Precision Ag for Ecological Farming Systems

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Dr Charles N Merfield

www.merfield.com and www.physicalweeding.com

1. Synopsis

This paper considers what precision agriculture means and is used for in ecological farming systems. It starts by explaining what ecological agriculture (eco ag) is, why it matters, including how eco ag techniques are increasingly important for mainstream agriculture. It then reviews the main precision technologies used in eco ag, which are mostly for weed management, including GPS and vision based computer guidance systems for interrow hoes. It then discusses how these technologies have created a paradigm shift in this old technology to create a technological platform that facilitates whole new areas of possibilities including discriminatory intrarow weeding and heat-treatment to kill the intrarow weed seedbank. The combination of these techniques now means that complete non-chemical control of all weeds originating from seeds (therophytes [17]) in all annual / biennial crops is now possible.

2. Introduction

2.1. What is ecological agriculture?

Ecological agriculture is an emerging term that describes farming systems that are based on the premise that agriculture is part and parcel of the biosphere's natural systems / ecosystems and that therefore agriculture has to work with, not against, those systems if it is to be successful and sustainable in the long term. Ecological agricultures is also system-based / holistic rather than reductionist and linear. There are a wide range of agricultures that fall under the broad remit of ecological ag: organic agriculture is the most widely known and established, particularly in the market-place; systems such as permaculture [10] are at the 'hard-core' end of the ecological spectrum while precision ag and no-till ag have aspects that are ecological in their approaches, e.g., aiming to maximise soil health / quality in no-till.

2.2. Why does ecological ag matter?

Mainstream agriculture (also called industrial agriculture) has achieved a significant amount, particularly yield increases, over the last seventy odd years that it has been in widespread existence [1]. However, the evidence of the deleterious side-effects of some mainstream agricultural practices is becoming increasingly clear, for example, dependence on fossil fuels, especially indirect use such as nitrogen fertiliser [14] and pesticides [2], climate change [4], nitrogen pollution [15, 16] and biodiversity loss [13]. Ecological agriculture, and the techniques it employs, aim to maintain productive and profitable farming while simultaneously addressing / avoiding such problems to make agriculture both environmentally and economically sustainable e.g., see www.agassessment.org [9]. One perspective with which to view this concept is integrated management.

2.2.1. Integrated management

Integrated management approaches use a range, rather than just one tool, to manage agricultrual systems and problems. IPM (integrated (insect) pest management) is a well known such approach, it uses a range of techniques, e.g., monitoring of insect numbers, along with biological and chemical tools to manage insect pest populations within economic thresholds. There are a range of other IM systems, e.g., integrated weed management, integrated disease management, etc. IM is comprised of four 'sub-divisions' based on the four main sciences of the natural world: physics, chemistry, biology and ecology Figure 1.

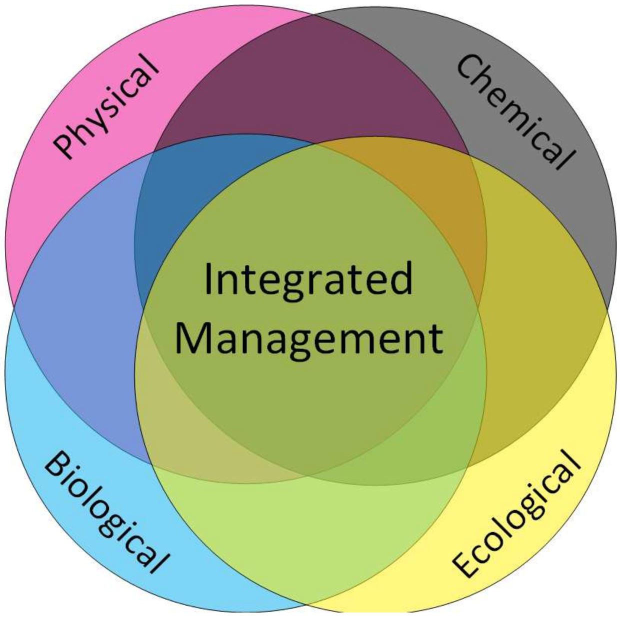

Figure 1. The four 'fundamental' sciences that when used together create integrated management in agricultural systems.

