Assessment of land use systems in the Swiss Plateau

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Preface

After finishing all the lectures and semester theses the finding of a topic for the diploma thesis, a topic which would accompany me for the best part of a year, proofed to be a great challenge. After all the years of studying something had not changed for me: the attraction for my subject was still in its diversity. There were many aspects and topics that could catch my interest. Therefore I found it extremely difficult to focus and decide on just one. So it might not be surprising that this here is the second thesis I started – but the first I also finished. In the process of starting the first thesis I found that mainly theoretical work accompanied by very technical laboratory analysis was frustrating for me. I more and more felt that I was missing the chance to go out there, to do practical work and gain field experience. So I took courage and went for the adventure. I dropped the more secure option for the more creative and for me certainly more exciting way. I have to admit that I had to take the decision for this second topic under pressure. I was running out of time if I wanted to finish the work in due course. Therefore the choice was a bit random too. Nevertheless I knew that it would involve a lot of fieldwork and a creative process of adapting and testing a mapping instrument. I was happy with that. With new motivation and spring I started the work and I never regretted my change of heart. Of course the process of conceptualising this thesis, of planning and carrying out the field work, of finding ways of digitalising and evaluating the collected data was not always easy. At some points the initial enthusiasm seemed to be nothing but a very distant memory. My most cordial and genuine thanks go to all the people who supported me in the when I lost courage and helped me regain the focus when I was confused.

Firstly I would like to thank Professor Hans Hurni, the leader of the thesis. With his great experience in the field of soil and water conservation he repeatedly gave me inputs and guidance that really made a difference. Him and Dr. Hanspeter Liniger, the co-leader of this thesis, I would further like to thank for their flexibility and spontaneity which for me made the cooperation pleasant and the integration of their knowledge and advice effective. Hanspeter Liniger was my teacher for fieldwork. His continued advice and encouragement kept me going. For very practical advice and support, especially in the beginning of the study, I am thanking Thomas Ledermann who, with his PhD thesis, paved the way for this thesis.

Further my thanks go to Urs Grob who is currently writing his master thesis on a very similar topic. The exchange of thoughts with him was valuable for solving many problems that turned up, work with him was enriching to the thesis, and the fieldtrips undertaken together were a lot of fun. Also during the fieldwork Othmar Gassmann, mayor of Murist and farmer, was a profound source of local and practical knowledge

as well as an extraordinarily welcoming host. My sincere thanks go to him for his ready support.

I am thankful for all the support from my friends and companions who also wrote their theses in the last year. Especially I would like to thank Sylvia Lörcher for her hands-on help and generous advice with the many practical problems that turned up, Lorenz Ruth for his GIS support, and Franziska Grossenbacher for all the challenges we tackled together. No less I would like to thank them and many others for all the coffee-, lunch-, and other breaks and distractions without which the writing of this thesis would have been a sad and lonely task. Thank you for the memorable hours in the small student's office at the CDE. With gratefulness I am thanking the people who offered to co-read my work. The effort they put in is not self evident and extremely valuable to me.

Last but not least my thanks go to my family and friends. Their constant support and encouragement enabled me to choose and go my way. Especially for the patience, advice and many a good meal in this last eventful year made me confident for whatever the future brings.

Judith Gasser, January 2009

Summary

This thesis is an assessment of land use systems in the Swiss Plateau. Ideologically and methodically this assessment is based on two international initiatives: WOCAT and LADA. WOCAT is a global network of soil and water conservation specialists that was founded in 1992 with the aim of enabling the dissemination of knowledge about sustainable land management to improve livelihoods and the environment. LADA is a project of different subdivisions of the United Nations. The goal of the project is it to develop and test an assessment methodology to assess land degradation to identify status and trends of land degradation in order to plan ways to promote the adoption of sustainable land management practices.

The approaches of the two projects are complementary but with the same final mission. Following this insight a mapping tool was developed based on the methods of both projects in order to make use of the apparent synergies. This tool is called “Questionnaire for Mapping Land Degradation and Sustainable Land Management” and it is the methodological basis of this thesis. The aim of this questionnaire is it to assess the state of the cultivated land by categorising different land use systems with respect to theirs impact on the land. Not only degradation but also conservation efforts should be mapped and described in order to find ways to mitigate the negative effects of agricultural use. The tool was designed for a small scale approach with the aim of making statements on a national or regional level.

In this thesis the tool was adapted for the Swiss Plateau and for a very large scale. The mapping took place on the communal level and was based on plots of homogenous land use. The WOCAT/LADA questionnaire provides a long list of possible indicators to map the state of the land. Out of these indicators a selection was made according to the local circumstances. In the process of adaption the list of indicators was altered and refined following the experiences made. The result is a mapping tool consisting of a field protocol which is a two-sided sheet of paper with the list of indicators that were mapped on each plot. Accompanying this process is a methodological catalogue, which was developed in a parallel way, giving instructions and explanations to guide the mapping. The indicators on the field protocol were grouped thematically. First there are indicators giving general information like the type of crop and land management or the density of ground cover. Second there is a block of indicators describing current potential and actual degradation, featuring indicators describing the soil surface (sealing and crusting), the soil structure (porosity and bearing capacity) or the soil life (amount of earthworms). The third group is giving evidence about the causes for the detected degradation. Possible causes might be the use of heavy machinery or the management practice (e.g. tillage). The last group of indicators is then describing conservation efforts like crop rotation or the use of a soil conserving management practice (e.g. direct seeding).

This mapping was carried out three times within the growing season – once each in spring, summer, and autumn. This intensive fieldwork resulted in a substantiated appraisal of the advantages and disadvantages of each mapping season. Further the different land use systems could be defined in the field. “Land use systems” are defined here as a combination of the mapped land use (e.g. annual cropping or grassland) and the land management (e.g. direct seeding or conventional tillage).

The methods used here were based on pure field work; there were no analyses in the laboratory, no interviews with farmers or other soil and water specialists. The goal was to assess what is visible in the field with rough methods but with very intensive field work. The mapping tool was created so it could be adapted to whatever local conditions while still ensuring the comparability and reproducibility between mappers and regions. The adaption of the method to the small scale in the Swiss Plateau proofed to be a creative and successful process. Ensuring of the transparency and traceability of the results was expectedly more difficult. This point was thus treated with much care and effort.

The achieved distinction of the land use systems in this thesis is based on the sheer quantity of indicators. A differentiation of the kinds of indicators was not possible because the same indicators occurred on the plots with few indicators as on the ones with many. It would need further research including experts and / or analysis in the laboratory to make a qualitative classification of the indicators. The most obvious results found with the method used here are on the one hand the differences between plots with a tillage system where the soil is upturned and those with no soil disturbance and on the other hand between plots where grass is grown and such where other crops are cultivated. There are of course also differences within the other crops or land managements but they are less stringent than the ones mentioned above.

The mapping results in the conclusion that the different land use systems leave characteristic imprints on the land or in other words that assessing land use systems to make statements about the state of the land is sensible and the potential to integrate the information to the smaller scale is given. The outcome of the adaption of the WOCAT/LADA questionnaire is an appraisal of the different land use systems in the Swiss plateau and a sound basis for further research on the topic.

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Part I

Introduction

1 Introduction

1.1 Problem and motivation

Agricultural land use has shaped the landscape since living memory. If the equilibrium of exchange between the land and the agricultural use of it is disrupted, the natural functioning of the system is under threat. We then speak of degradation. The system that is firstly and most acutely affected by degradation due to agriculture is the soil. Soils are very complex systems, providing habitat for many species and the basis for food production in agriculture. Fertile soils take hundreds of years to form but they can be seriously degraded within very short time. To recover from the damage takes a lot of time, is often costly and laborious and frequently requires a change in agricultural practice (BAFU 2007). When speaking of soil degradation we mainly think of soil erosion. It is the most frequent and most obvious form of soil degradation. In Switzerland soil erosion has increased significantly in the last 50 years. This has induced a number of laws and regulations with the aim of controlling the damage and promoting soil conservation practices (Ledermann, Herweg et al. 2008a). The degradation of soil causes degradation processes in other systems. During an erosive rainfall event, a lot of soil material that is washed out and lost for the agricultural use, may be swept into a water body, either directly or indirectly through the sewage system. This causes physical damage by clogging up the drainage pipes and chemical degradation of the water quality by excess addition of washed out nutrients and fertilizers.

This thesis is not only focusing on degradation but it is also looking into measures and practices of conservation. It is thus following the conviction that knowledge about the reactions of the land users to threats of degradation is equally important to scientifically justify policies to prevent, mitigate or rehabilitate damage through agricultural practices. While this includes knowledge about what is socially and economically implementable as well as information about what has the best desirable impacts on the land, this thesis concentrates on documenting the latter, methodologically following the WOCAT/LADA procedure, which will be explained later on. By doing so, this thesis classes as part of a greater project. The Centre for Development and Environment (CDE) of the University of Bern is contributing to the WOCAT/LADA project aiming at classifying land use systems as to how they are affecting the used land. This is taking into account impacts of land use leading to degradation as well as conservation practices. A second thesis is currently carried out at the CDE by Urs Grob with very similar objectives. The exchange between students and supervisors working on the project is therefore bound to be close and important for the success of the work.

1.2 Personal motivation

The motivation for this work is the conviction that a sustainable agriculture is extremely important, facing the coming global challenges of a growing population, a threatened environment and a rapidly changing climate. The temperate zone will most probably in the next decades not be affected by droughts and desertification. But the issues of soil and water degradation and conservation cannot be underestimated. There is not a country in the world that is not affected by some aspect of the topic. In some regions they are still more of scientific interest, hopefully with the aim of preventing the worst. In other world regions soil and water degradation is causing life threatening conditions for millions of people. Critical life conditions of large proportions of the world’s population are of great concern also of the people not primarily affected. There will be enhanced migration, affecting countries that are not directly affected by poverty due to a changing environment. There is a humanitarian obligation in taking on responsibility for the consequences of economical injustice and ecological damage (Gisladottir and Stocking 2005).

Even if changes and threats are not as dramatic here as in other regions of the world, soil and water degradation has impacts on the ecosystem, on- and off-site. As mentioned above, soil erosion has been increasing steadily over the last decades and the agricultural sector is very vulnerable to changes in policies, economics or on a different level, the climate. Knowledge about impacts of land use on the ecosystem is therefore crucial. These impacts can be described and finally assessed with help of the WOCAT/LADA mapping tool. The tool was developed for mapping degradation and conservation and their impact on ecosystem services on a national or regional level. It is currently tested in six pilot countries on all continents. The adaptation of this tool to the Swiss setting is a creative and tempting challenge. Soil and water degradation can have impacts on a large spatial scale. They are triggered, however, by decisions made on plot-level.

1.3 Setting

Comprehensive information about how different land use systems affect the environment, including not only degradation but also conservation, is missing. It is a principal motivation for this thesis to contribute closing this gap. Concretely the area covered by the thesis is spatially limited to a single commune. As its topic is of global relevance it is important all the same to put it in the context of the large-scale problem of soil and water degradation. To describe the setting of this thesis first the global problem of soil and water degradation and the manner of awareness development in the last two decades is described briefly. The latter caused the international initiatives, The “World Overview of Conservation Approaches and Technologies” (WOCAT) and the “Land Degradation Assessment in Drylands”

(LADA), to be formed, giving concrete suggestions as how to tackle the challenge of land conservation. These two initiatives give the methodological and ideological setting of this thesis. In a second part the natural, geographical setting is described.

1.3.1 Background and global perspective

Globally land degradation seems to be a problem of poorer countries, especially of the south, where land degradation can lead to life threatening situations in short timescales. LADA was particularly designed to fight desertification; already the name suggests that it is regionally exclusive for drylands. For this thesis it is thus essential to emphasize that soil and water degradation is not associated with a certain type or system of agriculture or with a certain climate zone.

In poorer regions agriculture is often on a small scale level, dominated by production for self-sufficiency or small, local markets. In developed countries, agriculture is strongly industrialized and aimed at production for a large population. Soil and water degradation however is not associated with either system of agriculture but the causes and impacts are very different. This is a significant point when analyzing the state of the agriculturally used land and especially when designing strategies for sustainable management of natural resources (Hurni, Herweg et al. 2007).

Self-sufficiency of primary food production is comparably small in European or North American countries, overpopulation or famine is improbable. This is due mainly to economical structures, saying the economical predominance of the developed countries. For one, the proportion of wages spent on food is small in these countries, making people far less vulnerable to rising prices. The other important issue is, as mentioned above, that agriculture in the temperate zone is not affecting the ecosystem in such an acute way, as in tropical or subtropical areas. Water is still abundant and soils are comparably fertile and robust towards overexploitation and unsuitable management practices. But also in the temperate zone and in countries with a functioning, growing third sector economy, sustainable land management is an important concern – at least in the long run. The effects may not be as drastic in the short term but degradation is still affecting production, the environment and livelihoods. There are important impacts of land degradation in our region. There are impacts of top soil erosion, causing on- and off-site damage. Off-site damage often affects water quality, which is also negatively affected by other agricultural practices, namely the input of fertilisers or herbicides and pesticides, which themselves are used to compensate the negative effects of topsoil loss, evoking a vicious circle.

Because processes of degradation are much slower here than in other environments, it seems less worthwhile taking measures against it. Also farmers have more possibilities to compensate the effects of top soil loss: they can counteract fertility decline with growing input of fertilizers. In highly subsidized agriculture the income effect of these measures is often too small to change the farmer's behaviour (Kilpatrick 2003). This implies however that agriculture is still a vulnerable sector. Firstly and probably most importantly, it is exposed to the political mainstream. If subsidies are shortened or distributed following a changing incentive system, the structure of the agricultural sector will coercively change. Also rising diesel prices change the behaviour of farmers and further the unpredictable developments on the international commodity and stock markets are very important, as we have truly seen this last year. Changes in management practices in the agricultural sector have an implicit influence on the ecosystem. This makes sound knowledge about responses of the ecosystem to changing land use crucial.

The first time soil degradation was globally and systematically addressed was in the late 1980s. The GLASOD (Global Assessment of Soil Degradation) produced a map of soil degradation worldwide by integrating existing expert knowledge, i.e. without field mapping. Even so, it was an important document for the establishment of the UN Convention to Combat Desertification, UNCCD, at the Rio Conference in 1992. This event in particular was a turning point to raise awareness towards ecological problems in general and therein the issues of soil and water degradation.

1.3.2 WOCAT/LADA

In this context, the World Overview of Conservation Approaches and Technologies, WOCAT was initiated, also in 1992. This is a network set up to show ways of soil and water conservation (SWC). It was recognized, that efforts and knowledge of soil and water conservation technologies are often hidden, because there is no systematic documentation and dissemination of knowledge. WOCAT designed tools to make such documentation of technologies possible while always also linking them to the approaches that led to their establishment. It is a comprehensive methodology, considering many aspects of SWC. In 2007 WOCAT published a book, called “where the land is greener” (Liniger and Critchley 2007), giving an overview of the project, summarizing experiences, analyzing practices and pointing out further challenges:

- Knowledge management is of high priority, to make scattered knowledge widely available, enabling the people who work the land to make informed choices. A respectable amount of work has been done there but there is still a lot to do.
- The implemented practices need to be monitored and evaluated. It is important to gather knowledge about the impacts of a technology, also in the long term. Mapping of conservation coverage is crucial for further planning.

- As prevention and mitigation of degradation in most cases is less time and money consuming than rehabilitation, the focus should be on these technologies – even if the effects are often not spectacular, they may be even more effective.
- This is especially the case in humid areas. Here the problem is that soil fertility decline happens comparably slow and impacts of degradation and conservation may not be so perceptible. This point makes the implementation of SWC technologies difficult. Therefore long time investments are needed to minimize on- and off-site impacts of soil erosion.

In the late 1990s, the international community recognized on the one hand, that just knowing about the causes and types of degradation is not enough and on the other hand that there are new developments in research and monitoring of land degradation. The Global Environmental Facility, GEF, gave land degradation and sustainable land management highest priority on its agenda. Together with the Food and Agriculture Organization of the United Nations, FAO, the United Nations Environment Program, UNEP and the UNCCD, it set up the Land Degradation Assessment in Drylands, LADA. The purpose of LADA is to develop an integrative assessment for land degradation by data and information collection and networking (GEF 2001).

1.3.3 Cost 634

Cost stands for “European Cooperation in the field of Scientific and Technical Research”. Cost projects aim at enhancing the cooperation between researchers in Europe. These projects are called and numbered as “actions” and in the Cost action 634 the CDE is involved amongst many other institutions. Cost 634 is called “On- and Off-site Environmental Impacts of Runoff and Erosion”. The action is based on the insight that erosion and runoff are major environmental threats related to agricultural land use in Europe. The main consequences of erosion and runoff are not only on-site, like declining soil fertility or limited infiltration capacity, but also off-site, like related water pollution or siltation of sewage systems. In north and central Europe, erosion is mainly due to farming practices and land management. It seems obvious that implementation of soil conservation measures must thus happen at this level but there are large gaps between existing knowledge on processes of runoff and erosion on the one hand, and its application to soil protection at different scales from farm to catchment on the other hand. Thus the main objective of the Cost action 634 is the development of an integrated understanding of on- and off-site impacts of soil erosion at the catchment scale. It further emphasis how important the aspect of implementation of conservation measures is. It is so addressing different levels (scientific, political, administrative and management) involved in land use so that soil protection can be accepted by all stakeholders. As soil erosion in Europe is implicitly related to agricultural land use, it is very important to keep in mind that while soil erosion is often effective at catchment scale, the actual soil erosion risk is determined by decisions on management practices taken at farm and even plot scale (COST 2004).

Since 2005 two PhD theses are running within the Cost action 634 at the CDE that are about to be completed (Ledermann and Schneider in progress). Several Diploma theses have been carried out within that time, on related subjects (e.g. comparison of soil properties in relation to the soil management by Christine Hauert 2007 or modelling of potential soil erosion by Mike Chisholm 2008). This thesis here is not set within the project. But its subject is closely related in some aspects. Further the personal contact with the PhD and MSc students and with CDE staff which is very important during a thesis is closely related to the Cost action 634. Last but certainly not least, the selection of the investigated commune is based on research carried out for the Cost project. This thesis will map land use and related indicators in the commune of Murist in the canton of Fribourg. This commune has been subject to mapping and research within the Cost action 634, resulting in a broad basis of information and an established network with local farmers and students and staff at the CDE who are familiar with the local circumstances. These were very helpful resources for carrying out this diploma thesis.

1.3.4 Area

Murist is part of an exclave of the canton of Fribourg within the canton of Vaud. It lies in the hinterland of Lake Neuchâtel, close to Estavayer-le-Lac. The medium altitude of the commune is at 662 masl, going from 524 to 685 masl. It is situated on a ridge between two valleys on the molasse underground typical for the Swiss Plateau. The commune has a good 500 inhabitants and is 8.2 km^2 large. Of this area only about 6% is residential area, about 18% is forest and 76% is agricultural land. The population is slightly growing but an increasing number of people live in Murist but work elsewhere in the nearby small cities. There is a little bit of industry in Murist, mostly construction companies but most people working in the commune are framers (http://de.wikipedia.org/wiki/Murist 3.10.2008).

The map below (figure 1) shows an overview of the commune with the assessed plots in red. The map in the background gives an impression of the gentle hills on which the village is situated.

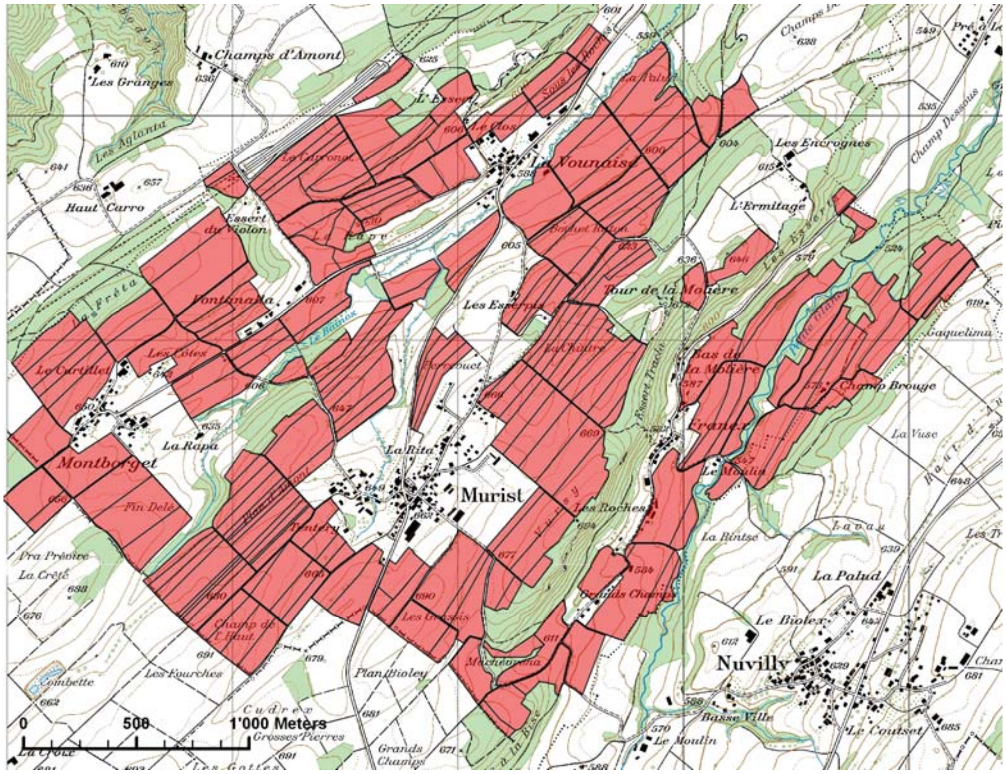


Figure 1. Map of the assessed area with the assessed agricultural land in red and the individual plots distinguished (source: swisstopo 2000).

Farming in Murist is intensive compared to other Swiss regions. There is a rather high percentage of root crops (potatoes and sugar beets) and maize while comparably little arable land is under temporary ley (Ledermann, Herweg et al. 2008a). About 50% of the plots are still under conventional tillage. The arable area under mapping covers a good 450 ha divided into about 220 plots, resulting in an average plot size of about 2 ha.

Economical structure

The Federal Office for Spatial Development, ARE, classifies the region in which Murist lies as agro-industrial, Murist itself as agro-tertiary. Typical for these regions is a growing portion of inhabitants commuting to the next larger centre. Agriculture is shrinking, less (but also) in area and more in number of farms, resulting in larger and more industrialised farms. In rural areas socio-economic indicators are reacting much slower to structural change in the economic system than urban agglomerations. But on the long term they show a downwards trend in most of the important indicators, i.e. population numbers grow significantly slower than in urban areas or are even shrinking, and the same is true for wages. In Switzerland these processes are not as striking as in other parts of Europe because of the federal political system which up until recently aimed at ensuring an even development for all regions in Switzerland. Even the most active political and financial support cannot impede structural change forever. Therefore the policy is now more towards equality than homogeneity. This accounts for the fact that rural areas are still very important in Switzerland. They are part of our national self-perception. They have crucial ecological functions and they are also economically important, balancing quick economical fluctuations. This might even be accentuated in the future making it important to conserve the value of the area and its economical structure. This does not mean to preserve everything exactly as it is now, at all cost (Schuler, Perlik et al. 2004). People living and working in the rural area are very aware of these developments. Because of the uncertainty of how policies will change in the near future, they are nervous, sometimes afraid. When talking to Ottmar Gassmann, farmer and mayor of Murist, he is giving a good insight into the structural changes and the subsequent worries and adaptation strategies of the farmers of his commune. He is emphasising that innovative and broad thinking farmers always have a good chance to make a living (Gassman 2008). While this is certainly true it also implicates that there will always be victims of structural and political change.

Agriculture in Murist is characterised by a specialisation on arable farming. Typical for Swiss agriculture is a well balanced crop rotation with a comparably large percentage of temporary leys. That means that within a crop rotation cycle there are often a couple of (consecutive) years of grass-clover meadows for fodder production or used as grazing land. In typical Swiss agriculture there are virtually no monocultures.

Climate and weather

Climate data was obtained from the nearest weather station which is situated in Payerne and more general information was taken from MeteoSwiss (MeteoSwiss http://www.meteoschweiz.admin.ch/web/de.html 3.1.2009). The average temperature of the 1961 to 1990 period was just under the freezing point in January and at 18 degrees Celsius in July and the average rain sum for this period was 846mm.

