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Adaptation and Implementation of SALCA-SQ for Quality Analysis of Agricultural Soils in Austria

Arnoud Joris Maaswinkel

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Supervisor:
Priv.-Doz. Dr. Gernot Bodner
H95100 Department of Crop Sciences (DNW), Division of Agronomy,
Konrad Lorenz-Straße 24, 3430 Tulln an der Donau, Austria

Co-supervisor:
Dr. Markus Herndl
Abteilung Umweltökologie, Höhere Bundeslehr- und Forschungsanstalt (HBLFA)
Raumberg-Gumpenstein, Raumberg 38, 8952 Irdning-Donnersbachtal, Austria

Head of the supervising institute:
Univ.Prof. Dipl.-Ing. Dr.nat.techn. Hans-Peter Kaul
H95100 Department of Crop Sciences (DNW), Division of Agronomy,
Konrad Lorenz-Straße 24, 3430 Tulln an der Donau, Austria

2nd examiner:
Ao.Univ.Prof. Dipl.-Ing. Dr.agr. Jürgen K. Friedel
H93000 Department of Sustainable Agricultural Systems, Division of Organic Farming,
Gregor-Mendel-Straße 33, 1180 Wien, Austria

Arnoud Maaswinkel, Nederlinger Straße 56b, 80638 München, Germany
arnoud.maaswinkel@web.de

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Abstract

The assessment of soil quality (SQ) of agricultural areas forms a substantial component of the life cycle assessment (LCA) of value chains in agriculture. This makes the evaluation of SQ highly valuable for facilitating the realisation of ecological sustainability. However, at present only few forms of LCA exist which consider SQ as forming part of the various assessment output parameters. One attempt of remedying this deficiency was the development of the Swiss Agricultural Life Cycle Assessment (SALCA) model, which was designed under the assumption that the term 'soil quality' can be defined as being a cumulative representation of several independent, in-field directly measurable indicators. However, on a larger scale those indicators cannot be quantified within the framework of LCA due to the lack of time or financial means. Therefore, their magnitudes need to be estimated in turn by indirect SQ indicators, including site-specific data on geographical conditions and on farm management, like crop rotation, soil tillage or pasturing. The aim of this work was to adapt the existing SALCA model to definitions on geographic conditions present in Austria, which might differ from definitions used for the original version of the model from Switzerland. Therefore, a statistical reclassification of the three types of climate (TOCs) via cluster analysis was conducted, soil moisture levels (SMLs) were redefined and climatic suitability zones (CSZs) were allocated throughout Austria, the latter with regard to the ambient vegetation periods. Furthermore, the applicability of the model for Austrian farming businesses was assessed and validated by entering at first data sets obtained from field trials from five different sites in Austria and subsequently analysing SQ of three practically operating farming businesses (POFBs). Amongst others, it was investigated to which extent which of the indirect SQ indicators influence which direct SQ indicators. From a statistical analysis, it was found that to a certain extent all three TOCs as formulated for Austria differ significantly ($p < 0,05$) from those defined for Switzerland. SMLs could not be redefined due to an incompatible method; however, the majority of the cases are not assumed to differ substantially in practice from the Swiss levels. CSZ were attributed to 260 sites all over Austria, with 87,7% being located in CSZ A or B. A map depicting the CSZs of Austria was created from this study; yet the zones are defined rather imprecisely, which accounts in particular for highland areas with much variation in vegetation periods. Various tillage systems and crop rotations were found to impact especially the macropore volume, aggregate stability, microbial biomass and microbial activity. However, it was found that the tested version of the adapted model is partly based on questionable assumptions and that some input parameters which were assumed to be less relevant turned out to have a considerable impact on direct SQ indicators. Therefore, the model should be developed further and handled with knowledge and care when it is used for assessing SQ of agricultural land.

Kurzfassung

Die Bewertung der Bodenqualität (SQ) landwirtschaftlich genutzter Flächen spielt eine wesentliche Rolle in der Ökobilanzierung (eng. *life cycle assessment*, LCA) landwirtschaftlicher Wertschöpfungsketten. Zurzeit existieren allerdings nur wenige LCA-Bewertungsmethoden, bei denen SQ ein Beurteilungsparameter ist. Um diesem Mangel abzuhelfen, wurde das Swiss Agricultural Life Cycle Assessment (SALCA)-SQ-Modell entwickelt, bei dem davon ausgegangen wird, dass sich der Begriff 'Bodenqualität' aus mehreren, in der Praxis direkt messbaren Indikatoren zusammensetzt. Aufgrund von zeitlich und finanziell eingeschränkten Möglichkeiten lassen sich diese jedoch oft nicht auf größerem Maßstab messen, weshalb sie anhand von anderen, indirekten SQ-Indikatoren abgeschätzt werden müssen. Davon betroffen ist die Datenerhebung zu standortspezifischen und geographischen Gegebenheiten und zum Betriebsmanagement, wie etwa die Gestaltung der Fruchtfolge, die Bodenbearbeitung und die Beweidung. Ziel dieser Arbeit war es, das bereits existierende SALCA-Modell an österreichische Bedingungen anzupassen, welche u.U. von den in der Schweiz herrschenden geografischen und klimatischen Gegebenheiten und den entsprechenden Definitionen abweichen. Deshalb wurde mithilfe einer statistischen Clusteranalyse eine Neuklassifizierung von Klimatypen (TOCs) durchgeführt, Bodenfeuchtestufen (SMLs) wurden für jeden TOC neu definiert und Klimaeignungszonen (CSZs) für österreichische Standorte in Abhängigkeit der örtlich herrschenden Vegetationsperiode zugewiesen. Darüber hinaus wurde die Anwendbarkeit des angepassten Modells anhand von Datensätzen von fünf Feldversuchen in Österreich überprüft und validiert; anschließend wurde die SQ dreier Praxisbetriebe abgeschätzt. Statistische Analysen ergaben, dass sich alle drei der für Österreich klassifizierten TOCs signifikant ($p < 0,05$) von den in der Schweiz gebräuchlichen Definitionen unterscheiden. Die SMLs konnten innerhalb dieser Arbeit aufgrund einer ungeeigneten Methode nicht angepasst werden, es wird jedoch davon ausgegangen, dass sich die Einteilung der österreichischen Feuchtestufen in der Praxis größtenteils nicht wesentlich von den in der Schweiz gebräuchlichen Definitionen unterscheidet. Eine Karte mit CSZs innerhalb Österreichs wurde angelegt. Diese bietet einen Überblick über die am jeweiligen Standort herrschende Vegetationsperiode, sie ist jedoch für Berglandgebiete unpräzise, da dort große Schwankungen in der Vegetationsdauer vorherrschen. Die Modellvalidierung zeigte, dass verschiedene Bodenbearbeitungsvarianten und Fruchtfolgen sich vor allem auf das Grobporenvolumen, die Aggregatstabilität, die mikrobielle Biomasse und die mikrobielle Aktivität auswirken. Allerdings musste zur Überprüfung des angepassten Modells von teilweise unpräzisen Annahmen ausgegangen werden. Einige Eingabegrößen, denen relativ wenig Bedeutung beigemessen wurde, schienen einen durchaus beachtlichen Einfluss auf die direkten Indikatoren zu haben.

Dementsprechend wird eine Weiterentwicklung des Modells befürwortet, welches im Falle einer Bodenqualitätsanalyse landwirtschaftlich genutzter Flächen nur mit Fachkenntnissen und großer Sorgfalt eingesetzt werden sollte.

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List of Abbreviations

AGES	Austrian Agency for Health and Food Safety (Ger. *Österreichische Agentur für Gesundheit und Ernährungssicherheit GmbH*)
BAW	Federal Office for Water Management (Ger. *Bundesamt für Wasserwirtschaft*)
BFW	Austrian Research and Training Centre for Forests, Natural Hazards and Landscape (Ger. *Bundesforschungs- und Ausbildungszentrum für Wald, Naturgefahren und Landschaft*)
BOKU	University of Natural Resources and Life Sciences, Vienna (Ger. *Universität für Bodenkultur Wien*)
C_{org}	Soil organic carbon content
CSZ	Climatic suitability zone (Ger. *Klimaeignungszone*)
CT	Conventional tillage (Ger. *konventionelle Bodenbearbeitung*)
DS	Data set
LAKO	Agricultural Coordination Office (Ger. *Landwirtschaftliche Koordinationsstelle*)
LU	Livestock unit (Ger. *Großvieheinheit*, GVE)
MT	Minimized tillage (Ger. *Minimalbodenbearbeitung*)
MTD	Multicriterial thermal definition
MUBIL	Long-term Monitoring of Effects of Conversion to Organic Farming (Ger. *Langzeit-Monitoring der Auswirkungen einer Umstellung auf den biologischen Landbau*)
NT	No tillage (Ger. *keine Bodenbearbeitung*)
POFB	Practically operating farming business
RT	Reduced tillage (Ger. *reduzierte Bodenbearbeitung*)

RTD	Relational thermal definition
SALCA	Swiss Agricultural Life Cycle Assessment
SML	Soil moisture level (Ger. *Bodenfeuchtestufen*)
SOC	Soil organic carbon content
SQ	Soil quality
STD	Simple thermal definition
TOC	Type of climate (Ger. *Klimatyp*)
ZAMG	Central Institution for Meteorology and Geodynamics (Ger. *Zentralanstalt für Meteorlogie und Geodynamik*)

1. Introduction

The assessment of the quality and quantity of various in- and outputs which form part of agricultural systems has continuously gained importance over the last few years among society in Austria (Herndl et al., 2013). The consumption of energy, natural resources and other assets and the causing of waste streams at various stages throughout the production, processing and consumption chain can be analysed by conducting life cycle assessment (LCA). This method is required for identifying processes in the value chain which can be improved from an ecological or environmental point of view, which eventually should contribute to creating a more sustainable balance of a certain agricultural product (Friedel and Osten-Sacken, 1998).

However, only few methods of LCA exist currently which are applicable for the assessment of agricultural processes in Austria (Herndl, 2013). Methods developed in other countries, like the Swiss Agricultural Life Cycle Assessment (SALCA) method, are valuable for single-farm-based actors in the production chain for optimizing ecological efficiency of their businesses. SALCA considers output magnitudes which in many cases are not included in usual LCA methods, like the impact on biodiversity, on the local landscape or on soil quality (SQ) (Roesch et al., 2016). However, the model is not designed for the analysis on an international level, i.e. input parameters frequently are adapted to local or national conditions and might neglect in the assessment factors which can be for other sites of considerable importance, or which simply might not be applicable for other geographical areas. For instance, the monthly water balance (precipitation minus evapotranspiration, run-off and seepage or change in soil storage) of a certain site within a certain region can differ considerably from another site which is located in the same geographical region. Hence, a locally adapted definition of the ambient climate zone and soil moisture level (Ger. *Bodenfeuchtestufen*, SML) is required (Geng et al., 2014a and 2014b). Those differing definitions need to be considered for conducting LCA.

Correspondingly, stakeholders within the food production chain might share the need for a comprehensive, elaborately developed but at the same time reasonably comprehensible LCA method which is applicable under site-specific conditions. Over the last few years, Austrian scientists have put efforts to develop such a method within the project 'FarmLife'. This project includes a version of the Swiss SALCA method which should be altered according to locally applicable, Austrian conditions. FarmLife was developed in order to assess the quality of the soil on which agricultural commodities are produced. As it is the case for SALCA-SQ, the assessment of this tool should be based on a single-farm-analysis and it should consider in particular the impact of farm machinery on the soil (Roesch et al., 2016). However, SQ is a rather complex concept as there is not merely one definition which is valid and applicable for every case.

Furthermore, SQ cannot be expressed by only one property; it is influenced by several factors, like soil tillage, vegetation cover and crop rotation, fertilisation and soil moisture management. Within the framework of SALCA, Oberholzer et al. (2006) expressed SQ in a qualitative way. This should enable farmers and other stakeholders to get informed in a comprehensible manner about specific ecological 'strengths' and 'points of improvement' of running a farming businesses, and it should facilitate comparisons to other soil parcels. Obviously, the tool needs to be designed in such a way as to enable stakeholders to analyse SQ independent from their type of business (grassland management, arable farming, animal husbandry or viticulture) and their management system (conventional, integrated or organic farming). In short, the adapted SQ model should play a valuable role by advising farmers on their environmental management.

This study aims at contributing towards the realization of a virtual tool which can be used for the assessment of SQ of individually run farming businesses in Austria. Initially, the original version of the LCA tool should be adapted in such a way that data on indirect SQ indicators can easily be entered into the calculation model. The applicability and correct operating procedure of the adapted model will then be verified by comparing its output values with measurements taken at selected agricultural field trials. Although the outputs of the model are no quantitative expressions, the results of a data set (DS) can easily be compared with results from another data set, depending on which parameter is to be assessed (the effect of a change in tillage management or crop rotation, for instance). Information for creating data sets will be collected from three expert institutions which investigate similarly the impact of different tillage systems or varying crop rotations on various parameters, like soil organic carbon content (SOC) or yields. The correctness of the adapted version will then further be analysed by entering data obtained from practically operating farming businesses (POFBs) which participate in the project FarmLife. In this study, data sets of three different farms with various business sizes and business forms were designed in such a way as to fit the model in an applicable way. Finally, the model assessments of the field trials as well as of the POFBs will be analysed and compared with each other. An overview on the workflow of this study is depicted in Figure 1.

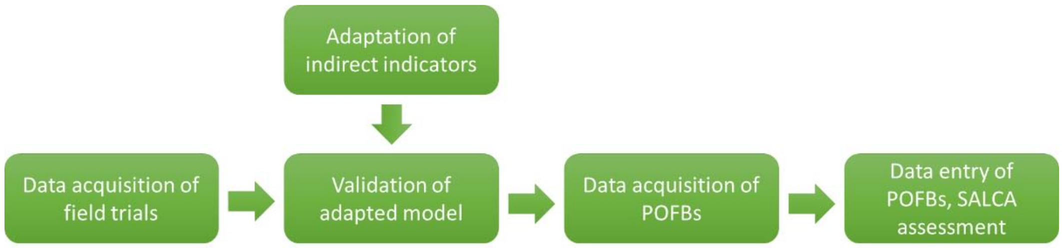

Figure 1. Overview on the workflow of this study.

2. Materials and Methods

In some cases, factors which influence SQ can be measured quantitatively; however, they usually have rather indirect impacts on SQ and therefore can be considered as indirect SQ indicators. They determine a number other scientific variables – direct SQ indicators – which all are quantitatively measurable and which represent the potential of a given soil for fulfilling one or more criteria which are premises of healthy, sound soils. In analogy to this, soils of high quality are in this paper considered to possess values of direct SQ indicators which are highly favourable, as it was done for the SALCA model by Oberholzer et al. (2006). For this latter model, nine direct SQ indicators were selected: aggregate stability (Ger. *Aggregatstabilität*), macropore volume (Ger. *Grobporenvolumen*), rooting depth (Ger. *pflanzennutzbare Gründigkeit*), soil organic carbon content (Ger. *Gehalt an organischem Kohlenstoff*, SOC or C_{org}), organic pollutants content (Ger. *Gehalt an organischen Schadstoffen*), heavy metal content (Ger. *Schwermetallgehalt*), earthworm biomass (Ger. *Regenwurmbiomasse*), microbial biomass (Ger. *mikrobielle Biomasse*) and microbial activity (Ger. *mikrobielle Aktivität*). Those and other indicators can be selected for representing the state of soils depending on their ability to comply with several criteria. For instance, the environmental relevance (i.e. the ability to represent certain agronomic, economic, social or other functions of the soil) or the short term irreversibility (i.e. the non-susceptibility to rapid changes) are preconditions which need to be fulfilled by every direct SQ indicator (Oberholzer et al., 2012). Certain threshold values for each of those are stipulated in order to define quality levels of parcels of land which are used for grassland management or for arable farming. However, solely data collected on indirect SQ indicators are used as calculation inputs for the final LCA tool. Although direct SQ indicators are quantitatively measurable, in the tool they are expressed qualitatively, ranging from strong deterioration or a very weak state (--) to strong improvement or a very strong state (++) of the given indicator. The overall impact on SQ is expressed likewise and is considered to be threatened as soon as one or more of the nine mentioned direct SQ indicators reaches unfavourable values, like Oberholzer et al. (2006) did (Figure 2).

The calculation procedure of the model is reasonably complex, it therefore seems to be challenging to determine which variables and parameters have a relatively strong impact on a certain direct SQ indicator and which are of rather low importance. From this improved insight into soil processes, stakeholders of the production chain should eventually be able to assess more accurately which aspects of farm management in particular ask for care and consideration in order to improve ecological efficiency. Adding on to this, the question about which indirect SQ indicators are the most influential can be posed, as well as whether or not (and if so, to which extent) indicators influence each other mutually. In addition, since the model will be adapted to conditions which are applicable and relevant for agriculture in Austria, it could be profitable to ascertain the degree to which input data differs among different sites within the country as well as compared to foreign sites. The two latter points will ask for an assessment which takes statistical methods into account.

Input data for the model was acquired on several ways. Amongst others, surveys for farming businesses on agricultural data, like the height of mowing and the utilization of machinery, were created. For the first step, several professionals from expert institutions were consulted and asked for information on indirect SQ parameters, like farmland management and vegetation yields of field trials. Institutions which are concerned are BOKU (University of Natural Resources and Life Sciences, Vienna), AGES (Austrian Agency for Health and Food Safety), LAKO (Agricultural Coordination Office) and expertise from MUBIL (Long-term monitoring of effects of conversion to organic farming).

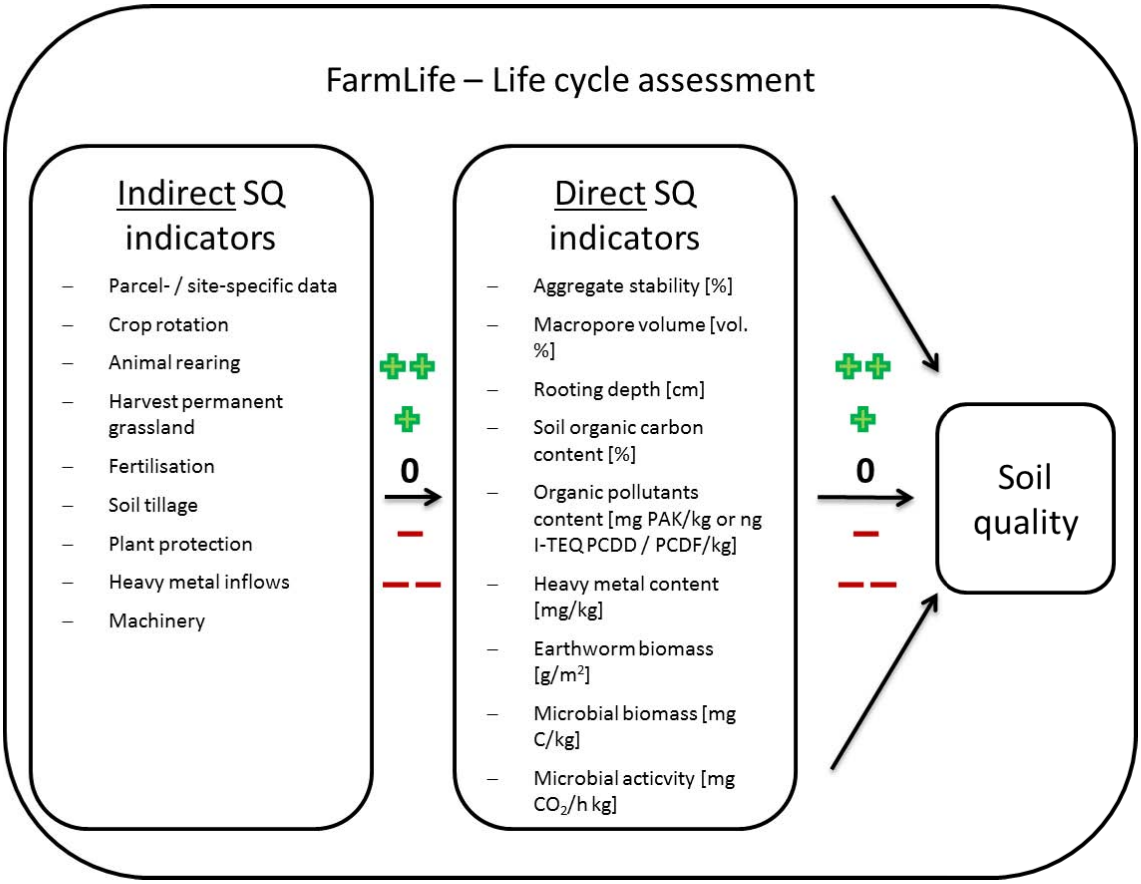

Figure 2. SQ analysis as part of the project 'FarmLife'. Indirect SQ indicators influence direct SQ indicators as depicted by the arrows. The direct SQ indicators, in turn, influence soil quality as a whole. Impacts are expressed qualitatively and can range from a strongly deteriorating / strongly negative (--) to a strongly improving / strongly positive (++) effect.