For example chemical management mostly involves the agri-chemical pesticides (pesticides in the broad meaning such as insecticides, herbicides, fungicides etc.). Physical techniques include mechanical hoeing, and thermal such as flame weeding and ecological techniques those work at the level of the whole-farm system, e.g., rotations and are also called 'cultural management'.

For most of the 20th century, pest management in mainstream farming was dominated by chemical management techniques. In ecological farming systems, especially organics, xenobiotic chemicals are prohibited so they have mostly relied on physical, biological and ecological management techniques. Such techniques (e.g., interrow hoeing) have often been referred to as being an 'organic technique' e.g., organic weed management. However, this is a misnomer as such techniques are not the sole preserve of organic or any other agriculture, they are simply physical, chemical, biological and/or ecological techniques that can be used by any agricultural system that considers them appropriate.

2.3. The blurring of eco and mainstream ag

At the end of the 20th and start of this century there has been an increasing blurring of ecological and mainstream ag. Techniques, such as mechanical weeding, that were once the sole preserve of eco ag's such as organics, are increasingly being used by mainstream agriculture. This is due to multiple reasons, but two key points are that non-chemical (i.e., physical, biological and ecological) techniques are increasingly (1) more effective and/or cheaper and (2) chemical options are declining. The latter is due to: increasing evolved resistance of pests to agri-chemicals; increasing legislative restrictions on their use e.g., [2]; and that the peak of pesticide discovery was in the 1980s with new discoveries continuing to decline, of the new discoveries ever smaller numbers make it to market, as they have to be both effective and safe, which is often mutually exclusive, plus they need to turn a profit. These trends are set to accelerate for the foreseeable future [3, 5, 8, 11, 12]. Therefore, all forms of agriculture will become more reliant on physical biological and ecological techniques and less dependent on chemical techniques in future.

3. Precision Ag for Eco Ag

Mainstream precision ag is mostly focused on targeted and variable rate fertiliser and pesticide application based on measuring actual soil and crop variations, often in real-time. In comparison, in eco ag and especially organic ag, precision is mostly about repeatedly very high accuracy, machinery /

implement placement. This is due to multiple reasons but the primary one is that, particularly in organic ag, xenobiotic pesticides are banned, as are synthetic / mineral nitrogen fertilisers, so there is limited use for variable rate fertiliser and pesticide application techniques. Also, in eco ag disease and invertebrate pests are mostly managed using biological and ecological management techniques which don't have a need for precision application. However, the management of weeds, the third main pest class, and the one that is most problematic in non-chemical ag systems, is well suited to precision techniques.

3.1. Precision ag for physical weed management

To assuage any beliefs that non-chemical weed management inevitably means weedy crops Figure 2 shows examples of what non-chemical weed management can achieve.

Figure 2. Examples of weed management in organic crops: direct drilled leaf beet / chard (left two photos) which has received no post-crop emergence weeding (circles show locations of remaining weeds); processing carrots (right two photos) just after crop emergence, with some couch / twitch grass (*Elytrigia repens*) and the same crop, after interrow hoeing (no hand-weeding) with only the occasional uncontrolled fathen (*Chenopodium album*) in the crop row.

Figure 3. False seedbed tiller, capable of 100% kill of small weed seedlings (e.g., less than six true leaves) across the whole cropping soil surface while consistently penetrating only approx. one centimetre deep.

These photos also make it clear than in-crop weeding techniques, e.g., interrow hoeing, are only, and can only be, responsible for a small part of weed management in non-chemical systems. Key to effective weed management are rotations, crop competition, pasture species / mixtures and grazing / topping management, pre-planting tillage and thermal weeding for direct sown crops.