Most months in 2008 were warmer compared to the reference period. Especially the winter months were much warmer and drier. This warm period ended abruptly around Easter (25th of March) with a very late and heavy onset of winter. Spring weather was variable with a very warm and dry May and a very wet and colder June. In the end the weather in spring was about average. This is generally true for summer as well with the exception of September that was wetter and colder than average. Autumn in the Swiss plateau was very sunny due to extraordinarily few fog days. Especially November was very sunny and dry. This is important to remember because in November the last mapping for this thesis took place. Very heavy rainfalls were rather rare and occurred in August and September (thunderstorms). In April and December there were a couple of days with very high precipitation but that was in the form of snow.

Alltogether the year was a little warmer than average by about 1 degree Celsius. Also the average rain sum only made up about 80 percent of the normal values and on the Swiss Plateau it was more sunny than normal (MeteoSwiss http://www.meteoschweiz.admin.ch/web/de/klima/klima_heute/letzte_monate.reg3.stationPAY.html 3.1.2009).

Soils

Soils are the uppermost weathered layer of the earth's crust. They consist of mineral components, humus, air, water, and life organisms. To describe soils they are divided into horizons, the uppermost horizon is where there is humus and where organisms live and plants grow, below that there is a horizon of mineral material and below that there is the bedrock. There are many differentiations within that classification. For this thesis only the uppermost (A-) horizon is relevant. Soils have a regulating function of the natural cycles of air, water and organic and mineral substances. They are thus an important link in the ecosystem earth. In area and substance soils fulfil a lot of fundamental functions. They are the basis for food production, they are a source of energy and resources, we build our houses, cities and roads on soil and we deposit our waste in and on soil. To fulfil these functions a healthy water and air balance is important, plants need sufficient room for their roots, nutrients have to be balanced, and pollutants must not excess a certain value. It is therefore important to emphasise that soil is in this context to be regarded as a non-renewable resource. Even though soil formation is a constant process, the processes involved are extremely slow and the rates at which soils are degraded or destroyed very high. Soils are inert systems so that problems are often only detectable very late. A healthy soil has a clear structure and only an intact structure ensures the functioning of the soil (BAFU 2007).

The soil types in Murist are cambisols and luvisols with a sandy loamy texture (Ledermann, Herweg et al. 2008a). Cambisols (brown earths) have homogenously brownish or reddish subsoils because of oxidised iron and are frequently agriculturally used. Luvisols are depleted in clay with a clay rich horizon deeper down. They have a brownish colour and are also often used for agriculture (Mc Rae 1988).

2 Objective

This thesis is working with a mapping tool based on the WOCAT/LADA methodologies. Not only in methodology but also regarding general aims and ideas it is linked to the contents of the two projects. Therefore firstly the objectives of WOCAT and LADA will be briefly summarised and secondly a synthesis of these two approaches will be made. In a following step the objectives of this particular work will be concretised.

2.1 WOCAT

WOCAT is a global network of soil and water conservation specialists. One of this network's focuses is it to establish means to collect, document and share existing knowledge of SLM technologies. A second focus is the collection and description of approaches, as how to motivate the people who work the land to adopt these technologies and how to enhance the knowledge about possible SWC technologies. The overall goal is to improve livelihoods and the environment. WOCAT's intention is to connect stakeholders and to develop and apply standardized tools for the documentation, evaluation, and monitoring of soil and water conservation knowledge thus enabling exchange of the improved knowledge. By means of this documentation WOCAT's objective is to show that there are ways of maintaining the productive state of the land or to improve or even rehabilitate where there has been degradation. WOCAT's mean of attempting the realisation of its goals is to provide a prototype for standardised documentation (Liniger and Critchley 2007).

2.2 LADA

The Land Degradation Assessment in Drylands, LADA, was set up to obtain an "accurate assessment of land degradation at flexible scale combining socio-economic and biophysical aspects and driving forces […] to plan actions and investments to reverse land degradation" (GEF 2001). On the background of advances in information technology (remote sensing and GIS in particular), it is now possible to collect and integrate data about land resources and land use from different sources, i.e. ecological, social and economic. In these three "pillars" of sustainable development and management it aims at including recent and successful developments. Key concepts are, amongst others: integrated ecosystem approaches, participatory planning and management of resources and strategic impact assessment of policies and interventions. The main objectives of LADA are 1) to assess and quantify the nature, extent and severity of land degradation by describing the impact of inappropriate land use on the ecosystem. To achieve this it develops tools, strategies, and methods that are applicable at a range of spatial and temporal scales; and 2) to build an assessment network at different levels (national, regional and global) to exchange knowledge about degradation and to enable the planning and implementation of interventions to prevent, mitigate or rehabilitate land degradation by promoting sustainable land use and management practices in a sensible and efficient way (GEF 2001).

2.3 Synthesis

While WOCAT is focusing at the documentation of conservation technologies, LADA focuses on describing causes and effects of degradation. They have the same overall aim – to improve the state of the land and thereby improving livelihoods and the environment. The project's objectives are complementary. By combining the two approaches synergies occur. To make use of these synergies is what is attempted with the "Questionnaire for Mapping Land Degradation and Sustainable Land Management" (Liniger, van Lynden et al. 2008). Parts of this Questionnaire are essential in this thesis, some are adapted to the objective and possibilities of this work others can even be taken as they are. For a detailed description of this adaptation process see chapter four.

2.4 Objective, questions and hypothesis of this thesis

The supraordinate objectives of the international projects WOCAT and LADA are mirrored in the objective of this diploma thesis, at a much smaller scale but with a very high resolution. This implies the adaptation of the above mentioned questionnaire. The methodology is based on existing WOCAT/LADA tools, altering it where necessary.

The concrete objectives are:

- Adapting the WOCAT/LADA methodology to assess degradation and conservation effects of land use in the Swiss plateau. Adapting it to the ecological, economical and social circumstances of the region and breaking the methodology down to a very large scale level, i.e. the level of homogenous land use.
- Mapping land use and indicators describing the state of the ecosystem by using the adapted methodology. Enhance the methodology in the field, altering and adapting it to the experiences made.
- Displaying the collected data by using GIS and Excel. Evaluate if this enables an interpretation of the data by defining land use systems.
- Evaluating the procedure and giving an opinion about the applicability of the method.

To guide the work, questions and hypotheses have been set up. They will not be tested empirically because this would not make sense for the objective of this thesis. The result will rather be a general appraisal as if different land use systems leave characteristic traces that can be identified by experts, different stakeholders, and interested laypersons.

The working question of this thesis is how the different land use systems used in the investigated area affect the land.

The hypotheses are thus:

- Different land use systems mark the land in a particular way.
- There are indicators to describe the state of the land on plot level.
- Every land use system has its own particular set of qualities (described by the indicators), making it possible to integrate the information to the level of land use systems.

Part II

Methodology

3 Theory

This chapter starts with a rather abstract level to become more and more concrete and specific for this work. It starts with the comment and illustration of an important theoretical model, the DPSIR model. On this model the WOCAT/LADA methodologies are based and thereby also this work. In a next step the state of research relevant for this thesis is shown, again beginning with a wide focus. WOCAT and LADA methodologies will be addressed and in the end the state of research about the investigated area will be outlined.

3.1 The DPSIR Model

The DPSIR model is a useful theoretical concept to describe the chain of components of the interactions between the environment and human use. DPSIR stands for Drivers-Pressures-State-Impact-Responses. The model enables a straight forward and comprehensive description of environmental damage. It looks at ecological degradation as the result of a chain of causal links. At the end of this chain there is the impact on the ecosystem that is considered harmful and degrading. The recognition of this impact and the underlying chain of causes then results in response actions that can act on any or several components of the reaction chain.

Figure 2 illustrates the model. **Drivers** are needs. They are basic human necessities like the need for shelter, food and water. Secondary drivers might also be the need for culture, mobility, and education. These driving forces are the cause for human activities like for example food production and transport. These activities aim at meeting the individual needs, resulting in **pressures**. Pressures might manifest in the form of pollutants or overexploitation of resources. These pressures affect different qualities of the environmental compartments (soil, water, air etc.). The **state** of the environment changes depending on the different pressures. These changes in the physical, chemical or biological state of the environment may have ecological, economical or social **impacts** on the functioning of the environment. In the DPSIR model the society's reaction to undesired impact is called **response**. The response can affect any part of the chain between driving forces and impacts.

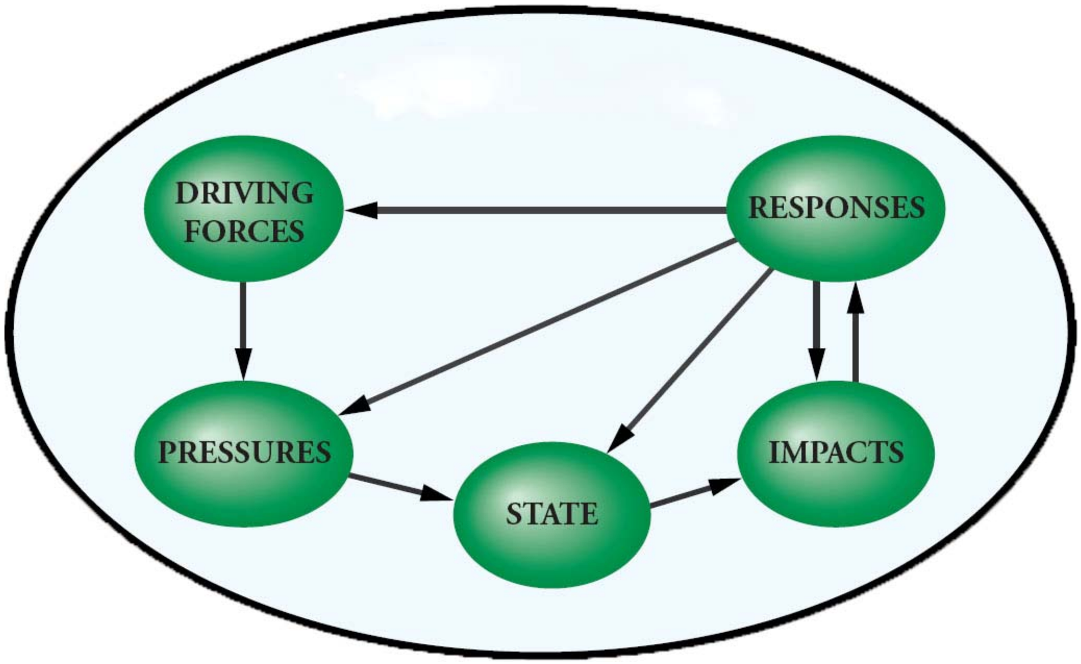


Figure 2. The DPSIR assessment framework with the links of the causal chain displayed. It is visible in the figure that responses can act on any of the chain’s links (LADA 2002).

Figure 2 makes the chain of causal links visible and shows that the responses can act on any of the components. What further makes the model useful is that it can be broken down into sub-tasks. Research can concentrate just on one aspect of the chain, e.g. only the relationship between drivers and pressures or state and impact can be looked into (Kristensen 2004). This is relevant for this thesis. Here mainly the state will be analysed. As defined above ‘state’ describes how different qualities of the environment are affected by pressures. To actually assess the state indicators that are visible in the field are necessary. The requirements these indicators have to meet are described in the next paragraph. The actual indicators that were mapped for the purpose of this thesis are explained in detail in chapter 4.

Pressures in the form of different land use systems are an important aspect of the thesis. This point is referred to in more detail further down. The impact further shows the change in environmental functions. This change has a temporal component, it can only manifest over time. Describing the impacts of different land use systems is beyond the scope of this thesis. Responses in the form of conservation measures are also mapped and their effectiveness to restore or preserve a comparably good state of the land.

3.2 State of research

3.2.1 Definitions

LADA often uses the term ecosystem, frequently in expressions like ecosystem processes and ecosystem services. This requires a definition of the term ecosystem. In an encyclopaedia of geo sciences (Martin 2002) **ecosystem** is defined as a model of the interactions between organisms and their habitat. The ecosystem forms an interactive system which is self regulating and being in or tending towards a state of dynamic balance. It is vital point in this definition that life organisms are in the centre of the model.

Environmental science, adopting the terminology of economics, identifies **ecosystem "services"**. These include provisioning, regulating, cultural and supporting services. Provisioning services are products obtained from the ecosystem, like food, fuel or medicine. Regulating services buffer the effects of human activities. Examples are air quality regulation or water cycle functions. Cultural services are nonmaterial benefits provided by the ecosystem. They could include spiritual or recreational experiences, as well as aesthetic and pedagogical values. Supporting services are those that are necessary for the provision of all other services, for example soil formation or photosynthesis (Millennium Ecosystem Assessment 2005).

LADA is using these terms a lot and therefore they are also used in this thesis. However, it is important to state that life organisms are not necessarily in the centre of this assessment, as opposed to in the ecosystem theory. Because of that the terms 'land' or 'land use system' are preferred here.

In this sense **land** stands for the arable land in the Swiss Plateau that is in the centre of this assessment. It stands here for the complex of soil, (mostly) cultivated plants and water. This is again a vast field and only the relevant aspects are taken into account. That means for instance that only visible features can be included.

In the agricultural context of this thesis, **land use** is then the purpose of the **land management**. The land is used to produce goods, like crops or wood. Land management is the land users' way to achieve this aim. For the same crop output there are different means of production. Land users might till the soil to prepare it for sowing or they might use no till techniques. Different management practices pursue the same aim, which is the production of a certain good through land use.

Different management practices may leave different traces and affect the land in different ways. They directly and/or indirectly influence the capacity of the land to produce ecological services and the potential of land users to sustain the resources and produce goods (Bunning and Lane 2003).

If land use and management practices are grouped, **land use systems** can be determined. A land use system is then a certain way of managing the land in order to produce certain goods. In the context of this thesis the land use might be annual cropping and the management conventional tillage. Annual cropping under conventional tillage is then the land use system. It is one of the objectives of this thesis to describe the land use systems of the investigated area and to find out if they show similar characteristics of the state of land.

Land degradation always means, that at least one of the above mentioned ecosystems services can only be provided to a degree that is under its potential or, in the extreme case, cannot be provided at all (Millennium Ecosystem Assessment 2005). The central issue of this thesis there is soil condition. Therefore this compartment of the ecosystem is often singled out and **soil degradation** is then the more accurate term to describe the observed indicators. Soil degradation essentially means a decline in soil quality in terms of productivity and environmental regulatory capacity (Lal 1997).

For this thesis a lot of indicators describing the state of the arable land and many of them the soil in particular have been mapped. Many of these indicators do not describe degradation in the narrow sense but give hints about **disposition to degradation**. This means that if we see low earthworm activity on a field this does not necessarily mean that soil macro fauna is existing in too small numbers and that therefore the soil is not enough aired and loosened. But if on the same field we find a poor soil structure, combined with sealing on the surface and a poor ground cover we assume that this field has a high disposition to land degradation.

The mapping took place at three different times within a growing season (spring, summer and autumn). This further makes it possible to evaluate this disposition at three different times of the year, giving an overall appraisal.

‘Resilience’ is another important ecological concept to be mentioned here. It is a general concept that can be used for many components of the ecosystem. **Soil resilience** addresses the ability of the soil to recover from anthropogenic or natural disturbance. Most soils are able to recover. Important factors determining the grade of resilience are however the rate at which the recovery is taking place and the range of grades of changes from which a recovery is possible. Processes of soil resilience are defined by specific properties of a soil type and they are driven by socio-economic and political forces (Lal 1997). In the context of this thesis the aspect of soil resilience is important when comparing the state of fields under conventional management practices to such under conservation agriculture.

3.2.2 Research on soil condition in the investigation area

In the last years some research has been carried out from the CDE in the Swiss Plateau and also in Murist itself and on soil condition, especially on soil erosion. Thomas Lederman has for the last three years been working on a PhD thesis investigating the effectiveness of soil and water conservation (Ledermann and Schneider in progress). Therefore he mainly looked at soil erosion processes. His aim was not to theoretically enhance knowledge about soil erosion itself but rather look at the circumstances leading to it. Thereby soil management and crop types are very important. In that aspect his work gives useful information for this thesis. Further he has established a GIS layer and data basis that could be adopted for digitalising the data collected here with only minor modifications, making it possible for to concentrate on field methods rather than ways and means of digitalising data. Further some of the results of his studies give important background information. Some of them were compared to the results of this thesis:

- Ledermann determined that depending on region, land management, precipitation, and other factors soil erosion may affect 10 to 40% of arable farm land on the Swiss plateau. This is valuable information as this thesis is asking which factors affect the disposition to erosion damage in what way.
- Ledermann also made out larger erosion rates for the Murist area than for other investigated areas. According to him this is due to the larger plots in Murist, the comparably small portion of temporary leys and the larger percentage of root crops as well as the small share of land under conservation agriculture. Even though the erosion did not in a major share occur on the fields with root crops, Ledermann assumes that the fraction of root crops in a crop rotation has an influence on the occurrence of erosion damage. This result was also compared with the results of this work.
- As the most important factor controlling erosion Ledermann determines vegetation cover, which in this context is a result of the crop type and soil management. This too will be compared to the outcome of this thesis. The same counts for the importance of head lands and furrows as accelerators for erosion that he describes (Ledermann, Herweg et al. 2008a).

Michael Chisholm (2008) tested a GIS modelling tool to predict soil erosion rates in Murist and two other investigation areas. He produced maps showing how exposed to erosion the area is. He carried out the analysis on different scales, one with a 100 m^2 grid and one with a 25 m^2 grid. The factors determining the model are precipitation, type of soil, relief, soil management and soil cover and soil conservation measures. He compared his maps to the erosion rates estimated by

Ledermann and other quantitative estimations of soil erosion rates in the relevant areas. He describes a systematic over estimation of the erosion rates but also gives reasons and suggestions on how to improve the accuracy of the results concluding that even though the absolute rates of erosion might be too high the picture of the distribution of vulnerable spots is still giving a good impression of the actual situation (Chisholm 2008). As the ‘disposition to erosion’ is a relevant field within this thesis the maps of Chisholm hold relevant information that was compared to the results of mapping for this thesis.

A third work that has been carried out in the region is the bachelor thesis of Matthias Engesser. He built on Chisholm's diploma thesis, adding terraces and hedges to the model. He found that these hydrological barriers significantly lower soil erosion in the model. According to the GIS model this is mainly true for the field below the hydrological barrier but not only. Hedges and terraces can also lower soil erosion damage a couple of metres upslope. He concludes that the calculations he carried out probably overestimate the effectiveness of the barriers, because they cut the slope completely, starting the calculation of the potential erosion anew below. This is not necessarily representing a realistic situation. Nevertheless he concludes that the result is probably still better with the hedges and terraces than without and that his contribution is therefore an improvement to Chisholm's results (Engesser 2008).

Not in the same region but also in the Swiss Plateau on a topic important for this thesis, for her diploma thesis Christine Hauert estimated the soil organic matter of 495 soil samples of 22 plots. These plots are 11 sets of two, always two neighbouring fields, one that is not tilled and one that is conventionally tilled. She found that no till fields have a higher soil organic matter than tilled fields, especially if they are under direct seeding (Hauert 2007).

3.2.3 Indicators

LADA proposes a framework for indicators to describe the biophysical condition of the land. Management practices directly or indirectly affect the capacity of land users to conserve and sustain resources and provide goods and ecological services. Management practices also mark the land and leave traces that can be observed. To monitor the state and changes of the land a set of indicators is necessary. The indicators should enable to monitor key plants and organisms combined with observations of physical aspects of land condition, like for example soil surface condition. Good indicators allow an assessment of the status of biodiversity and landscape functioning. The indicators are designed for a local level application. They should then provide information for the integration to the smaller scale (Bunning and Lane 2003).

There are a number of criteria good indicators have to meet. Four key points thereby are: 1) they have to be policy relevant, i.e. represent key environmental issues (which are again varying locally); 2) they have to be analytically sound, meaning that they have to be based on science and taking into account new developments; 3) they have to be measurable and 4) they have to make an interpretation possible by communicating the relevant and important issues. Especially number three, the measurability, might seem very obvious. However, some important indicators are not that easy to classify and to make objectively comprehensible. But only this enables an assessment that is comparable in space, also on different scales, and over time (OECD 2003). This aspect is vital for this thesis as finding, testing, and evaluating indicators that are visible in the field are its main objectives. The following chapter is to a large part dedicated to this challenge. The objective comprehensibility was one of the greatest challenges in defining the indicators. Another crucial point is the relevance as to if the indicators help assessing the effect of land use on the used land.

LADA proposes a list of possible indicators, emphasising that the set of indicators has to be adapted to each assessment. Land management, environmental policies, and land user needs are locally specific. Therefore there is no simple recipe to assess the state of the land but the method and the set of indicators always have to be adapted to the current local situation. The LADA list contains amongst many others, indicators like presence and abundance of selected macro-fauna, soil organic biomass, soil surface condition, ponding, erosion and vegetation cover, composition, structure, and health (Bunning and Lane 2003). It is obvious that these indicators cannot all be gathered and mapped with the same methods. Some, like soil organic biomass, are not visible to the naked eye and have to be measured in a laboratory. When defining an objective of a work this aspect is very important. Accordingly, for this thesis only visible indicators or such that can be easily detected in the field were taken into account. This is a limitation to the choice of possible indicators. It is one of the above defined objectives of this thesis to determine indicators that are visible and to find out if it is possible with this limited set of indicators to define land use systems according to the LADA theory.

LADA also presumes that land management practices directly affect the intensity of pressures on land resources. For example tillage reduces soil organic matter thereby reducing soil fertility and soil surface stability. The derivation of this is that management practices can be used themselves as indicators of the functioning of land resources. This makes an assessment for a larger area possible. LADA gives a list of such land use systems with their indicators and typical land degradation. For example ‘rain fed cropping’ would be such a system. Within such a system there are different management practices. Indicators for these practices might be the crop types or the tillage practice. For each they determine land degradation forms that might occur, e.g. for tillage practice this might be loss of soil organic matter, compaction or surface erosion. This is followed by specific possible responses. In the tillage example this might be zero tillage (Bunning and Lane 2003). This thesis will look at this but from the other point of view. It aims at finding out if it is possible to group the management systems only from the field work perspective. The question is, if they really leave characteristic traces that are visible and that then demand specific responses. Here it is important to distinguish the indicators for degradation on the one hand and indicators for the disposition to degradation on the other hand.

4 Methods and Data

4.1 Indicators

Finding, adapting and testing indicators to describe the state of agriculturally worked land in the Swiss Plateau is an essential part of this thesis. It is the means to answer its working questions and hypotheses. Because it is important for the assessment to cover the whole area of the commune, plot by plot, it is not the idea to make an in depth analysis of the soil or to count the number of species on a meadow. Indicators have to be visible (or tangible) in the field, without any special, complicated or heavy material. They have to be reproducible, so that anybody assessing the same set of indicators would come to the same conclusions. This is much rather said than done. Agricultural land is a changing environment, farmers have their individual ways of working their land, plants and soils are constantly interacting with each other and with other spheres of the ecosystem. Each assessor in the field will judge the state indicators in a subjective way. Some indicators are very difficult to define in an objective way. This will always lead to differences in the assessment. Therefore it is most important to put a lot of effort into a good description of the indicators and the methods of how to assess them.

There are some important limitations to degradation mapping. What is visible in the field strongly depends on a number of factors with a high variability. Recent rainfalls, humidity and wind influence the state of the mapped plot. Maybe the farmer has recently ploughed the field possibly covering tracks of erosion or compaction. Then there are factors depending on the season: in summer the visible earth worm activity is generally much lower because they retreat deeper down under ground in the warm season. Therefore one fieldwork phase is not enough and not leading to a result that is satisfactorily accurate. Different field work phases within a year are necessary.

Even with the greatest possible effort, the accuracy of the method will never be absolute. There is no error estimation for the method used for this thesis. Ledermann (2008a) states that for the damage mapping methods he used there is a mapping accuracy of ± 15%, if the observer is experienced. He further argues that he achieved the best possible accuracy firstly because all mapping was carried out by the same two observers and secondly they undertook close coordination and harmonisation efforts beforehand.

As it is an aim of this thesis to find out if the mapping can be carried out by anyone, not only soil and water conservation specialists, the methods are bound to be rather rough. It should therefore not be necessary to be an experienced cartographer of degradation and conservation indicators. A fine accuracy is not the purpose of the methods used here. On the other hand it is the desired outcome of the method to obtain results that can be compared to assessments made in other areas. It is therefore important that a second thesis with very similar objectives is carried out simultaneously. A close coordination accompanied all stages of the theses, ensuring the best possible consistency of the results. The adaptation of the methodology for the purpose of the theses was undertaken in accordance.

4.2 The mapping tool

The material for mapping consists mainly of two things. One is a sheet of paper with tables on the front and back. This is the field protocol. For every plot such a sheet of paper has to be filled in. In the following sections parts of this field protocol are shown. It guides the whole process of mapping and is thus the very heart of the field work. The other thing that has to be carried along in the field at all times was the methodological catalogue for field work.

