savings in cost and energy and in the optimization of the operations. The problem is that the controlling parameters such as “soil fertility” are almost impossible to measure by commercially available sensors or sensor systems. In addition, it is quite difficult to transform to a mathematical model.

Though there are potentially gains both in a planning and graduated intensity over the field that can be performed by use of existing technology. For example, the plowing depth can be controlled by both semi-automated means and automatically [14]. From an overall point of view, the precision-based application can be performed at least due to three challenges that normally occur locally and delimited on the field:

1. Emerging problems with root-emerging weeds
2. Dense soil with low capacity of water accessible for the crop
3. Compacted soil with reduced efficiency in the drainage

The abovementioned effects can be mapped by manual inspection. In recent years, the use of drones for these types of inspections is developed for commercial use [15, 16]. Since the last approx. 2 decades, the global positioning system (GPS) positioning, the tractor computers, and auto guidance have been commercially developed and are now installed on more than 50% of new tractors. Having the digital application map, it is therefore possible to perform precision-controlled tillage operations. This can be done using selected implements that allow for the wanted adjustments, where the precision-based operations in farm level are introduced in the strategy of utilizing possible benefits and build the necessary profile of knowledge and technology needed to be prepared to utilize the upcoming versions of the new implement prepared for precision applications. One example here is the plow. Here, it is already possible to adjust the plowing depth within a given range using existing technology. New developments [14] show systems that are dedicated for depth control in the individual plowing sections. It is also possible to build on double plow sections in front of the main moldboard that controls



if plant residuals primarily are mixed in the lower layer of the plowing profile or if they are placed into the bottom of the profile to optimize the control of root-emerging weeds.

The dedicated strategy in relation to optimizing the soil structure by using existing technology relies more on the operation only for the areas, where the operation is needed. In these situations, it is important to be aware, that the tillage operation is only a part of the solution. The aim here is in a gentle way to loosen the soil as a part of a plan involving more actions that together are aiming to revitalize the soil fertility, that beneficially also involves the introduction of dedicated crops, where the roots actively contribute to soil loosening and applying organic matter from manure, compost, or similar.

The state-of-art research in drone technology is concerned not only with mapping the density of weeds but also determining the species [15, 16]. This information will be beneficial as the growing weed species can be used as indicators for soil fertility, and hereby there are also problems with drainage and water capacity. This is important due to crop growth and yield, but it also plays a very important role in weed management as the fertile soil generates vital and robust growing crops, that compete effectively with the weed.

Due to this context, it makes sense to pay most attention to the optimization of soil fertility by means of the tillage system and other means.

### **3. Seed bed preparation and seeding**

Ideally, the seed bed preparation must take place some days prior to seeding. This performs the task smoothly in the soil. During the days of rest prior to seeding the soil aggregates stabilize, such that the soil structure after seeding has less risk to slam and potential for erosion. Due to weed control the seed bed preparation prior to the seeding operation has another advantage as it can be used as a false seed bed, initiating weed seeds to germinate, and then removed in the seeding operation. In the planning of crop rotation, it makes good sense to make space for the false seed bed operation prior to the seeding of selected spring crops. More tests have been performed to reduce the pool of weed seeds in the soil. Results show that this is almost impossible [17, 18]. The seeding operation is normally performed by the use of implements, that also involves some tillage in the top layer. For a good establishment of the crop, precise seeding depth is important. This is also an advantage for weed control, as it is possible then to perform a weed harrowing operation just prior to the time where the new seeds breakthrough the soil surface. Hereafter it is important that crops perform a fast and robust establishment in this that the crops benefit from fertile soil, due to access to fertilizers, moisture, and the soil structure. Problems with slammed soil surface restrict the access for oxygen into the soil and thereby inhibit the growth. For more cases, the first establishment of the crop is essential. Due to weed control, it is in this period that the competitive strength of the crop due to weeds is established. In the next section, it is described how the competitive strength for crops improves the possibility of getting good results with weed harrowing. More tests [19, 20] show the importance of the timing in the tillage and weed management operations. Due to competitive characteristics there can be two alternative systems

for seeding: one is that the seed is distributed evenly over the area to give the best coverage possible and thereby the best competitive strength against weeds. Danish experiences show good results with this system for crops such as rye and barley. If the crop is less competitive in general, or particularly in the early stage, another system can be favorable, to grow crops in rows this enable the possibility of performing weed harrowing and hoeing. In row cropping, the competitive strength due to weeds in the in-row area has improved substantially, as also the overall resistance for the crop in operations as weed harrowing is improved. The disadvantage of row cropping is that operations for weed control are needed in the inter-row area. Due to yield the crop is not that sensitive. The Danish test has shown that for row distances, up to approx. 18 cm for cereals, there is almost no decrease in yield. Other crops such as rape are even less sensitive to the open row distance.