In addition, those institutions provided data from measurements on direct SQ indicators. This data was required for the comparison of those values with the outputs of the adapted SALCA model – by this, the adapted version could be validated. That is to say, although the SALCA model does not offer quantitative outputs, data sets can be compared with each other and the model can be validated by comparing values measured in-field from the corresponding data set. As a next step, data sets of three POFBs were created, with every data set representing a certain parcel of one of the businesses. The original SALCA model from Switzerland was updated several times – for the adaptation and the assessment of SQ of all data sets, version 4.1 of Agroscope FAL Reckenholz was used. For processing obtained data, software developed for conducting complex mathematical and statistical calculations (Microsoft Excel and IBM SPSS Statistics 21) was applied. Calculating soil water potentials for given soils and water balances was done with the programme 'Hydrus-1D' (version 4.15.0110), which should eventually serve as basis for the definition of SMLs ambient in Austria. Creating new maps or editing already existing maps, like a map of Austria presenting the various climatic suitability zones (Ger. *Klimaeignungszone*, CSZs) was done with the software ArcMap 10.2 (ArcGIS10). Finally, the model was checked for the correctness of its calculations and possible errors were recorded. A list of errors found in the computation procedure of the model is provided in annex 8.6.

2.1 Adaptation of Indirect SQ indicators

2.1.1 Redefinition of the Types of Climate

For a certain site, the TOC (Ger. *Klimatyp*) can be determined by comparing values of the monthly water balance (i.e. precipitation minus evapotranspiration, run-off and seepage or change in water storage) and subsequently categorizing the location either as 'dry', 'humid' or 'wet' TOC (Ger. *trocken*, *feucht* and *nass*, resp.). The values of the monthly water balance can for instance be found in maps of climate zones used for analysing the suitability of agriculture in a certain region, like Oberholzer et al. (2006) did for Switzerland. For this study, data provided by the Central Institution for Meteorology and Geodynamics (Ger. *Zentralanstalt für Meteorlogie und Geodynamik*, ZAMG) was taken. For adapting the SQ model of FarmLife, monthly water balances were measured at 513 different ZAMG locations (spread all over Austria) for the years between 1971 and 2000. A redefinition of the TOCs was done by comparing the average values for every month and every location and subsequently classifying them via k-means clustering with SPSS. With a preliminary determined number of exactly 3 clusters, every site should be allocated to the cluster with the lowest distance to the cluster mean value, i.e. the cluster which included the most similar values of monthly water balances. For every cluster, mean values of every month were depicted in a chart (section 3.1.1, Figure 4). In addition, cluster analysis was conducted by increasing the stipulated number of clusters to '4'. This step was necessary since the location '15412 Sonnblick' appeared to have an extremely positive water balance throughout the year. This statistical outlier therefore would not have suited the mean values of one of the other three clusters (section 3.1.1, Figure 5). Subsequently, the obtained curves of the three TOCs were compared graphically and statistically with the curves representing Swiss TOCs (section 3.1.1, Figure 6). The statistical comparison was done with an independent samples test – t-test for equality of means. For all months of all TOCs, the average values of Austria were compared with the average values of Switzerland ($\alpha = 0{,}05$).

2.1.2 Redefinition of the Soil Moisture Levels

Depending on the ambient soil type (sandy, loamy, silty and clayey soils), soils prove to have different potentials in infiltration rate and storage capacity of precipitation water, which is mainly due to their differences in size of soil particles (Saxton et al., 1986). As a consequence, SMLs vary depending on the time of the year, the ambient soil type and the ambient TOC (which will determine the monthly water balance). Like for the classification of the TOCs, SMLs can be classified as 'wet', 'humid' and 'dry'. Expressed in quantitative terms, the levels depend on the soil water potential (ψ) or the pF-value, which is closely related to the soil moisture content (θ) via a soil-specific water retention curve. The threshold values between the different SMLs are given in Table 1. For the SALCA model, the SML plays a decisive role in determining the risk of soil compaction and structure degradation which is due to pasturing and the implementation of heavy machinery. It is considered in the model that soils with a less negative soil water potential (wetter) are more susceptible to pressure from farming activities than soils with a more negative soil water potential (drier). Although it is acknowledged that the moisture content and hence the plasticity strongly varies among different soil types, for simplicity reasons it needed to be assumed that threshold values are the same for sandy, loamy, silty and clayey soils. In fact, defining levels of plasticity rather than of moisture levels would possibly make the impact of this parameter more obvious: in the model, it seems to be likely that aggregate stability and the macropore volume depend on the allocation of the ambient SML.

Table 1. Classification of the SMLs, depending on the ambient soil water potential. '*nass*' and '*sehr feucht*' are considered to be wet soils, '*feucht*' are humid and '*trocken*' are dry soils. Depending on the moisture content, samples of wet, humid and dry soils appear to have a kneadable / malleable, friable and hard consistency, respectively. The soil water potential (Ger. *Saugspannung*) is expressed in cbar and hPa. Source: BAFU and BLW, 2013.

		Fühlprobe	Saugspannung [cbar]	Soil Water Potential [hPa]
Feuchtestufen[a]	nass	knetbar; schmierig	< 6	< 60
	sehr feucht	formbar	6–10	60-100
	feucht	brüchig	10–25	100-250
	trocken	hart	> 25	> 250

For calculating soil water potentials, measurement data derived from six meteorological stations (two stations for each TOC) were entered into the programme 'Hydrus-1D': This data comprised values of daily precipitation and evapotranspiration values. By making several estimations on the remaining input data (see list below), it was aimed to develop for every soil type a pedotransfer function which would predict for every centimetre of the topsoil (0-35 cm) the monthly average soil water potential. Estimations being made for this aim concern the following parameters:

- Water Flow as well as Root Water Uptake and Root Growth were simulated.
- The Depth of the Soil Profile (one layer, one material) was assumed to be 100 cm.
- There were 396 records of Variable Boundary Conditions (precipitation, evaporation and transpiration) for every location. Hence, Initial Time was set to '0' and Final Time was set to '396'. This was done because data records of December were entered twice, since the soil water potential of the first month is not calculated but always equals to a previously stipulated value. This value was assumed to be the soil water potential at field capacity (which is frequently assumed for laboratorial experiments and set to ψ = -60 hPa or pF = 1,8).
- Depending on the soil type, the Initial Time Step and the Minimum Time Step were chosen to range between 0,02 and 1 days and 1E-5 and 0,1 days, respectively. The Maximum Time Step was fixed to 5 days.
- Print Options (T-Level Information and Print Time Interval) were both set to '1', the Number of Print Times to '12'.

- Concerning Iteration Criteria, default values for Time Step Control were taken. The Maximum Number of Iterations was set to '10', the Water Content tolerance to '0,001' and the Pressure Head Tolerance to 1 cm.
- The Single Porosity-'Van Genuchten-Mualem'-Soil Hydraulic Model was selected for describing the relation between pressure head and water content. For clayey soils, an Air-Entry Value of -2 cm was selected. Hysteresis was not assumed to take place.
- For every soil type (Sand, Loam, Silt and Clay) the default settings of the Van Genuchten-Mualem parameters (predicted via a pedotransfer function and implemented into Hydrus ("Rosetta" from Schaap et al., 2001)) were accepted.
- Atmospheric Boundary Conditions with Surface Run Off and Free Drainage were selected as Upper and Lower Boundary Conditions, respectively.
- Feddes' Root Water Uptake Reduction Model was assumed for Water Stress behaviour for plant roots; however, the option of No Solute Stress was activated, and the Critical Stress Index was kept as default.
- To all Root Water Uptake Parameters values determined by Wesseling et al. (1991) for Pasture were used. The idea behind was that pasture areas are one of the most frequently found vegetation covers in Austria, and that the correspondingly defined SMLs would therefore be applicable for SQ analysis of a major part of parcels of land.
- The Root Growth Factor was set to 50% after 50% Growing season. The Initial Root Growth Time and the Harvest Time were decided to be day 105 (mid of March, since day 1 = 1st of December) and day 283 (mid of September), respectively. The Initial and Maximum Rooting Depth were considered to be 0,1 and 90 cm, respectively.

After Hydrus-1D had calculated soil water potentials, the average potential in the upper 35 cm below the soil surface was taken for each of the six measurement sites. The upper layer of the soil is of special interest for the assessment of the SQ since most of the soil damages which are due to farming activities occur at this depth (Arvidsson and Keller, 2007). Subsequently, the average of the two locations was calculated for the dry, humid and wet TOC, respectively. Classification for the SMLs then was done according to the values found in Table 1.

2.1.3 Allocation of the Climatic Suitability Zones

The extent to which the use of machinery has a damaging impact on the cultivated soil depends amongst others on the season of the year and the corresponding soil temperature. In particular, this will pertain for the influence on the ambient earthworm population: as it appears to be, earthworm activity is in general highest in the months of spring and autumn (Johnson-Maynard et al., 2007; Crittenden et al., 2015), whereas under more extreme temperature conditions (i.e. in summer and winter), their activity is reduced. As a consequence, more activity implies also a higher vulnerability of earthworms for soil tillage and soil compacting machines. This assumption is considered by the SQ model by allocating higher values of physical weighting factors (Ger. *physikalischer Gewichtungsfaktor*) to months with increased earthworm vulnerability (Oberholzer et al., 2006).

However, soil temperatures at different places throughout Austria are not always equal for a given month. According to Schaumberger (2011), the western, mountainous areas of the country in general appear to stay cold after winter for a longer time period than areas in the lower, eastern part, and at the end of the year they also cool down at an earlier stage. This fact is also represented by a shorter vegetation period, which can be defined as being the time of the year when environmental conditions are appropriate for plant growth (Schaumberger, 2011). As a matter of fact, plant species vary in their tolerance against extreme temperatures or water shortage, which consequently complicates for a certain region the determination of the day of the year when plant growth starts and the day it stops again. This especially holds true for grassland parcels which frequently consist of various plant species. Moreover, other factors than temperature – irradiance and slope, for instance – can also exert a considerable influence on the ambient vegetation.

However, for stakeholders in agriculture it is necessary to estimate in some way the beginning and the end of plant growth in order to plan farm management, like the cutting of grass or letting the cattle go outside for pasturing. Experiences from practice have proven that the above mentioned dates can be approximated most extensively by stipulating certain threshold values of the daily mean temperature. Schaumberger (2011) refers to three different definitions for determining the duration of the vegetation period: the Simple, the Multicriterial and the Relational Thermal Definition (STD, MTD and RTD, respectively). For adapting the SQ model to Austrian conditions, the STD was selected. According to this definition, the vegetation period will start at the point of the year when for the first time the ambient air temperature stays continuously above a certain level for a certain minimum of time. Inversely, the end of the vegetation period is reached when for the same duration the temperature stays continuously below the same threshold. For the adaptation of the SALCA model, 5°C and 5 days were chosen as temperature and time threshold value.

Values of daily mean temperatures were collected from 260 meteorological stations throughout Austria, and for every location values were calculated for the years from 1971 until 2000. Depending on the length of the corresponding vegetation period, each site was categorized in one out of seven CSZs. The classification of the zones was conducted according to the intervals as described in Table 2. Subsequently, a map of Austria was drawn in which for every station and its surrounding area a certain CSZ was attributed. It needs to be considered here that approximately

10% of the stations are located in so-called "highland areas". This definition was taken over from Schaumberger (2011), who identified among several meteorological sites via regression analysis different relations between the altitude and the monthly average temperatures. Stations of highland areas prove to have a higher temperature gradient (i.e. change in temperature per unit of change in altitude) than lowland stations which is likely to be due to the generally high altitude and the diminishing heat holding capacity by the atmosphere. In addition, the border between highland and lowland areas was considered to be located where the difference in altitude (Ger. *Höhenschwellenwert*) exceeded a certain value within a certain radius (Ger. *Umkreis*).

Table 2. Classification of CSZs depending on the duration of the ambient vegetation period. Source: Brunner et al., 2002.

Duration of Vegetation Period	CSZ
> 210 days	A1-A6
190-210 days	B1-B6
180-190 days	C1-C6
170-180 days	D1-D2
150-170 days	E1-E2
100-150 days	F
< 100 days	G

2.2 Data Acquisition of Field Trials and Validation of the Model

For examining the correctness of the adapted version of the SALCA model, data sets of field trials conducted by AGES, LAKO and MUBIL were entered into the model, and the consequent model outputs – results on direct SQ indicators – were compared with measurements taken at the corresponding sites. Values of the in-field measurements were received by direct communication with the corresponding contact people of the institutes and can be viewed in Table 3 (section 2.4). Due to data protection requirements, in the following parts data will not be connected with the corresponding site or organisation where it was derived from. Therefore, names of the fields from AGES, LAKO and MUBIL and the various parcels of land were coded. In total, 20 different data sets were created, of which information on varying management practices was collected from five different experimental sites in Lower Austria, including Fuchsenbigl, Hollabrunn, Mistelbach, Pyhra and Rutzendorf (Figure 3). Information on the field trials conducted by LAKO at Hollabrunn, Mistelbach and Pyhra was derived from reports on crop experiments ('Agronomy – Erosion Control and Soil Tillage', Ger. '*Pflanzenbau – Erosionsschutz und Bodenbearbeitung*') of the year 2013. Data on the field trials of AGES and MUBIL (Fuchsenbigl and Rutzendorf, respectively) was gathered for the major part by consulting those institutions directly (see also section 2.4).

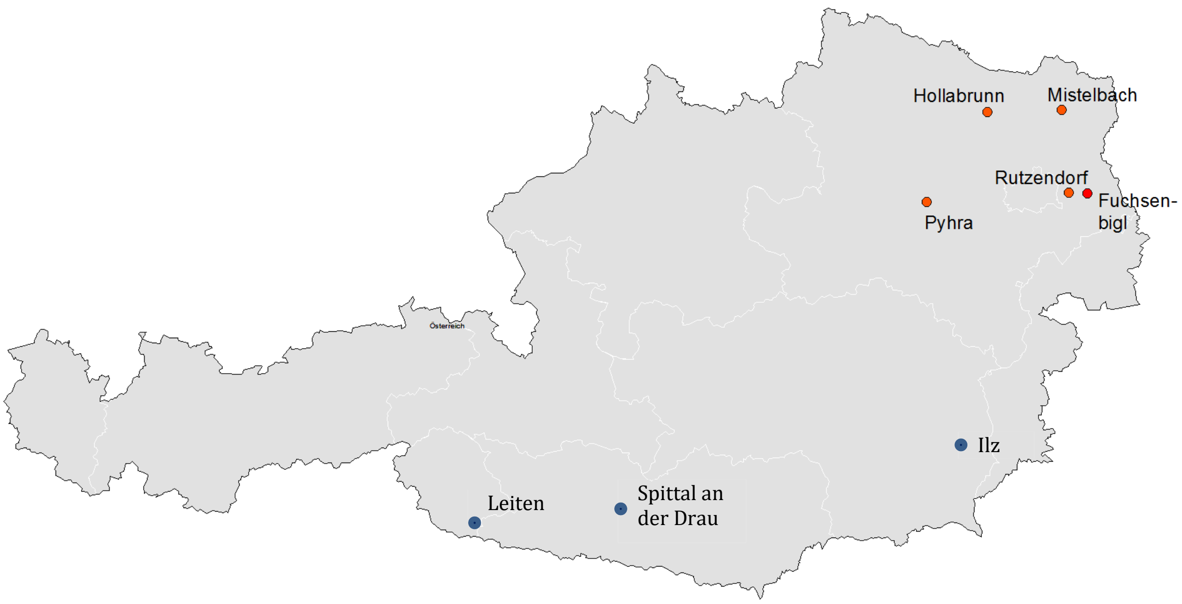

Figure 3. Location of the five experimental sites (red dots) where data on field trials was collected from and rearranged as data sets for validating the adapted SALCA model. Subsequently, data sets from three POFBs (blue dots) were created and analysed.

Field trials were conducted with the main aim of assessing the influence of different soil tillage practices as well as the influence of crop rotation on the yield of the cultivated crop. In regard to the tillage experiments, for a given site the ambient soil was treated under three or four different variants, including the use of various machines and tillage intensities:

- Conventional tillage (CT). Conventional tillage includes the use of a soil-inverting mouldboard plough, which usually works at depths of approx. 25-30 cm below the surface. For some data sets, CT includes in addition shallower soil tillage conducted with a disc harrow or with seedbed combinations.
- Reduced tillage (RT). RT is similar to CT; however, the main difference is the use of a chisel plough instead of a (conventional) mouldboard plough. In contrast to the latter, the

chisel plough does not invert the soil but only loosens it, usually at depths around 15 cm below the surface. Like for CT, also RT can include the additional use of a disc harrow or of seedbed combinations.

- Minimized tillage (MT). This variant should aim at exerting only minor influences on the soil structure by omitting the application of a mouldboard or a chisel plough. Merely a disc harrow should incorporate stubbles and other residues of the previous crop into the soil, working them between 5 and 15 cm deep into the soil. Besides, the application of a rotary hoe (in combination with other seedbed-preparing tools) pertains to minimized tillage as well, as it is the case for DS-T3.
- No tillage (NT). NT does not encompass soil tillage prior to sowing; however, in some cases (e.g. DS-T7), this variant includes a more frequent spreading of plant protection materials, as weed pressure on those plots of land might be higher. The distribution of the seeding material is conducted mechanically or pneumatically.

For the crop rotation field trial, cereal grains, legumes and root crops are cultivated alternately. The five data sets created for those parcels include the cultivation of winter barley (2004), alfalfa (2005), peas (2010), winter rye (2012) and again alfalfa (2013). Since the year 2005, a regular crop rotation scheme has been realized which looks as follows:

Alfalfa – alfalfa – winter wheat (including catch crop) – maize (Ger. *Körnermais*) – spring barley (including catch crops) – peas (including catch crops) – winter wheat – winter rye.

Unfortunately, for the validation of the model it was not possible to collect data on indirect indicators or on measurements of direct indicators from five subsequent years.