Of the pre-planting tillage techniques the 'false seedbed' is a vital tool. Figure 3 shows an example of a precision machine in the form of a false seedbed tiller that achieves 100% kill of small weeds while consistently tilling approx. one centimetre deep, to minimise the amount of further weeds stimulated to germinate due to tillage disturbance.

3.2. Interrow hoes

Interrow hoes were the dominant form of mechanical weed control prior to the herbicide era. Many of these machine designs had been exceptionally well honed over many years and are highly effective. However, their work rates were low as they were manually steered and they were typically only tractor width wide Figure 4.

Contemporary interrow hoes are as different from their predecessors as pretty much any other piece of current agricultural equipment, e.g., a plough or sprayer, is from their forebears in the 1930s Figure 4. While the size of hoes has increased dramatically, it is not just machine width that is critical for effective hoeing. The crop-gap, i.e., the space between the hoe blades running either side of the crop row, is even more important, as it is the weeds closest to the crop plants that exert the largest competitive effect, so it is these that are most important to kill.

Figure 4. Pre-herbicide era Nicholson Webb interrow hoe (left) contemporary, multi-section folding interrow hoe (right and lower). Right and lower image © copyright Garford Farm Machinery Ltd 2010.

3.2.1. Maximising the hoed area.

To illustrate the effect of different crop gaps consider this simple example. Assume an interrow spacing of 30 cm, which is typical of hoed cereals and many hoed vegetable crops. On a manually steered interrow hoe, a typical crop gap would be 10 cm / ~4” (unless the operator was highly skilled or work rates low when 7 cm / ~3” can be achieved). This means that 67% (one third) of the field surface would be hoed. In comparison, a 3 cm / ~1” crop gap, which is considered the minimum that is practically possible for a large interrow hoe travelling at speed, will hoe 90% of the field surface. That is a 34% increase over the 10 cm gap and straightforwardly equates to 34% less weeds, all of which are close to crop weeds which means that the reduction in weed competition will much much greater than 34%. However manually steering a hoe with such a small crop gap, at speed, and manually steering such large machines is impossible. Clearly machines have to take over all these tasks. However, designing a machine to follow a crop row over a wide range of crops and weeds, and different crop and weed sizes and populations, and varying soils and illumination, is exceptionally difficult.

3.3. Computer guidance / steering systems

There are two approaches to mechanically steering / guiding interrow hoes: RTK GPS and computer vision. GPS systems use a ‘double-steer’ approach, where there are GPS antennas on both tractor and implement and tractor and implement are independently steered. Computer vision systems use a digital cameral connected to a computer running proprietary software running extraordinarily smart algorithms to differentiate crop rows from weeds and soil, and then use that information to steer the hoe via standard mechanical systems.

To date the only GPS double steer systems are made by Trimble® AgGPS® TrueTracker™ www.trimble.com, SBG Innovatie www.sbg.nl.and AutoFarm’s AFTracker www.gpsfarm.com. Trimble’s TrueTracker and AutoFarm’s AFTracker are designed to minimise crabbing of larger implements being used on slopes, while SBG’s machine is designed to maximise in-field accuracy, rather than interrow hoeing *per se*. However, all machines can be used for interrow hoeing, in some cases after modification.

The vision guidance systems are made by (in chronological order) ECO-DAN A/S (who were purchased in 2006 by CLAAS AGROCOM and has been re-branded as Eye-Drive and are now focused on tractor rather than hoe guidance), Garford Farm Machinery Ltd www.garford.com, and Frank Poulsen Engineering ApS. www.visionweeding.com. The difficulty of achieving effective and reliable computer vision identification of crop rows among weeds, with many different crops and weeds of different sizes and populations against a multitude of different soil backgrounds and vastly variable illumination should not be underestimated: it is among the most difficult computer vision tasks there is and this is reflected in the development time these systems have taken and that only three companies have produced farm-ready systems, despite many people trying.

3.3.1. GPS vs vision

The blindingly obvious (deliberate pun!) difference between vision and GPS is one can see while the other is blind. Ironically, being able to see and being blind are both advantageous and disadvantageous.