### 3.1. Digital tools

Due to seeding there are commercial systems that allow for graduated seed density over the field. The graduation can aim for eliminating locally weak conditions for germination or if an improved coverage is required in the early stage. The control input for this must be given by the operator prior to the operation, as there are no systems available that can sense the input for this. Modern seeding implements are designed to operate with a constant seeding depth, with mechanical means that is adjusted prior to the operation in the field. Ongoing research aims to develop systems that by monitoring the actual working depth are adjusted by a dedicated control system. In the system tested the control systems are operating individually on each seeding section. With such a system in operation I will make sense to expect a coming version designed for adaptive control of the seeding depth, for example, to ensure the access to moisture and thereby the best possible conditions for germination.

Systems for automatic change from broad seeding to row cropping are also commercially available. Though not fully flexible, they are designed such that every second seeding unit can be closed. With such systems, row cropping can be established only in the areas where it makes sense due to reduced soil fertility or structure. For more reasons, there is a big interest in establishing cover crops. This can be quite challenging under Nordic conditions as the cover crops in general require early seeding for success. Here, row cropping also enables some good conditions under seeding in the inter-row band prior to harvest. In good conditions cover crops can contribute in stabilizing the growing system due to harvest of nitrogen and controlling weed growth. Though the capacity from cover crops to control weeds is not good enough as it can be used to solve problems, stubble cultivation must be brought into play.

### 3.2. Weed harrowing and hoeing

To avoid weed problems it is important that all means to control the weed is integrated and optimized together with other elements in the cropping system. The interactions and the connections to the tillage operations and other factors are described in the sections earlier.

The weed harrow is normally designed with a flexible frame mounted with more sections, equipped with a set of long elastic tines that all are in touch with the soil surface. It is commercially available to have systems, where the load on the individual sections is equally

distributed by an active control system. The intensity from the tines to the soil surface is controlled by the load on the section and the working angle for the tines. This working angle can also be controlled by a central control system that is normally controlled by the operator. The challenge for the operator is to adjust the settings for the harrow and the operation forward speed such that the damage on the crop is limited and the effect on the weeds is optimized. One important factor here is to make the best use of all factors to optimize the growth difference, such that the crop continuously is bigger and more established than the weed. It is also important that the soil is workable without a slammed and hard surface. In an optimal setup the first treatment is performed approx. 1 week before the seeding process to initiate the germination of the first generation of weed seeds. Hereafter follows a precision seeding as earlier described; this does reset the weeds. Then, just before the crop breaks the soil surface, a weed harrowing operation is again performed. Hereafter a break is needed for the crop to be established such that it sustains a next operation. For this operation the operator needs to pay the most attention to the timing and to the adjustment of the harrow as the best result is achieved by carrying out the operation as early as possible, without damaging the crop and when it is still possible to control the weed. Hereafter two more operations can be performed.

As described the weed harrow is a uniform implement that work in the full working with based on the preconditions that it is possible to establish a difference in the sensitivity for the crop and the weed to the treatment. In comparison to this is the hoe that only operates in the inter-row area without crops. By modern implements the guidance of the hoe can be automatically controlled by a vision-based system that enables the hoe to operate quite precisely in relation to the row. As the competitiveness from the row of crops is bigger and closer to the row, it is important to perform hoeing as close as possible without absolutely damaging the crops. A very precise and dedicated operation can be performed by a hoe equipped with elements such as brushes or other tools that work close to the row. The advantage of the hoe is that it has very high efficiency in the inter-row area.

A normal cropping system does normally include weed harrowing for weed control. The overall effect and weed control can be improved by also introducing the hoe for operations where it can be possible operated. Compared to weed harrowing the hoe is less sensitive on hard surfaces and so on, which means that the effect of hoeing is more reliable. Hoeing can also be an important part of the strategy to bring the system back to normal for areas where the weed has had the chance to develop to a level that is problematic for balance in the system. This can be done by opening the rows to make space for the hoe operations in the problematic areas in the field. The hoe is very efficient in the inter-row area. For the operation close to the row some additional systems can be built [21] such as flexible tines or rotating fingers.

#### **4. Discussion and conclusion**

Many farmers and research activities have shown that it is possible to control the weed in cropping systems only by use of mechanical and agronomic means. It is essential that the cropping system is carefully planned and adaptively optimized in relation to the local conditions and challenges. The fertile soil is key both to the growth and to the yield of the crops but



also in relation to create the best conditions for successful tillage operations and weed control. One of the core elements is if the cropping system makes space for cutting grass. A perennial grass for feed that is cut three times or more in the growing season contributes substantially to weed control and to the optimizing the soil fertility and hereby the soil structure.

Going a little into the details and interdependency of the different elements and operations in the cropping systems, it appears that there are many balances to be aware of and many optimizations to be made. Here, many new technologies can assist in positive results. In this matter it is important also to follow technical development. Some of the concepts that automatic solutions. This must create value in the operation and the cropping system, but it also prepares the farmer to take in the new technical solutions when they are ready and when they potentially can create value in the individual cropping system.

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