While carrying out the mapping in the field the field protocol (see Figures 3, 10 and 21 and annex) is sometimes not self-explanatory. For example the estimation of the soil cover needs a lot of experience and even then it is helpful to have a guideline. Along with the repeated adjustment of the field protocol a catalogue giving assistance and explanations for each indicator was developed. A prototype version already existed. As many points from the field protocol were missing the methodological catalogue was completed while paragraphs giving lengthy background information were left out. The aim was to produce a useful guide for the field work.

The careful use of this methodological guide during field work makes sure the mapped information to be objectively comprehensible and reproducible. Even though there will always be individual differences between two mappers' judgements and results the diligent use of the catalogue and the careful filling in of the protocol make the results comparable in a relative way. This should then enable the comparison between different regions and an integration of the information to a smaller scale. This is also dependent on the collected data and it is a main aim of this thesis to give an appraisal of the possibilities of an integration on the basis of the collected data.

4.3 Head of the field protocol

The first part of the field protocol holds general information and identifies the plot mapped. Figure 3 is the first part of the protocol as used for each plot in the field. The indicators that need explaining are listed below.

Date		**Canton**			**Notes** (weather, other distinctions):		
Plot-ID/Nr.		**Commune**					
Collected by		**Slope & landform**					
Land use type		**Plant/ crop type**		**Plant/mulch cover/bare [%]**	/ /	**Soil management**	

Figure 3. Top part of the field protocol, used for mapping essential information, which is filled in for every plot (source: Hauert, Herweg et al. 2008; altered by Gasser and Grob 2008).

4.3.1 Land use type

Only two types are distinguished so far: **cropland** and **grassland**. Further along the process the distinction was refined. Cropland was divided into annual and perennial cropping, perennial cropping standing for all the temporary leys within the crop rotation. In the beginning the term ‘cropland’ included all annual crops and temporary leys, while the term ‘grassland’ is used for permanent meadows and pastures. The distinction was easy to make afterwards because the part of grass within the cropland is easy to determine (Ledermann, Herweg et al. 2008b). In the traditional crop rotation system of Switzerland the distinction between perennial ley within a crop rotation and permanent grassland is sometimes not as easy at it might seem. In a typical seven year crop rotation there is usually a two to three year phase of grass land for fodder production. Sometimes it might be considerably longer for a variety of reasons. After a few years it becomes more and more difficult to distinguish real grassland from cropland that has not been used for growing something other than grass. For the questions asked in this thesis this does not matter greatly. We can only look at the surface to judge on the condition of the soil and plants. From that point of view grassland and crop land that has been used to produce grass for many years do not show visible differences. So to assess how different land use systems mark the environment is not dependent on the real accuracy of this distinction.

Figure 4. a: an example of cropland and b: grassland. The denser plant cover is well visible on the photographs and also, looking closely at the grassland clover and daisies can be seen on in the grassland, indicating a larger number of species than for the cropland (pictures: J. Gasser).

Figure 4 shows an example of the two different land use systems. The picture on the left shows a field of winter wheat in spring. To illustrate cropland there is a wide variety of possibilities, the picture could also show maize or rape or a potato field. The picture above on the right hand side shows a meadow that is never used for crop cultivation and thus host to a larger number of species.

4.3.2 Crop type

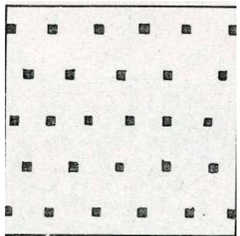
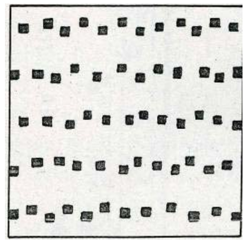
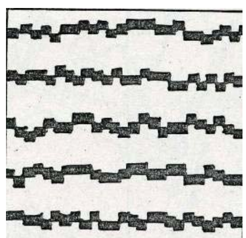
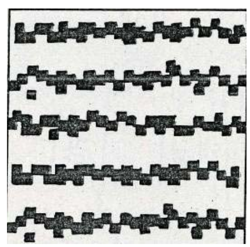
Usually this is not difficult, especially after some practice, to identify different crop types. In the field work for this thesis different kinds of cereal are not distinguished. This is mainly because during the first phase of field work in spring, the plants were still small and thus very hard to distinguish without more profound botanical knowledge. Apart from that the state of the fields with cereal seemed very comparable at that growing stage but for the different soil management systems (see further down). In the second field phase in late summer, all the winter grain had already been harvested and where new grain had been recently sown, it was again too small to differentiate.

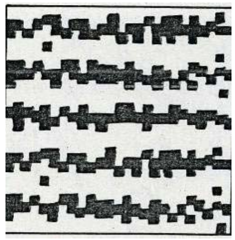
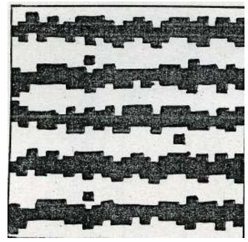
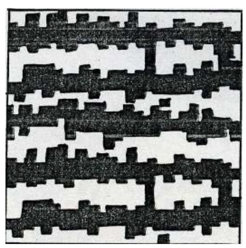
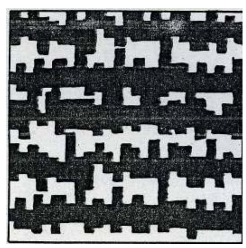
Figure 5. Different crop types. From top left clockwise: maize; sugar beet; tobacco; grass in crop rotation; cereal; rape. The pictures in the row above are taken in summer when many crops are large and easy to define. The photographs in the bottom row are taken in autumn, the crops are smaller and less easily distingushed (pictures: J. Gasser).

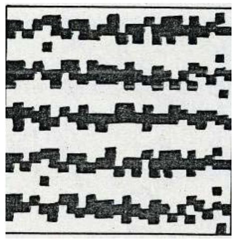
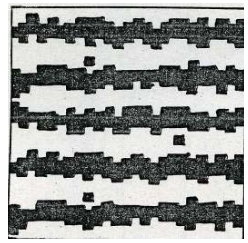
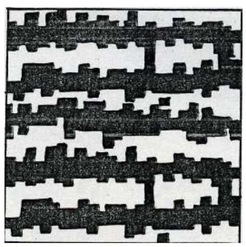
Figure 5 shows some pictures of common crop types. The top row from left to right shows maize, sugar beet and tobacco in summer. In the bottom row from left to right there is first rape then winter cereal both in autumn and therefore still young. The last picture shows grass as part of a crop rotation. This is the most common crop type as it is part of every crop rotation circle, usually for two consecutive years.

4.3.3 Soil cover

To determine the plant or mulch cover or the part of bare soil respectively there are useful charts in the manual directly linking the soil cover to the degradation form ‘reduction of ground cover’ with the four categories extreme, strong, moderate and light (see Figure 6 below). These categories belong to the chapter on degradation and will be explained in a more detailed way further down. The charts show pictures that can be compared with the ground right in the field. For a better illustration of the method corresponding photographs oppose the abstract black and white pictures above.

Category	Plant cover		Reduction
1			Extreme < 15%
			
	5%	**10%**	
2			Strong 15 < 30%
			
	20%	**25%**	

Category	**Plant cover**		**Reduction**
3	 	 	**Moderate** **30 - 50%**
	30%	**40%**	
4	 	 	**Light** **50 - 70%**
	50%	**60%**	

Category	Plant cover		Reduction
3			Moderate 30 - 50%
			
	30%	40%	
4			Light 50 - 70%
			
	50%	60%	

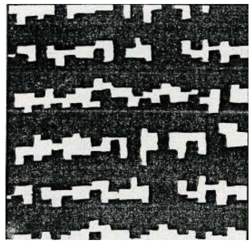
Category	Plant cover		Reduction
5			**No degradation** **> 70%**
			
	70%		

Figure 6. Tool to help estimating the ground cover in the field (Hauert, Herweg et al. 2008), complemented with pictures taken during fieldwork (April – November 2008 by J. Gasser).

In the field only the black and white version is used. Like that a good accordance of the results of different mappers can be achieved. As soil cover is a crucial indicator for the assessment of soil quality it is good to have a high level of consistency among different mappers in this point. This method leads to a satisfactory result, preventing the quite common overestimation of ground cover.

4.3.4 Soil management

We distinguish five categories of soil management: (1) direct seeding; (2) no-till with extensive mechanical soil treatment; (3) no-till with intensive mechanical soil treatment; (4) ploughing followed by extensive soil treatment and (5) ploughing followed by intensive soil treatment. Direct seeding is usually easy to identify: there are no characteristic traces of tillage, especially no trench on two sides of the field; also a typical sign of direct seeding is a good groundcover, even if the field is freshly sown there is a good cover of remains of the previous culture and older mulch. Generally the soil is over all in a better state (Benites 2007; Hauert and Liniger 2007). Figures 7a and 7b are fields under direct seeding. Picture 7a shows a freshly sown field with the characteristic slits of the direct seeding machine still visible. Also visible is the comparably high ground cover. There is mulch visible, especially the stumps of the maize stems of the previous season. There is also a cover of grass or maybe sprouting up cereal remains of a previous crop. As there is no ploughing it is a normal side effect of no-tillage that unwelcome weeds or remains of previous crops have to be managed. The input of herbicide used for this purpose is the main subject of critique on this land use system. Picture 7b shows the ground of a directly seeded maize field. Even though the ground is not densely covered with mulch under the maize plants the number of earth worm casts is remarkable, indicating a well aired, moist soil.

Figure 7. a: freshly sown field with the characteristic slits, the mark of the direct seeding machine and b: ground of a maize field covered with earthworm casts (pictures: J. Gasser).

Not tilled but mechanically disturbed soil (e.g. with a grubber), compared to that has less mulch cover; there might still be rows of last season’s crop stubbles visible but typically they are uprooted, uneven, and no longer in a straight line. This is well visible in picture 8a, which shows both the pell-mell maize stubbles and the not very dense plant and mulch cover. Picture 8b shows the same but later in the growing season. Still the old maize rows are just perceivable. Usually the soil is not as firm as with direct seeding.

Figure 8. a and b: fields under a no till system but with use of a grubber. Both pictures show fields in the season after maize, which is best suited to illustrate a soil management with a grubber because of the left over maize stems (pictures: J. Gasser).

Ploughed fields are marked by the mentioned trench on the side of the field. This is very well visible on the picture 9a below on the left hand side. When a field is prepared for seeding typically there is no soil cover at all. This is shown in picture 9b on the right hand side. In this state the soil is not protected at all and therefore very prone to erosion during heavy rainfalls. Also the soil is not very firm. Often it is either soggy or dusty.

Figure 9. a: characteristic trench on the side of a ploughed field and b: completely bare field right after seeding (pictures: J. Gasser).

While it is usually relatively easy to distinguish direct seeding, no-till and ploughing it is harder to judge if the treatment of the soil was intensive or extensive. If there are stubbles of previous crops on a no-till field, they might be an indicator: well visible lines of stubbles hint a less intensive treatment than stubbles that lie crisscross. There is also a simple test to distinguish intensive from extensive seed bed preparation: If there is a large portion of soil crumbs larger than a coin of five Swiss Francs, this indicates extensive treatment if there are only smaller crumbs, the treatment has been more intensive (Anken, Berweger et al. 2001). The problem with this technique is that if we look into a field that has been rained on it is no longer really possible to give good evidence.

4.4 Degradation

To map the degradation indicators, four degrees are distinguished: light, moderate, strong and extreme. The WOCAT/LADA manual (Liniger, van Lynden et al. 2008) distinguishes them as follows:

Light*: there are some indicators of degradation, but the process is still in an initial phase. It can be easily stopped and damage repaired with minor efforts.*

Moderate*: degradation is apparent, but its control and full rehabilitation of the land is still possible with considerable efforts.*

Strong*: evident sings of degradation. Changes in land properties are significant and very difficult to restore within reasonable time limits.*

Extreme*: degradation beyond restoration.*

These categories are used like this in most cases. The degree “extreme” though is used in a less absolute way. Especially for the indicator “reduction of ground cover” it is used in a different sense. If the soil is completely bare right after ploughing, the category “extreme” is used. Even though, it is not irreversible. For assessing vulnerability of the soil it makes sense to use this category (see under chapter “reduction of ground cover”).

Figure 10 shows the field protocol for the degradation part. Each point is briefly explained further down.

Land degradation (state indicators)

Indicator / Type		Exists	No occurrences	Absolute value	*Extent* [% of area] *with Degree* (category 1-4)			
	Name:	Y	No	e.g. [t/ha] / #	Light	Moderate	Strong	Extreme
O	***No degradation***							
On								
W	***Soil erosion by water***							
Wt	Loss of topsoil /surface erosion							
Wg	Gully erosion / gullying [From the depth of 50 cm]							
Wm	Mass movements / landslides							
C	***Chemical soil deterioration***							
Cn	Fertility decline/reduced soil org.matter							
P	***Physical soil deterioration***							
Pc	Compaction							
>Pc1	Soil structure: ***soggy*** [durchnässt]							
>Pc2	Bearing capacity of soil [Boden-tragfähigkeit] ***pulverized***							
Pk	Sealing and crusting							
Pw	Waterlogging							
H	***Water degradation***							
Ha	soil moisture loss (aridification)							
B	***Biological degradation***							
Bc	Reduction of ground cover							
Bl	Loss of soil life (earth worms)			**Light** 20-50%:	**Moderate** 5-20%:		**Strong** <5%:	
Bp	Pest / disease			***Species:***			***#/m:***[2]	
OT	***Other categories***							
OTo	Other (specify) observations:							
Wo	***Offsite degradation effects***							
Wog	Accumulation on grassland							
Woc	Accumulation on cropland							
Woe	Impact on ecological comp. areas							
Wod	Pollution of drainage channels							
Wow	Pollution of open water bodies							
Woi	Accumulation on roads/infrastr.							
Wor	Triggering degradation downslope							

Figure 10. 'Degradation' section of the field protocol. In this scheme all visible degradation indicators on a plot are registered. In the grey column a tick is added if an indicator occurs and to the right in the row the estimated degree and affected extent is given (source: Hauert, Herweg et al. 2008; altered by Gasser and Grob 2008)

4.4.1 Loss of topsoil/surface erosion

Prasuhn and Fischer (2007) published a manual to categorise and estimate surface erosion. In this work there are never absolute estimations, because even with the help of this good manual it is an elaborate process to estimate absolute values of soil erosion. Only the classes are used here. Especially the pictures (examples are here always below the corresponding grade of seriousness) illustrating form and seriousness of the surface erosion are very helpful in the field, as they can always be compared to the current situation.

Prasuhn and Fischer define the categories for surface erosion as follows:

- Light:

- Only surface erosion, without rills on the entire plot (or parts of it); or
- locally limited erosion damage of moderate degree on a small part of the plot; or
- single rills on a large plot; or
- a combination of surface and linear erosion on a small part of the plot.

Figure 11. Surface erosion, category ‘light’. a: suface erosion on the entire plot, and b: a single rill in the headland of a plot (Prasuhn and Fischer 2007).

- Moderate
    - A combination of surface and several rills; or
    - multiple small rills (up to 15cm deep), for example in machinery tracks or depressions; or
    - a single large rill (between 15 and 45cm deep) on a large plot.

Figure 12. Surface erosion, category ‘moderate’. a: shallow but large rills and surface erosion on the whole plot, and b: a single large rill in the middle of a plot (Prasuhn and Fischer 2007).

- Strong
    - Surface and linear erosion on the whole plot; or
    - a net of rills on parts of the plot; or
    - large rills on a small plot.

Figure 13. Surface erosion, category ‘strong’. a: multiple large rills and surface erosion, and b: a single large rill and severe surface erosion (Prasuhn and Fischer 2007).

- Extreme
    - Spectacular singular occurances; or
    - a laminar net of rills; or
    - a combination of small and large rills and surface erosion.

Figure 14. Surface erosion, category ‘extreme’. a: numerous large and small rills and severe surface erosion, and b: a laminar net of rills (Prasuhn and Fischer 2007).

4.4.2 Gully erosion and mass movements

Gully erosion and mass movements are rare in the area mapped. Gully erosion did not occur at all during the field work. On a very steep pasture there is a constant very small rip in the turf, that might classify as ‘mass movement’ but it is certainly nothing dramatic like for example a land slide. Because of that neither of these two indicators and processes behind will be explained any further.

4.4.3 Fertility decline/reduced soil organic matter

As mentioned above, for the purpose of this thesis only visible indicators are taken into account. Fertility decline is only mentioned if it is clearly visible in the field. This is the case if there are gaps in the plant cover, if parts of the crop are less developed than others or if parts of the crop have a lighter colour. Occurrences were thus rather rare and possibly not representative. The degree here is determined in relation to other fields with the same crop that are close by.

Figure 15. a: light patches in cereal and b: underdeveloped rape with signs of nutrient deficiency (pictures: J. Gasser).

Figure 15 shows two examples of fertility decline that were visible in the field. On the left hand side we can see light patches within the cereal field. On the photo they might not be as obvious as they are when looking at it outside. The light patches are also smaller than the darker, indicating a lack of nutrients. The picture on the right shows rape with colourless fringes that are signs of nutrient deficiency.

'Reduced soil organic matter' is an indicator of the WOCAT/LADA tool. But it is left out here. Only 'fertility decline' is mapped because reduction of soil organic matter is not visible in the field. The colour of the soil might give hints (the darker the soil, the more organic matter) but this is not always true and can lead to false conclusions. To really determine soil organic matter an analysis in a laboratory is necessary. This is beyond the scope of this work.

4.4.4 Compaction

Compaction of soil is mainly caused by heavy machinery. How badly the traffic of the tractors and harvesters affects the soil depends on the properties of the soil. In this context the most relevant properties are the bearing capacity and the moistness of the soil. The bearing capacity again is dependent on the management system. It is in itself an indicator mapped and is thus explained further down. Compaction causes the porosity of the soil to deteriorate. This negatively affects the root growth and thereby the development of the plants. It also diminishes the circulation of air and the infiltration capacity in the soil (Frei and Peyer 1991).

Compaction is in the field mainly perceivable in the actual wheel tracks but it affects the soil as deep as one metre down, depending on the over all bearing capacity of the soil. Soils with a comparably weak structure are those with a high fraction of silt and clay. This includes the fertile soils used for agriculture on the Swiss plateau. It is not observable in the field how far down the compaction affects the soil but we know from other research that especially the combination of subsoil compaction and topsoil sealing leads to a serious disposition for erosion and reduces the fertility of the soil (BAFU 2007). In the field a good way to determine the degree of compaction in the wheel tracks is to use a pen knife. The blade of the knife is first pushed into the soil in the track and then in the soil some distance from the track. If a difference in resistance is just perceivable the compaction can be classified as ‘light’. If the difference between the effort needed to push the blade into the wheel track and the one in the soil next to it is great, the compaction is ‘strong’. The classification is thus relative, depending on the state of the plot. This makes sense because for instance on a field under direct seeding the soil is over all much firmer than on a ploughed field. So it takes more effort to push the blade into the ground in the first place but the difference between the wheel tracks and the soil next to them will be marginal or not noticeable at all.

Figure 16a shows wheel tracks in a bare field. Right after ploughing and harrowing heavy machinery causes severe compaction. Figures 16b and 16c illustrate the method used to determine the actual compaction. The blade of the knife is pushed into the compacted ground and with the same force into ground next to it. In the example below the blade can only be pushed half as far down in the wheel track than next to them. The compaction is thus rather strong.

Figure 16. a: Well visible wheel tracks in a bare field; b a knife pushed into the compacted soil in the wheel tracks and c: the knife pushed with the same force into the loose ground next to it in the same field (pictures: J. Gasser).

4.4.5 Soil structure and Bearing capacity of soil

These two indicators were added during the field work. They were divided into one describing the state of the soil as ‘soggy’ the other as ‘pulverised’. They are really describing the same thing. One is in the wet and the other in the dry state. These indicators describe the overall quality of the soil structure. Soil particles can combine and stick together in aggregates. These aggregates are what we colloquially also call ‘crumbs’ (Mc Rae 1988). They are between 0.2 and 2mm wide. The soil structure is then defined as the arrangement of the solid soil components, the aggregates, and the pores. If the aggregates are destroyed big pores vanish and the structure becomes less permeable for water and air. The character of the soil changes visibly. The particles of the destroyed crumbs again stick together but as the chemically binding substances are reduced, they don’t form a porous structure consisting on many small crumbs. They rather clot into large lumps. These lumps are much larger than the crumbs of a healthy soil. They are at least 2cm wide, reaching up to several decimetres (Frei and Peyer 1991). If the soil structure is consisting of crumbs and thus has a good porosity and bearing capacity, or if it is a homogenous lumpy mass is well visible in the field. If the soil is wet stepping into the field leaves a clear footprint. On a healthy soil this is hardly ever the case. Dry soil has a pulverised quality if the structure is deteriorated. Generally soil with a bad structure is wetter than a healthy soil when wet and drier when dry. If the porosity is diminished (in number and size of the pores) the soil has no longer a good capability of storing water.

Figure 17. Ways of determining poor soil structure. a: stepping into the field in order to see and feel how easily a deep footprint can be left in the soil; b: if taking out a handful of soil is easy the soil structure is not natural and healthy and c: pushing a knife into the ground gives a further impression of the coherence of the soil components (pictures: J. Gasser).

Figure 17 shows the field methods for determining the quality of the soil structure. Stepping into the field, as shown in figure 17a, is a first good method of getting an impression of the soil structure. If the step leaves a clear and rather deep footprint the bearing capacity of the soil is poor and using heavy machinery on this soil would leave deep traces. If a handful of soil can be taken without effort this is a further indicator for a poor soil structure (figure 17b). A healthy soil, as for instance under a permanent meadow, is forming a firm compound and it is not possible to take out a sample without the use of an instrument. Figure 17c finally shows a knife that is nearly completely pushed into the ground. If a longish object like a knife or a pencil can be pushed into the ground with ease this too indicates poor soil structure and bearing capacity.

4.4.6 Sealing and Crusting

Other symptoms of a damaged soil structure are sealing and crusting. These forms occur on the soil surface, which is most prone to stresses and strains from rain or agricultural soil management. This vulnerability is greatly enhanced if the soil is bare. Or looking at it from the other perspective: a dense vegetation cover effectively protects the soil surface from that kind of degradation. If raindrops fall onto bare soil without being intercepted by a vegetation cover, they splash with a lot of energy onto the ground destroying the structure in the top most part of the soil. If a soil is affected by sealing, there are no crumbs visible and the ground seems covered by a homogenous mass. Sealing causes the soil to become more impermeable and especially if it dries out it becomes very difficult for the next rainfall to infiltrate. It also hinders the gas exchange between soil and air and makes it more difficult for plants to sprout and grow (Frei and Peyer 1991).

Such a sealed soil surface is shown in the pictures of figure 18. It is well visible there that there is a poor porosity on the soil surface. This makes it difficult for rainwater to infiltrate into the ground and heavy rains flow off superficially developing a high erosive energy (Mc Rae 1988).

Figure 18. a and b: sealed soil surfaces. These pictures show how the pores on the soil surface are destroyed causing a poor permeability of the soil (pictures: J. Gasser).

4.4.7 Waterlogging

If the soil has a horizon of impermeable material it is probable that water is retained there, causing puddles of water to appear on the surface. Because the water cannot drain quickly enough, an anaerobic situation occurs and most plants and microorganisms cannot survive under these conditions. Marshes and swamps are natural forms of waterlogging, hosting specialist plants and organisms. There is also man-made waterlogging, arising from the use of heavy machinery on soils with an insufficient bearing capacity. The threat of waterlogging is enhanced if the ground water level is already rather high, e.g. close to an open water body (Mc Rae 1988). It does not occur very often in the investigated area and is then in most cases restricted to the wheel tracks, as shown in figure 19a. Figure 19b shows an example of waterlogging as a puddle in the middle of a field. This situation is exceptional in the mapped area.

Figure 19. a: Waterlogging in compacted wheel tracks. This phenomenon is often observable after strong rainfalls while ponding in the middle of a field, picture b, is less common and indicates a compacted layer deeper down (pictures: J. Gasser).

4.4.8 Soil moisture loss

This indicator is closely linked to “soil structure” and “reduction of ground cover”. If the soil structure is poor and the soil insufficiently covered it is likely to lose a lot of moisture very quickly. When the first sun falls onto the fields, the difference is very obvious. A badly covered field has often got a layer of steam on it in the morning while the meadow next to it does not. The problem with this indicator is that it is only significant in dry conditions. If it has been raining just before the field work, all the fields are wet and the indicator will never occur, so in the mapped area it only occurred in summer. But while it is dry it is a good indicator, giving hints about the connection of ground cover, soil structure and soil moisture loss. In drier countries the relation between the land use system and the water needed for irrigation has been shown. Benites (2007) shows that between the percentage of soil covered and the amount of water needed for irrigation there is a negative linear correlation.