Vision systems need something to see to be able to work. Seeing the crop is hard, as noted above, and is not always possible, sometimes, to frequently not possible, e.g., the crop has not emerged, it’s too small, too tall, the wrong colour (red, mottled), its fallen over in the wind, rain, the tractor casts a shadow, etc. However, when vision system work they can deal with real-world variation because they see the actual crop not an ‘imaginary’ line. GPS is blind. It keeps on working to its ‘invisible’ GPS line and keeps working to its ideal line, regardless of the crop and weeds and what they do or don’t look like. That is perfect if everything is on the GPS line, it’s bad if things vary from the ideal line, e.g., due to not enough satellites, there are trees in the way, the crop was not put in correctly, e.g., the drill moved from the GPS line, etc.

My perspective is that in the medium term, GPS has the edge for row ‘following’ because it is blind so it is not disabled by real world variation, with the caveat that it requires current technology that is sufficiently reliable e.g., using both US and Russian satellites. Vision systems have the edge for adaptive intrarow weeding, as it accommodates real-world variation and can therefore get really close to the crop.

3.3.2. A new paradigm

The term 'a new paradigm' is often overused, however, I consider it a fair description of what computer guidance systems have achieved for interrow hoeing. Previously, manually guided interrow hoeing required continual and high operation concentration, which is very hard work, it is slow, with varying accuracy depending on operator skill and fatigue, plus it often required specialist tool-carrier tractors or extra staff for steering. When all goes well, computer guidance is as simple a field operation as any other in-crop tractor operation, there is no need for specialist tool-carriers, steering operator fatigue is eliminated, as are extra operators, and speed, accuracy, consistency and machine width dramatically increase.

Figure 5. Intrarow finger-weeders on Eco-Dan computer guidance system.

However, it is not only that computer guidance has turned a dog of a job, little changed from the 1930s, into a technique that is a match for the best of current tractor operations, e.g., spraying, it has also created a completely new platform that greatly facilitates existing approaches making them much more effective, e.g., intrarow finger weeders, Figure 5. More importantly they have been the essential stepping stone to high-tech discriminatory intrarow weeders. Non-discriminatory weeders are those that apply their weeding action to both crop and plant alike and rely on the crop having greater resistance to the weeding action so they survive (e.g., the finger weeders in Figure 5), discriminatory weeders actively differentiate between crop and weed and apply the weeding action only to the weeds, as the weeding action, e.g., a knife blade, is equally lethal to crop and weed alike.

I believe that the discriminatory approach can only be fully achieved by computer vision systems. While GPS can get part of the way e.g., [6, 7] it can't deal with real-world variation, e.g., missing plants, which is critical for optimum success.

Figure 6. Two discriminatory intrarow weeders, Garford (left) using rotating hoes, Frank Poulsen (center and right) using micro-flames. Center and right photos © copyright Frank Poulsen Engineering ApS.

3.3.3. Computer vision based discriminatory intrarow weeders

There are two discriminatory weeds on the market from Garford and Frank Poulsen, the former uses rotating cut-out-disk hoes while the latter uses banks of rapid switching micro flames Figure 6.

To fully appreciated what these machines are capable they need to be seen in action, video is available from the manufacturers websites (listed above). Both machines detect individual crop plants, mostly larger transplants by the Garford and seedlings by the Poulsen, which was designed to thin and weed sugar beet seed crops. Working speeds are up to approx. 4 kph for the Garford and about 6 kph for the Poulsen, though these vary depending on conditions. Simple estimates indicate that these machines would have a work rate equivalent to at least twenty people using hand hoes, plus they don't get bored or fatigued, need a 'smoko', etc.

These machines may well be the first finalists in the physical weeding endgame, in that they are capable of physically weeding the whole field surface within a crop, which only a few years ago could only be practically achieved by humans. Both however, fail at the final hurdle, the 'next-to-crop weeds', i.e., the ones growing right next to the crop and which have the largest competitive effect. This barrier has now been breached.