2.3 Data Entry of Practically Operating Farming Businesses

As a final operation step, the practicability and applicability of the revised model was analysed by introducing another 53 data sets from three farming businesses: ‘DS-A’, ‘DS-G’ and ‘DS-M’ are data sets derived from arable farming, grassland management and mixed arable farming / grassland management, respectively. The respective businesses are located at Ilz (Styria), Leiten (Tyrol) and Spittal an der Drau (Carinthia) (see Figure 3). Information for creating the data sets was derived for one part from entries done on an online platform of FarmLife (http://www.farmlife.at/cap). Those entries were published by the farmers with details on size and location of their parcels of land, the cultivated crops, herd sizes and pasturing intensities, date and type of implemented machinery etc.. Those details were captured and revised in separate Excel files, with further details for every single parcel of land (e.g. data on the ambient soil, like the clay content, pH, exact measurements of the area size etc.). For the other part, literature needed to be reviewed – in particular for technical specifications on machinery, information provided on the websites of various manufacturers of farm machines was collected (see also annex 8.1). Unlike it was done for the field trials, however, for every business data sets were not separated from each other but kept together as one file, as there was the need for an assessment of SQ of every business as a whole. Additionally, this approach would also facilitate the comparison of the assessments depending on the type of business form.

2.4 Data Acquisition of Remaining Indirect SQ indicators

2.4.1 Details on Parcel / Location

Values of the soil **clay content**, **organic matter content, pH** and the **soil type** were derived via consultation of AGES (Spiegel, 2015) and MUBIL (Surböck, 2015). LAKO was for one part consulted as well (Bartmann 2015; Ecker, 2015; Schuster, 2015); for the other part, literature on previous field trials at the same locations needed to be studied (Rosner, n. d.; Klik, 2015). For DSs-A, DSs-G and DSs-M, the corresponding Excel summaries were studied as described in section 2.3. **Erosivity** has never been quantified for any of the field trial locations. Therefore, the Austrian Federal Office for Water Management (Ger. *Bundesamt für Wasserwirtschaft*, BAW) was consulted; the exact geographic coordinates for every research field were determined and average annual soil erosion could be estimated for every site, based on measurements previously taken by BAW (Eder et al., 2014). However, one issue for data entry appeared to be the measurement unit: values taken from BAW were expressed in kilograms per hectare and year, whereas the model requires inputs expressed in millimetres of topsoil layers per year. Therefore, BAW values needed to be recalculated by assuming a soil density of 1300 kg/m^3 which can frequently be found for the first metre of soil on agricultural areas in Austria. The equation applied for this step looks as follows:

$$\text{Erosion}\left[\frac{\text{mm}}{\text{a}}\right]=\frac{\text{Erosion}\left[\frac{\text{kg}}{\text{ha a}}\right]}{1300\,\frac{\text{kg}}{\text{m3}}\cdot 10000\,\frac{m2}{ha}}\cdot 1000\,\frac{mm}{m} \qquad \text{(Equation 1)}$$

It needs to be considered here that the recalculated values pertain for soil-intrinsic susceptibility to erosive forces. Like described above, those were applied for the model as in-field measurements were not taken; hence all values are site-specific but do not differ among different cultivations or different tillage systems. However, it is appreciated that erosivity in practice does considerably depend on those latter two aspects, like other scientific studies have proven (Stoate et al., 2001; Holland, 2004). For the POFBs, data on erosivity was taken from the Excel files. Since no further details on erosive forces were provided, for none of the data sets **linear erosivity** (Ger. *Linienhafte Erosion*) was considered.

2.4.2 Crop Rotation Arable Farming

Information on the kind of the **(previous) culture**, the **sowing** and **harvesting date** and the **fresh weight / dry weight yield** was retrieved for all three LAKO-data sets from the reports made available on the website (LAKO, 2015). Obviously, **ploughing with normal seedbed preparation** was only included for field trials with CT as well as for the practically operating businesses where a plough was applied. However, the option '**strip-tillage / direct drilling**' (Ger. '*Mulch-/Streifen-/Direktsaat*') was activated for all LAKO field trials (as there was always mulch applied and / or seeds were sown in strips or directly drilled into the soil) and for some data sets of AGES and MUBIL. For all data sets of the practical fields, it needed to be assumed that – where no further information was provided – seedbeds of parcels were prepared merely on the conventional way.

For all data sets, the share of a certain parcel to the total surface area of a location was expressed as percentage in regard to assessing whether or not **root crops** were cultivated, **meadows or fallow areas** were included, **strip tillage / direct drilling** was done on the parcel or whether or not **lime was applied at pH < 6,2**. For grassland areas, the assumption was made that the **height of mowing** was always below 8 cm.

2.4.3 Animal Husbandry

For pasture areas (i.e. DSs-G and DSs-M), the **time** and the **duration of pasturing** as well as the **stocking density** (recalculated as livestock units per hectare [LU/ha]) was looked up via the online database of FarmLife. Unless specified, the assumption was made that livestock was not kept in **enclosures** but that it could move around freely (like it is suggested by default by the model).

No data was available on whether or not the **length of time** parcels were cultivated with meadows or pasture areas exceeds two years, which is asked by the model. The business of DSs-G is economically based on the regular cultivation of grassland areas and the majority of grassland parcels of business DS-M appear to be too small or unsuitably inclined for arable farming (arable farming would consider those parcels to be only temporarily covered with grass). Therefore, it seems reasonable to assume that all parcels are cultivated already for two years or longer as grassland areas.

Furthermore, information on the **vegetation cover** (Ger. *Qualität des Bestandes*) is required. Were no data was available, the assumption has been made that all grassland areas are covered for reasonably equal shares with grassy, leguminous and herbaceous plant species.

2.4.4 Harvest Grassland Management

The **height of mowing** of grassland parcels is required as well. Like mentioned in paragraph 2.4.2, neither there was data on this indirect SQ indicator available, nor it was possible to make reasonable estimations, so no entries were made at all here.

2.4.5 Fertilisation

Organic fertilisation merely applies to the POFBs, as all three of those are run organically and therefore are not allowed to apply mineral nitrogen fertilisers, as it was done on the parcels of the field trials. As a rough simplification, three **kinds of organic fertilisers** were applied: mixed solid and liquid manure of dairy cattle (Ger. *Milchvieh – Vollgülle*), liquid manure (Ger. *Gülle, kotarm / Jauche*) and degraded stable manure (Ger. *Stallmist – verrottet*). Those kinds of fertilisers are coded in the SALCA worksheet 'orgDünger' with '1', '2' and '21', respectively. Since liquid manure was not available in the list of organic fertilisers, manure of dairy cattle with a low dry matter content (Ger. *Milchvieh – Gülle, kotarm*) was selected as a most appropriate alternative.

In addition, it is asked by the model whether or not **lime fertilisers** are applied on the parcel (more than 10 dt/ha of quicklime (Ger. *Branntkalk*, CaO)). However, some liming agents which were used in the data sets contain a lower fraction of calcium oxide than quicklime. CaO-contents of the various agents therefore were recalculated for every fertiliser according to average values found in literature (Boelcke, 2008; Molitor et al., 2012; Landwirtschaftskammer Nordrhein-Westfalen, 2015).

2.4.6 "Humod" Soil Assessment

The **amount of mineral N-fertilisers** applied in the field trials was noted in the reports.

For the assessment of the **quality of the location** (Ger. *Standortqualität*), eBOD (an electronic soil map presenting various soil data for Austria, provided by the Austrian Research and Training Centre for Forests, Natural Hazards and Landscape (BFW, 2016)) was used. This map, depicting arable and grassland areas on a scale of 1:5000, provides detailed information on the value of plots of land, with five different levels used for classifying. The first level was considered to match the SALCA definition "sehr gut" (very good), the second to match "gut" (good), the third and the fourth to match "mässig" (reasonable) and the fifth to match "ungünstig" (unfavourable). As a result, to each of the data sets the quality of the location could be assigned which in turn would also influence the yield level (see next point).

The **yield level** (Ger. *Ertragsniveau*) ranges from "high" to "low" and does not only depend on the dry weight of the harvest of a certain culture but also on the quality of the land it was grown on. For instance, for winter wheat a yield of 6 tonnes may be considered to be rather low for a high quality location, whereas 6 tonnes at a low quality location is reasonably high. However, threshold values for yield levels were not exactly defined but simply compared with the norm yield values for every culture as listed by Oberholzer et al. (2006) in the original version of the SALCA model.

For entering the **nitrogen content** of the cultivated plant species, it was assumed that the amount as a percentage of the fresh weight yield (i.e. including moisture content) was asked for. Hence, for instance a nitrogen content of 0,5% for all harvests of parcels managed as grasslands was assumed, which equals to a share of 2,0% N-content for the dry weight if moisture is considered to contribute for 75% to the fresh weight of grass (Huguenin-Elie et al., 2008; Roschke, 2009; LfL, 2013). N-contents in the range of 0,5 – 1% were assumed for all cereal grains (LfL, 2013). Maize was considered to contain on average 0,5% nitrogen, whereas for silage maize slightly higher N-contents were assumed (LfL, 2013). With an estimated nitrogen content of 3,6%, rapeseed had one of the highest values (however, this pertained only for the main product – for the by-product, a value of 0,5% was assumed) (Schliephake et al., n. d.; LfL, 2013).

Ascertaining the nitrogen content, however, requires the determination of the average **moisture content** of certain cultures or culture groups (e.g. cereal grains). This pertains to both the main product as well as the by-product. For grassland areas, an average moisture content of 75-80% (Riehl, 2001) was assumed. A comparable value may be expected for alfalfa (Schweinzer and Gollner, 2013).

2.4.7 Soil Tillage

The **date on which the soil was ploughed** could be looked up in the reports or the Excel files for the field trials and the POFBs, respectively. The same accounts for the **date the rotary hoe was used**, although this implement was used rarely (see also paragraph 2.4.10).

2.4.8 Plant Protection

This indirect SQ indicator was skipped for the POFBs as all three of them are not allowed to spread synthetic pesticides, herbicides, fungicides and other synthetically produced **plant protection agents**. In contrast, the amount and variety of substances sprayed by the field trials of LAKO is quite considerable. No abbreviations or codes for the various plant protection materials are provided by SALCA, though, so it appears to be unclear how this indicator is considered by the model.

2.4.9 Heavy Metals

For the estimation of the **inflow of heavy metals** which is due to the application of organic fertilisers, median values as found for various manure substances by Menzi and Kessler (1998) and Desaules and Studer (1993) (in Freiermuth, 2006) were taken.

2.4.10 Machine Rides

The completion of data entries for this indirect SQ indicator (category) formed a major share of all information collecting and literature reviewing as well as calculations and estimations done for this study. The SALCA model offers the opportunity to enter for every data set up to six different rides with machinery (tractors, transporters etc.) including farm tools / implements (ploughs, cultivators, harrows etc.). It needs to be remarked here that (heavy) machines are considered to have adverse effects on the soil structure and soil biota. Therefore, data was entered from those machines and tools which would have the highest working weight (although it is considered that the heaviest machines do not necessarily damage the soil more than lighter machines. This was already proven for instance by researchers who examined the effect of driving tractors with a low tyre inflation pressure and hence exerting a lower contact area pressure on the topsoil (Arvidsson and Keller, 2007; Schjønning et al., 2008)).
Where available, data on the **date of the ride**, the **working weight** of the implemented machinery and the **working width** was taken from the reports or from the Excel files. Like proposed in the original version of the SALCA model, for seeding, spraying of plant protection materials, application of fertilisers and harvesting, merely 75% of the maximum working weight of the corresponding machine or tool was used for calculating the working weight of a ride. For all other data, it was considered to be rather impracticable or, at least, enormously time-inefficient to ask all institutions about the exact manufacturer and model of the various machines which were utilized. Therefore, for every machine and tool the technical specifications of farm machinery of common producers in Austria (Steyr, Fendt, Pöttinger, Vogel & Noot etc.) were taken as representative values. The same accounts for the utilized tractors: for many data sets of the field trials as well as of the POFBs, the only specification given was the engine power. Consequently, a list of 25 tractors from different manufacturers and with different maximum engine powers was compiled, including the corresponding working weights. Via regression analysis, a regression line could be drawn from which it was possible to inter- / extrapolate the working weight of other tractors (see also annex 8.1). The calculated regression line was formulated as follows:

$$\text{Working weight [kg]} = (33{,}44 \text{ [kg/hp]} \cdot \text{maximum engine power [hp]}) + 731{,}48 \text{ [kg]} \qquad \text{(Equation 2)}$$

With a correlation coefficient of R^2 = 0,91, estimations done with this formula on the working weight of tractors may be considered reasonably realistic.

Depending on the activity of the ride (ploughing, harrowing, seeding, harvesting etc.), the **degree of loosening of the soil** (Ger. *Lockerungsgrad des Bodens*) was suggested to be either tight, settled or loose (Ger. *fest*, *abgesetzt* or *locker*, respectively). The respective term was taken from the sheet 'Befahrung' of the original SALCA model. Likewise, the **depth at which soil compaction can occur** was determined like it is suggested by the original version of the model: for ploughing, the concerned soil depth was said to be the topsoil at 0,1 m; for all other activities, subsoil layers of 0,35 m below the surface were considered to be most susceptible to compaction.

Neither the field trials nor the POFBs provided information on the **axle load** (Ger. *Achslastverteilung*), the **tyre diameter** or the **tyre width**. The task of suggesting for every implemented machine and tool with wheels a realistic value for the axle load seemed to require too much technical knowledge for this study; therefore, values entered in the original SALCA version of Burgrain, Switzerland, were taken over. Whenever a tractor was implemented, the distribution of the axle load between front and rear axle was assumed to be 38:62 % (for rides with only two axles), regardless the maximum engine power or the purpose they were used for. The same accounts for the tyre width and the tyre diameter of tractors. Those were specified in many cases as tyre dimensions, expressed in metric values or in inch. The standard expression for the dimensions looks as follows:

$$\text{Tyre dimensions} = \text{XXX/YY R ZZ} \qquad \text{(Equation 3)}$$

Where:

- XXX = tyre width [in or mm]
- YY = height of tyre side (Ger. *Reifenflankenhöhe*) as percentage of the tyre width
- R = radial tyre (bias-ply tyres were not assumed to be used for any ride)
- ZZ = diameter of wheel rim [in].

For calculating the tyre diameter, the following equation was used:

$$\text{Tyre diameter} = (2 \cdot XXX \cdot YY) + ZZ \qquad \text{(Equation 4)}$$

Values found frequently in literature on working weights, tyre dimensions and working widths of various machines and tools were collected and listed – those can be found in annex 8.1.

Table 3 is a detailed part of the data entry into the SALCA model and presents some of the indirect SQ indicators which are considered by the model. A more detailed part considering all indirect SQ indicators can be found in annex 8.4.

Table 3. The data entry worksheet of the SALCA model, here with some of the indirect SQ indicators.

Data entry for the estimated influence of farm management on soil quality		
NAME	Farming Business XY	
Name of parcel / business-specific no.	Parcel 1	
Number of concerned parcels	14	
Details on parcel / location		
Total area of arable land at the business (ha)	113,39	
Total area of grassland at the business (ha)	0	
Area size parcel (ha)	13,96	
Clay content (%)	38	
Organic matter content (%)	4,3	
pH (-)	5,6	
Type of climate (dry, humid, wet)	dry	
Climatic suitability zone (A - G)	A	
Crop rotation arable farming		
Harvesting date previous culture (day.month.year)	1. Aug. 12	
Sowing date main culture (day.month.year)	12. Okt. 12	
Harvesting date main culture (day.month.year)	17. Jul. 13	
Culture (code: see work sheet 'Cultures')	WW	
Fresh weight yield (dt/ha)	45,4	
Dry weight yield (dt/ha)	39,8	
Ploughing with normal seedbed preparation (yes=1, no=0)	1	
Animal Husbandry		
Time of pasturing (month, 1-12)		
Duration of pasturing (days)		
Stocking intensity (LU/ha)		
Harvest Grassland Management		
Height of mowing (cm)		

Fertilisation	
Fertiliser 1: kind according to list (code)	21
Fertiliser 1: amount applied (t or m3)	14,33
Fertiliser 1: dilution (fertiliser:water)	1
Humod soil assessment	
Amount mineral N-fertiliser applied (kg N/ha)	
Quality of the location (very good, good, reasonable, unfavourable)	good
Yield level (low, medium, high)	high
N-content main culture (%)	1,8
Fresh weight yield main culture by-product (dt/ha)	37,0
Dry weight yield main culture by-product (dt/ha)	31,8
Soil tillage	
Date of ploughing main culture (day.month.year)	15.09.12
Date of rotary hoeing main culture (day.month.year)	
Plant protection	
Plant protection agents	
Heavy metals	
Cadmium inflow into the soil (Cd, mg)	6588,86
Copper inflow into the soil (Cu, mg)	959966,70
Machine Rides	
Ride 1:	
Description of ride	Ploughing
Date of ride (month, 1-12)	9
Working weight (merely 75% of total weight if weight varies during ride)	9260
Axle load 1st axle (%)	38
Tyre diameter 1st axle (m)	1,34
Tyre width 1st axle (m)	0,50
Working width (m)	1,60

3. Results

3.1 Adaptation of Indirect SQ indicators

3.1.1 Redefinition of the Types of Climate

As explained in section 2.1.1, it appeared to be unreasonable to allocate climate zones for Austria under a standard 3-clusters-variant since one of the measurement locations showed to have an enormously positive water balance which differed substantially from values of other locations (Figure 4). A standard 3-clusters-variant would therefore stand for three climate zones with one of them consisting of only one measurement location, which appears to be rather impractical. Therefore, clustering was conducted again by increasing the previously stipulated number of clusters from three to four (Figure 5) and subsequently excluding the measured values from the location '15412 Sonnblick'.

After having compared and statistically analysed the curves of Austrian and Swiss climate zones, it was found that for 50% of the months of all three TOCs net precipitation values from Austria differed significantly ($p < 0,05$) from net precipitation values from Switzerland. A graphical comparison of the two countries can be viewed below (Figure 6). The statistical output from the comparison of TOCs between the two countries is recorded in annex 8.2.

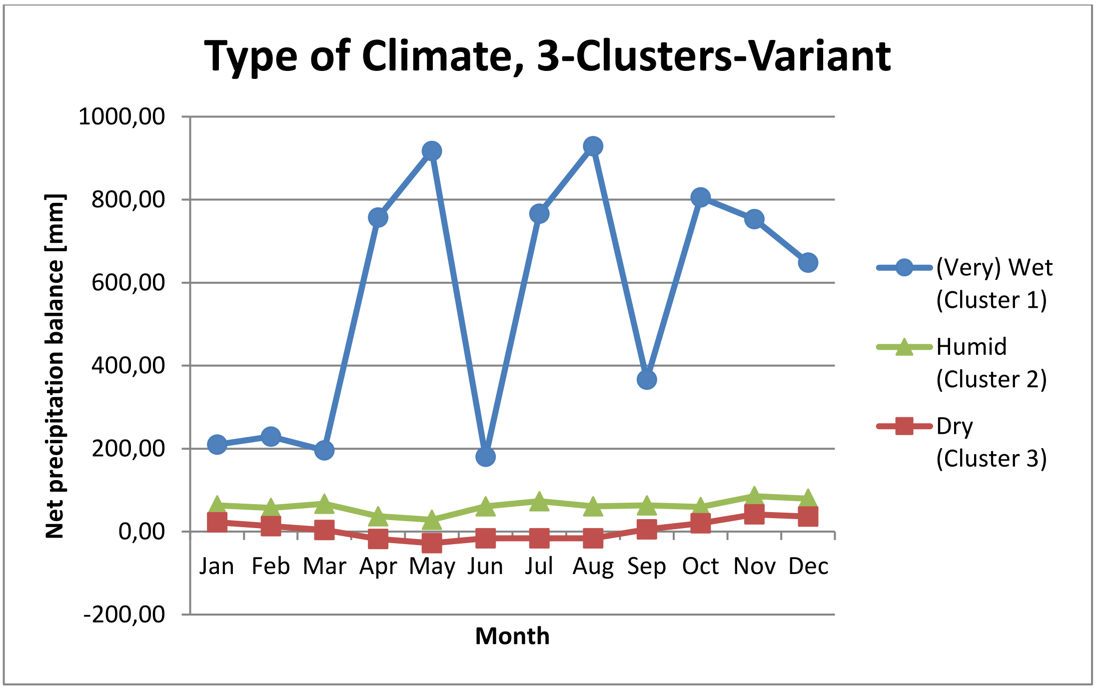

Figure 4. Definition of the Austrian TOCs by cluster analysis with a preliminary determined number of three clusters. Cluster 1 presents the water balance of a statistical outlier (ZAMG station '15412 Sonnblick') and therefore is not representative for the typical wet TOC present in Austria.