4.4.9 Reduction of ground cover

This degradation indicator is closely related to “soil cover” (chapter 4.3.3). In the head of the field protocol the amount of plant cover, mulch cover and the percentage of bare ground respectively are noted. With help of the diagram (again compare 4.3.6, figure 6) the degree of the degradation is determined. The part of bare cover is the decisive factor for the degree of degradation. So for example if 30% of the ground is covered by a vegetation cover and 10% by mulch, 60% of the ground is bare. This results in a ‘moderate’ degree of degradation by reduction of ground cover. The degree of reduction of ground cover can be derived in a straight forward way from the noted percentage of plant and mulch cover above.

4.4.10 Loss of soil life

This indicator too has to be reduced to what can be observed in the field. Therefore the relevant factor is the earthworm population. Earthworms prefer fertile well-drained organic-rich soils which are not too acid. They serve as the main agents of soil mixing and physical incorporation of fresh organic matter on the soil surface. In suitable undisturbed soils they are very effectively mixing the soil, producing so called mull (Mc Rae 1988). Earth worms are therefore also an indicator for how much a soil has been mechanically disturbed.

The classification agreed upon is that if earth worm casts cover more than 50% of the ground, there is no degradation. If they cover between 20 and 50% percent, the degradation is light, between 5 and 20% moderate and if less than 5% of the soil is covered by earthworm casts, the degradation is strong. This convention has been established in the field together with H.P. Liniger, K. Herweg and U. Grob. It proved useful for the fieldwork. Figure 20 gives an impression of a healthy population on the left and a strongly reduced population on the right. Figure 20a shows a dense cover of earthworm casts indicating a healthy population. Note that there are also plant residues visible indicating a soft soil management. This leads to the assumption that indicators for good soil quality often occur together (and vice versa). Picture 20b shows a ground between the crops with hardly any earthworm casts and also hardly any cover at all. However the earthworm activity is strongly dependent on the weather, the season, and on the soil moisture. In summer it is natural to find less earthworm casts. This has to be taken into account for the assessment.

Figure 20. a: high and b: low level of earthworm activity (pictures: J. Gasser).

4.4.11 Off site degradation effects

Off site effects of degradation include accumulation on grassland, cropland or roads, further there can pollution of drainage channels and open water bodies, they can be negative impacts on ecological compensation areas or they might trigger degradation down slope. Visible in the field are only off site effects of soil erosion. Other off site effects also include pollution of ground water by fertilisers or herbicides. As they cannot be observed in the field, they are not taken into account for the mapping.

4.5 Causes for degradation

If degradation indicators are visible and mapped according to the list of indicators shown in figure 21 the reasons for the manifest degradation must be given as well. The mapping of the cause indicators has a subjective component. It depends on the judgement and experience of the mapper. In many cases however the determination of causes is rather straight forward. If there are clearly visible tracks from the machinery used for land management and there is compaction in these tracks it is trivial to conclude that “heavy machinery” is in this case a cause for compaction. The part of the field protocol dedicated to the causes of land degradation is shown in the figure below and afterwards explained briefly one by one.

Direct causes of land degradation (direct pressure indicators) → *Fill in land degradation codes (Pw, Pc...)*

Indicator									
	Name:	Major				Minor			
s	***Soil Management***								
s1	Cultivation of unsuitable soils								
s3	Heavy machinery								
s4	Tillage / cultivation practice (ploughing, harrowing)								
c	***Crop Management***								
c1	Reduction of plant cover and residues								
g	***Overgrazing***								
g2	Trampling of animals								
u	***Infrastructure***								
u1	Runon from roads, settlements								
w	***Water cycle***								
w1	Lower infiltration rates/increased surface runoff								
ot	***Other (specify):***								
ot1	Topography/Relief								
ot2	Runon from plot above								

Figure 21. Section of the field protocol used to determine the causes for the mapped degradation indicators. For each indicator registered in the section above (see figure 10) the assumed major and minor causes are given here (source: Hauert, Herweg et al. 2008; altered by Gasser and Grob 2008).

Cultivation of unsuitable soils is very rare in the mapped area. As mentioned above the typical soils are cambisols and luvisols, both are apt for agricultural use. Therefore the soils are usually suitable. The only case in which it might occur is if a cultivated field is in a depression close to an open water body where the groundwater level is close to the soil surface. In this case there would be an increased disposition to waterlogging, especially if the management system includes ploughing. In these cases the farmers usually dig drainage systems to prevent the water rising too high beneath the surface. If the farmers have drained their fields is not visible in the field.

Heavy machinery on the other hand is a common cause for degradation indicators, especially for compaction. This is then most often in combination with a soil management that damages the natural healthy soil structure reducing its bearing capacity.

This leads to the next point, **tillage** or **cultivation practice** as cause for degradation. This is considered a common reason for many forms of the mapped degradation indicators. Many of the degradation indicators are directly or indirectly dependent on soil structure. Soil management or cultivation practices are the factors that are altering the soil structure most, on the macroscopic scale at any rate. Therefore management practices are considered responsible for many degradation indicators or for indicators describing a tendency for degradation.

Reduction of plant cover and residues is in a way a secondary cause. While it may often be a cause for degradation it is in itself caused by the management practice. Undisturbed, the soil would be covered to a large extent and only if the soil surface is upturned the plants and plant residues are no longer covering the soil. Once the soil is bare to an extent of 30% or more there are typical degradation indicators induced by the absence of a dense soil cover.

Trampling of animals is a cause for degradation that is easy to see in the field. Often it is more difficult to estimate the degree and extent of the caused degradation, which is mostly compaction.

Runon from roads and settlements can cause degradation by channelling a water flow onto an adjacent field. The erosive energy of the water can thus be strongly enhanced. Especially if the field affected hasn't got a dense plant cover combined with a bad soil structure it may be very prone to erosion during a heavy rainfall.

In the land under agricultural use in Switzerland **lower infiltration rates** or **increased surface runoff** are mostly also due to the cultivation practices. Ploughing destroys the large pores in the soil and it diminishes the earthworm population. This makes it more difficult for large water quantities to infiltrate into the ground in a sufficiently small amount of time. If it can no longer infiltrate at the necessary rate surface runoff is increased causing the surface to seal. This process is greatly enhanced by the splash effect as described above in the section "sealing and crusting".

Topography and relief are often a crucial factor for larger forms of erosion damage like rills. Erosion mapping is not the aim of the mapping tool used in this thesis. Therefore the timing for the mapping was not planned to catch maximum current erosion damage. Consequently more often indicators describing the disposition to erosion are mapped than actual erosion damage. On these indicators the topography has generally no great effect, if any at all.

Runon from plot above has rarely been witnessed as a cause for degradation. This is also due to the fact that the times for mapping were not selected according to potential erosion but to get a picture of different stages of a growing season. Often erosion damage that might have occurred between mapping phases might not be visible anymore while mapping because it is already overgrown or ploughed under.

4.6 Conservation measures

After mapping indicators and causes for degradation, the mapping tool also takes visible conservation measures into account. According to the DPSIR model described in the theory chapter the conservation measures taken by the farmers are responses to a deteriorated state or respectively to a negative impact caused by a land use system on the land. After describing the state indicators and the reasons for the degradation, in a third step the responses, i.e. the conservation measures are mapped. Different possible measures are distinguished based on the WOCAT manual. WOCAT provides documentation for a large number of conservation technologies distinguishing four different types of conservation measures:

Agronomic measures are amongst others conservation agriculture or manuring. They are associated to annual cropping, so they have to be repeated each season, they are not permanent, and independent of slope. **Vegetative meaures** like hedges or grass strips are of longer duration as they involve the use of perennial plants. They are set up according to given parameters like slope or wind direction and might thus lead to a change in slope profile. Terraces are **structural measures**. They are mostly permanent or at least of a long duration and often they require a substantial input of labour or money. Structural measures are aligned along the contours as their main purpose in our climate is it to control runoff and erosion. Finally there are **management measures** like land use change, area closure or rotational grazing. They involve a fundamental change in land use but no agronomic or structural measures. These measures quite often lead to an improved soil cover, stressing the great importance of this factor and they quite often lead to a more extensive land use. Examples are the change of land use system or a major change of changes in the timing of activities and of their intensity. These measures can be combined, for example direct seeding (agronomic) with terraces (structural) (Liniger, van Lynden et al. 2008).

Out of the measures described by WOCAT the ones relevant for the Swiss plateau situation are selected:

Conservation agriculture is a land use system based on the following basic principles: minimum soil disturbance, a sufficient degree of permanent soil cover, and crop rotation. As there are no monocultures and therefore crop rotation is characteristic of Swiss agriculture this point is given here. We therefore call the system “conservation agriculture” if the fields are directly seeded. In that case the soil is not disturbed at all and the soil is mostly covered with a dense mulch or plant cover.

From that system **in-mulch seeding** is distinguished. In-mulch seeding means that the soil is not upturned as it is with ploughing but it is still mechanically disturbed with a harrow or grubber. Usually the mulch cover is relatively dense (as the name implies) and often the fields are in a better overall state (see point 4.3.4 with figure 8a and b).

Manuring/composting/nutrient management is rather difficult to assess. It can be assumed that farmers frequently discharge slurry, dung, and also chemical fertilisers but often this is not visible after a few days or weeks. Chemical fertilisers might not be visible at all. Either way, it is strongly dependent on timing if the manuring is visible or not. Therefore the selection of fields where this conservation measure has been seen might not be representative without further information from farmers.

Crop rotation is a special conservation measure here. As mentioned above in Swiss agriculture there are no monocultures and therefore it can be taken as given that on all cropland there is a crop rotation system. The issue is then to decide if the crop rotation system is an effective conservation measure or not. In comparison to monocultures the crop rotation system would be a great improvement and probably this would be visible in the field as well. But this comparison does not exist here. So the judgment as if the crop rotation system is an effective conservation measure has to be made by comparing different crop rotation systems and the different crops within the rotation.

There are quite a lot of **Vegetative strips and hedges** as well as **terraces** in Murist, often in combination (overgrown terraces). To assess if this conservation measure is effective is very difficult in the field. Terraces might be important barriers for surface erosion. The problem seeing this in the filed is twofold: judgement is only possible if there is obvious surface erosion in nearby fields with a comparable land use system and a similar degree of soil cover. If on the fields with terraces there are no signs of surface erosion we might assume that the terraces are effective in preventing surface erosion. The other difficulty is that the terraces and hedges are quite often between fields of grassland. Because they usually have a very good ground cover and are mostly in an over all good state, no differences between 'normal' grassland and grassland on terraces are visible. These observations are confirmed by the modelling carried out by Matthias Engesser (see sections 3.2.2 and 6.2.4).

Grassland management is the measures farmers take to prevent overgrazing or other forms of deterioration of pastures and meadows. In the Swiss plateau farmers always use fences to prevent their live stock to walk away. A second effect of the fencing is that farmers can periodically lead their animals from one pasture to another so to prevent overgrazing. A little bit of compaction caused by the many hooves and some bare patches in places where the animals gather, e.g. around a well, are inevitable. Not only measures taken against overgrazing are in this category but any kind of grassland management, including mowing. Consequently all grassland is under grassland management in the area.

4.7 Data structure and display

After the collection of the data in the field it must be brought into a form that enables to display it in a way that makes it possible to answer the questions of the thesis. As the data processing methods used for this purpose are nothing out of the ordinary they will not be further explained here.

To get an overall picture and to make relative comparisons between the different land use systems and between the three considered seasons maps are produced using GIS. Further there will be graphs and tables to illustrate the outcome.

Photo documentation was always part of the field work. Pictures were taken where special forms and phenomena were found. It is not a complete photo monitoring that was carried out but descriptive or distinctive situations can be further illustrated with pictures. Thus they are a means to enhance the traceability of the results.

Part III

Results and Discussion

5 Results

5.1 Overview

In the course of the field work a vast amount of data has been collected. Each agriculturally used plot in the area of Murist was assessed three times: once in spring, summer, and autumn respectively. For each plot a large number of indicators was collected and digitalised according to the above described methods. This approach resulted in an amount of data that proved difficult to manage. To find ways to file and display this data is a major challenge to this work. Not the sheer amount was the greatest challenge thereby but the different data structure of the indicators, depending if they describe degradation, the causes leading to it or the conservation measures. Therefore the decision had to be made whether to go into detail with some indicators or to choose a descriptive approach to create an overview of the whole data in a more superficial way. In accordance with the aim of the thesis the second way was chosen. Only the creation of an overview gives insight into what indicators are relevant, reliable and informative. After the judgement as to which are the key indicators for the assessment of different land use systems a more in-depth analysis of those could be carried out.

Before starting to describe the results the focus shall here be widened once more. In the theory (see 3.1) the DPSIR model was described. Already then it was stated that the aim of the work should be to obtain a picture of the state of the agriculturally used land of the investigated area. According to that purpose the indicators were chosen. This was done, as described above, with methodological limitations. The outcome – a detailed description of the state – is the content of this picture. The other components of the model are mainly left out with the exception of some response mechanisms. Conservation measures visible in the field have also been mapped and are thus part of the described and displayed results. The link of how these measures act on the state of the land can thus also be established.

In the following chapter the collected data is thus displayed and explained in an overview fashion. According to the field protocol the chapter is divided into a part giving general information for each plot, followed by a part on degradation indicators and thereupon a part on causes considered responsible for the observed degradation indicators. The last part treats conservation measures taken by the farmers. Each of these parts has a different data structure and therefore requires a different manner of display.

5.2 General Information

In this paragraph information is explained and displayed that was collected for each plot, independently of signs of degradation or conservation. It is a vital point for this thesis that not only degradation or conservation is mapped and measured but also a general overview of the state of the land is given. This general information will then be linked to the indicators collected later on with the aim of showing possible connections between the characteristics of the field and the state of the land.

5.2.1 Land Use Type

WOCAT distinguishes several types of land use. This land use is determined by the land cover (forest, agricultural land, urban area, wetlands etc.). Each of these types is then further divided according to the possible land uses (Liniger, van Lynden et al. 2008). Here only the types for agricultural land are relevant as only this is assessed. For the agricultural land in the Swiss Plateau three types are distinguished: annual and perennial cropping and grassland. Grassland is land that is agriculturally used but only for grazing of animals and/or fodder production. The only crop on this land use type is grass. Cropland on the other hand is used for the production of all kinds of crops (maize, rape, cereal etc.). The distinction there is between annual crops like the ones mentioned and grass which is grown within the crop rotation for two to three years, thus it is there called perennial crop. To make the distinction between these two types of cropping might be a somewhat academic. Together they are the typical crop rotation cycle in the Swiss plateau with about five years of annual cropping followed by about two years of ley before it starts anew. For the purpose of the questions asked in this thesis the distinction between annual and perennial cropping is sensible because the state of the land is significantly different.

Figure 22 shows the assessed land use types for the investigated time (spring – autumn 2008). Crops and soil cover are changing quickly, sometimes several times within a year. But even so, in general the picture is similar for the different seasons. About half is annual cropping, about one quarter each is temporary ley and grassland. The total grass fraction is highest in autumn. It is also visible however that it is not always clear if a field is constantly grassland or if it is just momentarily used for grass production within a crop rotation circle.

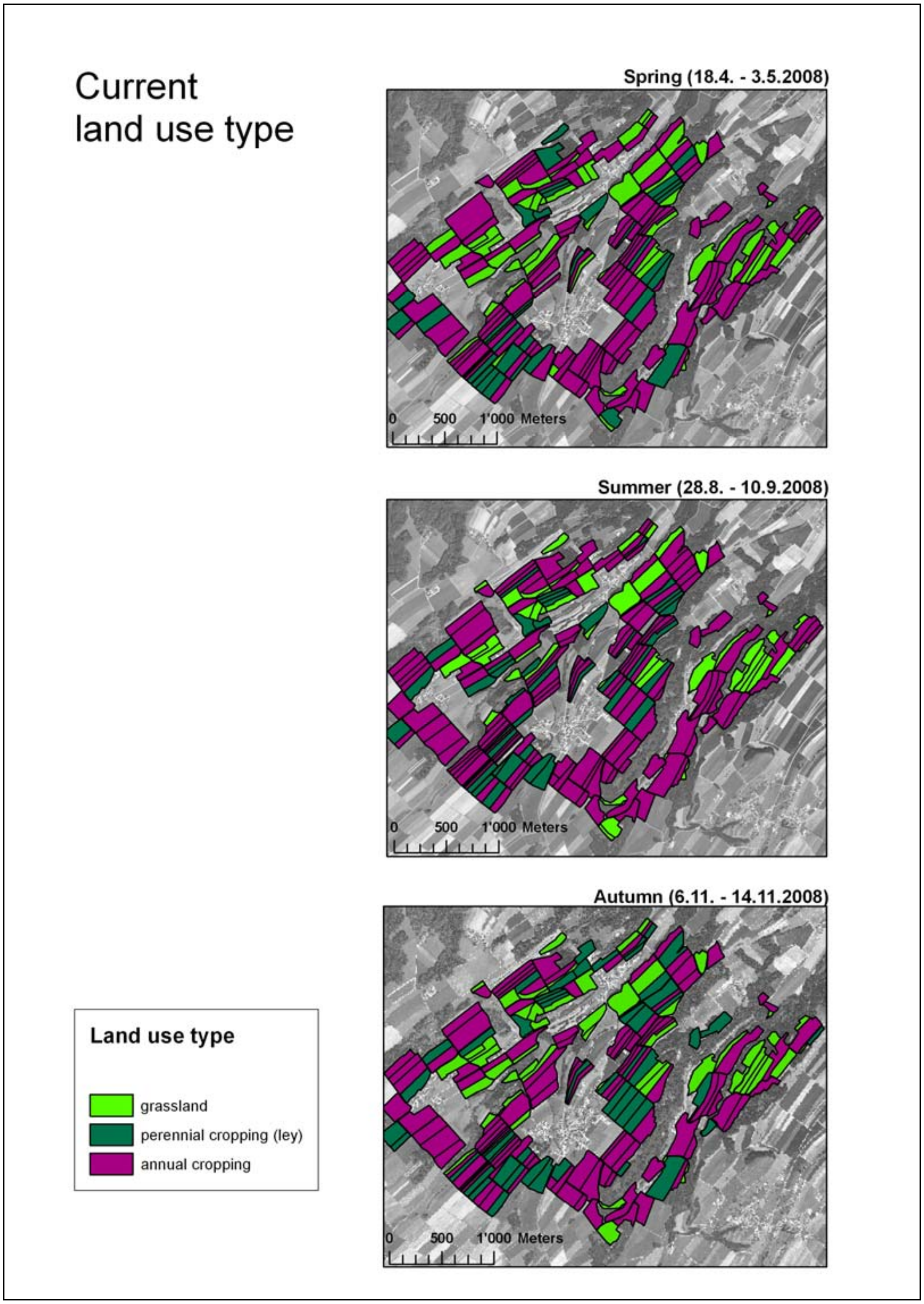


Figure 22. Seasonal maps of the land use type with more annual cropping in summer and more leys in autumn (maps: J. Gasser).

To establish the connection to the degradation indicators, the number of indicators per field was calculated. The result is rather unambiguous as in all cases there are by far the most indicators per field for annual cropping, with values between 3.9 and 4.8 indicators per field, with the peak in summer. Perennial cropping reached values between 0.7 and 1.5 indicators per field and grassland always has less than one indicator per field with values between 0.3 and 0.5.

5.2.2 Crop Type

Fifteen crop types have been distinguished throughout the year (see legend for figure 23). Most of them are the typical crops grown in the Swiss Plateau. Exceptional is only tobacco which is not commonly grown in Switzerland. Cultivation of tobacco was traditionally an important income for the people in the western Swiss regions of Vaud and Fribourg. This is in a much smaller way preserved until today. Apart from that the selection of crops is usual for Swiss low land agriculture.

Green colours in the legend for table 1 represent grass or similar cover. Blue, yellow, purple and red colours are all the other cultures and the brown shades are different kinds of fallows. In spring the green and dark blue colours are dominant as there is a large amount of grass fields and winter cereal after the cold season. As expected, in summer the picture is much more colourful. In this season most crops are growing and thus the diversity is largest. In autumn there are again far more green colours. A lot of freshly sown meadows have been observed. Also typical for autumn are the brown colours.

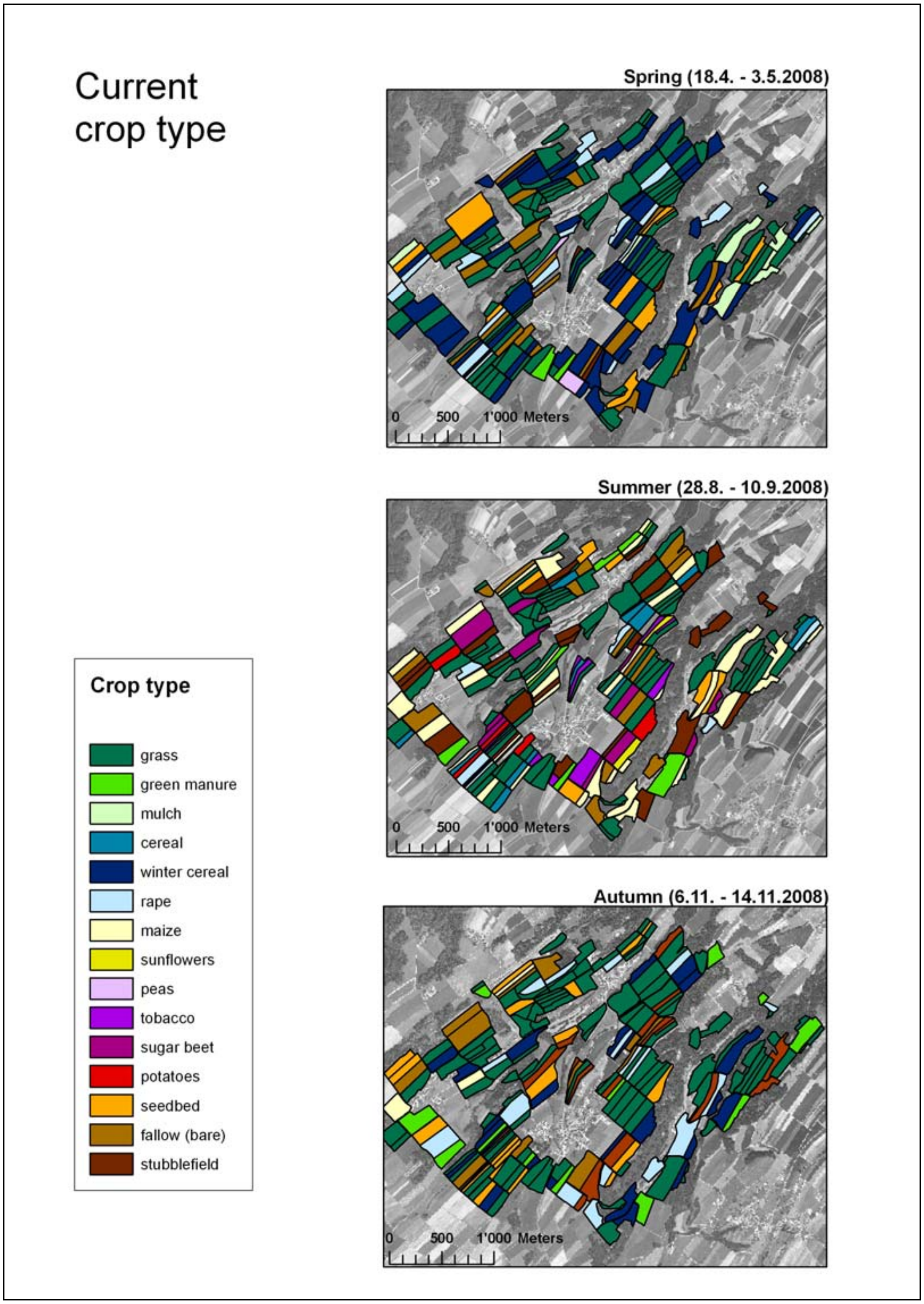


Figure 23. Seasonal maps of the currently cultivated crops with a wider variety of crops in summer than in the other seasons and a large part of green and brown colours (grass and fallows) in autumn (maps: J. Gasser).

The number of degradation indicators per field was also calculated. Because there is a large variety of crop types and the differences are strong the relevant results are shown in the following table:

	Season		
Crop type	Spring	Summer	Autumn
Grassland	0.5	0.8	1.0
Cereal	4.4	5.8	4.3
Rape	3.7	2.5	4.6
Maize	–	4.3	5.3
Potatoes	–	6.6	–
Sugar Beet	–	4.6	–
Stubble Field	2.5	3.9	4.4
Fallow (bare)	3.4	6.5	5.0
Seedbed	4.3	5.8	4.7

Table 1. Number of Indicators per field, according to crop type (source: Gasser 2008).