3.4. Intrarow soil steaming

Intrarow soil steaming is a technique developed in Denmark and Sweden whereby only the soil in the crop row (intrarow) is steamed to a depth of 5 to 7 cm which is the maximum from which most annual weed seeds can emerge Figure 7. This can be viewed as a precision technique itself, i.e., rather than steaming the whole field to depth, only the critical areas of the field are treated.

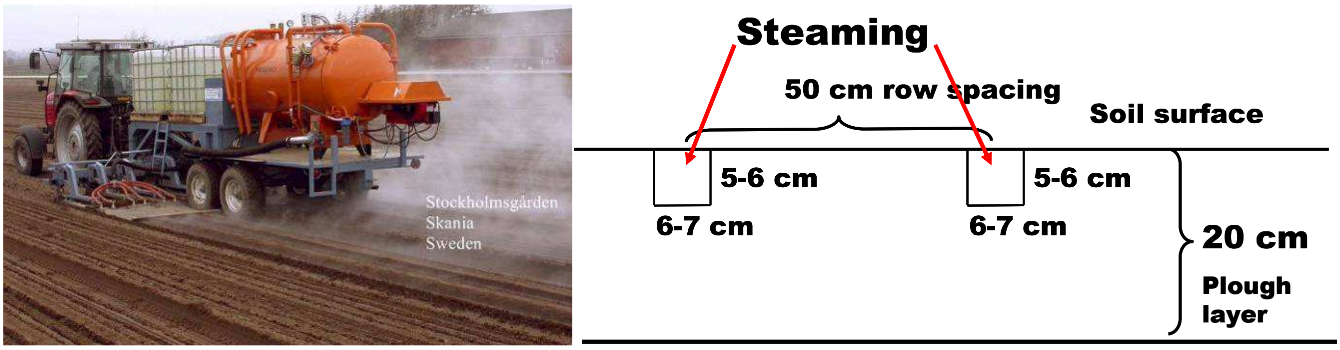

Figure 7. Intrarow soil steaming © copyright 2009 Bo Melander.

The steaming kills the entire weed seed bank (weed seeds in the soil) to the maximum depth of emergence (approx. 5-7 cm), which mean that no weeds will emerge into the crop row. As the weed seed bank has been eliminated no weeds will emerge from the steamed soil until new viable seeds are introduced, e.g., from weed seed rain or seed infested soil.

Combining intrarow soil steaming with interrow hoes is the end-game of non-chemical weed management in that it can control all weeds that emerge from seeds (therophytes [17]) in all row crops. In comparison selective herbicides can only control some weeds in some crops. At present the steaming technologies is still bleeding-edge, not widely available and only suitable for very high value crops. But, using computer guidance systems to minimise the width of heated soil and dramatically improving the efficiency of the heating process and therefore reducing energy consumption by equally large amounts and doing the same for work rates would make it viable for a wide range of vegetable and other high value crops. Unlike pesticides that are at risk of evolved resistance and legislative prohibition there is no obvious way weeds can evolve resistance to physical techniques such as hoes and heat and as the techniques are unlikely to have the same negative effects as pesticides legislative restrictions are also considered unlikely. This means these techniques should remain effective for the foreseeable future.

Figure 8. Effect of intrarow soil steaming, sugar beet emerging into weed-free strip among high weed populations (left) and long term effect of treatment (right). Images © Copyright 2009, Bo Melander (left) Hans Kjærås (center and right).

4. Conclusions

The technologies now available for ecological and non-chemical farming systems are now considerable. Many of these technologies rely on repeatable, very high precision, machine and tool placement, including adapting to real-world crop variability that was impossible only a decade ago. These have transformed techniques, such as interrow hoeing, from technologies that were so difficult to implement that only those with no alternatives would consider using them, into everyday tasks that are increasingly competitive with chemical management approaches and therefore offer a realistic and economic alternative. These solutions to existing problems have even more importantly created new platforms and development paths for entirely new types of machines, such as discriminatory intrarow weeders that can perform tasks that were simply impossible a few years ago.

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