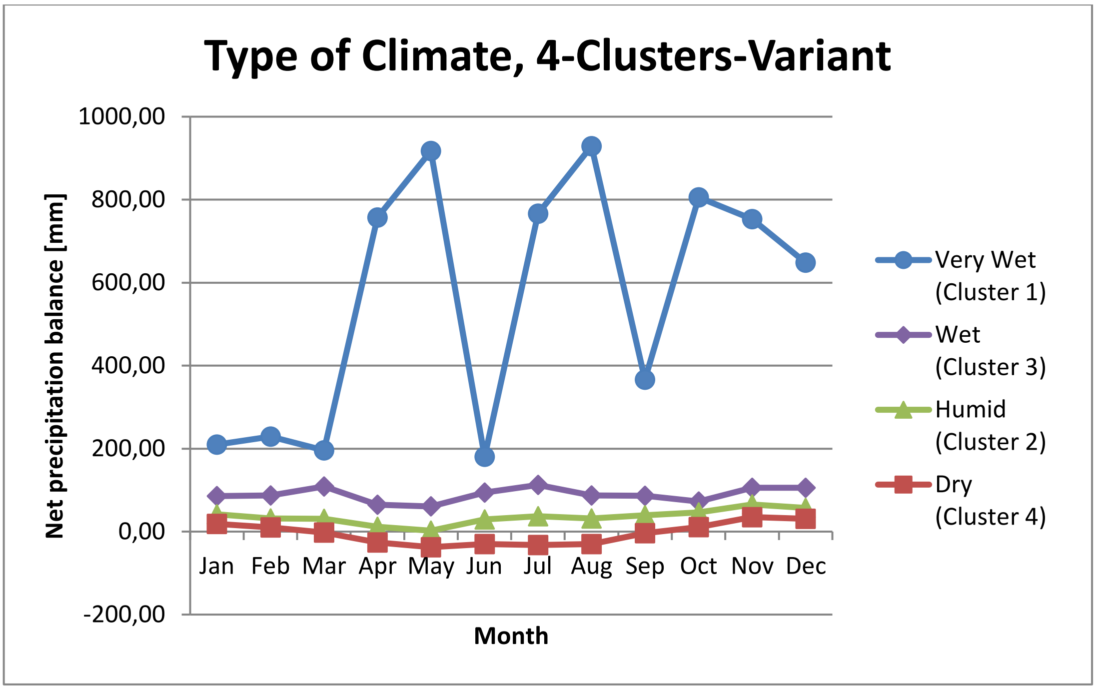

Figure 5. After having corrected for the statistical outlier by increasing the number of clusters from three to four, representative curves (purple, green and red curve) of the Austrian TOCs were derived.

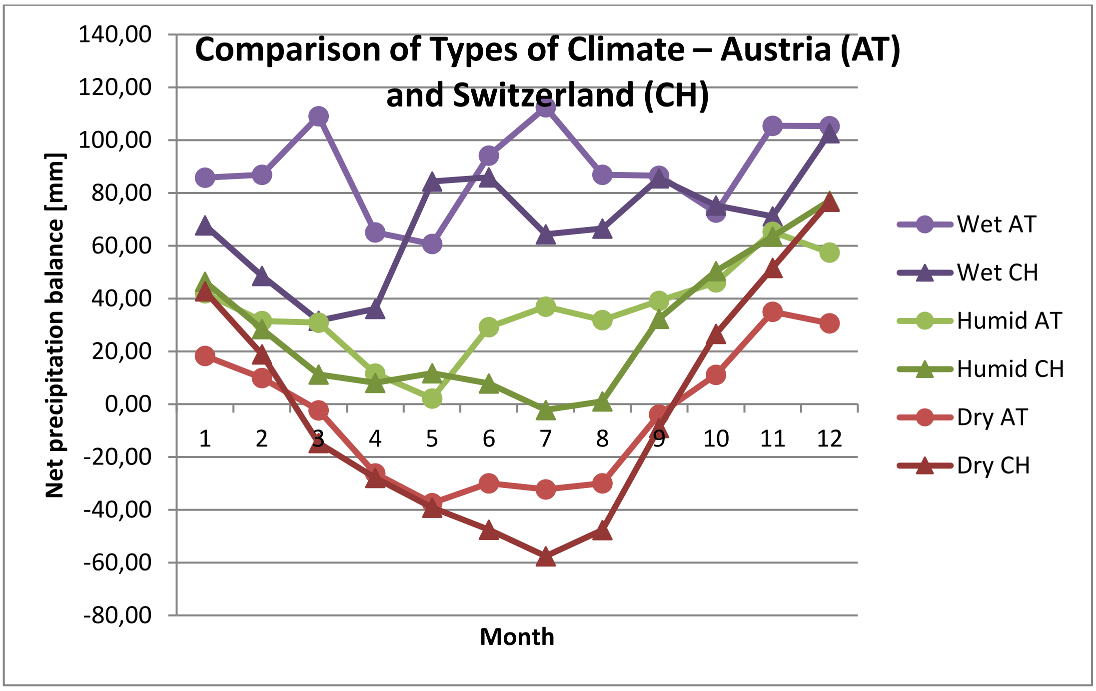

Figure 6. A graphical comparison of the TOCs representative for Austria with the ones representative for Switzerland.

3.1.2 Redefinition of the Soil Moisture Levels

According to the values of the input parameters for Hydrus-1D which are listed in section 2.1.2, the programme calculated soil water potentials for sandy, loamy, silty and clayey soils for dry, humid and wet TOCs. The new definitions are summarized in Table 4 (see annex 8.3 for the exact values of every measurement location and of every month).

Table 4. SMLs applicable for Austria were redefined by calculating for every month and every soil type the average soil water potential and by a subsequent classification according to the definitions as listed in Table 1, section 2.1.2.

Month	Sandy soil / normally permeable soil	Loamy soil / slightly water logged soil	Silty soil / slightly water logged soil	Clayey soil / considerably water logged soil
0	Sand	Loam	Silt	Clay
1	wet	humid	humid	dry
2	wet	humid	humid	dry
3	wet	humid	humid	dry
4	wet	dry	dry	dry
5	wet	dry	dry	dry
6	wet	humid	dry	dry
7	wet	dry	dry	dry
8	dry	dry	dry	dry
9	wet	humid	humid	humid
10	wet	humid	humid	wet
11	wet	humid	humid	dry
12	wet	humid	humid	dry

Month	Sandy soil / normally permeable soil	Loamy soil / slightly water logged soil	Silty soil / slightly water logged soil	Clayey soil / considerably water logged soil
0	Sand	Loam	Silt	Clay
1	wet	wet	humid	humid
2	wet	humid	humid	dry
3	wet	humid	humid	dry
4	wet	dry	dry	dry
5	wet	humid	humid	dry
6	wet	wet	wet	dry
7	wet	humid	humid	dry
8	wet	wet	wet	humid
9	wet	wet	wet	wet
10	wet	wet	wet	wet
11	wet	wet	wet	wet
12	wet	humid	humid	dry

Month	Sandy soil / normally permeable soil	Loamy soil / slightly water logged soil	Silty soil / slightly water logged soil	Clayey soil / considerably water logged soil
0	Sand	Loam	Silt	Clay
1	wet	wet	wet	humid
2	wet	wet	wet	humid
3	wet	humid	humid	dry
4	wet	humid	humid	dry
5	wet	wet	humid	humid
6	wet	wet	wet	wet
7	wet	wet	humid	dry
8	wet	wet	wet	humid
9	wet	wet	wet	wet
10	wet	wet	wet	dry
11	wet	wet	wet	wet
12	wet	wet	wet	humid

According to the calculations of Hydrus-1D, clayey soils are suggested to have in general the most negative values of soil water potentials, followed by silty and loamy soils and finally sandy soils with the least negative (i.e. closest to zero) potentials. One could conclude from this that sandy soils, in general, are the ones with the highest moisture content of all soil types and clayey soils are the ones with the lowest, hence being the most and the least susceptible to pressure from animals and machinery, respectively. However, it needs to be taken into account that soil moisture content strongly depends on the texture or the size of soil particles, like for instance Miller et al. (2002) demonstrated. In the latter study, clayey soils usually prove to have a higher water content than soils with a higher fraction of coarse particles (i.e. sandy soils). This can be confirmed by Kozak and Ahuja (2004) who – similar to drawing water retention curves – illustrated graphically the relation between soil water potential and soil moisture content, with consideration for the soil type (see Figure 7). Those findings base on an equation as formulated by van Genuchten (1980).

Furthermore, soil stability (i.e. the resistance against compaction and shearing) seems to be negatively correlated with the soil moisture content, as it was found by Gitau et al. (2006) and stated by Hunt et al. (2013). Hydrus-1D calculates for the upper soil layer less negative water potentials for sands than for clays; however, the water content of the clayey soil – and, likewise, the risk of soil damage caused by farming activities – might still be higher than for sandy soils (Figure 7). In this latter case, it seems to be impractical to assume for all soil types the same threshold values for defining the SML, like it was done with the values listed in Table 1 (section 2.1.2). Presumably, threshold values of loamy and silty soils (and in particular of clayey soils) would be more negative than the ones of sandy soils. Like already mentioned in section 2.1.2, defining the levels according to the plasticity of the soil would be more appropriate than allocating to them the terms 'dry', 'humid' and 'wet', since the meaning of the SMLs is to assess the resistance of soils towards pressure and not, for instance, to estimate water availability for plant growth. However, for the assessment of SQ of the data sets in section 3.2, the Swiss SMLs were used since those definitions are considered to be more appropriate than the output of Hydrus-1D for predicting the outcome of the direct SQ indicators.

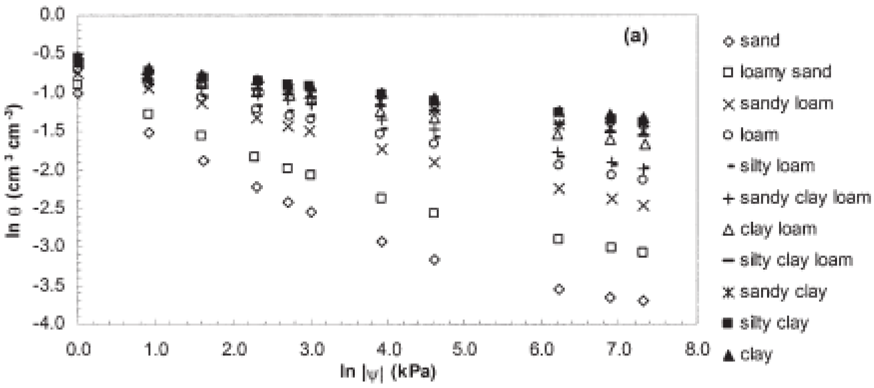

Figure 7. Relation between the soil water potential ψ and the soil moisture content θ. With an increasingly negative soil water potential (x-axis, pF-value), the moisture content (y-axis, $e^{-θ}$) declines the most rapidly for sandy soils and the least rapidly for clayey soils. Source: Kozak and Ahuja, 2004.

3.1.3 Allocation of the Climatic Suitability Zones

On the basis of measurements on the average length of the vegetation period, taken at 260 different sites throughout Austria, it was found that 195, 33, 6, 2, 8, 14 and 2 sites were located in the zones A, B, C, D, E, F and G, respectively. According to those results, for the majority of agricultural areas in Austria earthworm populations seem to be the most active (and therefore the most vulnerable) in March and April and from mid-September until mid-November, like concluded amongst others by Johnson-Maynard et al. (2007) and Crittenden et al. (2015). A map of Austria with the allocation of the CSZs is depicted in Figure 8.

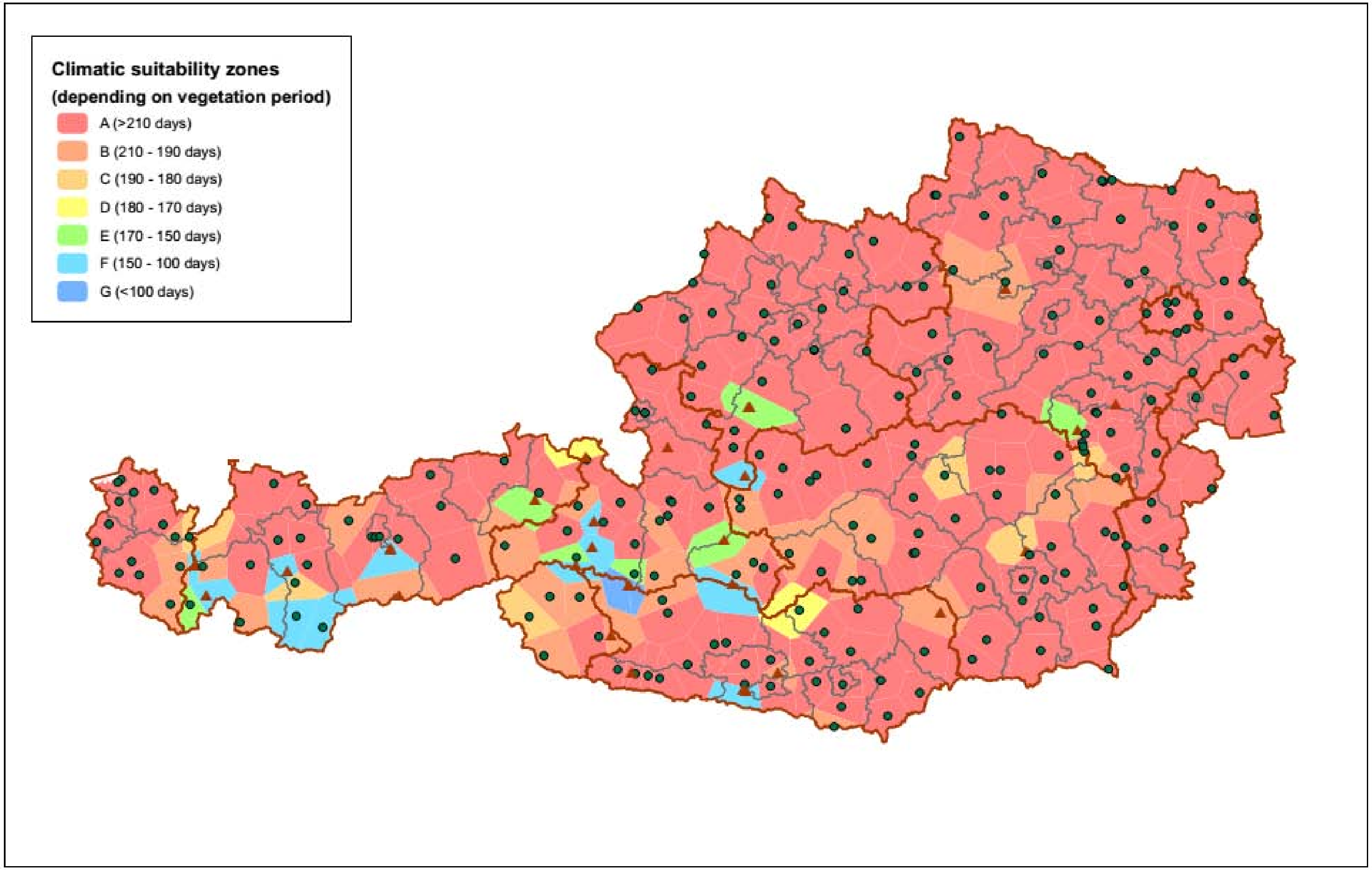

Figure 8. A map of Austria presenting the distribution of the seven CSZs as well as the location of the in total 260 highland (triangles) and lowland (dots) meteorological stations. Districts are enclosed by grey lines, federal states are enclosed by red lines.

3.2 Validation of the Adapted Model and Analysis of the Assessment

The validation of the Austrian model could be achieved only to a limited extent. For one part, this is due to the unsuitable approach of revising indirect SQ indicators for Austria: the map of CSZs presented in section 3.1.3 (Figure 8) only makes it possible to roughly estimate the CSZ in which a certain farming business is located. Even worse, the revised tables of SMLs ambient in Austria (section 3.1.2, Table 4) stand in considerably sharp contrast with the levels as defined for Switzerland, and therefore their practicability for implementing them in the SQ model can be questioned. For the other part, it needs to be considered that none of the data sets of the field trials include influences of pasturing animals and the following effects on SQ, as the focus of all field trials was on the comparison of certain tillage systems or crop rotations and not animal husbandry. As a consequence, input data for instance on animal husbandry (section 2.4.3), fertilisation (section 2.4.5) or heavy metals (section 2.4.9) is missing. This, in turn, confers in some way DSs-G and DSs-M the status of 'validation data sets' for the latter mentioned input categories. In addition, the institutions could only provide measurement data on a few (usually two or three) direct SQ indicators, which makes it impossible to fully validate the adapted SALCA model. A comparison between the measured values of the field trials and the assessment of the SALCA model can be drawn with Table 5.

In the following, each direct SQ indicator will be analysed individually by comparing the data sets of the same location among each other as well as by comparing the POFBs:

- **Rooting depth**. Like Oberholzer et al. (2006) already explained, the depth to which plants (here only considered cultures used in arable farming) can penetrate with their roots into the soil depends on the structure, the water balance and on compacting forces, amongst others. However, in the model the rooting depth merely depends on erosivity, which is the reason for why this direct SQ indicator cannot be assessed positively (+ or ++) by the model. If erosivity exceeds a threshold value of 0,33 mm or 2,6 mm/(ha*a) loss of soil, it will be assessed with - or --, respectively. According to Oberholzer et al. (2006), soil compaction primarily influences the macropore volume and therefore is not considered for assessing the rooting depth. Only the soil from DSs-T12-T15 showed to have relatively high values of soil erosion; those, however, are likely to be due to the natural conditions (a steep slope, for instance) as erosion of all four tillage systems was said to be equally high. However, erosivity due to farming activity can clearly be reduced when the soil is tilled less intensively, like for instance Klik (2015) already suggested. In this way, the SALCA model only offers a qualitative assessment of rooting depth made dependent on the magnitude of erosivity; however, it appears questionable whether the erosion rate is easier to determine for SQ-LCA than the rooting depth in itself in the field if erosivity which is due to farming activities needs to be estimated.