The table confirms that the variety of crops is largest in summer, only then all the fields of the table show a value. It further shows that there are significant differences between the different crops in relation to the number of degradation indicators. The results are however not unambiguous. The number of indicators is also strongly dependent on the season. Cereal for example has a higher value in summer, while rape fields show the most indicators in autumn. Grassland generally has the lowest values. Root crops seem to have higher values than cereal, maize, or rape. This is however difficult to determine because of the seasonal changes. All the land without any crops on it (stubble field, fallow and seedbed) has generally high values.

5.2.3 Soil Cover

Three different aspects of soil cover were assessed: plant cover, mulch cover and bare ground. How the percentage of plant cover is determined in the field is explained in chapter 4.3.3 in a detailed way. The determination of mulch cover is carried out in an analogous way. In a last step the percentage of bare ground is estimated. This might seem redundant but it is not. There might be a light layer of mulch (i.e. 30% coverage) under the crop (i.e. 70% coverage) but there might still be some bare ground because the plants and mulch might cover the same patch of soil. Therefore the sum of the three assessed components of soil cover might sum up to more than 100%. The most important aspect for the description of the sate of the soil is thus the fraction of bare ground because this is the fraction that is directly exposed and thus most vulnerable. Only when 70% or more of the ground are covered the risk for degradation because of bare ground is considered small.

For the above mentioned reasons the percentage of bare ground is displayed in Figure 24. In autumn the fraction of plots with 70% and more of bare ground is visibly much larger than in the other seasons. This makes sense when remembering that also the amount of fallows (brown shades in figure 23) is largest in autumn.

For five categories of soil cover the number of indicators per field was calculated. The categories are: <10%; 10-30%; 31-50%; 51-70% and >70% of ground covered. The highest number of indicators per field is found for the lowest percentage of ground covered, throughout the seasons. The ratio between the categories “<10%” and “>70%” is about 5 to 1, meaning that there are around 5 times more indicators per field if the soil coverage is low than when it reaches 70% and more.

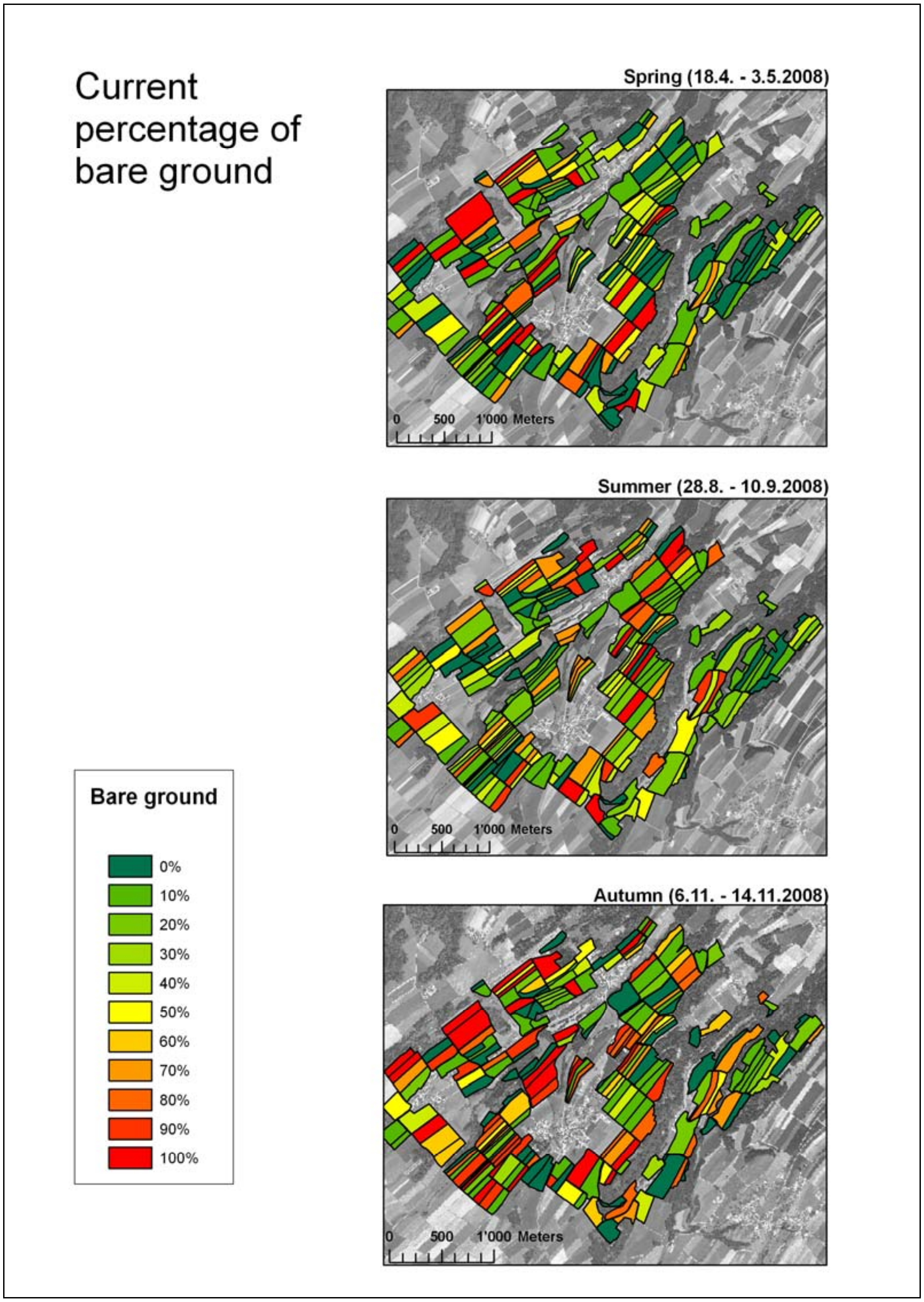


Figure 24. Seasonal changes in ground cover displayed as the current percentages of bare ground. In autumn a generally higher percentage of bare ground (red colours) than in the other two seasons (maps: J. Gasser).

5.2.4 Soil Management

The last point that is assessed for every field is the soil management. As explained in section 4.3.4 we generally distinguish five soil management systems: direct seeding; no-tillage, extensive; no-tillage, intensive; tillage, extensive and tillage, intensive. To these five categories a sixth was added, which is referring to plots that are not under a soil management system, at least not at the moment. As it is often difficult to tell the difference between extensive and intensive management for the aforementioned reasons, this distinction is not made for the display where only the four main categories are shown (see chapter 4.3.4).

Theoretically the soil management on each plot should not change much within one year. It is unlikely that a farmer switches from tillage to direct seeding and back within a year. Even so there are some changes especially with the fourth category "(currently) no land preparation". This category refers to the plots where the management system is impossible to determine because the soil there is either not managed at all (grassland) or it is no longer visible because on the plot in question there has been grass for more than one season and thus old traces of past management are obliterated. There is also some change with fields in the categories "direct seeding" and "in-mulch seeding". They will be commented in chapter 6.2.2.

Looking at the number of degradation indicators per field, the number of indicators on the prepared fields is lowest for directly seeded fields with values between 0.4 and 1.0 indicator per field. For in-mulch seeding the values are between 2.5 and 4.1 indicators per field. Even though the latter value is higher than the lowest for conventional tillage, which reaches values of between 3.9 and 4.8, on average the fields under in-mulch seeding were still showing less indicators. By far the lowest numbers of indicators per field were seen in the plots without any soil preparation at all. For those the numbers lie between 0.4 and 0.7 indicators per field.

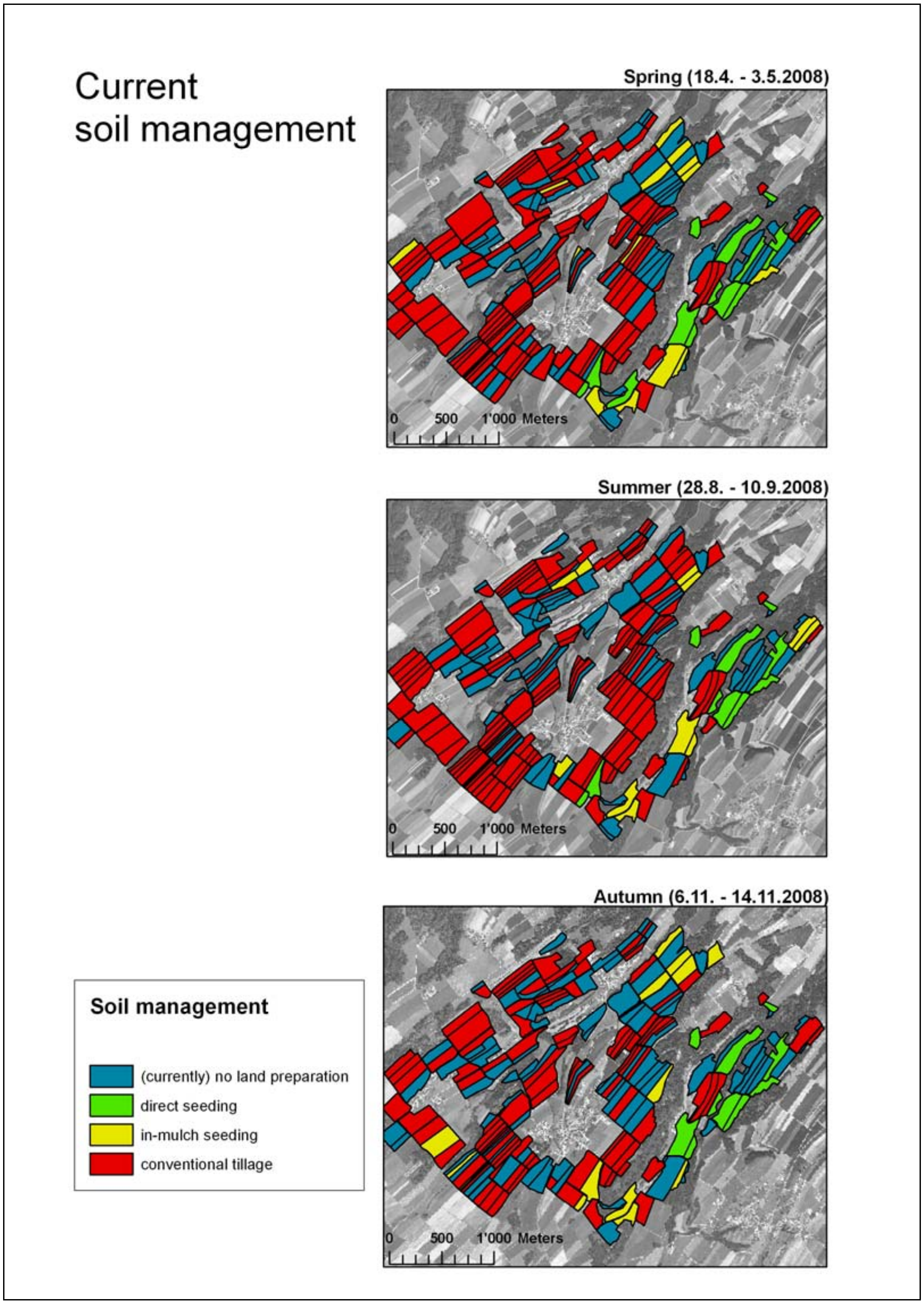


Figure 25. Seasonal changes in soil management with apparently fewer plots under direct seeding in summer and a large part of fields with no apparent signs of land preparation in autumn (maps: J. Gasser).

5.3 Degradation

In a second step degradation was assessed in a detailed way. It was attempted to obtain a plot by plot overview of all the above described visible indicators. On a vast majority of plots there are some indicators visible even though some of them are not severely degraded. It is very important here to keep in mind that many “degradation indicators” are really indicators giving evidence about a disposition to degradation (e.g. “sealing and crusting” or “poor soil structure”). This implicates that only plots with no soil disturbance at all are completely free of degradation indicators. This is possible on directly seeded plots and on grassland and on the latter only if no cattle is grazing there because this is in most cases causing some compaction.

Not all indicators for degradation and for disposition to degradation will be treated in a detailed way. The most common and most significant are commented and illustrated with maps.

5.3.1 Sealing and crusting and surface erosion

Sealing and crusting on the one hand and surface erosion on the other hand have been mapped independently. Sealing and crusting is not necessarily considered to be degradation damage. It is certainly indicating a disposition to degradation. Surface erosion is an actual form of degradation. The two indicators are grouped together in this study because there is a strong connection between the two. Surface erosion never occurred without sealing and crusting. This implicates that sealing and crusting is a pre form of surface erosion. This is because through sealing the erosive energy of the water running on the surface is enhanced and in that sense surface erosion is the damage finally caused by severe sealing and crusting.

Sealing and crusting have been visible on a great number of plots. Figure 26 shows the distribution of affected soil and the severity of the degradation indicator. The pattern is quite similar for all seasons and there are no hints that sealing and crusting are worse in one season than the others.

The picture of surface erosion damage seems much more harmless in comparison (figure 27). No specific erosion damage mapping was carried out and the times for mapping were not chosen for the highest probability to find erosion damage. Even so the picture of the three seasons is quite similar. In autumn during the last mapping session, the assessment of the grade of the damage was handled more restrictively, closely following the manual. Therefore the damage was always considered to be light.

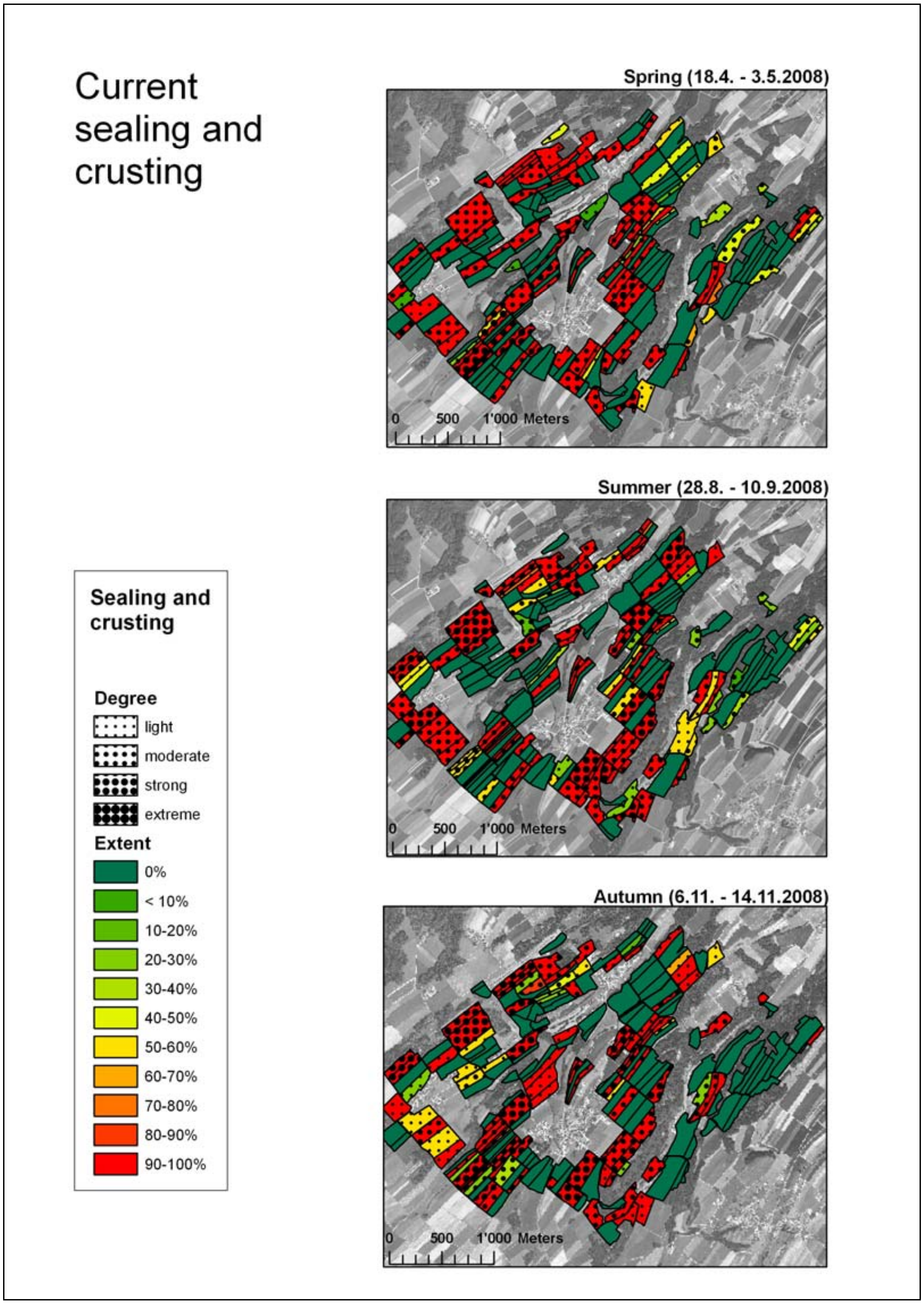


Figure 26. Seasonal maps displaying the current degree of sealing and crusting with different size dots and the corresponding extent of the field affected in the green to red colours (maps: J. Gasser).

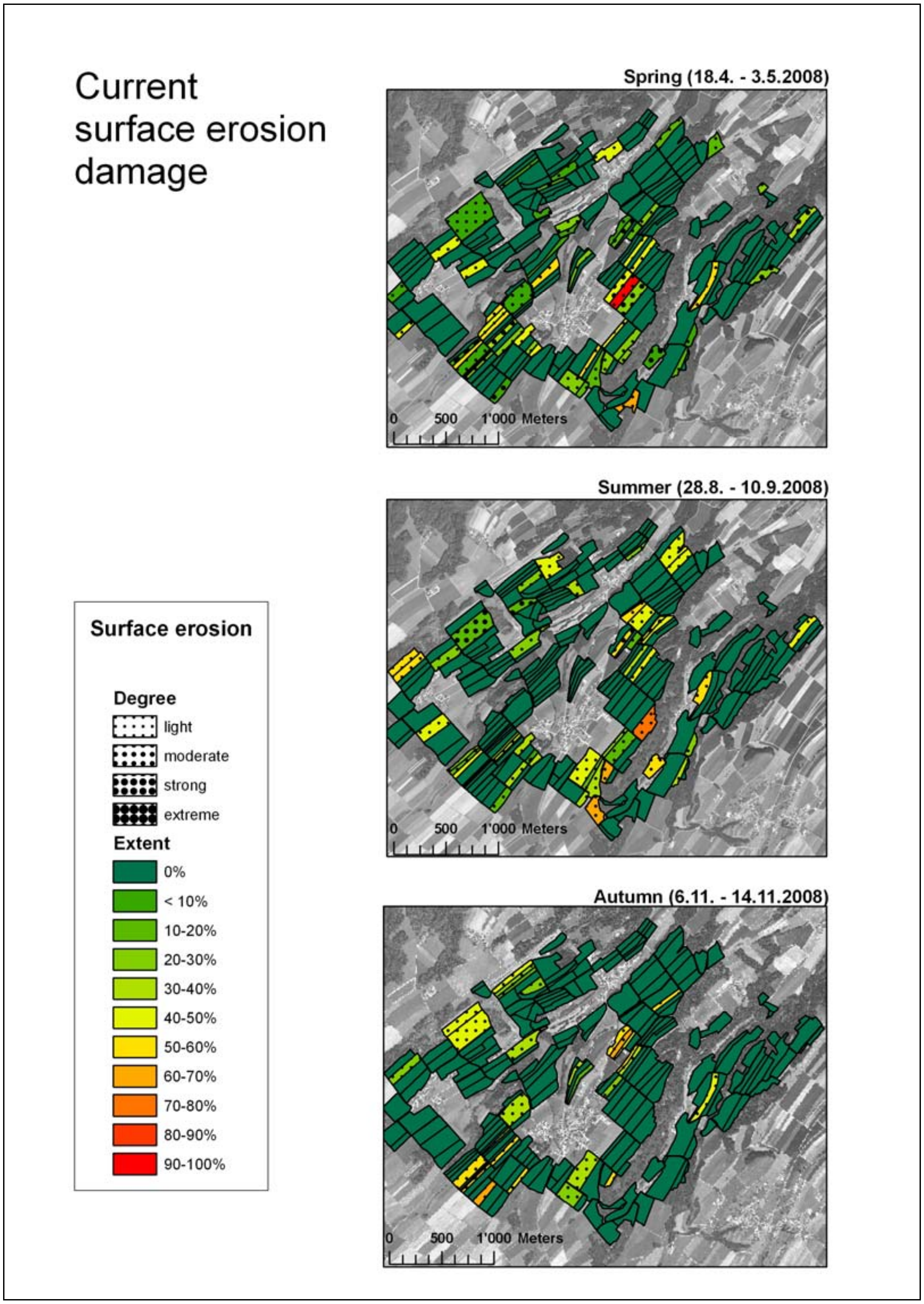


Figure 27. Current degree and extent of surface erosion damage with rather low extents and light degrees (maps: J. Gasser).

5.3.2 Poor soil structure

This indicator has been developed within the scope of the field work. During the first field work phase it was found that sometimes the soil was not sealed or crusted or there was no visible compaction but still the structure of the soil could not be considered to be in a healthy state. The definition of the indicator was quite intricate because soil structure is complex. Intuitively we think of a bad soil structure to manifest in a very hard, compacted soil. Even many farmers say that the soil under a meadow or on a directly seeded field is “hard”. But after comparing many fields it is obvious that even if the soil is harder it has a better structure than the soil on a ploughed field. Vital in the discussion of soil structure are the soil crumbs. If the crumbs are healthy they form a firm (but not compacted) structure, ensuring the bearing capacity of the soil as well as the porosity and thereby the good mix of solid, liquid and gas components of the soil. Poor soil structure can thus appear in different ways. Especially the difference between the wet and dry state is striking. In the wet state the soil is soggy, completely wet and a homogenous mass if the soil structure is bad. In dry weather the soil is absolutely dry, taking a pulverised and dusty form. Basically the amplitude of humidity is much more extreme than if the soil has a healthy structure. Good porosity makes sure that water can infiltrate into the soil in rainy weather and that water is stored in the soil in dry weather. This function of the soil is no longer working when the crumbs and thereby the pores are destroyed (Frei and Peyer 1991). Hence a flexible approach is needed to assess the soil structure. This is explained in the methods chapter (see 4.4.5) in more detail. The result of the assessment is shown in figure 28 below.

On the map displaying poor soil structure (figure 28) the extent of the field affected by poor soil structure is in the vast majority of cases covering the entire plot (90-100%). Because the plots are fields of homogenous land management and the soil structure is strongly influenced by this it seems logical that the state is extending to the entire field. It is also remarkable that in spring fewer plots seem to be affected. This is probably not giving the right impression. Because the indicator was only set up during the field work it is well possible that it was not taken into consideration in the first phase. It was attempted to complete the missing information but probably this was not achieved thoroughly. Overall about half the plots are affected by a bad soil structure. This is a strong and explicit result.