- **Macropore volume**. The in-field measured macropore volumes of DSs-T12-T15 seem to be in some conflict with the assessment of the SALCA model: According to the model output, macropore volume will in general receive a better ranking for RT, MT and NT compared to CT. However, measurement findings suggest the opposite (Table 5), but it is not known whether those measurements are also statistically significant and in which way or under which circumstances the macropore volume was measured at the site. DS-T17 demonstrates the strongly improving effect grassland (in this case: alfalfa) has on this indicator. The absence of this effect for DS-T20, where alfalfa was cultivated, too, might be explained by the machine rides – on the land of DS-T20 at least one ride more was taken than on the land of DS-T17, and the machines of DS-T20 were in general much heavier than the machines used for DS-T17. Therefore, the supporting effect might have been compensated by the damage caused by farm machinery.
- **Aggregate stability**. In general, DSs-T1-T15 attribute a neutral or slightly positive effect of RT, MT and NT on aggregate stability, whereas CT is considered by the model to impact aggregate stability not or slightly negatively. Aggregate stability predicted for DS-T12, for instance, is considered to be lower than for DS-T13, -T14 and -T15 because only for -T12 a plough was implemented. Ploughing is done in many cases under a relatively narrow working width, which results in a higher risk of soil compaction since more rides up and down the field need to be done. In regard to arable farming, a major part for the assessment of this indicator also depends on the organic matter balance (Ger. *Humusveränderung*): especially parcels with a high clay content seem to have an elevated net loss of organic matter due to a high mineralisation coefficient, which in turn is determined by the fraction of clay in the top soil. The risk of compaction by pasturing and, in particular, by machines, play an important role for this direct SQ indicator, too. Furthermore, fallow areas (Ger. *Buntbrache*) can have a considerably high loss of organic matter when the ambient soil has a high fraction of clay (see DSs-A). At the same time, they intrinsically contribute only little to the formation of new organic matter as there are no roots or other parts of plants left in or on the soil (contrasting apparently any kind of cultivation, also plant groups which are rather "degraders" of organic matter, like cereal crops and root crops). This fact can explain the low assessment of aggregate stability for DSs-A, where soils are quite clayey and where some parcels are left as fallow. The partly contradicting values of in-field measured aggregate stability (Table 5) compared with the results of SALCA might be due to a gradual, long-term increase in aggregate stability in

Table 5. Comparison between in-field measured values and SALCA assessments on direct SQ indicators. For all of the five locations, the most favourable results of the measured values as well as of the SALCA outputs are highlighted in green. For cells where no comparison is possible, e.g. because direct SQ indicators were not measured in-field, highlighting was omitted. RD = rooting depth, MV = macropore volume, AS = aggregate satbility, Corg = soil organic carbon content, HM = heavy metal content, OP = organic pollutants content, EB = earthworm biomass, MB = microbial biomass, MA = microbial activity.

Data Set	RD [cm]	RD (SALCA)	MV [vol.%]	MV (SALCA)	AS [%]	AS (SALCA)	Corg [%]	Corg (SALCA)	HM [mg/kg]	HM (SALCA)	OP [ng I-TEQ/kg]	OP (SALCA)	EB [g/m2]	EB (SALCA)	MB [mg biomass-C/kg]	MB (SALCA)	MA [mg CO2-C/h*kg]	MA (SALCA)
DS-T1 (CT)		0	14	0	10,4	0	1,74	0		0		0		-		0	8,5	0
DS-T2 (RT)		0	13	+	12,8	+	1,75	0		0		0		0		0	9,5	0
DS-T3 (MT)		0	16	+	25,1	+	1,88	0		0		0		0		0	10,5	0
DS-T4 (CT)		0		0	37,0	0	0,88	0		0		0		0		0		0
DS-T5 (RT)		0		0	41,0	0	0,94	0		0		0		0		0		0
DS-T6 (MT)		0		0	41,0	0	0,94	0		0		0		0		0		0
DS-T7 (NT)		0		0	43,0	0	0,83	0		0		0		0		0		0
DS-T8 (CT)		0		0		0	1,72	0		0		0		- -	2,5	0	8,8	0
DS-T9 (RT)		0		0		+	1,80	0		0		0		0	2,6	0	10,4	0
DS-T10 (MT)		0		0		+	1,80	0		0		0		0	2,6	0	10,4	0
DS-T11 (NT)		0		0		+	1,86	0		0		0		0	2,6	0	10,0	0
DS-T12 (CT)		- -	16	0	34,0	0	1,44	0		0		0		0	1,9	0	4,2	0
DS-T13 (RT)		- -	11	+	45,0	+	1,40	0		0		0		0	2,1	0	4,6	0
DS-T14 (MT)		- -	11	+	45,0	+	1,40	0		0		0		0	2,1	0	4,6	0
DS-T15 (NT)		- -	12	+	55,0	+	1,42	0		0		0		0	2,0	0	4,6	0
DS-T16 (2004-WG)	70	0	18	0	25,5	0		0		0		0		0		0		0
DS-T17 (2005-KW)	70	0	18	++	17,5	+	2,30	0		0		0		+		0		0
DS-T18 (2010-SEE)		0		-	31,5	-	2,30	0		0		0		+		-		-
DS-T19 (2012-WR)	94	0	17	-	27,0	-		0		0		0		-		-		-
DS-T20 (2013-KW)	94	0	17	0	30,5	0	2,30	0		0		0		+		0		0

practice (possibly due to crop rotation), whereas the differences calculated by the model are merely due to differences in machine rides. This might demonstrate the need for revising and further developing the model.

- **Soil organic carbon content**. In contrast to the macropore volume or aggregate stability, the soil organic carbon content (or C_{org}) is influenced only by one impact category since it depends merely on the organic matter balance. From this fact it may be concluded that the risk of a low assessment of aggregate stability is high when C_{org} is predicted by the model to be low. Organic matter in the soil is considered to consist of all chemical compounds where carbon is bond organically; the organic matter content may therefore be approximated by multiplying the SOC-content with 1,725 (Oberholzer et al., 2006). Like mentioned above, increases and losses of organic matter will depend on the fraction of clay in the soil, the pH (values above pH=7 will decrease mineralisation and by this reduce the losses of organic matter), the fraction of fallow or artificial pasture areas to the total surface area (natural pasture is considered as grassland and is therefore not taken into account for assessing C_{org}), plant residues and the organic fertilisation. Despite SOC depends on those several indirect SQ indicators, measurement data from practice confirm the assumption that SOC changes only gradually and substantial changes can be recognized only in the long-term (see the comparison of C_{org} of the year 2005 with C_{org} of 2013, Table 5). Moreover, as various forms of soil tillage (as data is entered under the indirect SQ indicator category *machine rides*) are not considered for assessing the impact on C_{org}, it appears obvious that for the field trials (DSs-T1-T15) no differences are calculated by the model.
- **Heavy metal content**. This direct SQ indicator will be assessed according to the time it takes for a certain parcel or business to exceed the upper guidance level (Ger. *Richtwert*) of any of the listed heavy metals, including cadmium, chromium, copper, lead, mercury, nickel and zinc. Those guidance levels are listed in the description of the SALCA model (Oberholzer et al., 2006). Heavy metals are considered to be introduced into the soil via organic fertilisers. The concentration of every metal depends on the kind of fertiliser applied; average background values were calculated from a review conducted by Freiermuth (2006). Applying to all heavy metals, SQ is regarded not to be under threat (heavy metal content = 0) if the upper guidance level will be reached after 300 years or later, and a low threat (-) is assumed if this time period is between 30 and 300 years. For any time shorter than 30 years, this direct SQ indicator is assessed highly negatively (--). However, this latter case does not account for any of the data sets, as only little (if any) organic fertiliser was applied on the parcels of the field trials as well as of the POFBs.

- **Organic pollutants content**. Like heavy metals, organic pollutants (PCDDs, PAHs and PCBs) are considered to enter the soil via organic fertilisers but can also occur in plant protection materials or engine fuel. However, average background values were not (yet) stipulated for the various kinds of organic fertilisers, meaning that the default assessment of this direct SQ indicator equals zero. If there is a potential risk of organic pollutants entering the soil, concentrations (optionally expressed as international toxicity equivalents) found in the relevant substance need to be estimated by the user. Upper guidance levels are listed as well by Oberholzer et al. (2006).
- **Earthworm biomass**. Earthworms play a vital role in maintaining and improving soil structure by digesting organic material, which stabilizes soil aggregates and promotes microorganisms which, in turn, contribute to the nutrient availability for plant growth. In addition, they dig burrows in the topsoil, thus homogenising and loosening the upper soil layers and enhancing aeration and infiltration of precipitation water (Oberholzer et al., 2006). Not tilling the soil, applying lime and organic fertilisers, mowing grassland areas not below a cutting height of 8 cm, growing plants with a high vegetation value (Ger. *Kulturwert*) and leaving crop residues on the fields are farming activities which are considered by the model to be beneficial for earthworm viability. However, earthworms can also be affected by mechanical / physical as well as by chemical stresses resulting from farming. For almost all data sets where tillage variants were investigated, the damage resulting from ploughing (CT) is represented by a lower assessment of this indicator. Like already implied in section 2.1.3, the intensity of damaging earthworms by ploughing depends on the time of the year and the ambient CSZ. Chemical damage comprises the spreading of (mixed solid and) liquid manure and even more the spraying of plant protection materials. In general, cultivating pasture has the most benign effect on this indicator, which seems to be due to the minimized tillage activity and the high vegetation value which is attributed to grassland covers.
- **Microbial biomass**. Microorganisms (bacteria, fungi etc.) form a valuable part of degrading organic compounds and by this making nutrients available for plants. In addition, they stabilize soil aggregates like earthworms do (Oberholzer et al., 2006). Apart from the application of plant protection materials (which is seen as having adverse effects on the microbiota and even more on earthworms), microorganisms are harmed by soil compaction, by heavy metals and by organic pollutants entering the soil. The damage which is due to compaction might be due to the circumstance that many of them respire obligatory aerobically. However, since no or only little organic fertilisers, lime, plant protection materials, heavy metals (via organic fertilisers) and organic pollutants were

spread on the parcels of the field trials, the assessment of this direct SQ indicator turned out to be equal for all data sets with different tillage systems. Negative values of DSs-T18 and -T19 can be explained by a negative assessment of the macropore volume which is in those two cases the result of soil-damaging machine rides.

- **Microbial activity**. Microbial activity in fact is assessed by the model the same way as microbial biomass is – this is also declared by Oberholzer et al. (2006) who found for those two direct SQ indicators a correlation coefficient r_s of 0,96 (Spearman's rank). The only difference concerning impact categories is the option of applying easily degradable organic substances (Ger. *Zufuhr schnell abbaubarer organischer Substanz*) which are considered for microbial activity. Those are substances which are considered by the model to contain less than 10% of organic matter (liquid manure of dairy cattle, for instance).

A more detailed analysis on which direct SQ indicators are influenced by which indirect SQ indicators and impact categories is provided by Marbot (2012). Differences between the assessments of arable farming and grassland management may be explained by the fact that for several impact categories, like damage on structure by pasturing (Ger. *Gefügeschädigung durch Beweidung*) and stabilisation of structure (Ger. *Gefügestabilisierung*), the weighting (Ger. *Gewichtung*) is set lower. Therefore, the overall evaluation of a direct SQ indicator is likely to be closer to zero. In addition, impact categories like the organic matter balance and the two direct SQ indicators 'rooting depth' and 'soil organic carbon content' are not considered for grassland management (compare Figures 10 and 11).

When the complete assessments of the POFBs are compared, the data sets of mixed arable farming / grassland management (Figure 12) appear to represent the best practices of maintaining SQ. Neither the parcels of grassland management nor the parcels of arable farming appear to be affected negatively for any of the direct SQ indicators. The macropore volume and C_{org} were assessed as slightly positive and aggregate stability even as very positive for arable farming. On the contrary, the parcels of DSs-A1-A14 were predicted to be managed in an obviously adverse manner, like the calculations for aggregate stability, C_{org}, microbial biomass and microbial activity prove (Figure 9). Negative values on those four direct SQ indicators are mainly due to a heavy net loss of organic matter, since only little organic fertiliser was applied on merely a few parcels. The parcels of DSs-G1-G10 (Figure 10) were fertilised rather poorly, too; however the earthworm biomass and especially the macropore volume obtained a better result than parcels of DS-A. This difference is mainly due to the machines used for DSs-G which were lighter than the ones used for DSs-A.

Based on those outcomes, however, it would not be recommendable to assess mixed arable farming as the "best" way of managing a business, although numerous scientific studies might exist which in total support this assumption. Firstly, it should be taken into account that those three businesses are only examples of their types of business and do not necessarily represent the typical assessment of other arable or grassland businesses. Secondly, to a certain extent it seems like the model has the potential of being developed further considerably and that several assumptions which are made for entering data can have a higher influence on the model output than previously expected. This latter point will be further discussed in chapter 4. The assessments of the POFBs are presented below.

Ackerbau					
	Bewertung				
Direkte Indikatoren	**--**	**-**	**0**	**+**	**++**
pflanzennutzbare Gründigkeit			0		
Grobporenvolumen		-			
Aggregatstabilität	--				
Corg-Gehalt	--				
Schwermetallgehalt (Cd, Cr, Cu, Pb, Hg, Ni, (Zn))			0		
Organische Schadstoffe			0		
Regenwurmbiomasse		-			
Mikrobielle Biomasse	--				
Mikrobielle Aktivität	--				

Gesamtergebnis SALCA-Bodenqualität Ackerfläche:	-2
Gesamtergebnis SALCA-Bodenqualität Grünlandfläche:	0
Gesamtergebnis SALCA-Bodenqualität:	**-2**

Figure 9. SQ Assessment of DSs-A1-A14.

Ackerbau					
	Bewertung				
Direkte Indikatoren	**--**	**-**	**0**	**+**	**++**
pflanzennutzbare Gründigkeit			0		
Grobporenvolumen					++
Aggregatstabilität		-			
Corg-Gehalt		-			
Schwermetallgehalt (Cd, Cr, Cu, Pb, Hg, Ni, (Zn))			0		
Organische Schadstoffe			0		
Regenwurmbiomasse				+	
Mikrobielle Biomasse		-			
Mikrobielle Aktivität		-			

Gesamtergebnis SALCA-Bodenqualität Ackerfläche:	-2
Gesamtergebnis SALCA-Bodenqualität Grünlandfläche:	0
Gesamtergebnis SALCA-Bodenqualität:	**-2**

Figure 10. SQ Assessment of DSs-G1-G10 when artificial pastures (Ger. *Kunstwiese*) are cultivated on the parcels, which are considered by the model as arable land.

Grasland					
	Bewertung				
Direkte Indikatoren	--	-	0	+	++
Grobporenvolumen			0		
Aggregatstabilität			0		
Schwermetallgehalt (Cd, Cr, Cu, Pb, Hg, Ni, (Zn))			0		
Organische Schadstoffe			0		
Regenwurmbiomasse			0		
Mikrobielle Biomasse			0		
Mikrobielle Aktivität			0		

Gesamtergebnis SALCA-Bodenqualität Ackerfläche:	0
Gesamtergebnis SALCA-Bodenqualität Grünlandfläche:	0
Gesamtergebnis SALCA-Bodenqualität:	**0**

Figure 11. SQ Assessment of DSs-G1-G10 when natural pastures (Ger. *Naturwiese*) are cultivated on the parcels, which are considered by the model as grassland.

Ackerbau					
	Bewertung				
Direkte Indikatoren	--	-	0	+	++
pflanzennutzbare Gründigkeit			0		
Grobporenvolumen				+	
Aggregatstabilität					++
Corg-Gehalt				+	
Schwermetallgehalt (Cd, Cr, Cu, Pb, Hg, Ni, (Zn))			0		
Organische Schadstoffe			0		
Regenwurmbiomasse			0		
Mikrobielle Biomasse			0		
Mikrobielle Aktivität			0		

Grasland					
	Bewertung				
Direkte Indikatoren	--	-	0	+	++
Grobporenvolumen			0		
Aggregatstabilität			0		
Schwermetallgehalt (Cd, Cr, Cu, Pb, Hg, Ni, (Zn))			0		
Organische Schadstoffe			0		
Regenwurmbiomasse			0		
Mikrobielle Biomasse			0		
Mikrobielle Aktivität			0		

Gesamtergebnis SALCA-Bodenqualität Ackerfläche:	1
Gesamtergebnis SALCA-Bodenqualität Grünlandfläche:	0
Gesamtergebnis SALCA-Bodenqualität:	**1**

Figure 12. SQ Assessment of DSs-M1-M29 (including an assessment of both arable (Ger. *Ackerbau*) as well as grassland (Ger. *Grasland*) areas).

4. Discussion

One major step of adapting the already existing model of SALCA-SQ to geographical and geological conditions in Austria was taken by collecting data on indirect SQ indicators, entering them into the tool and comparing the outcomes with data on direct SQ indicators, measured in-field at the corresponding site. This comparison was required for validating the correctness of input values attained from model computations as well as of input values which were acquired from interviews and literature research. Eventually, the results of the tool should equal most extensively the measurements on direct SQ indicators, by this verifying the correct operation procedure of the tool. However, two issues need to be addressed here which potentially deteriorate both the validation of the adapted model as well as the results obtained from the model.

The first issue concerns the validity and applicability of input parameters, especially those for which data was derived from field trials of LAKO. Apparently, numerous variables and parameters which are asked by the model have either never been assessed for the field trials at all, or measurements were taken numerous years ago and thus are obsolete. Rough estimations and assumptions worsen the inaccuracy of the input data. For instance, all soil cultivation techniques which do not belong to the CT or NT variant were termed as RT variant, regardless which machines came into use and with which intensity they cultivated the soil. Likewise, the allocation of the CSZ appeared to be equal for all sites with a vegetation period of 190 days or more per year – that is to say, no (substantial) difference was seen between sites located in CSZ A and sites located in CSZ B. In fact, according to the Swiss Federal Office for Agriculture (BLW, 2012), the variety of cultivable crops is more restricted for sites of CSZ B and yield quantity and security is lower than for sites of CSZ A. Whether or not it would make sense to distinguish between those two groups regarding earthworm vulnerability is not assessed. However, further studies which would examine statistically significant differences in earthworm activity between a site with a vegetation period of just 190 days and another site with a vegetation period of e.g. 240 days could be helpful for further developing the model. For this study, at least a classification of the meteorological stations as “highland” and “lowland” was done. This seemed to be useful as this should avoid misinterpretations possibly made by landowners when looking for the CSZ in which their business is located. For every station as well as for the surrounding area, one CSZ was assigned – borders to neighbouring areas were defined by the Euclidean distance between two meteorological stations. However, with this approach an area could possibly contain more than one CSZ if changes in altitude level were quite high within this area. Due to this, a landowner might for instance consider his business to be located in CSZ D because the meteorological station lies on top of a mountain and only has a short vegetation period; however, the business is located at the foot of the mountain and therefore belongs in fact to CSZ B. An enhanced map of Austria taking steep slopes into account for the allocation of CSZs would therefore be recommendable.

For the majority of the data sets, further estimations were made in regard to the depth at which soil compaction can occur, the degree of loosening of the soil, the soil density and several other parameters. Those have never been investigated in the field trials, nor in the POFBs, therefore their magnitudes needed to be estimated by taking average values which were provided by the original Swiss agricultural model – see section 2.4.10 (Oberholzer et al., 2006). On the other hand, another assumption which has been made by the original version of the model but where input data was tried to represent better the real, given circumstances in this study pertains to the degree of loosening of the soil. For instance, it is supposed by default by the model that prior to every ride of harrowing (which can be done with substantial variation considering the type of implement, working depth and working speed) the soil would be in a loose state, regardless whether or not it was tilled beforehand with a plough or a cultivator. However, this assumption was not made for the data entry of e.g. DSs-T8-T10, where for the first ride the field was harrowed – thus, the soil here was rather considered to be in a tight state since no tillage was conducted previously.

For many indirect SQ indicators it is not assumed that the difference between the standard values of the original model and the real but not measured values from the field trials differ in such a considerable way that the outcome of the adapted SQ model is distorted substantially. However, there are some exceptions, like the correct choice of organic fertilisers which were applied. This concerns for instance the parcels of DSs-A5, -A8 and -A15, where solid manure was spread. Since this kind of organic fertiliser was not listed in the model worksheet 'orgDünger', the assumption was made that 'degraded stable manure' (code 21) was applied. 'Stacked manure' (Ger. *Stapelmist*, code 3) would have been a realistic option, too; however, if this fertiliser is entered into the data sets, the assessment levels of the overall aggregate stability, C_{org}, microbial biomass and microbial activity all improve by one stage (from (--) to (-)). Therefore, expert knowledge on choosing the most appropriate input data if substitutions need to be made, like described above for the DSs-A, would be required for a more accurate examination and subsequent implementation of the revised model. This expertise should be combined with the sound knowledge on the way the model calculates, and the entry of not merely estimated data but of real, in-field measurements is recommendable. Consequently, the planning and execution of additional field trials with special regard to measuring all parameters as required by the (new) model is advocated.