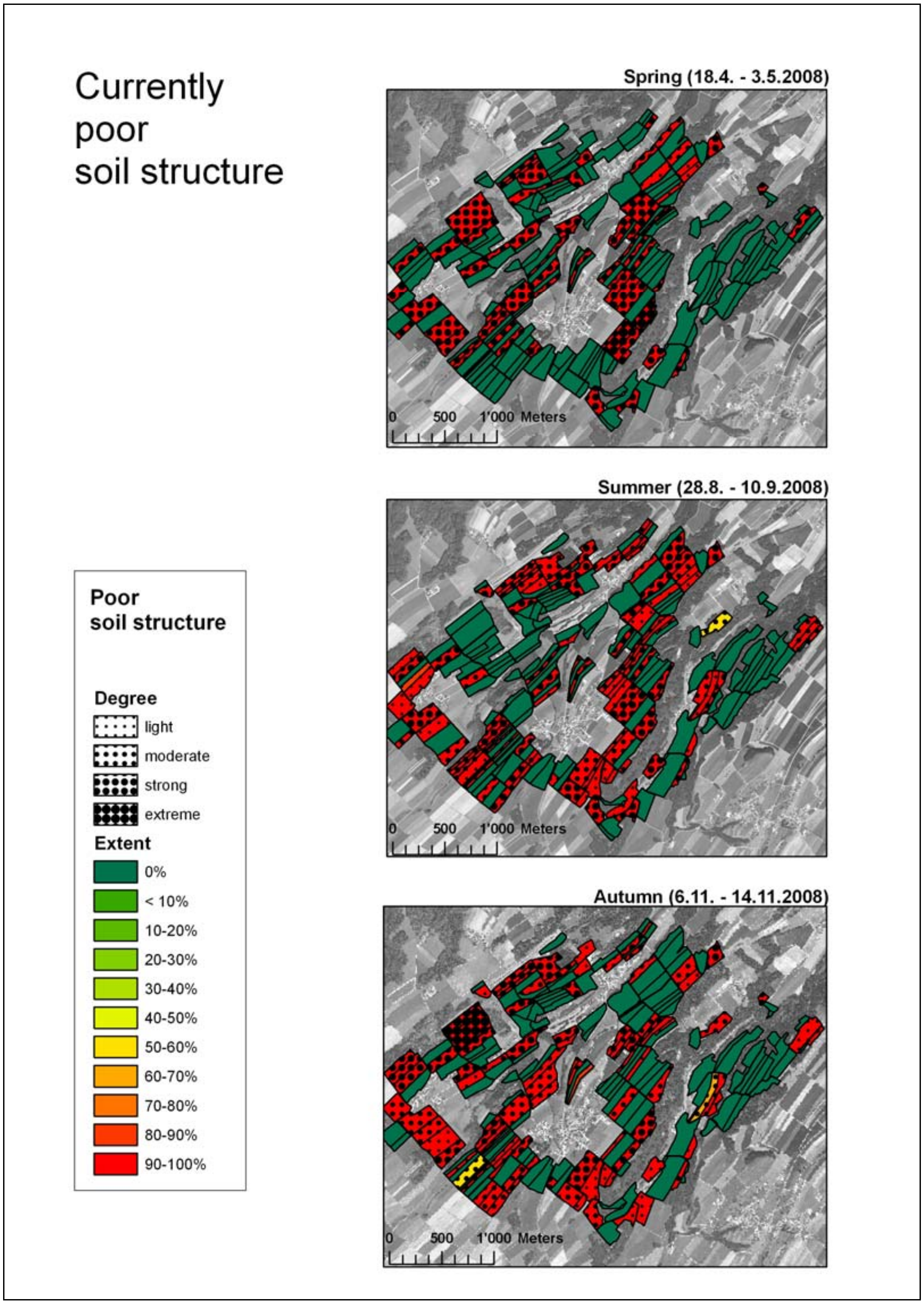


Figure 28. Seasonal maps of currently poor soil structure with changing degree and a nearly constant extent of 90-100% (maps: J. Gasser).

5.3.3 Compaction damage

Compaction in the area is either due to heavy machines like tractors and harvesters or to the trampling of large cattle. It is thus affecting both cropland and grassland. On cropland it is mostly restricted to the wheel tracks and so to a linear pattern covering between 5 and 20% of the whole field, depending on how close together the tracks are and on how wide the tracks are i.e. how big the machines were. On the grassland the distribution of the compaction is random according to the movements of the animals often with a concentration around a water tank or well. This concentration is not considered particularly but a kind of average compaction was estimated.

Instantly visible on the map (figure 29) is the large portion of affected plots. This reflects the fact that compaction is the most common degradation both on crop- and grassland. Furthermore the strong domination of green colours is obvious. This means that the visible and perceivable compaction is only affecting a rather small fraction of the whole field.

5.3.4 Reduction of ground cover and loss of soil life

These are the two “biological” degradation indicators. The first one, reduction of ground cover, is treated in a detailed way in 5.2.3. The judgement of this indicator followed a very clear procedure (see 4.3.3). Also there is no extra figure because figure 24 gives an impression of the ground cover in the course of the year. The reduction of ground cover was always assessed for a whole plot, estimating the average cover. The determination of the degree is following the clear instructions of the manual. The number of fields with a ground cover under a desired level is about the same for all seasons with a slight increase in autumn. Generally about half of the plots are affected. Also the reduction is more severe in autumn which confirms the larger number of fallows in this season. Reduction of ground cover too is an indicator that is not itself considered to be damage. It is also an indicator that can enhance and facilitate damage.

The second biological degradation indicator, loss of soil life, too is always assessed for a whole plot and thus always extending to the whole field. In spring fewer plots are affected than in the other seasons (see figure 30). In summer there were much less earthworms visible than in spring. In autumn as well the numbers were comparably low, which is a surprising result that is commented in detail in the discussion chapter (6.2.3).

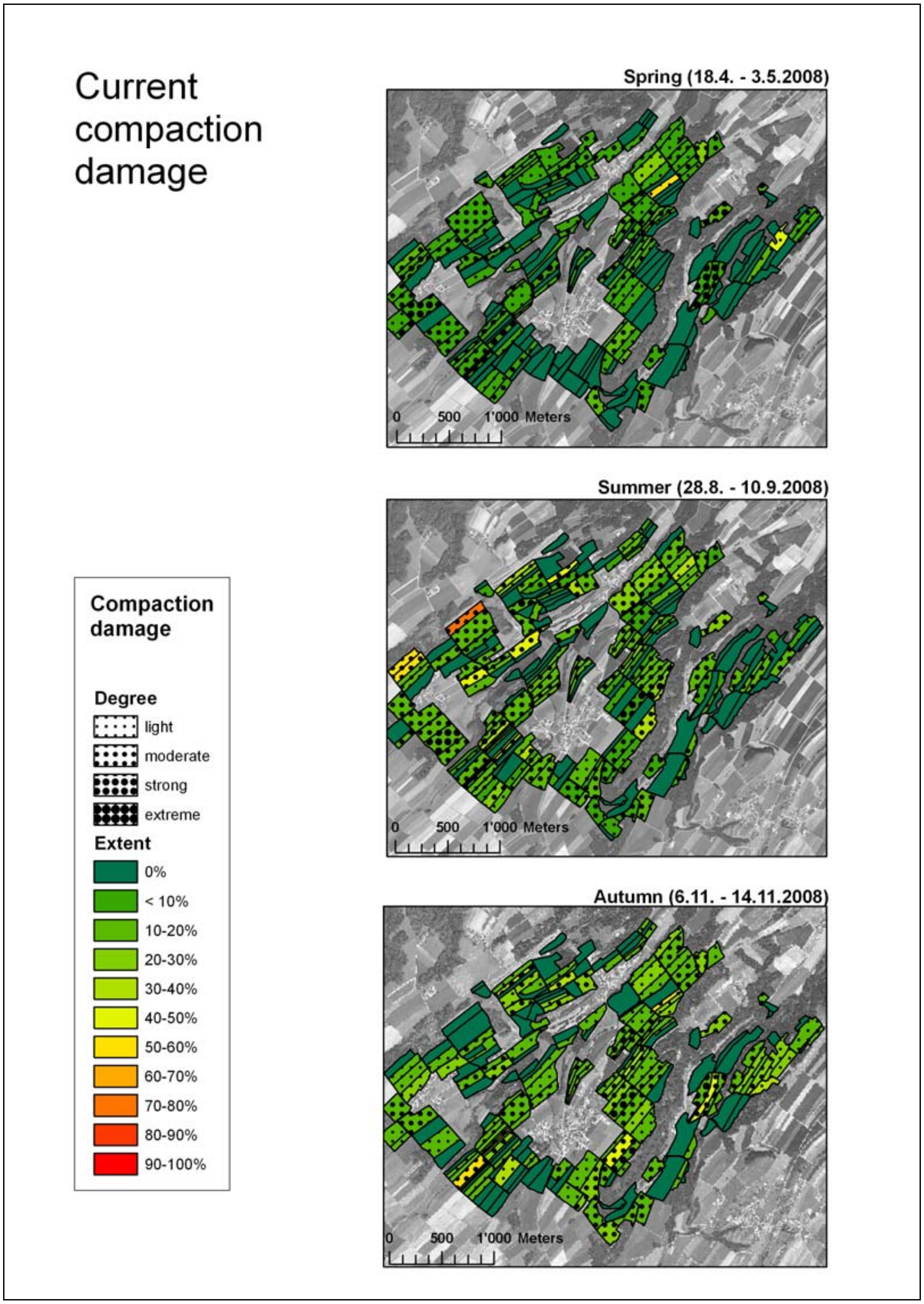


Figure 29. Because compaction damage is in most cases restricted to wheel tracks the maps of the assessed damage in the different seasons all show small extents of mostly around 20%. Obvious is the large fraction of total plots affected (maps: J. Gasser).

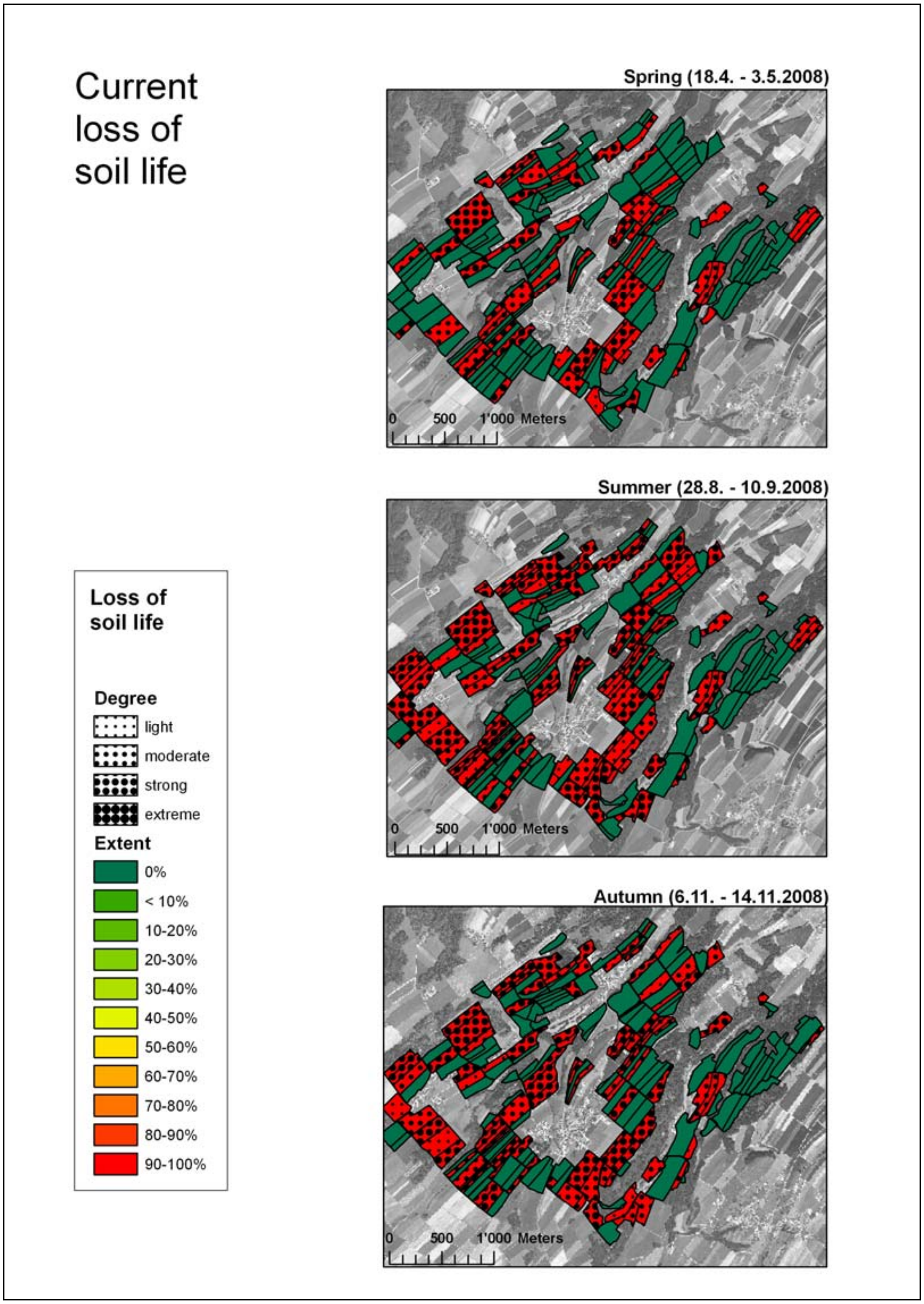


Figure 30. The assessed current loss of soil life is always taken as representative for the entire plot, therefore only the degree is changing (maps: J. Gasser).

5.4 Causes

For every plot on which some indication for degradation was mapped the cause for the indicator is determined. The causes are chosen from a list of plausible causes for degradation in the region according to the WOCAT manual. There might be different causes for one degradation indicator and one cause for several indicators. The decision on causes is less descriptive but more judgemental. The judgement of what the causes for the degradation are is in itself consistent. Similar fields will have very similar attributes. These might however change significantly with the mapper. It depends strongly on the background of the mapper, if it is a farmer or a scientist, if it is someone with a lot of mapping experience or not. Causes for degradation indicators cannot be measured. It always needs someone to evaluate the most plausible explanation why a certain indicator occurs. In the field a feeling for these causes grows. Often the choice for a certain cause is quite straight forward and easy to justify. For example if there is compaction in well visible wheel tracks “heavy machinery” is easily detected as the major cause for the compaction. We can then further ask why the bearing capacity of the soil was not good enough to carry the machines without leaving distinctive traces. If the wheel tracks are on cropland the answer might be that the natural structure of the soil has been weakened or destroyed. This happens through mechanical disturbance of the soil, e.g. through tillage. Therefore the “cultivation practice” is often considered to be a minor cause for compaction. Analogous to this example a connection between all the visible degradation indicators and their causes was established. Some of the causes here are also degradation indicators themselves. Once they appear they are again causes for further degradation. Examples are “reduction of ground cover” or “lower infiltration rates”. For a detailed list and explanation of the degradation indicators and the associated causes see chapters 4.4 and 4.5.

The following chapter will look at the most common causes. It is structured according to these causes. They will be discussed on the background of seasonal changes. There is a distinction between major and minor causes for a degradation indicator.

5.4.1 Heavy machinery

Heavy machinery is considered a very common cause for degradation, predominantly for compaction, with an average of about 50% of the fields affected. In spring the percentage is 47% and in autumn it is highest with 57%. If we take the grassland out of the calculation and only consider cropland the numbers are proportionally higher by around ten percent. This is an expected result because there is generally less degradation on grassland and rarely heavy machinery is used on grassland. Surprisingly the damage caused by heavy machinery is slightly higher in summer than in autumn (69 versus 67%) if we only look at the cropland (see chapter 6.2.3).

Heavy machinery was sometimes also considered to be a minor cause for degradation. This especially in the case of surface erosion, in 10 to 20% of the plots depending on the season and on the sample (grassland included or not). If surface erosion was visible it was commonly worse in the wheel tracks or in some cases even restricted to those. Generally surface erosion is much worse in the headlands of the fields where the machines turn around. This too argues for heavy machinery being a minor cause for surface erosion.

5.4.2 Tillage/cultivation practice

This is the cause most often considered to be responsible for several degradation indicators. It is not only a very frequent cause in proportion to the total number of plots but it is also the cause for a large variety of degradation indicators. It is solely responsible for important indicators like the reduction of ground cover or a poor soil structure. Table 2 shows an overview of different aspects of “tillage/cultivation practice” as a cause for degradation. The top half gives an impression of the number of plots where it causes degradation. The second column of the bottom half gives in the second column the number of different indicators. Apart from the above mentioned “reduction of ground cover” and “poor soil structure” these also include “loss of soil life” as well as fertility decline” for which too the cultivation practice is considered the only cause. Then there are “sealing and crusting”, “compaction” and surface erosion that are also determined by other causes and in summer additionally “soil moisture loss”. The numbers in the third column stand for the total number of indicators caused by “tillage/cultivation practice”. This number is quite accurately 3.5 times the number of plots with “tillage/cultivation practice” as a cause for degradation in all seasons. This means that if “tillage/cultivation practice” is a cause it is on average the cause for 3.5 indicators on the plot. This is quite a large number that implies that if “tillage/cultivation practice” causes damage, it does not cause just one indicator but several. This is different from “heavy machinery” that is always mainly responsible for compaction.

Season	fraction of all plots with "tillage" as cause	only cropland
Spring	111 of 220 or 50%	111 of 161 or 69%
Summer	147 of 225 or 65%	147 of 191 or 82%
Autumn	121 of 214 or 57%	121 of 159 or 76%
	No. of different Indicators	Total no. of indicators with "tillage" as cause
Spring	7	390
Summer	8	511
Autumn	7	442

Table 2. Aspects of **tillage/cultivation practice** as a cause for degradation (source: J. Gasser).

"Tillage/cultivation practice" is also in many cases considered to be a minor cause for degradation indicators. As mentioned above this is especially the case for compaction. While "heavy machinery" is mostly considered to be the major cause, "tillage/cultivation practice" is judged responsible for the poor bearing capacity of the soil that enables and enhances compaction.

5.4.3 Reduction of plant cover

"Reduction of plant cover" is at the same time a degradation indicator and cause for degradation. As described above the cause for a reduction of ground cover is the cultivation practice. Once the bare portion of the ground reaches 30% and more the soil is more prone to degradation. In the assessed area this was especially the case for the degradation indicators "sealing and crusting" and "surface erosion". If the plant cover is very dense they are both very rare. The percentage of plots where "reduction of plant cover" is considered a major reason for degradation is 38% in spring and 52% in summer while autumn is in between with 45%. If we only look at cropland the numbers are again a good 10% higher each time. Here too the rates are highest in summer.

5.4.4 Trampling of animals

"Trampling of animals" was only found responsible for the degradation indicator "compaction". In some places where animals gather around a well or water tank there is also reduction of ground cover caused by the trampling. But for the scope of the entire field this was regarded negligible. The percentage of affected plots is around 5% in spring and summer and 14% in autumn. The percentages here are much lower if we only look at cropland because the grazing of animals usually takes place on grassland. During the mapping in autumn the number of fields with grazing animals was much larger than in the other seasons. This also becomes apparent in the distinctively higher compaction damage caused by trampling of animals.

5.4.5 Lower infiltration rates

“Lower infiltration rates” were mapped as the major reason for the degradation indicators caused by water with high enough erosive energy on the soil surface. This is the case for sealing, crusting and surface erosion as well as waterlogging in spring and autumn, although this form of degradation occurred very rarely. “Lower infiltration rates” were thought to be a major cause for degradation on about 50% of the plots, again with a slight increase in summer.

5.5 Conservation

Essential for this thesis is that not only degradation is mapped and assessed but also conservation. Generally the extent and the effectiveness of the conservation measures were mapped. In the very most cases the extent was 100% because if a measure is taken it is usually applied to the whole field. The only exceptions are hedges and terraces. The effectiveness was sometimes hard to judge because there is no reference as in relation to what it is effective. The question is if for example crop rotation is effective in relation to a monoculture or in relation to a desired state of the field. For this work the second option was chosen because the relation to a state that is not vulnerable to degradation is much more relevant than the relation to a hypothetical cause that is very improbable. This means that for the judgement of the effectiveness of a conservation measure the number and severity of the degradation indicators was relevant.

5.5.1 Direct Seeding

Direct seeding is practiced on a small fraction of the total plots, i.e. around 5%. There is only one farmer that is consequently applying the method. In summer fewer plots were judged to be under direct seeding than in the other seasons. The reasons for this probable underestimation were given: they have to do with the crop rotation that includes root crops that are putting a lot of strain on the soil. Nevertheless the effectiveness of direct seeding was judged very high in comparison with conventional tillage systems (figure 31). It was common that on directly seeded plots no degradation was seen. This was never the case on a conventionally tilled field.

5.5.2 In-mulch seeding

This form of management too was not implemented very frequently. The percentages lie between 5 and 7% and are only slightly higher as the ones for direct seeding. Again in summer the percentages are lower than in the other two seasons.

The effectiveness of in-mulch seeding was judged lower compared to direct seeding (see figure 32). As only the soil surface was assessed this is not extraordinary because the top five to ten centimetres still get disturbed quite strongly with a grubber or similar tool. Therefore the soil is still prone to sealing and crusting and the structure on top is not in a very good state. The soil organic matter content and also the soil structure further down might be much better compared to conventional tillage but this would not appear in this assessment.

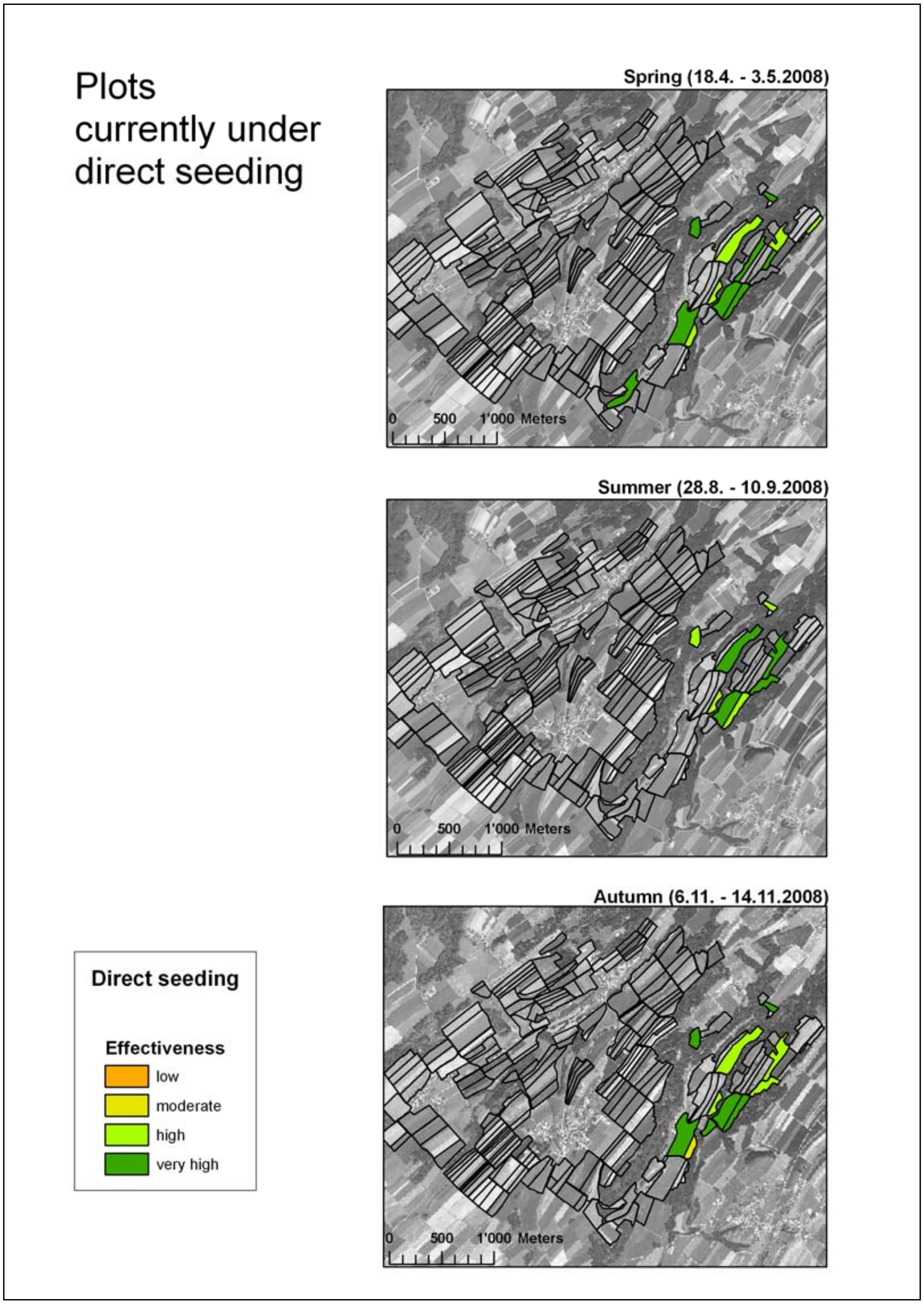


Figure 31. Seasonal maps of plots that are currently under direct seeding with a generally very high associated effectiveness of the conservation measure (green colours) (maps: J. Gasser).

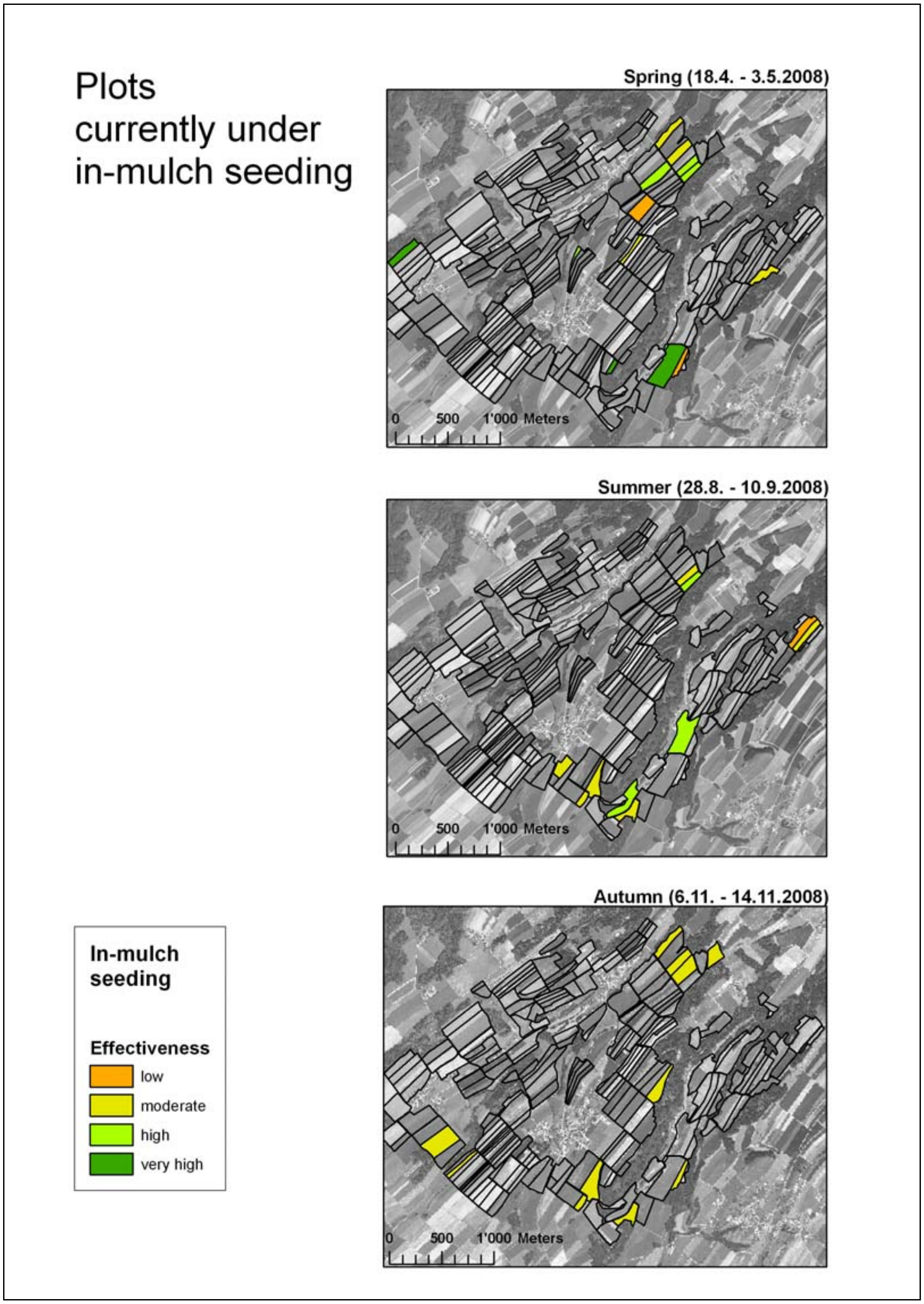


Figure 32. The observed effectiveness of in-mulch seeding, which is only implemented on few fields, is moderate to high for all seasons (maps: J. Gasser).

5.5.3 Crop rotation

The percentage of fields under crop rotation is the same as the one describing the fraction of cropland of the total area. In other words this means that there is no other system used, there are no monocultures. This is very typical for Swiss agriculture. It was therefore in the beginning difficult to decide on what basis to judge the effectiveness of the crop rotation system. In comparison to a hypothetical monoculture a crop rotation system would always be very effective. But then it did not seem sensible to draw a comparison to something hypothetical. Therefore, as explained above, it was decided to put it into relation to a desired state of the field. In short if there were many degradation indicators, the effectiveness was considered low and if there were few or none the effectiveness is thought higher. Figure 33 shows that the effectiveness of crop rotation was very often judged to be low. This is because it could not greatly lower the number of degradation indicators by itself (as opposed to direct seeding for instance). The effectiveness was only appointed higher if the field was currently under temporary ley.

5.5.4 Grassland management

Grassland management is used on literally all fields with grass on them. Not only if they are fenced but also if they are used for fodder production and within a crop rotation. In this point there were some problems in the first mapping period in spring. The conservation measure was then called “grazing land management” and therefore only fields with clearly visible signs of grazing were considered. This was then discussed and changed during the process. The name grazing land management proofed to be confusing and the conservation measure was renamed “grassland management”. All farmers take more or less effective measures to prevent overgrazing. As the animals are always fenced in and the grazing is rotational management conservation measures are also applied on the fields not used for grazing. There is no uncontrolled overgrazing possible.

The maps (figure 34) show that the interpretation was different at first in spring. There were significantly less plots marked to be under grazing land management. In summer and autumn the total number is larger. The picture combines all grassland with all temporary leys within the cropland. In summer and autumn the effectiveness is sometimes also considered to be moderate. Nevertheless in general the effectiveness is high or very high. This underlies the fact that under grassland the overall state of the soil is good.

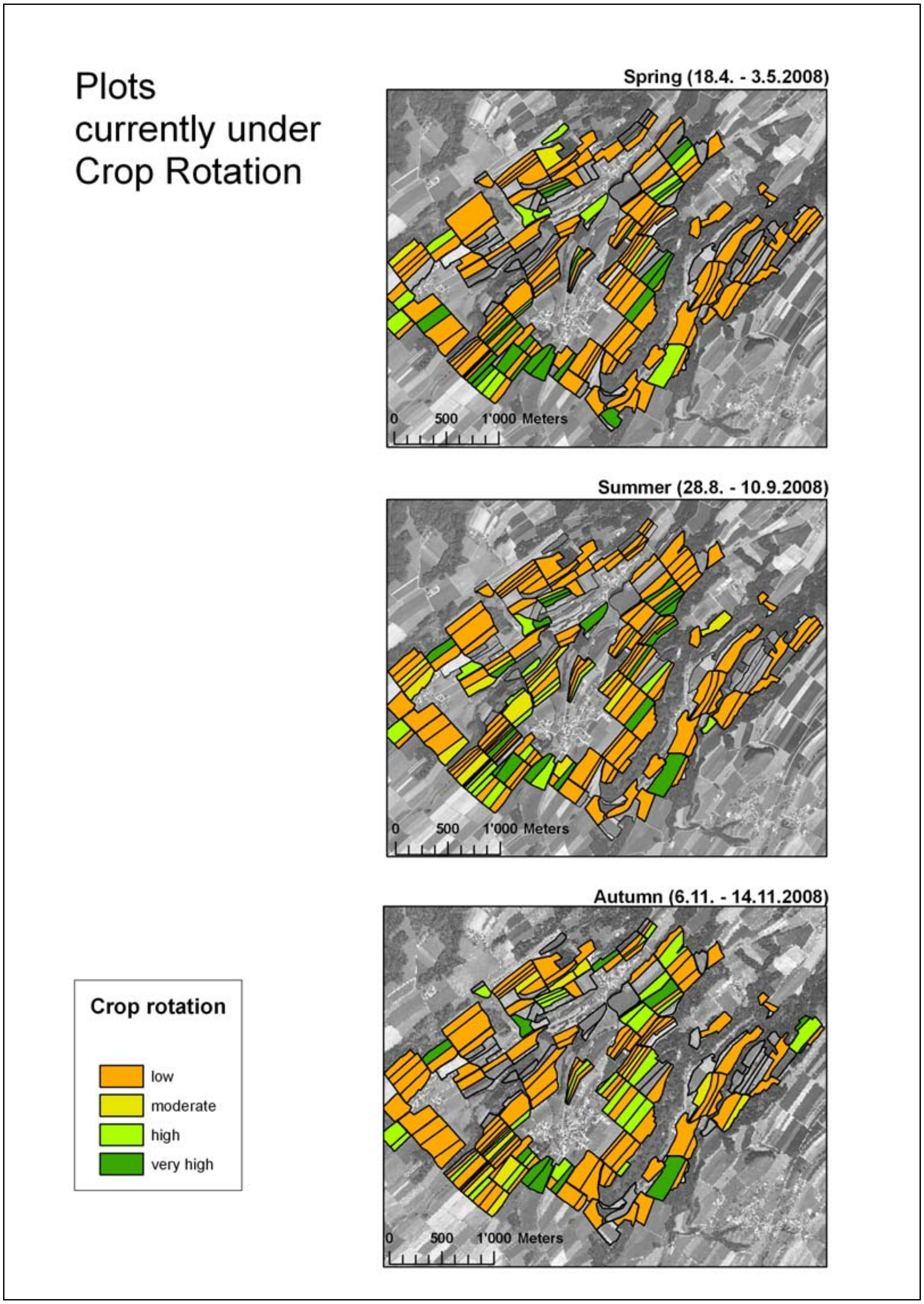


Figure 33. As all the fields used for the cultivation of crops as well as the ones under temporary ley are under crop rotation, the fraction of total plots is very large. The effectiveness of the conservation measure is however low in many cases (maps: J. Gasser).

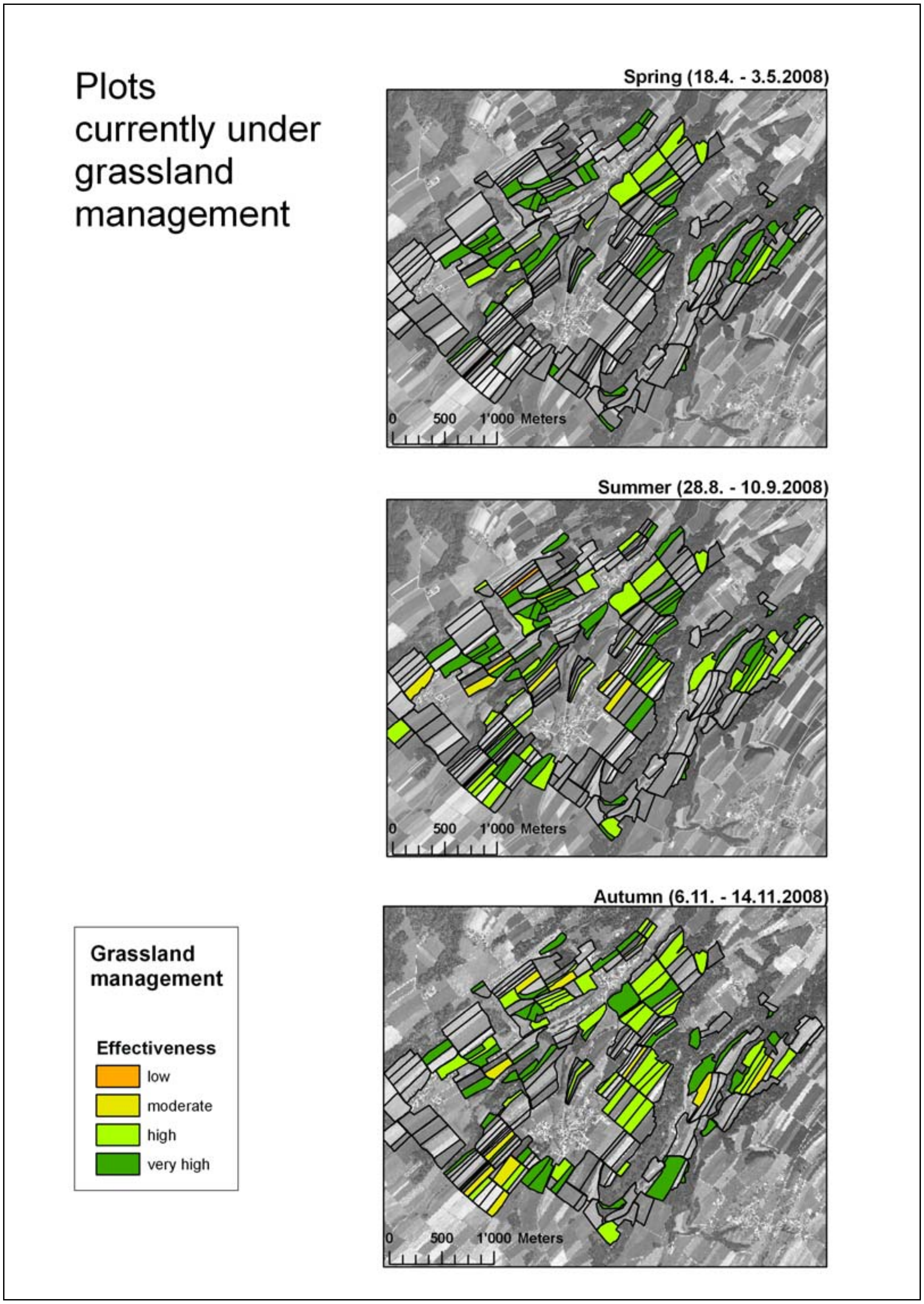


Figure 34. Seasonal maps for the use of grassland management show an increase in the fraction of plots in autumn. In all seasons the effectiveness is moderate to very high (maps: J. Gasser).

6 Discussion

6.1 Method

Speaking in the structure of this thesis discussion of the method is somewhat a mixture of “results”, “discussion” and “synthesis”. The adaption of the existing WOCAT/LADA methodology was a fundamental part and an objective of the thesis, the method used is also a result. To keep the work consistent and easy to understand the discussion of the method will take place here. In most points the adaption to the local circumstances was successful.

A first problem that emerged was that it was not possible was the assessment of the functioning of ecosystem services (see chapter 3.2.1). This is one of the main purposes of the WOCAT/LADA methodologies. To solve this problem the data series needs to cover several years and be completed with necessary information from experts and specialists. Both points were not possible within the scope of this thesis. The results of this thesis are however contributing towards that aim.

Also some desired indicators, like “reduction of soil organic matter”, proofed not to be possible to assess in the field and so they were left out while others, like “poor soil structure”, were added. This flexibility, to add, alter or leave out indicators, is a specific property of the method which proofed to be necessary, useful and well functioning.

A further difficulty lay in the mapping itself. As the mapping was carried out three times it was refined each time and the chosen times for mapping were evaluated as well. It seems now that the information gain was not very large between the seasons. The results generally showed the same tendencies. In summer the degradation indicators were usually somewhat more pronounced but maybe the conservation indicators were therefore underestimated. Opposed to the information gain between the seasons the effort is very large and the mapping is time consuming. Within this thesis it was therefore impossible to immerse in one or two selected aspects or to complete the picture with additional data. For future assessments it would probably not be worth while to carry out such an intensive effort, especially also because the amount of collected data is difficult to handle, not only because of its quantity but especially because of its heterogeneity (heterogeneity refers here to the fact that all the assessed aspects have different data structures: degradation indicators differ from the described causes etc). As the testing and adapting of the method was a purpose of this thesis the effort put into mapping is certainly justified. Also the mapping experience was enhanced. This is important while comparing the results. Probably the results of the autumn mapping period are the best. This not only because of the greater mapping experience and routine but also because many indicators are best visible in the more humid seasons. And in autumn the entire growing season has left its imprint on the land.

One of the goals of the mapping that was very successful was to find out if the distinction of different land use systems is possible and sensible in the field. The different land use systems do leave distinguishable traces on the land and they can be made out in the field. Thus the adaption of the method is possible and the integration of the results also. This point is elaborated in detail in chapter 7.2.

6.2 Results

In a wider perspective the aim was to the describe the state in a way that would allow to put it into the wider context of the interrelations of specific drivers, pressures and finally impacts and responses following the DPSIR model (see 3.1). In the scope of this thesis only a small aspect of this wide field could be treated. The achieved description of the state of the land in the area is however very detailed and it should thus be possible to put the result in line with further efforts made on the subject. Some suggestions thereupon are made in the following two chapters.

If the focus of what degradation is widened as it is here, including not only degradation damage but also indicators of the disposition to degradation, it is striking how much of the land is affected. In the introduction to this thesis land degradation was mentioned to be a world wide problem, of course with very different grades of severity and characteristics. Of course the state of the land in Switzerland is not leading to life threatening situations as it is elsewhere. Even so the statement made at the beginning of this work on the basis of literature read on the topic can now be confirmed with the results of the collected data. Land degradation is a threat in Switzerland. Yet there are signs that show that there are ways and methods that could prevent the worst.

There are some phenomena and particularities in the results that require explanation. They are here thematically grouped.

6.2.1 Soil cover

Here this subtitle is used in a wider sense, referring to all possible soil covers and not like above just to a percentage of covered ground, no matter what the cover is. A first particularity that stands out is the changes in land use types (see 5.2.1). Theoretically the land use type should not change much. Of course, according to the definition used here, there can be changes from annual cropping to perennial cropping and vice versa. The fields considered to be grassland, i.e. permanently used for grazing or hay production, should be the same at all seasons. Because grass is part of most crop rotations and usually for at least two years in a row it is sometimes not possible to distinguish cropland from grassland correctly.

Supposedly the picture is most correct in autumn. For one the plots have been assessed for the third time then and therefore they were mapped with more knowledge of the area and more mapping experience. Secondly all the plots considered to be grassland have not been used for the production of other crops within this year. Of course also here mistakes are not ruled out. The average overall ratio of 2:1:1 between annual, perennial cropping and grassland is consistant.

The number of degradation indicators was always strikingly lower on plots with a grass cover, with permanent grassland being in a better state than plots with a perennial (two to three years) grass cover within a crop rotation. A grass cover is soothing on the state of the soil. During the ley period of a crop rotation the soil is not disturbed. The soil structure is thus improved. this is further enforced by the fact that on grassland fewer rides with heavy machinery are necessary. For these reasons a moderate to high effectiveness of the conservation practice “crop rotation” was observed in the first year of temporary ley and a high to very high effectiveness in the following year(s). Consequently the effectiveness of grassland management was most often considered to be high or very high (see figure 34) with a few exceptions. This might be for fields that are under temporary ley for the first season so that the soil has not yet recovered from the tillage or it might be on plots where there are a large number of animals and therefore there is strong trampling damage.

6.2.2 Land management

There are seasonal changes in the category soil management. This is surprising as it is not common for a farmer to change the management system within a year. Yet there are other plausible explanations for the fact that the soil management is changing within the year. Depending on the crop rotation, farmers sometimes find it is not necessary to till even if they usually practice tillage. This might explain changes in the portion of fields that are under in-mulch seeding. There are also changes in the fraction of supposedly directly seeded fields. There the explanation is different. In summer the portion of directly seeded fields visible is smaller than in the other seasons. There are a couple of plots that are under direct seeding in spring and autumn and in summer they were assessed to have suffered some kind of soil preparation, although without tillage. At second sight it occurs that this is only the case for fields where sugar beet was grown. The harvesting of sugar beet disturbs the soil so much that the field is no longer distinguishable from a plot with a mechanically stirred up soil. This probably led to some wrong judgement in summer.

6.2.3 Seasonal particularities

In autumn the fraction of grassland (perennial cropping and grassland together) is larger than in summer. There were freshly sown meadows visible while mapping which was not the case in the other seasons. Obviously it is common to start the grass part of a crop rotation cycle with the end of the season. Maybe this is also thought to protect the soil in winter. Not only the percentage of grassland is larger in autumn but also there is overall more exposed bare ground than in the other seasons. Looking at figure 23 the overall impression is of more orange and brown colours in autumn. This is not surprising as autumn is the classic harvest season and thus many fields will either be just harvested (stubble fields), bare fallows that may be freshly ploughed or ready prepared seedbeds. Many freshly sown crops have been observed in autumn, not only the already mentioned young grass covering the fields but also several fields with just sprouting winter cereal or little rape plants have been counted. Especially winter cereal is problematic for the soil as the very young plants do not cover the soil sufficiently in the cold season. The soil on these fields is insufficiently protected against surface erosion during that time. If the soil is not frozen or covered in snow and there are a couple of heavy rainfalls, the danger of surface erosion is quite large. As the cereals do not cover the soil to a protective degree until late in spring, the soil is left prone to erosion for just about half a year and the probability that sometime during that period the soil is exposed to heavy rains is large.

Another seasonally changing degradation indicator is “loss of soil life”, i.e. the earthworm acitivty. In spring fewer plots are affected by this degradation indicator than in the other seasons. This is according to expectations as earthworms are active closer to the soil surface in wet than in wet weather than in dry. This might lead to a biased picture in summer because even if there are no earthworms visible they might still be there just deeper down under ground. The picture in autumn however is less expected. The earthworm activity should be about the same as in spring. Maybe autumn was dryer this year than in others. A second reason is that farmers might bring out slurry to manure their fields after harvesting. Autumn is considered the best season to bring out liquid manure as the danger for volatilisation or washing out is smallest then (BLW 1994). Liquid manure is harmful for the earthworms, killing significant numbers of them. This might be another reason for the unexpectedly small numbers of earthworms in autumn (Gassman 2008).

Also there is a general increase in compaction damage caused by heavy machinery in the second half of the year. This can be explained by the large number of fields that are freshly sown with winter cereal or rape in autumn. Soils are very prone to compaction damage if they are strained with heavy machinery when they are wet. This is more probable in autumn than in summer. Also in autumn there are more rides with the heavy machines necessary than in the other seasons. It is the main harvesting season and sometimes the farmers cannot wait for the soils to dry. Also new seedbeds are prepared and most farmers still use the conventional methods to do this what generally requires at least three worksteps, each including heavy machinery (see figure 23): First the field is ploughed, then some preparation has to take place to crush the large furrow slices and at last the fresh seeds have to be distributed. This puts a lot of strain on the soil.

In summer there is generally the largest number of visible degradation indicators. The summer mapping took place late in the season and therefore after the harvest of all winter cereal and rape, leaving many fields bare but not yet freshly cultivated. Further there are some indicators that are better or even only visible in summer. For example soil moisture loss was only mapped in summer because in the other seasons the last rainfall was never long enough ago for the soil to dry out. The indicator “loss of soil life” is problematic in the warm season. As explained above in dry and warm weather earthworms live deeper down underground and thus even if there are no earthworm casts visible on the soil surface there might be a healthy population further down. With the chosen method of of estimating the coverage of earthworm casts on a field their population must have been systematically underestimated in summer. Summer is not a good time to judge on this aspect of degradation and the result is surely biased. However as seen above the numbers or earth worms were not much higher in autumn. It seems more probable that this explains a real degradation. A further and maybe most important point that might to some extent explain the larger number of plots showing visible signs of degradation is that for the majority of the degradation indicators “tillage/cultivation practice” is considered a cause. In summer the largest number of plots is actually cultivated and bearing crops. In autumn there is a larger number of fallows, i.e. plots that are currently not managed. These also include green manure and temporary leys. These plots are in a generally better state and often the traces of the cultivation practice are obliterated. The same is true for spring with slightly different characteristics (less fallows, more freshly prepared fields). In summer the part of freshly prepared fields is smallest. As a consequence the signs of degradation have had most time to manifest and they are not wiped out by an upturning of the soil. This is also the explanation why there are many degradation indicators even though the soil cover is generally better than in autumn. In the months before the soil cover has been poorer for the time it took for the plants to grow. All the sealing and crusting or other signs of degradation are preserved on the soil surface. The soil would take longer to recover than the available time. Hence soil cover is only effective in protecting the soil from degradation if it lasts for a long enough time.

The one indicator that is strikingly higher in autumn than in the other seasons is “trampling of animals”. A possible explanation for this phenomenon is that many low land farmers in Switzerland shift their live stock to the Alps where it is looked after during the warm season. An additional explanation why there is less cattle and thus less trampling in summer is because in very hot weather the farmers also keep their animals inside. During mapping in summer temperatures were probably high enough for this.

6.2.4 Comparison with research carried out in the area

In the theory part some research made in the area was described. Some of the results of this research are here briefly compared to the results of this thesis.

According to Thomas Ledermann (2008a) 10 to 40% of the total arable farmland is affected by soil erosion. The percentage damaged by soil erosion made out here is rather smaller. This is certainly due to the fact that not an erosion damage mapping was carried out. If we look at the percentage of arable farmland that is showing a large number of indicators that describe the disposition to degradation we get a picture that is confirming the mentioned percentages: just less than half the cultivated land is conventionally tilled and these fields on average show more than four indicators of degradation. Compared with the result of Ledermann this seems plausible. He further made out larger erosion damage in Murist than in the other investigated areas. To comment on this the comparison with the results of the other thesis carried out on the subject would be necessary. This is not yet possible (see conclusions). Another very important point of his, which can be compared to this thesis, is that soil cover is the most important factor controlling erosion. Even though the superlative would here be used with caution, it is certainly in accordance with the results of this thesis, that soil cover is a very important factor for the protection of the soil surface. As described above, the difference in how many indicators there are per field, a ground that is covered by more than 70% is on average showing 5 times less indicators than one with a soil cover of fewer than 10%. This is an unambiguous result, confirming Ledermann's. Generally it can be said that there are no important discrepancies between the results of his mapping and this here, even though different methods were used and different indicators were mapped.