The second issue is about the question of completeness of the model – does this tool consider all variables and parameters which are of vital importance for the determination of the quality of the soil? And can one consider the computation procedure of the model to be correct? For instance, the model requires the documentation of the distribution of plant protection materials. However, neither it seems to take into account the amounts which are sprayed nor does it distinguish between different kinds used for protecting the plants – that means that all kinds of substances are considered to have equally adverse effects on the microbial biomass, the microbial activity and in particular on the earthworm biomass. The same simplification accounts for liming the soil: the model solely asks whether or not more than 10 dt of CaO is spread on a certain parcel – the exact amounts as well as the composition of the liming agent are not considered. Expert institutions do distinguish between the periods of effectiveness of various kinds of limes, though. Calcium carbonate (Ger. *kohlensaurer Kalk*), for instance, is considered to work rather on the long term, whereas quicklime has a relatively rapid onset on changing the soil's pH (Molitor et al., 2012; Landwirtschaftskammer Nordrhein-Westfalen, 2015). If quicklime is spread onto grassland areas or lighter soils, corrosive damages on plants could occur. Since the model does not distinguish between the various forms of CaO, however, this possibly adverse impact on SQ can't be considered.

Another considerable shortcoming of the SALCA version used for this study concerns the data entry of machine rides: for almost all data sets, at least one ride (usually more) needed to be neglected since the maximum number of rides which can be assessed by the model is six. Therefore, only those six rides with the heaviest vehicles or with the smallest working width were considered for the data entry. It could not be assessed how and to which extent the result of the SALCA calculation would change if another combination of machine rides was entered for a given parcel; however, for an updated version of the model this issue definitely should be taken into account. At least, when using the current version, it should be made obvious to all users according to which criteria machine rides should be selected if there are more than six for a data set. Likewise, onland-ploughing or controlled traffic farming – driving with farm machinery always on the same tracks as to reduce on the whole field negative impacts resulting from soil compaction – is not considered by this version of SALCA-SQ.

Furthermore, it appeared that several direct SQ indicators, in particular microbial biomass and microbial activity, are strongly positively correlated, like Oberholzer et al. (2006) already demonstrated. Impact categories of those two indicators are almost the same, and the outcome of the aggregate stability can be estimated fairly well if the assessment of C_{org} is known, as the change in the SOC content merely depends on the change of organic matter. Likewise, a high value is attributed to the change in organic matter for aggregate stability. However, Oberholzer et al. (2006) note that direct SQ indicators should not be included into the model if they do not contribute any further to the assessment of SQ. Thus, it appears to be reasonable to reconsider whether C_{org} and either microbial biomass or microbial activity should continue to be included for the overall SQ assessment. Alternatively, users of the model need to be informed about the similarities between those indicators.

All stakeholders who make use of the new model should be aware of the significance of the output – for some indicators, those only concern relative, specific changes in SQ on their parcels (Oberholzer et al., 2012). The results should not be compared with results from the assessment of another location, since SALCA for part only assesses the changes in farm management and not current SQ states. At least, this applies to the assessed improvement of the direct SQ indicators aggregate stability, macropore volume, earthworm biomass, microbial biomass and the activity of microorganisms when more than 80% of the total parcel area with a soil pH value of less than 6,2 is limed. The improvement of those indicators obviously is assumed to be due to an increase in the overall pH value. However, soils which do already include optimum pH values (above 6,2) are not assessed by the model to have better SQ conditions, since those favourable conditions were already there and not achieved by a change in farm management. A relative assessment is also given for the organic matter balance: the loss of organic matter depends amongst others on the desired minimum value of organic matter (Ger. *wünschenswerter Minimal-Humusgehalt*) as well as on the mineralisation coefficient. The higher the values of those two variables, the higher the loss of organic matter is said to be. The mineralisation coefficient, in turn, is partly determined by the fraction of parcels on which root crops are cultivated. Usually, the cultivation of root crops includes thorough soil tillage, which will increase the mineralisation coefficient; but even if the soil was not tilled in reality, the model will assume intrinsically tillage for any kind of root crop. The desired minimum value of organic matter is calculated higher the more clay in a given soil is present. From those two facts, it may be concluded that the model will compute the most severe losses of organic matter for soils with a high clay fraction and on which root crops are grown. This loss has a negative impact on the macropore volume, aggregate stability, C_{org}, microbial biomass and microbial activity. This final assessment, however, might not represent the real state of organic matter, since according to this calculation procedure grassland soils with a high fraction of clay might be assessed worse for those indicators than e.g. parcels with a very low clay content but on which the soil indeed was tilled heavily.

Despite all inaccuracies and estimations which inevitably need to be accepted for making the model work at all, one should keep in mind that this SQ model should serve in practice as advisory tool rather than as normative, prescribing technology. It does not present for every single landowner an all-over covering, case-specific solution for possibly emerging threats on SQ. Other aspects of farm management which are not considered by the model might still play a crucial role for the overall SQ – as another example, this may address temporarily extreme weather conditions which might influence the risk of erosion or the humification rate. However, constructing and realizing an even more elaborate, sophisticated model which takes an even larger number of input parameters into account will require considerable efforts. More importantly, this might also diminish its user-friendliness, especially in the case of farmers who might be short of time in general and therefore ask for not too complicated tools supporting them in managing their land.

5. Conclusion

The assessment of the soil pertains to its medium- and long-term quality and will be of value primarily for advisory services offered to producers. In addition, the outcomes of the tool can also serve as source of information for other stakeholders like authorities, policy makers or consumers. However, regardless the purpose, one should always keep in mind the various assumptions, estimations and simplifications which are being made by the SALCA model. Ideally, conclusions on (changes of) the state of SQ at a certain location should not be based merely on the outcomes of the model but should be verified by measuring direct SQ indicators at the site.

After having adapted the original version of the SQ model for the three indirect SQ indicators TOC, SML and CSZ, one can assume there is potential for a further improvement of the model adaptation: TOCs as formulated for Austria seem to differ for some parts significantly from the definitions from Switzerland. Nonetheless, it is questionable whether a few centimetres of differing water balances do have a significant effect on SQ in practice as well. SMLs need to be redefined according to the soil water potential or the moisture content which is soil type-specific. Like for the TOCs, however, it seems to be uncertain whether or not a reclassification of SMLs for Austria will differ significantly from the grouping as done for Switzerland. A new map of Austrian CSZs which is drawn in more detail would certainly offer more convenience for ascertaining the ambient vegetation period, especially considering stakeholders who intend to assess SQ in highland areas. A supplementary second map of Austria where altitude levels are depicted on the same scale could be useful as well.

Subsequent to having adapted the current version of the Austrian SALCA model, the correctness of the adaptation is still to be verified by collecting more appropriate, in-field measured input data. In this study, merely three indirect SQ indicators where redefined; however this redefinition was partly done incorrectly and possibly incompletely, if other indirect SQ indicators require an adaptation as well. At least, the overall correct operation of the original version has already been proven by other studies. If a more up-to-date and better applicable version of SALCA-SQ is adapted and implemented more profoundly, the likelihood is increased that this tool can support stakeholders in their decision-making by assessing SQ of agricultural soils in Austria in an elaborate and comprehensible way.

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Seedbed Combinations

- http://www.vogel-noot.info/Produkte/Saatbettkombi (Model „Vogel & Noot VibroCult M490") (last accessed on 06.06.16)
- http://www.kongskilde.com/in/de-DE/Agriculture/Soil/Seedbed%20Cultivation/Trailed%20Precision%20Seedbed%20Cultivator/GERMINATOR%20type%20SP (Models „Kongskilde Germinator SP3000" and „Kongskilde Germinator SP6000") (last accessed on 10.06.16)
- http://www.agrifarm-maschinen.com/produkte-agrifarm/europlan-ii/ (Model „Agrifarm Europlan", 7,0 m working width) (last accessed on 10.06.16)

Rollers

- http://www.vogel-noot.info/Produkte/Ackerwalzen/TerraRoll (Model „Vogel & Noot TerraRoll“, 5,3 m working width) (last accessed on 06.06.16)

Sowing Machines

- http://www.vaderstad.com/de/produkte/saat (Model „Vaderstad Rapid 300S“) (last accessed on 11.06.16)
- http://www.vogel-noot.info/Produkte/Saetechnik (Models „Vogel & Noot ProfiDrill D300“, 3,0 m working width, and „Vogel & Noot ProfiDrill D400“, 4,0 m working width) (last accessed on 06.06.16)
- info.amazone.de/DisplayInfo.aspx?id=696 (Model „Amazone D7 Garant“) (last accessed on 10.06.16)
- http://www.kuhn.de/de/range/saat/pneumatische-einzelkornsmaschinen.html (Model „Kuhn MAXIMA 2 RT“, 4,5 m working width) (last accessed on 11.06.16)
- http://www.poettinger.at/de_at/Produkte/Kategorie/65/saemaschinen (Models „Pöttinger Terrasem R3“ and „Pöttinger Terrasem C6“) (last accessed on 11.06.16)
- http://www.horsch.com/produkte/saemaschinen/scheibensaemaschinen/pronto-td/#id-techdata (Model „Horsch Pronto 8 TD“) (last accessed on 10.06.16)

Lime Spreaders

- http://www.bredal.de/index-1.html (Model „Bredal K105“, 12,0 m working width) (last accessed on 08.06.16)

(Liquid) Manure Spreaders

- http://www.lochmann-erich.it/de/produkte/cp-20/31-1303.html (Model „Lochmann RC 20 Garda“, 8,0 m working width) (last accessed on 08.06.16)
- http://www.fliegl-agrartechnik.de/vakuumfass-und-guellefass-von-fliegl/150/868/206/ (Model „Fliegl Einachs-Fasswagen 5000l“) (last accessed on 09.06.16)
- http://mengele.lely.com/de/dungstreuer_0/dungstreuer/es-5200--14000-ta/einachser#tab (Model „Mengele ES 5200“) (last accessed on 09.06.16)
- http://www.tebbe-landmaschinen.de/ (Model „Tebbe LS 120E“) (last accessed on 09.06.16)

Pneumatic Fertiliser Spreaders

- http://alt.rauch.de/front_content.php?idart=81 (Model „Rauch AERO 2212“) (last accessed on 10.06.16)

Plant Protection Material Spreaders

- http://www.schaffer.at/handel/rau/techdatspri.html (Model „Rau Spridomat D2“, 12,0 m and 15,0 m working width) (last accessed on 11.06.16)
- http://www.hardi-gmbh.com/de/produkte/anbauspritzen (Model „Hardy MASTER plus“, 12,0 m working width) (last accessed on 11.06.16)

Mower Combinations

- http://www.poettinger.at/de_at/Produkte/Detail/15/novacat-maehkombinationen (Model „Pöttinger Novacat X8“) (last accessed on 06.06.16)

Finger Mowers

- http://www.maschio.de/produkte/m%C3%A4hwerke (Model „Gaspardo Franca 205“) (last accessed on 10.06.16)

Mulchers

- http://www.hammerschmied.at/seite.mv?60-55-00-00+&set=60 (Model „Hammerschmied HMF-GU-300“) (last accessed on 10.06.16)
- http://www.schlegelmulcher.com/project/schlegelmulcher-vp/ (Model „Dragone VP 300“) (last accessed on 10.06.16)

Teders

- http://www.poettinger.at/de_at/Produkte/Detail/100/hit-vierkreiselzetter (Model „Pöttinger HIT 4.54“) (last accessed on 09.06.16)

Hay Rakes

- http://www.poettinger.at/de_at/Produkte/Kategorie/7/schwadkreisel (Model „Pöttinger TOP 382“) (last accessed on 10.06.16)

Combine Harvesters

- http://www.claas.de/produkte/maehdrescher (Models „Claas Lexion 570“ and „Claas Lexion 660“) (last accessed on 11.06.16)
- https://www.deere.de/de_DE/products/equipment/combines/combines.page? (Model „John Deere W330 PTC“) (last accessed on 11.06.16)
- https://www.wintersteiger.com/de/Pflanzenzucht-und-Forschung/Produkte/Produktprogramm/Parzellenm%C3%A4hdrescher (Model „Wintersteiger Parzellenmähdrescher Delta“) (last accessed on 10.06.16)

Forage Harvesters

- http://www.claas.de/produkte/feldhaecksler (Models „Claas Jaguar 60 SF“ and „Claas Jaguar 840“) (last accessed on 10.06.16)

Self-Loading Wagons

- http://www.poettinger.at/de_at/Produkte/Detail/265/primo-ladewagen (Model „Pöttinger PRIMO 351 L“) (last accessed on 09.06.16)

Balers

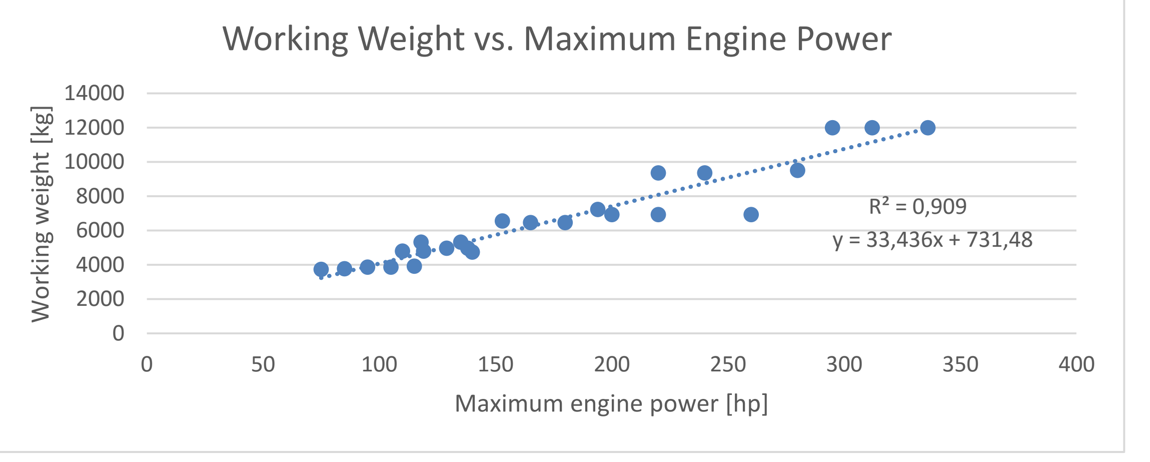
- http://www.poettinger.at/de_at/Produkte/Kategorie/20/rundballenpressen-wickelmaschinen (Model „Pöttinger Rollprofi 3120 L“) (last accessed on 09.06.16)

8. Annexes

8.1 Technical Specifications on Machinery Implemented in Field Trials and in POFBs

Tractors

Maximum engine power [hp]	Working weight [kg]
75	3750
85	3790
95	3870
105	3870
110	4810
115	3930
118	5325
119	4810
129	4970
135	5325
138	4970
140	4750
153	6560
165	6480
180	6480
194	7240
200	6950
220	6950
220	9370
240	9370
260	6950
280	9520
295	12000
312	12000
336	12000



Tractors

Tractors	Tyre width [m]	Tyre diameter [m]
front	0,5	1,34
rear	0,6	1,72

Transporters

Model / Type	Weight [kg]	Tyre width [m]	Tyre diameter [m]
Reform Muli 400	1570	0,25	0,77

Ploughs

Model / Type	Weight (2 shares) [kg]	Weight (3 shares) [kg]	Weight (4 shares) [kg]	Weight (5 shares) [kg]	Weight (9 shares) [kg]	Working Width [m]
Vogel & Noot cplus M 950 Vario		800	975			
Vogel & Noot cPlus XM 950 Vario			1110			
Vogel & Noot cPlus XMS 850 Vario			1240			
Vogel & Noot cPlus Hektor 1000					3880	

Cultivators

Model / Type	Weight [kg]	Working Width [m]
Regent Tukan MSG 270	950	2,7
Einböck HURRICANE 300 ON	825	3,0
Einböck HURRICANE 300 RP47	1335	3,0
Pöttinger SYNKRO 4020 K	1860	4,0
Pöttinger SYNKRO 6020 K	2765	6,0

Finger weeder

Model / Type	Weight [kg]	Working Width [m]
Hatzenbichler Originalstriegel	1150	12,0

Chain harrows

Model / Type	Weight [kg]	Working Width [m]
Mandam Nr. 0205	230	3,0
Mandam Nr. 0235	490	6,0

Disc harrows

Model / Type	Weight [kg]	Working Width [m]
Kuhn OPTIMER 303+	1715	3,0
TerraDiscpro 400	1750	4,0

Rotary harrows

Model / Type	Weight [kg]	Working Width [m]
Pöttinger LION 303 CLASSIC	1020	3,0
ArterraGrip	2100	4,0

Seedbed combinations

Model / Type	Weight [kg]	Working Width [m]	Tyre width [m]	Tyre diameter [m]
VibroCult M490	1220	4,9		
Kongskilde Germinator SP3000	1170	3,0		
Kongskilde Germinator SP6000	2370	6,0		
Agrifarm Europlan	3900	7,0	0,31	0,77

Rollers

Model / Type	Weight [kg]	Working Width [m]
TerraRoll	3200	5,3

Sowing machines

Model / Type	Weight [kg]	Max. Weight tank [kg]	Working Width [m]	Tyre width [m]	Tyre diameter [m]
Vaderstad Rapid 300S	2400	2250	3,0	0,19	0,74
ProfiDrill D300	910		3,0		
ProfiDrill D400	1030		4,0		
Amazone D7 Garant	740	500	4,0		
Kuhn MAXIMA 2 RT	800	310	4,5		
Pöttinger Terrasem R3	4550	3000	3,0	0,31	0,77
Pöttinger Terrasem C6	8600	3000	6,0	0,31	0,77
Horsch Pronto 8 TD	2990	1400	7,5		

Lime spreaders

Model / Type	Weight [kg]	Working Width [m]	Tyre width [m]	Tyre diameter [m]
K105	3200	12,0	0,75	1,68

(Liquid) Manure spreaders

Model / Type	Weight [kg]	Working Width [m]	Tyre width [m]	Tyre diameter [m]
RC 20 Garda	1250	8,0	0,29	0,86
Fliegl Einachs-Fasswagen 5000l	1450	8,0	0,29	0,93
Mengele ES 5200	1900	8,0	0,29	0,93
Tebbe LS 120E	4500	8,0	0,65	1,31

Pneumatic fertiliser spreaders

Model / Type	Weight [kg]	Max. Weight tank [kg]	Working Width [m]
Rauch AERO 2212	320	1700	12,0

Plant protection material spreaders

Model / Type	Weight [kg]	Max. Weight tank [kg]	Working Width [m]
Rau Spridomat D2	460	600	12,0
Rau Spridomat D2	770	1000	15,0
Hardi MASTER plus	913	800	12,0

Mower combinations

Model / Type	Weight [kg]	Working Width [m]
Novacat X8	2150	8,0

Finger mowers

Model / Type	Weight [kg]	Working Width [m]
Gaspardo Franca 205	215	2,1

Mulchers

Model / Type	Weight [kg]	Working Width [m]
Hammerschmied HMF-GU-300	900	3,0
Dragone VP 300	1255	3,0

Teders

Model / Type	Weight [kg]	Working Width [m]	Tyre width [m]	Tyre diameter [m]
Pöttinger HIT 4.54	550	5,4	0,16	0,25

Hay rakes

Model / Type	Weight [kg]	Working Width [m]	Tyre width [m]	Tyre diameter [m]
Pöttinger	535	3,8	0,16	0,25