The second work that was carried out in the region was Mike Chisholm's diploma thesis. He tested a GIS modelling tool to predict soil erosion in the region. He calculated a disposition to erosion with the help of this data processing tool. Figure 36 shows one of the maps he produced while figure 35 is a corresponding map based on the assessment for this thesis.

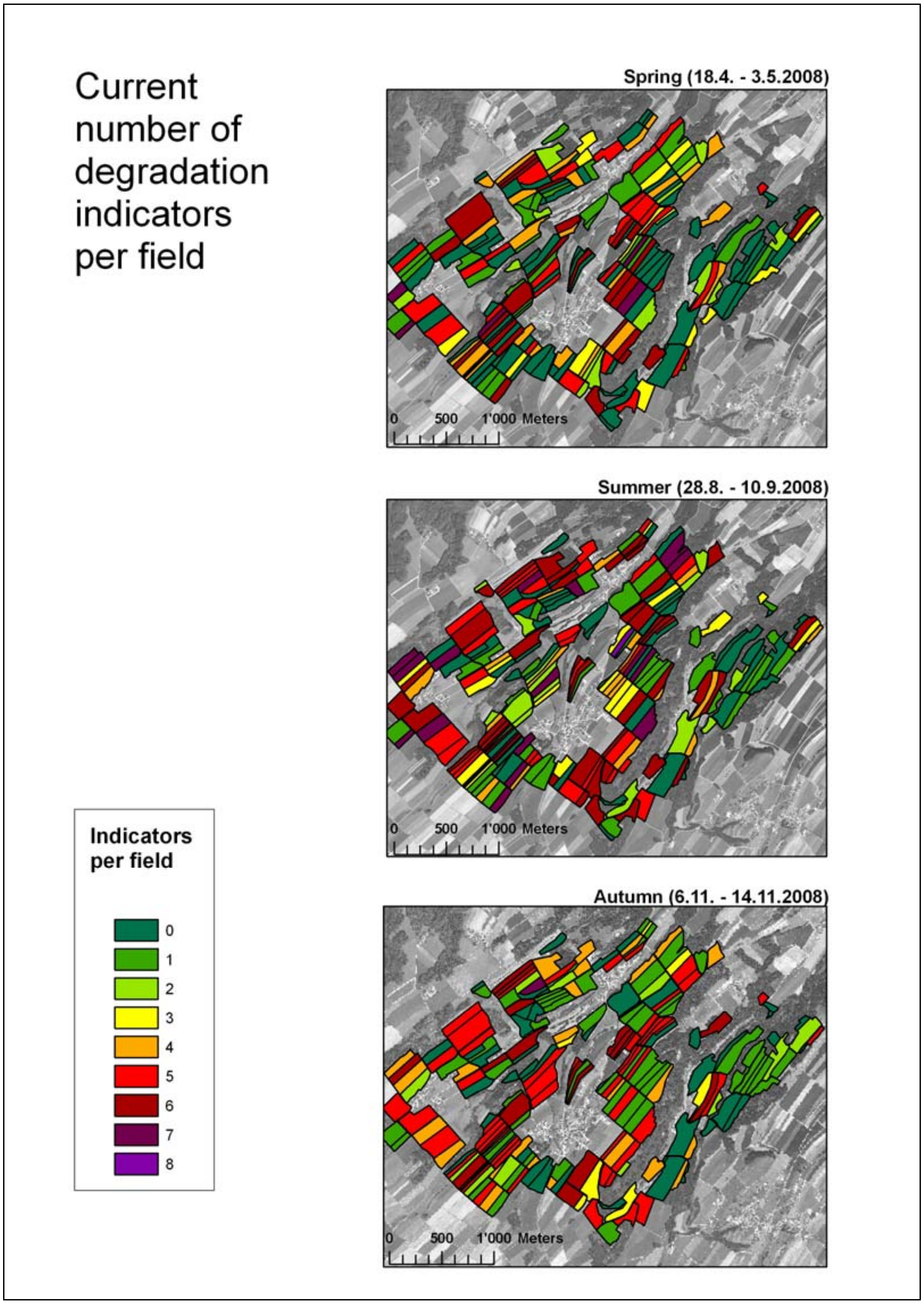


Figure 35. Seasonal maps of the number of degradation indicators per field showing a slight increase of red colours in summer and a generally similar picture (maps: J. Gasser).

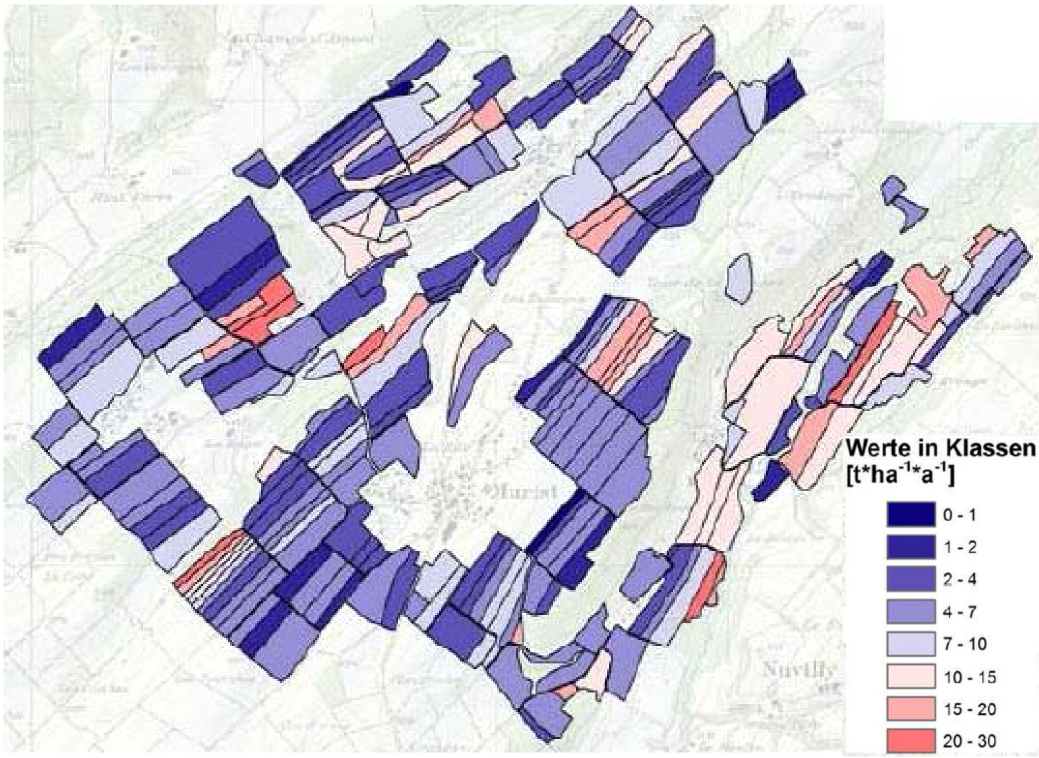


Figure 36. Modelled potential erosion in Murist with red colours on plots with high potential erosion damage and blue for those with a small one (source: Chisholm 2008).

On this map the potential erosion is modelled per field on the basis on a 2m grid. The legend shows the values in classes with the unit “tons per hectare per year”.

Opposed to that is the map showing the assessed indicators of this thesis here (figure 35). The number of indicators per field is thought to hold corresponding information. If we compare the rose and reddish colours in his map with the colours of the map in figure 35, we see a rather poor accordance. Where in his model plots are vulnerable to degradation, the results of this thesis mostly show fields with only few or no degradation indicators at all. This is probably due to the fact that in Chisholm’s model there is just one standard value for soil cover. For example he did not distinguish between grassland and bare fallows. Further there is no distinction in the model between different land use types. If we look at the map with the land use types (figure 22), we see that most of the plots that have a higher potential erosion calculated by Chisholm are actually grassland – probably exactly for that reason. In a follow up thesis is just now carried out by Simon Gisler. He is including crop rotation information into the model to enhance the accuracy of the factor describing soil cover in the model. Unfortunately his results are not yet ready but to compare them to these here will be highly insightful.

More difficult is the comparison to Matthias Engesser's results. He modelled the effectiveness of the hedges and terraces. Even though these hydrological barriers were mapped, their effectiveness in preventing soil erosion is difficult to estimate in the field. This would only be possible if there would be a field to compare nearby with considerably higher erosion damage. This was never the case in the field. As hedges and terraces slow down the erosive energy of the surface water or in the case of terraces even flatten the slope, it seems very probable that they do have some protecting effect against erosion. However, so far it was not possible to estimate the effectiveness of these conservation measures.

The comparison to the results of Christine Hauert's diploma thesis was equally impossible. She measured soil organic matter comparing different land management types. As repeatedly mentioned soil organic matter content is not visible in the field. Her results can therefore contribute to this thesis only on a theoretical level.

Part IV

Synthesis

7 Synthesis

7.1 Methods

The testing and adaptation of the WOCAT/LADA method is the fundamental part of this thesis. The “Questionnaire for Mapping Land Degradation and Sustainable Land Management” is designed to “obtain a picture of the distribution and characteristics of land degradation and conservation […] of a district, a province, a country, a region, or ultimately world-wide.” (Liniger, van Lynden et al. 2008). For this thesis the questionnaire was adapted for the use in the Swiss plateau and for a single commune, i.e. for a plot by plot analysis. The result of this adaptation is the detailed mapping tool, repeatedly described and mentioned above (also see annex). This tool is by now a good means to assess and evaluate the state of an agriculturally used field in a rough and simple way. To further use this description of the state of the land for a subsequent objective is a different matter. The aim of the work is it to integrate this information in order to gain knowledge about the impact of land use systems on the land. To adapt a method means that it is changing in the process. This happened several times. Sometimes because it was not possible to assess an indicator in the field, like in the case of soil organic matter. As described above, it is not visible in the field if a soil is rich of organic matter or not, this needs further laboratory analysis. Sometimes indicators also changed because they only became apparent during field work and were not thought of while designing the mapping tool. An example here is the indicator “poor soil structure”. Therefore the tool, and with it the mapping method, changed during the process. This was one aim of the thesis and the outcome is a useful mapping tool. While being absorbed in the field work and occupied with problems of digitalising and displaying of the data it was sometimes difficult to always keep the superordinate objective in mind.

7.2 Results

In this context it was a lesson learned in the process of writing this thesis to acknowledge the necessity of regularly comparing the results of the field work to the hypotheses of the thesis. The first of these hypotheses is that “different land use systems mark the land in a particular way”. In the theory part “land use system” was defined as a combination of the different possible land uses with the different management practices. Distinguished land uses are: 1) annual cropping; 2) perennial cropping (leys); 3) grassland (see figure 22). The observed land management practices are: 1) no soil preparation; 2) direct seeding; 3) in-mulch seeding and 4) conventional tillage. Theoretically this would result in twelve different land use systems. As grassland is never on prepared soil the three preparation methods are obsolete, reducing the number of land uses to seven: Grassland (which is thus a land use system without further differentiation); then the three land management techniques: direct seeding, in-mulch seeding and conventional tillage each with the options annual or perennial cropping. It was in a majority of cases possible to distinguish these land use systems. Only after more than one season of temporary ley it was sometimes not possible to distinguish the land management. This is described in more detail above (chapters 4.3.4 and 5.2.4). From the point of view of the impact on the land the case of several seasons of ley is very close to constant grassland and thus the conclusions stay the same.

The second hypothesis was that there were indicators to describe the state of the land on plot level. The search, trial and testing of these indicators is the main part of this study. Everything else is building on this effort, making the assessed indicators the basis of the thesis. In a narrower sense the aim was to find indicators to describe the state of the land that could be assessed right in the field without any expert consultation or analysis in the laboratory. There is a good set of indicators that can be used to describe the state of the land that way. The data that can be collected like that is however limited, which is also limiting the questions that can be answered with it. Also the collection of the indicators on plot level is very elaborate. That was necessary for this thesis as it was explicitly one of its aims. However the further gain of information for future assessments would be limited. It makes sense to go to the plot level and to assess a selection of indicators at this scale. For the reasons described in chapter 6.2.3 it is however not sensible to carry out the assessment three times a year. Not necessarily because the collected information is redundant but because in summer the indicators for degradation are systematically more severe than in the other seasons. Also the field work became more and more repetitive. With the experience gained during the field work it might now be possible to make a selection of fields to map rather than assessing all of them.

The third hypothesis was that every land use system has its own particular set of qualities (described by the indicators) making it possible to integrate the information to the level of land use systems. In other words this means that the collected indicators give specific information about the defined land use systems. It would then be further possible to make conclusions about the land use systems only by grouping the indicators accordingly. To this extent it is certainly not possible. It is not possible to unambiguously define the land use system simply by knowing the corresponding set of indicators. The land with all its components like air, water, and soil is too complex to allow such simple statements. It is in this context more realistic and more sensible to know general trends. The clusters of indicators per land use system are never exclusive and definite. They are collected, completed and grouped from the results in the following summary:

Land use system	N° of indicators per field
Annual cropping with direct seeding	0.78
Annual cropping with in-mulch seeding	3.51
Annual cropping with conventional tillage	4.95
Perennial cropping with direct seeding	–
Perennial cropping with in-mulch seeding	–
Perennial cropping with conventional tillage	1.85
Grassland	0.42

Table 3. Number of indicators per field according to land use systems (source: J. Gasser)

There are significant differences between the different land use systems. The highest number of indicators is found for annual cropping with conventional tillage and the lowest for grassland. This is very much in accordance to all that was displayed and described above. Unfortunately the indicators are not specific for a certain land use type. In other words it is not a speciality for one of the land use systems to bear signs of compaction or sealing and crusting etc. Thus it is not possible to make statements like: “if we find a combination of the following five indicators, we know what land use system is used on the field in question”. Analogous to its frequency, a certain indicator will occur on the fields, no matter what land use system. The occurrence of the indicators is much more dependent on other factors like the soil cover or the soil structure, which is then again dependent on the land use system.

Nevertheless the fact that the differences between the different land use systems are so large and consistent throughout the year needs to be emphasised. Even though the method was under construction and thus changing in the process, even though mapping experience was only obtained during this work and the judgement might be variable and dependent on the assessed spot on the field, the result is unambiguous. It shows clearly that with no or only little soil disturbance there are very few indicators of degradation or of disposition to degradation. The more the soil is mechanically disturbed the more it is prone to degradation. This outcome might not be surprising but it is a great result that the signs actually visible in the field are in accordance with the theory treated. In this context another point that was mentioned in the theory chapter is the concept of soil resilience. Looking at the results the resilience of the soil under the different land uses must be constantly high. No matter what the soil management is after two years of ley there are usually no signs of degradation visible. The soil seems to have recovered – at least superficially. This outcome should however be treated carefully. If we would look further down under ground, the result would probably be different. Deeper down the processes are slower and the soil takes longer to recover. To undo the compaction caused by tillage at about 30cm under the soil surface the micro- and macrofauna of the soil need many years. And for the soil organic matter to accumulate to a healthy level it might take even longer (Hauert 2007). It is therefore an assumption that the agriculturally used soils of the Swiss Plateau recover rather quickly. Even if this might be the case compared to soils of other world regions, before jumping to conclusions the concept of resilience of the soils of the area would need to be looked at with different methods.

8 Conclusion

The method used and developed is a good means to achieve the aim of this thesis. It makes possible to describe the state of the land in a comprehensive and systematic way. It is not sophisticated and thus applicable for anyone interested. It is further a good way to gain experience with field work and obtain a feeling for the addressed issues of land use and its influence on the state of the land. The comparison of the results of this thesis with the ones of another assessment with very similar objectives would give important insights about the soundness and the quality of the results. It would clarify if it is possible to compare the assessments of different mappers and it is thus crucial for the justification of the tested method. Because of that a second thesis with very similar objectives is carried out at the moment. Urs Grob is assessing land use systems in the Oberaargau region. Unfortunately his results are not ready yet and so they cannot be compared to those here.

After this thesis and especially after the comparison of the results with the ones from Urs Grob it should be possible to have enough information and experience that will make further elaborate mappings like these no longer necessary. It should then be possible to integrate to the level of land use systems which makes the selection of a sample of fields to assess possible. Also it does not seem sensible for further assessments to carry out the mapping several times a year. As mentioned, the information gain was small between the seasons. The conclusion after the intensive field work is here that autumn is the best season for mapping the impact of land use systems in the Swiss Plateau. This is because then many indicators are visible but not exaggerated as is sometimes the case in summer. It is also the end of the growing season and thus representing the state at the end of all the land and soil managing of the current year. In the case here the autumn results are further considered to be the best because the mapping experience was best trained then. This aspect has to be taken into account and the general recommendation to map in autumn has to be put into perspective of this speciality. Still the conviction remains that it is possible to build on the results of this thesis. Such a detailed mapping would in future only seem sensible if new land use systems could be added to the list.

Some other important aspects of the impact of land use systems are however not assessable with the method used here. To take the issue a step further, additional methods would be necessary. To complete the gathered data with information about soil organic matter would greatly enhance the knowledge about the land use systems. This has been started by Christine Hauert in her diploma thesis. A follow up diploma thesis is carried out at the moment by Lorenz Ruth. He is looking at soil organic matter on the background of land use systems and different crop rotation cycles. He too chose a very comprehensive approach that will hopefully make it possible to establish the connection between land use and soil organic matter.

A further very interesting addition to the results of this thesis would be an expert consultation. Such experts might be, first of all, the farmers. To get first hand information from the land users about their crop rotation systems, about input of fertilisers (organic and chemical) as well as use of herbicides, pesticides or fungicides would give further insight into the the connections of land use and the state of the land. If the impact of land use would be assessed like that it could possibly be further differentiated. Detailed information about different kinds of crop rotation might make it possible to divide annual cropping into different categories according to the current crop rotation, if there would be for example obvious differences in the necessary input of fertilisers or pesticides. In the field an extremely positive picture is assessed of the no-tillage system, especially direct seeding. Farmer interviews might add information about increased herbicide input or about smaller harvests. In other words the balance of economical inputs and outcome that is crucial to policy implications that might be drawn from the results of such a thesis must be obtained from the people directly affected. A second category of experts might be people working for the responsible environmental offices. Water and soil protection specialists might give information about pollution connected to land use. However this information would not be traceable to the single field level and could only be used for the assessment on a smaller scale.

Even without all of the now mentioned additions to the obtained results they show strong and seemingly unambiguous connections between land use systems and the state of the land. In a nutshell the conclusion is that the less the soil is disturbed, the better the overall state of the land. Without upturning of the soil all the subsequent problems are fought: 1) there is always a good ground cover, protecting the soil from surface erosion; 2) the natural soil structure is preserved, preventing compaction through heavy machinery; 3) the earthworm population is healthy, ensuring a good soil structure in the long term.

The testing and adaptation of the WOCAT/LADA questionnaire opened a field for further research. Even if many questions came during the process, still the rough methodology used and tested here shows that land use systems leave different imprints on the land. The results of this very practical approach correspond with the theory. The greatest advantage of the method is thereby that it forces the mapper to take a close look and thus ensures a vital closeness to the land that is investigated.

References

Anken, T., T. Berweger, et al. (2001). "Boden schonen mit dem Fünflibertest. Landwirtschaftliche Forschung und Beratung." UFA-Revue 7-8/00.

BAFU (2007). Bodenschutz Schweiz - Ein Leitbild, Bundesamt für Umwelt BAFU.

Benites, J. R. (2007). Effect of No-Till on Conservation of the Soil and Soil Fertility. No-Till Farming Systems. M. Goddard, M. Zoebisch, Y. Ganet al. Bankok, The World Associoation of Soil and Water Conservation (WASWC).

BLW (1994). "Düngen zur richtigen Zeit." Bundesamt für Landwirtschaft BLW

Bunning, S. and A. Lane (2003). "Proposed framework for indicators of biodiversity, land and socio-economic condition." LADA: http://lada.virtualcentre.org/eims/approver/pub_dett.asp?pub_id=93601&app=0&section=method, 10.07.2008.

Chisholm, M. (2008). Analyse der Bodenerosion mit der AVErosion-Extension für ArcView., CDE, University of Berne.

COST (2004). "COST: European Cooperation in the Field of Scientific and Technical Research: Memorandum of Understanding for the Implementation of a European Concerted Research Action designated as COST Action 634 "On and Off site Environmental Impacts of Runoff and Erosion"." COST: http://www.soilerosion.net/cost634/, 14.08.2008.

Engesser, M. (2008). Analyse des Einflusses hydrologischer Barrieren auf die Bodenerosion mit der AVErosion-Extension. CDE. Berne, University of Berne.

Frei, E. and K. Peyer (1991). Boden - Agrarpedologie. Bern, Haupt.

Gasser, J. and U. Grob (2008). Field protocol, unpublished.

Gasser, J. and U. Grob (2008). Methodological catalogue for the application of the WOCAT / LADA-Tool in Switzerland, unpublished.

Gassman, O. (2008). Fieldcourse, March 2008, oral source.

GEF (2001). "GEF: United Nations environment programme, global environment facility: Project Document: Land Degradation Assessment in Drylands." GEF: http://lada.virtualcentre.org/pagedisplay/display.asp?section=description, 10.07.2008.

Gisladottir, G. and M. Stocking (2005). "Land degradation control and its global environmental benefits." Land degradation & development 16: 99-112.

Hauert, C. (2007). Vergleich von Bodeneigenschaften im Direktsaat- und Pflugsystem mit Reflexionsspektroskopie und physikalischen Feldmethoden in den Gebieten Frienisberg und Oberaargau. CDE. Berne, Unversity of Berne.

Hauert, C., K. Herweg, et al. (2008). Methodological catalogue for the assessment of soil degradation and conservation in the Swiss Plateau, WOCAT/LADA.

Hauert, C. and H. P. Liniger (2007). Assessing Soil Properties in No-Till and Traditional Tillage Systems in Switzerland. No-Till Farming Systems. M. Goddard, M. Zoebisch, Y. Ganet al. Bankok, World Association of Soil and Water Conservation (WASWC).

Hurni, H., K. Herweg, et al. (2007). Soil Erosion and Conservation in Global Agriculture. Land Use and Soil Resources. A. K. Braimoh and P. L. G. Vlek. Berlin, Springer Netherland.

Kilpatrick, S. (2003). "Facilitating sustainable natural resource management: Review of the literature." Discussion paper D3/2003.

Kristensen, P. (2004). "The DPSIR Framework." Nationnal Environmental Research Institute of Denmark: http://enviro.lclark.edu:8002/servlet/SBReadResourceServlet?rid=1145949501662_742777852_522, 09.07.2008.

Lal, R. (1997). "Degradation and Resilience of Soils." Philosophical Transactions: Biological Science 352(1356): 997-1010.

Ledermann, T., K. Herweg, et al. (2008a). "Assessing Current Soil Erosion Damage in Switzerland." Advances in GeoEcology 39(Special Issue).

Ledermann, T., K. Herweg, et al. (2008b). "Applying erosion damage mapping to assess and quantify off-site effects of soil erosion in Switzerland." Land Degradation & Development submitted(Special Issue).

Liniger, H. P. and W. Critchley (2007). where the land is greener – case studies and analysis of soil and water conservation initiatives worldwide. Bern, WOCAT.

Liniger, H. P., G. van Lynden, et al. (2008). "WOCAT / LADA: A Questionnaire for Mapping Land Degradation and Sustainable Land Management." WOCAT: http://www.wocat.net/QUEST/mape.pdf, 02.10.2008.

Martin, C., Ed. (2002). Lexikon der Geowissenschaften. Heidelberg, Spektrum Akademischer Verlag.

Mc Rae, S. G. (1988). Practical Pedology - Studying Soils in the Field. Chichester, Ellis Horwood Limited.

MeteoSwiss. (2008). Retrieved 3.1.2009, from http://www.meteoschweiz.admin.ch/web/de/klima/klima_heute/letzte_monate.reg3.stationPAY.html.

Millennium Ecosystem Assessment (2005). Ecosystems and Human Wellbeing: Synthesis. Washington, DC, Millennium Ecosystem Assessment.

OECD (2003). Expert meeting on agricultural soil erosion and soil biodiversity indicators: summary and recommendations., Rome, OECD: http://lada.virtualcentre.org/eims/approver/pub_dett.asp?pub_id=96541&app=0&section=method, 02.10.2008.

Prasuhn, V. and M. Fischer (2007). "Wie viel Erde geht verloren?" UFA-Revue 11/07.

swisstopo (2000). SwissMap 25. Berne, Federal Office for Topography.

Wikipedia (2008). Retrieved 3.10.2008 from http://de.wikipedia.org/wiki/Murist.