Combine harvesters

Model / Type	Weight [kg]	Engine power [hp]	Working Width [m]	Front tyre width [m]	Front tyre diameter [m]	Rear tyre width [m]	Rear tyre diameter [m]
Claas Lexion 570	15300	360	6,6	0,85	2,00	0,60	1,45
Claas Lexion 660	15120	400	12,9	0,70	1,79	0,50	1,36
John Deere W330 PTC	10290	216	4,2	0,60	1,64	0,43	1,23
Wintersteiger Parzellenmähdrescher Delta	3750	84	1,5	0,35	0,94	0,26	0,74

Forage harvesters

Model / Type	Weight [kg]	Engine power [hp]	Working Width [m]	Front tyre width [m]	Front tyre diameter [m]	Rear tyre width [m]	Rear tyre diameter [m]
Claas Jaguar 60 SF	5000	120	1,6	0,47	0,66	0,29	0,38
Claas Jaguar 840	11050	408	7,3	0,75	1,86	0,50	1,34

Self loading wagons

Model / Type	Weight [kg]	Working Width [m]	Tyre width [m]	Tyre diameter [m]
Pöttinger PRIMO 351 L	4800	2,1	0,50	0,93

Balers

Model / Type	Weight [kg]	Weight bale [kg]	Working Width [m]	Tyre width [m]	Tyre diameter [m]
Rollprofi 3120 L	1950	750	2,0	0,29	0,85

8.2 Statistical Output from the Comparison of Swiss and Austrian TOCs

TOC = Dry

Group Statistics[a]

	Land	N	Mean	Std. Deviation	Std. Error Mean
Jan	AT	218	18,2820	15,08975	1,02201
	CH	14	42,7564	18,27620	4,88452
Feb	AT	218	9,9221	14,24572	,96484
	CH	14	18,9040	13,03935	3,48491
Mar	AT	218	-2,3244	16,71747	1,13225
	CH	14	-14,6377	19,95881	5,33422
Apr	AT	218	-26,2274	17,76641	1,20329
	CH	14	-27,9661	26,87959	7,18387
May	AT	218	-37,4707	18,06210	1,22332
	CH	14	-39,1399	30,34449	8,10991
Jun	AT	218	-29,9883	28,40802	1,92403
	CH	14	-47,5882	31,73508	8,48156
Jul	AT	218	-32,2668	34,48763	2,33580
	CH	14	-57,5809	31,86005	8,51496
Aug	AT	218	-29,9811	33,55431	2,27258
	CH	14	-47,6595	25,79319	6,89352
Sep	AT	218	-3,8582	19,57207	1,32559
	CH	14	-8,9905	25,54998	6,82852
Oct	AT	218	11,1481	20,81476	1,40975
	CH	14	26,6833	21,54635	5,75850
Nov	AT	218	34,9728	16,31854	1,10523

	CH	14	51,5908	22,93890	6,13068
Dec	AT	218	30,6695	16,75233	1,13461
	CH	14	76,6823	36,59689	9,78093

a. TOC = Dry

Independent Samples Test[a]

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Jan	Equal variances assumed	,149	,700	-5,807	230	,000	-24,47437	4,21493	-32,77918	-16,16956
	Equal variances not assumed			-4,904	14,162	,000	-24,47437	4,99029	-35,16605	-13,78270
Feb	Equal variances assumed	,082	,775	-2,297	230	,022	-8,98196	3,90964	-16,68524	-1,27868
	Equal variances not assumed			-2,484	15,064	,025	-8,98196	3,61601	-16,68645	-1,27747
Mar	Equal variances assumed	2,620	,107	2,640	230	,009	12,31339	4,66424	3,12328	21,50350
	Equal variances not assumed			2,258	14,196	,040	12,31339	5,45306	,63288	23,99390
Apr	Equal variances assumed	4,494	,035	,343	230	,732	1,73866	5,07367	-8,25815	11,73548

	Equal variances not assumed			,239	13,739	,815	1,73866	7,28395	-13,91174	17,38906
May	Equal variances assumed	11,644	,001	,319	230	,750	1,66915	5,23009	-8,63586	11,97416
	Equal variances not assumed			,204	13,598	,842	1,66915	8,20165	-15,97057	19,30887
Jun	Equal variances assumed	,102	,750	2,231	230	,027	17,59995	7,88705	2,05984	33,14007
	Equal variances not assumed			2,024	14,370	,062	17,59995	8,69705	-1,00839	36,20830
Jul	Equal variances assumed	,505	,478	2,673	230	,008	25,31408	9,46910	6,65681	43,97134
	Equal variances not assumed			2,867	15,025	,012	25,31408	8,82952	6,49713	44,13103
Aug	Equal variances assumed	2,710	,101	1,933	230	,054	17,67839	9,14366	-,33765	35,69443
	Equal variances not assumed			2,436	15,968	,027	17,67839	7,25846	2,28863	33,06815
Sep	Equal variances assumed	1,231	,268	,933	230	,352	5,13232	5,50254	-5,70951	15,97415
	Equal variances not assumed			,738	13,997	,473	5,13232	6,95599	-9,78710	20,05174
Oct	Equal variances assumed	,054	,817	-2,702	230	,007	-15,53513	5,75042	-26,86536	-4,20490
	Equal variances not assumed			-2,620	14,602	,020	-15,53513	5,92856	-28,20163	-2,86863

Nov	Equal variances assumed	4,052	,045	-3,596	230	,000	-16,61801	4,62161	-25,72410	-7,51191
	Equal variances not assumed			-2,668	13,858	,019	-16,61801	6,22951	-29,99184	-3,24417
Dec	Equal variances assumed	23,259	,000	-9,044	230	,000	-46,01277	5,08742	-56,03667	-35,98887
	Equal variances not assumed			-4,673	13,352	,000	-46,01277	9,84652	-67,22800	-24,79754

a. TOC = Dry

TOC = Humid

Group Statistics[a]

	Land	N	Mean	Std. Deviation	Std. Error Mean
Jan	AT	227	42,0467	25,46405	1,69011
	CH	29	46,3979	13,53670	2,51370
Feb	AT	227	31,5340	22,42934	1,48869
	CH	29	28,4796	15,35245	2,85088
Mar	AT	227	30,8263	25,53117	1,69456
	CH	29	11,1920	27,77159	5,15705
Apr	AT	227	11,6040	21,48717	1,42615
	CH	29	8,0554	31,54187	5,85718
May	AT	227	2,1708	18,88653	1,25354
	CH	29	11,7269	39,70974	7,37391
Jun	AT	227	29,2134	26,97008	1,79007
	CH	29	7,9079	38,37129	7,12537

Jul	AT	227	36,9428	27,99028	1,85778
	CH	29	-2,1737	45,18389	8,39044
Aug	AT	227	31,8026	27,84303	1,84801
	CH	29	1,0417	47,24251	8,77271
Sep	AT	227	39,1433	18,70179	1,24128
	CH	29	32,3297	26,72372	4,96247
Oct	AT	227	46,2129	27,08521	1,79771
	CH	29	50,4495	24,47728	4,54532
Nov	AT	227	65,2835	23,79239	1,57916
	CH	29	63,4676	19,92151	3,69933
Dec	AT	227	57,4106	22,57448	1,49832
	CH	29	77,0223	21,93166	4,07261

a. TOC = Humid

Independent Samples Test[a]

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Jan	Equal variances assumed	12,506	,000	-,903	254	,367	-4,35117	4,81887	-13,84121	5,13887
	Equal variances not assumed			-1,436	57,580	,156	-4,35117	3,02905	-10,41542	1,71308
Feb	Equal variances assumed	2,458	,118	,712	254	,477	3,05440	4,29155	-5,39715	11,50595

	Equal variances not assumed			,950	44,938	,347	3,05440	3,21616	-3,42353	9,53233
Mar	Equal variances assumed	,068	,794	3,861	254	,000	19,63432	5,08535	9,61951	29,64913
	Equal variances not assumed			3,617	34,323	,001	19,63432	5,42833	8,60645	30,66218
Apr	Equal variances assumed	3,507	,062	,789	254	,431	3,54865	4,49892	-5,31129	12,40858
	Equal variances not assumed			,589	31,405	,560	3,54865	6,02830	-8,73974	15,83703
May	Equal variances assumed	19,160	,000	-2,186	254	,030	-9,55602	4,37059	-18,16323	-,94880
	Equal variances not assumed			-1,278	29,639	,211	-9,55602	7,47970	-24,83942	5,72739
Jun	Equal variances assumed	1,673	,197	3,797	254	,000	21,30549	5,61072	10,25603	32,35495
	Equal variances not assumed			2,900	31,630	,007	21,30549	7,34678	6,33372	36,27727
Jul	Equal variances assumed	2,946	,087	6,532	254	,000	39,11649	5,98836	27,32332	50,90966
	Equal variances not assumed			4,552	30,804	,000	39,11649	8,59365	21,58510	56,64788
Aug	Equal variances assumed	5,939	,015	5,099	254	,000	30,76087	6,03255	18,88067	42,64106
	Equal variances not assumed			3,431	30,533	,002	30,76087	8,96525	12,46478	49,05695

Sep	Equal variances assumed	,838	,361	1,750	254	,081	6,81365	3,89403	-,85506	14,48235
	Equal variances not assumed			1,332	31,598	,192	6,81365	5,11536	-3,61120	17,23849
Oct	Equal variances assumed	,511	,475	-,801	254	,424	-4,23662	5,28698	-14,64852	6,17528
	Equal variances not assumed			-,867	37,332	,392	-4,23662	4,88791	-14,13749	5,66425
Nov	Equal variances assumed	2,346	,127	,394	254	,694	1,81592	4,61392	-7,27049	10,90233
	Equal variances not assumed			,451	38,974	,654	1,81592	4,02229	-6,32010	9,95194
Dec	Equal variances assumed	,289	,591	-4,419	254	,000	-19,61164	4,43790	-28,35141	-10,87186
	Equal variances not assumed			-4,519	36,011	,000	-19,61164	4,33948	-28,41242	-10,81086

a. TOC = Humid

TOC = Wet

Group Statistics[a]

	Land	N	Mean	Std. Deviation	Std. Error Mean
Jan	AT	67	85,7373	46,12461	5,63502
	CH	10	67,7798	26,14257	8,26701
Feb	AT	67	86,8266	38,15831	4,66178
	CH	10	48,5566	22,60927	7,14968

Mar	AT	67	109,1042	55,49712	6,78005
	CH	10	31,6407	24,77115	7,83333
Apr	AT	67	65,0073	40,64593	4,96569
	CH	10	36,0484	28,30420	8,95057
May	AT	67	60,6449	40,09417	4,89828
	CH	10	84,3811	61,31318	19,38893
Jun	AT	67	94,1879	43,88468	5,36137
	CH	10	85,9700	44,59414	14,10191
Jul	AT	67	112,4027	42,53100	5,19599
	CH	10	64,3543	32,99043	10,43249
Aug	AT	67	86,8599	41,18593	5,03166
	CH	10	66,5339	44,54259	14,08560
Sep	AT	67	86,5030	27,27893	3,33265
	CH	10	85,5994	30,32082	9,58828
Oct	AT	67	72,5818	33,05485	4,03829
	CH	10	75,2623	28,02275	8,86157
Nov	AT	67	105,4146	29,04153	3,54799
	CH	10	71,1176	14,41750	4,55921
Dec	AT	67	105,3213	32,42774	3,96168
	CH	10	102,6368	41,94430	13,26395

a. TOC = Wet

Independent Samples Test[a]

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Jan	Equal variances assumed	2,090	,152	1,198	75	,235	17,95752	14,98621	-11,89654	47,81158
	Equal variances not assumed			1,795	18,754	,089	17,95752	10,00484	-3,00147	38,91651
Feb	Equal variances assumed	2,104	,151	3,081	75	,003	38,26998	12,42204	13,52402	63,01595
	Equal variances not assumed			4,484	17,839	,000	38,26998	8,53523	20,32657	56,21340
Mar	Equal variances assumed	2,587	,112	4,331	75	,000	77,46344	17,88712	41,83048	113,09641
	Equal variances not assumed			7,477	25,578	,000	77,46344	10,36002	56,15101	98,77587
Apr	Equal variances assumed	,673	,415	2,170	75	,033	28,95896	13,34659	2,37118	55,54674
	Equal variances not assumed			2,829	15,197	,013	28,95896	10,23576	7,16650	50,75142
May	Equal variances assumed	4,553	,036	-1,621	75	,109	-23,73621	14,64317	-52,90690	5,43448
	Equal variances not assumed			-1,187	10,180	,262	-23,73621	19,99810	-68,18828	20,71586

Jun	Equal variances assumed	,641	,426	,551	75	,583	8,21789	14,90626	-21,47690	37,91268
	Equal variances not assumed			,545	11,756	,596	8,21789	15,08668	-24,72890	41,16468
Jul	Equal variances assumed	,344	,560	3,415	75	,001	48,04843	14,06948	20,02060	76,07627
	Equal variances not assumed			4,123	13,902	,001	48,04843	11,65483	23,03481	73,06206
Aug	Equal variances assumed	,446	,506	1,441	75	,154	20,32591	14,10370	-7,77009	48,42191
	Equal variances not assumed			1,359	11,418	,200	20,32591	14,95733	-12,44848	53,10029
Sep	Equal variances assumed	,265	,608	,096	75	,923	,90357	9,37747	-17,77730	19,58445
	Equal variances not assumed			,089	11,283	,931	,90357	10,15095	-21,37023	23,17737
Oct	Equal variances assumed	,022	,883	-,243	75	,808	-2,68053	11,01506	-24,62365	19,26259
	Equal variances not assumed			-,275	13,049	,787	-2,68053	9,73834	-23,71083	18,34978
Nov	Equal variances assumed	2,636	,109	3,653	75	,000	34,29701	9,38959	15,59198	53,00203
	Equal variances not assumed			5,937	22,096	,000	34,29701	5,77708	22,31911	46,27491
Dec	Equal variances assumed	1,125	,292	,235	75	,815	2,68458	11,42854	-20,08225	25,45140

Equal variances not assumed			,194	10,666	,850	2,68458	13,84295	-27,90043	33,26958

a. TOC = Wet

8.3 Soil Water Potential [hPa] Output of Hydrus-1D Used for Redefining SMLs

Tables for TOCs Dry (Krems and Poysdorf), Humid (Windischgarsten and Wolfsegg) and Wet (Lunz am See and Mondsee)

Table 6. SML outputs for the TOC 'dry'.

Krems	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sand	-54,37	-54,37	-68,78	-76,57	-79,78	-34,98	-35,31	-29,82	-33,68	-42,73	-45,84	-43,06
Loam	-105,61	-124,67	-147,06	-187,56	-262,06	-185,08	-173,59	-141,88	-139,87	-149,06	-163,95	-182,30
Silt	-118,29	-143,59	-170,47	-208,44	-254,81	-211,74	-207,48	-182,95	-186,95	-199,87	-217,38	-238,73
Clay	-144,53	-180,63	-253,14	-433,21	-812,39	-331,31	-261,18	-149,03	-175,64	-210,79	-238,90	-279,04
Poysdorf	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Sand	-51,43	-47,90	-54,00	-56,04	-45,28	-43,12	-24,46	-742,14	-17,38	-33,66	-44,94	-52,06
Loam	-107,56	-125,21	-269,82	-351,25	-277,95	-237,42	-399,69	-2168,33	-63,18	-87,71	-102,13	-118,44
Silt	-119,00	-143,66	-247,84	-586,21	-550,84	-501,73	-552,25	-1218,85	-131,16	-103,45	-123,51	-142,28
Clay	-405,68	-540,99	-1756,70	-1049,37	-1274,45	-1091,84	-332,74	-2492,71	-68,36	550444795,89	-3924,88	-4736,04
Average	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Sand	-52,90	-51,14	-61,39	-66,30	-62,53	-39,05	-29,89	-385,98	-25,53	-38,19	-45,39	-47,56
Loam	-106,59	-124,94	-208,44	-269,41	-270,00	-211,25	-286,64	-1155,10	-101,53	-118,39	-133,04	-150,37
Silt	-118,64	-143,63	-209,15	-397,33	-402,82	-356,73	-379,87	-700,90	-159,05	-151,66	-170,45	-190,51
Clay	-275,10	-360,81	-1004,92	-741,29	-1043,42	-711,58	-296,96	-1320,87	-122,00	275222292,55	-2081,89	-2507,54
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
SML Sand	nass	nass	nass	nass	nass	nass	nass	trocken	nass	nass	nass	nass
SML Loam	feucht	feucht	feucht	trocken	trocken	feucht	trocken	trocken	feucht	feucht	feucht	feucht
SML Silt	feucht	feucht	feucht	trocken	trocken	trocken	trocken	trocken	feucht	feucht	feucht	feucht
SML Clay	trocken	trocken	trocken	trocken	trocken	trocken	trocken	trocken	feucht	nass	trocken	trocken

Table 7. SML outputs for the TOC 'humid'.

Windischg	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sand	-19,37	-33,60	-46,16	-43,59	-23,98	-22,83	-20,12	-18,76	-14,13	-21,54	-41,51	-18,28
Loam	-43,51	-69,03	-165,94	-200,82	-62,40	-45,20	-61,91	-31,39	-21,25	-50,16	-67,57	-43,25
Silt	-39,39	-74,80	-157,83	-217,14	-70,69	-42,54	-75,13	-22,31	-3,99	-45,59	-71,27	-40,76
Clay	-64,96	-199,60	-743,97	-983,77	-113,98	-356,19	-191,33	-73,35	-6,23	-61,24	5847012544,01	-374,03
Wolfsegg	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Sand	-35,80	-28,58	-51,68	-46,61	-26,77	-31,25	-25,10	-24,33	-18,76	-22,13	-41,02	-34,57
Loam	-110,04	-95,44	-263,72	-332,34	-167,03	-49,82	-377,02	-68,15	-36,67	-57,79	-71,94	-127,07
Silt	-120,91	-113,11	-222,85	-549,73	-321,59	-52,01	-326,82	-89,12	-32,38	-55,30	-76,16	-144,33
Clay	-365,13	-314,07	-1249,79	-1391,93	-1661,31	-169,44	-794,38	-251,25	-51,91	-49,77	-229,90	-456,45
Average	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Sand	-27,58	-31,09	-48,92	-45,10	-25,38	-27,04	-22,61	-21,54	-16,44	-21,84	-41,27	-26,43
Loam	-76,78	-82,23	-214,83	-266,58	-114,71	-47,51	-219,47	-49,77	-28,96	-53,98	-69,75	-85,16
Silt	-80,15	-93,96	-190,34	-383,44	-196,14	-47,28	-200,98	-55,71	-18,18	-50,45	-73,72	-92,55
Clay	-215,04	-256,83	-996,88	-1187,85	-887,65	-262,81	-492,85	-162,30	-29,07	-55,51	2923506157,05	-415,24
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
SML Sand	nass	nass	nass	nass	nass	nass	nass	nass	nass	nass	nass	nass
SML Loam	nass	feucht	feucht	trocken	feucht	nass	feucht	nass	nass	nass	nass	feucht
SML Silt	feucht	feucht	feucht	trocken	feucht	nass	feucht	nass	nass	nass	nass	feucht
SML Clay	feucht	trocken	trocken	trocken	trocken	trocken	trocken	feucht	nass	nass	nass	trocken

Table 8. SML outputs for the TOC 'wet'.

Mondsee	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sand	-19,54	-28,09	-45,73	-43,02	-25,02	-23,87	-22,19	-18,97	-14,27	-21,94	-40,89	-18,44
Loam	-40,66	-55,25	-100,80	-167,39	-102,71	-42,42	-83,01	-28,02	-20,51	-49,84	-66,66	-38,67
Silt	-34,20	-53,39	-108,34	-136,21	-144,77	-38,18	-125,91	-23,17	-3,81	-43,03	-69,40	-31,47
Clay	-66,96	-146,70	-390,95	-695,10	-317,31	690116053,00	-842,52	-96,65	-6,66	-33,87	836400187,11	-124,76
Lunz am Se	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sand	-23,48	-30,86	-44,72	-43,12	-21,81	-22,34	-19,19	-19,13	-13,80	-26,19	-41,26	-22,92
Loam	-54,73	-72,00	-103,84	-176,87	-54,06	-38,36	-52,48	-28,01	-18,62	-52,00	-65,52	-53,76
Silt	-53,65	-78,59	-116,50	-151,95	-53,60	-32,13	-51,75	-22,70	-1,29	-49,29	-68,14	-53,04
Clay	-115,20	-194,64	-381,49	-683,76	-67,67	-157,10	-52,36	-73,38	-3,39	-555,07	-233,60	-102,26
Average	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sand	-21,51	-29,48	-45,22	-43,07	-23,41	-23,11	-20,69	-19,05	-14,04	-24,06	-41,08	-20,68
Loam	-47,69	-63,63	-102,32	-172,13	-78,39	-40,39	-67,74	-28,02	-19,57	-50,92	-66,09	-46,21
Silt	-43,92	-65,99	-112,42	-144,08	-99,19	-35,15	-88,83	-22,93	-2,55	-46,16	-68,77	-42,25
Clay	-91,08	-170,67	-386,22	-689,43	-192,49	345057947,95	-447,44	-85,02	-5,02	-294,47	418199976,76	-113,51
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
SML Sand	nass	nass	nass	nass	nass	nass	nass	nass	nass	nass	nass	nass
SML Loam	nass	nass	feucht	feucht	nass	nass	nass	nass	nass	nass	nass	nass
SML Silt	nass	nass	feucht	feucht	feucht	nass	feucht	nass	nass	nass	nass	nass
SML Clay	feucht	feucht	trocken	trocken	feucht	nass	trocken	feucht	nass	trocken	nass	feucht

8.4 Data Entry of Indirect SQ indicators into the SALCA Model

Table 9. Detailed part of the data entry sheet, with the first eight data sets of the arable POFB.

	Dateneingabe für die Wirkungsabschätzung der Bewirtschaftung auf die Bodenqualität								
		DS-A1-A14							
	NAME	**Input**							
	Parzellenname / Betriebsspezifische Nr.	1A Hofacker	2A Hofacker	3A Hammerte	4A Tavernena	5A Schloßacke	6A Waldacke	7A Schielleite	8A Karpfenteic
	Anzahl betrachtete Parzellen	14							
	Angaben zur Parzelle / Standort								
	Fläche Ackerkulturen insgesamt auf Betrieb (ha)	113,39	113,39	113,39	113,39	113,39	113,39	113,39	113,39
	Fläche Dauergrünland insgesamt auf Betrieb (ha)	0	0	0	0	0	0	0	0
Parzelle	FlächeParzelle (ha)	13,96	12,51	9,98	21,60	14,50	0,91	14,51	24,84
Parzelle	Tongehalt (%)	38,0	38,0	38,0	38,0	38,0	19,0	38,0	38,0
Parzelle	Humusgehalt (%)	4,3	4,3	4,3	4,3	4,3	3,9	4,3	4,3
Parzelle	pH (-)	5,6	5,6	5,6	5,6	5,6	6,8	5,6	5,6
	Klimatyp (trocken, feucht, nass)	*trocken*	*trocken*	*trocken*	*trocken*	*trocken*	*trocken*	*trocken*	*trocken*
	Klimaeignungszone (A - G)	A	A	A	A	A	A	A	A
Parzelle	Bodenart/-durchlässigkeit (Sand, Lehm, Schluff, Ton)	Ton	Ton	Ton	Ton	Ton	Schluff	Ton	Ton
Parzelle	Bodenabtrag durch Erosion (mm)	0,07	0,07	0,07	0,07	0,07	0,07	0,07	0,07
Parzelle	Linienhafte Erosion berücksichtigt (JA;NEIN)	NEIN	NEIN	NEIN	NEIN	NEIN	NEIN	NEIN	NEIN
	Fruchtfolge Ackerbau:								
Parzelle	Ernte Vorkultur (Tag.Monat.Jahr)	1. Aug. 12	1. Aug. 12	15. Jul. 12	15. Jul. 12	1. Aug. 12	30. Sep. 12	15. Jul. 12	1. Aug. 12
Parzelle	Zwischenkultur (Code siehe Tabelle Kulturen)								
Parzelle	Zwischenkultur fakultative Ernterückstände verbleiben auf Parzelle JA = 1, NEI	0	0	0	0	0	0	0	0
Parzelle	Saat Kultur (Tag.Monat.Jahr)	12. Okt. 12	12. Okt. 12	18. Jul. 12	13. Okt. 12	10. Apr. 13	30. Sep. 12	13. Okt. 12	10. Apr. 13
Parzelle	Ernte Kultur (Tag.Monat.Jahr)	17. Jul. 13	18. Jul. 13	18. Aug. 13	18. Jul. 13	14. Okt. 13	18. Aug. 13	18. Jul. 13	14. Okt. 13
Parzelle	Kultur (Code siehe Tabelle Kulturen)	WW	WK	KW_Int_T	WW	KM	KW_Int_T	WW	KM
Parzelle	Hauptkultur fakultative Ernterückstände verbleiben auf Parzelle JA = 1, NEIN=(	1	0	0	1	1	0	1	1
	Ertrag Hauptkultur dt/ha (FG)	45,4	35,9	93,9	42,7	46,7	93,9	42,7	46,7
	Ertrag Hauptkultur dt/ha (TG)	39,8	31,5	18,8	37,5	39,7	18,8	37,5	39,7
Parzelle	Pflügen mit normaler Saatbettbereitung JA=1, NEIN=0	1	1	0	1	1	0	1	1
Parzelle	Mulch-/Streifen-/Direktsaat JA=1; NEIN=0	0	0	0	0	0	0	0	0
	Für Systemgrenze = Parzelle (Schlag) (Keine Werte eingeben für Betrieb/mehrere Parzellen!):								
	Systemgrenze = Parzelle (ja / nein)								
Parzelle	%Anteil Hackfrüchte in Fruchtfolge	35	35	35	35	35	35	35	35
Parzelle	%Anteil Kunstwiese u. Grünbrache in Fruchtfolge	11	11	11	11	11	11	11	11
Parzelle	%Anteil Mulch-/Streifen-/Direktsaat in Fruchtfolge	0	0	0	0	0	0	0	0
Parzelle	Kalkdüngung bei pH<6.2 -> %-Einsatz in Fruchtfolge	44	44	44	44	44	44	44	44
	Schnitthöhe %-Anteil von Dauergrünland mit Schnitthöhe > 8cm	0	0	0	0	0	0	0	0
Parzelle	**Tierhaltung**								
Parzelle	1. Beweidung Monat (1-12)								
Parzelle	1. Besatzzeit (Tage)								

Parzelle	1. Besatzstärke (GVE/ha)								
Parzelle	1. Wiese älter als 2 Jahre (1=ja; 0=nein)								
Parzelle	2. Beweidung Monat (1-12)								
Parzelle	2. Besatzzeit (Tage)								
Parzelle	2. Besatzstärke (GVE/ha)								
Parzelle	2. Wiese älter als 2 Jahre (1=ja; 0=nein)								
Parzelle	3. Beweidung Monat (1-12)								
Parzelle	3. Besatzzeit (Tage)								
Parzelle	3. Besatzstärke (GVE/ha)								
Parzelle	3. Wiese älter als 2 Jahre (1=ja; 0=nein)								
Parzelle	4. Beweidung Monat (1-12)								
Parzelle	4. Besatzzeit (Tage)								
Parzelle	4. Besatzstärke (GVE/ha)								
Parzelle	4. Wiese älter als 2 Jahre (1=ja; 0=nein)								
Parzelle	5. Beweidung Monat (1-12)								
Parzelle	5. Besatzzeit (Tage)								
Parzelle	5. Besatzstärke (GVE/ha)								
Parzelle	5. Wiese älter als 2 Jahre (1=ja; 0=nein)								
Parzelle	6. Beweidung Monat (1-12)								
Parzelle	6. Besatzzeit (Tage)								
Parzelle	6. Besatzstärke (GVE/ha)								
Parzelle	6. Wiese älter als 2 Jahre (1=ja; 0=nein)								
Parzelle	7. Beweidung Monat (1-12)								
Parzelle	7. Besatzzeit (Tage)								
Parzelle	7. Besatzstärke (GVE/ha)								
Parzelle	7. Wiese älter als 2 Jahre (1=ja; 0=nein)								
Parzelle	Beweidung in Koppeln (1=ja; 0=nein) (Standard = 0)								
Parzelle	Dauergrünland: Qualität des Bestands (1=gräserreich; 2=Ausgewogen; 3=Leguminosenreich; 4=Kräuterreich)								
	Ernte Dauergrünland								
	Schnitthöhe (cm)								
	Düngung:								
Parzelle	Angaben Düngermengen: 1=t bzw. m3/ha; 2= t bzw. m3 / Parzelle					1			1
Parzelle	Dünger 1: Düngerart gemäss Liste (Nummer)					21			21
Parzelle	Dünger 1: Menge org. Dünger t bzw. m3					14,33			14,33
Parzelle	Dünger 1: Verdünnung (nur f. Gülle)					1,0			1,0

Parzelle	Dünger 2: Düngerart gemäss Liste (Nummer)								
Parzelle	Dünger 2: Menge org. Dünger t bzw. m3								
Parzelle	Dünger 2: Verdünnung (nur f. Gülle)								
Parzelle	Dünger 3: Düngerart gemäss Liste (Nummer)								
Parzelle	Dünger 3: Menge org. Dünger t bzw. m3								
	Dünger 3: Verdünnung (nur f. Gülle)								
Parzelle	Anzahl Gülleapplikationen pro Jahr	0	0	0	0	0	0	0	0
Parzelle	Kalkdüngung > 10 dt CaO pro ha (JA = 1; NEIN = 0)	0	0	1	0	1	0	0	1
	Humod Zusatzangaben: Bodenbewertung und								
	Mineralische N-Düngung Summe kg N/ha								
	Standortqualität	gut	mässig	ungünstig	mässig	ungünstig	mässig	mässig	mässig
	Ertragsniveau	hoch	niedrig	mittel	mittel	mittel	mittel	mittel	mittel
	N-Gehalt Hauptkultur [%]	1,8	1,6	0,5	1,8	1,5	0,5	1,8	1,5
	Ertrag Hauptkultur Nebenprodukt dt/ha (FG)	37,0	25,1	93,9	34,8	46,2	93,9	34,8	46,2
	Ertrag Hauptkultur Nebenprodukt dt/ha (TG)	31,8	21,6	18,8	30,0	39,7	18,8	30,0	39,7
	N-Gehalt Hauptkultur Nebenprodukt [%]	0,5	0,5	0,5	0,5	0,9	0,5	0,5	0,9
	Ertrag Zwischenkultur dt/ha (FG)								
	Ertrag Zwischenkultur dt/ha (TG)								
	N-Gehalt Zwischenkultur [%]								
	Bodenbearbeitung:								
Parzelle	Datum Pflügen Zwischenkultur (Tag.Monat.Jahr)								
Parzelle	Datum Fräsen zur Saatbettbereitung Zwischenkultur (Tag.Monat.Jahr)								
Parzelle	Datum Pflügen Hauptkultur (Tag.Monat.Jahr)	15.09.12	15.09.12		15.09.12	10.04.13		15.09.12	10.04.13
Parzelle	Datum Fräsen zur Saatbettbereitung Hauptkultur (Tag.Monat.Jahr)								
	Pflanzenschutz:								
	Schwermetalle Gesamtbetrieb:								
Parzelle	Cadmium in Boden (Cd, mg)					6588,86			11287,40
Parzelle	Kupfer in Boden (Cu, mg)					959966,70			1644522,26
Parzelle	Zink in Boden (Zn, mg)					3975134,84			6809817,19
Parzelle	Blei in Boden (Pb, mg)					122613,93			210050,34
Parzelle	Nickel in Boden (Ni, mg)					187629,86			321429,35
Parzelle	Chrom in Boden (Cr, mg)					170175,92			291528,95

Parzelle	Quecksilber in Boden (Hg, mg)					17453,94			29900,41
Parzelle	Dichte des Bodens (kg/m3) (1300 kg/m3)	1300	1300	1300	1300	1300	1300	1300	1300
	Befahrungen:								
	Befahrung 1:								
Befahrung 1	Bezeichnung (z.B. Grundbodenbearbeitung, org. Düngen, Saat, Ernte)	**Pflügen**	**Pflügen**	**Eggen und S**	**Pflügen**	**Pflügen**	**Ernten**	**Pflügen**	**Pflügen**
Befahrung 1	Maschinentyp	Allradtraktor 1	Allradtraktor 1	Allradtraktor 1	Allradtraktor 1	Allradtraktor 16	Allradtraktor 1	Allradtraktor 1	Allradtraktor 16
Befahrung 1	Datum (Monat, Zahl)	9	9	7	9	4	6	9	4
Befahrung 1	Arbeitsgewicht (75 % Maximalgewicht falls Gewichtsveränderung) (kg)	9260	9260	9240	9260	9260	7900	9260	9260
Befahrung 1	Achslastverteilung % 1.Achse (%)	38	38	38	38	38	34	38	38
Befahrung 1	Achslastverteilung % 2.Achse (%)	62	62	62	62	62	66	62	62
Befahrung 1	Achslastverteilung % 3.Achse (%)								
Befahrung 1	Reifendurchmesser 1.Achse (m)	1,34	1,34	1,34	1,34	1,34	1,34	1,34	1,34
Befahrung 1	Reifendurchmesser 2.Achse (m)	1,72	1,72	1,72	1,72	1,72	1,72	1,72	1,72
Befahrung 1	Reifendurchmesser 3.Achse (m)								
Befahrung 1	Reifenbreite 1.Achse (m)	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50
Befahrung 1	Reifenbreite 2.Achse (m)	0,60	0,60	0,60	0,60	0,60	0,60	0,60	0,60
Befahrung 1	Reifenbreite 3.Achse (m)								
Befahrung 1	Arbeitsbreite (m)	1,6	1,6	4,0	1,6	1,6	8,0	1,6	1,6
Befahrung 1	Lockerungsgrad Boden (fest / abgesetzt / locker; s. Tabelle Befahrung)	fest	fest	fest	fest	fest	abgesetzt	fest	fest
Befahrung 1	Bodentiefe (m)	0,1	0,1	0,35	0,1	0,1	0,35	0,1	0,1
	Befahrung 2:								
Befahrung 2	Bezeichnung (z.B. Grundbodenbearbeitung, org. Düngen, Saat, Ernte)	**Säen**	**Säen**	**Kalken**	**Eggen und S**	**Eggen und Wa**	**Ernten**	**Eggen und S**	**Eggen und Wa**
Befahrung 2	Maschinentyp	Allradtraktor 1	Allradtraktor 1	Allradtraktor 6	Allradtraktor 1	Allradtraktor 16	Allradtraktor 1	Allradtraktor 1	Allradtraktor 16
Befahrung 2	Datum (Monat, Zahl)	10	10	4	10	4	7	10	4
Befahrung 2	Arbeitsgewicht (75 % Maximalgewicht falls Gewichtsveränderung) (kg)	9170	9180	22800	9170	9240	7900	9170	9240
Befahrung 2	Achslastverteilung % 1.Achse (%)	38	38	21	38	38	34	38	38
Befahrung 2	Achslastverteilung % 2.Achse (%)	62	62	39	62	62	66	62	62
Befahrung 2	Achslastverteilung % 3.Achse (%)			40					
Befahrung 2	Reifendurchmesser 1.Achse (m)	1,34	1,34	1,34	1,34	1,34	1,34	1,34	1,34
Befahrung 2	Reifendurchmesser 2.Achse (m)	1,72	1,72	1,72	1,72	1,72	1,72	1,72	1,72
Befahrung 2	Reifendurchmesser 3.Achse (m)			1,68					
Befahrung 2	Reifenbreite 1.Achse (m)	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50
Befahrung 2	Reifenbreite 2.Achse (m)	0,60	0,60	0,60	0,60	0,60	0,60	0,60	0,60
Befahrung 2	Reifenbreite 3.Achse (m)			0,75					
Befahrung 2	Arbeitsbreite (m)	4,0	4,0	12,0	4,0	5,0	8,0	4,0	5,0
Befahrung 2	Lockerungsgrad Boden (fest / abgesetzt / locker; s. Tabelle Befahrung)	locker	locker	abgesetzt	locker	locker	abgesetzt	locker	locker
Befahrung 2	Bodentiefe (m)	0,35	0,35	0,35	0,35	0,35	0,35	0,35	0,35
	Befahrung 3:								
Befahrung 3	Bezeichnung (z.B. Grundbodenbearbeitung, org. Düngen, Saat, Ernte)	**Striegeln**	**Ernten**	**Ernten**	**Ernten**	**Säen**	**Ernten**	**Ernten**	**Säen**

Befahrung 3	Maschinentyp	Allradtraktor 6	Allradtraktor 8	Allradtraktor 1	Allradtraktor 8	Allradtraktor 65	Allradtraktor 1	Allradtraktor 8	Allradtraktor 65
Befahrung 3	Datum (Monat, Zahl)	4	7	6	7	4	8	7	4
Befahrung 3	Arbeitsgewicht (75 % Maximalgewicht falls Gewichtsveränderung) (kg)	4820	15120	7900	15120	4720	7900	15120	4720
Befahrung 3	Achslastverteilung % 1.Achse (%)	38	73	34	73	38	34	73	38
Befahrung 3	Achslastverteilung % 2.Achse (%)	62	27	66	27	62	66	27	62
Befahrung 3	Achslastverteilung % 3.Achse (%)								
Befahrung 3	Reifendurchmesser 1.Achse (m)	1,34	1,79	1,34	1,79	1,34	1,34	1,79	1,34
Befahrung 3	Reifendurchmesser 2.Achse (m)	1,72	1,36	1,72	1,36	1,72	1,72	1,36	1,72
Befahrung 3	Reifendurchmesser 3.Achse (m)								
Befahrung 3	Reifenbreite 1.Achse (m)	0,50	0,70	0,50	0,70	0,50	0,50	0,70	0,50
Befahrung 3	Reifenbreite 2.Achse (m)	0,60	0,50	0,60	0,50	0,60	0,60	0,50	0,60
Befahrung 3	Reifenbreite 3.Achse (m)								
Befahrung 3	Arbeitsbreite (m)	12,0	12,3	8,0	12,3	4,0	8,0	12,3	4,0
Befahrung 3	Lockerungsgrad Boden (fest / abgesetzt / locker; s. Tabelle Befahrung)	abgesetzt	abgesetzt	abgesetzt	abgesetzt	abgesetzt	abgesetzt	abgesetzt	abgesetzt
Befahrung 3	Bodentiefe (m)	0,35	0,35	0,35	0,35	0,35	0,35	0,35	0,35
	Befahrung 4:								
Befahrung 4	Bezeichnung (z.B. Grundbodenbearbeitung, org. Düngen, Saat, Ernte)	**Ernten**		**Ernten**		**Düngen**			**Düngen**
Befahrung 4	Maschinentyp	Allradtraktor 85 kW (116 PS		Allradtraktor 110 kW (150 P		Allradtraktor 160 kW (218 PS), Kompoststr			Allradtraktor 16
Befahrung 4	Datum (Monat, Zahl)	7		7		4			4
Befahrung 4	Arbeitsgewicht (75 % Maximalgewicht falls Gewichtsveränderung) (kg)	15120		7900		18520			18520
Befahrung 4	Achslastverteilung % 1.Achse (%)	73		34		21			21
Befahrung 4	Achslastverteilung % 2.Achse (%)	27		66		39			39
Befahrung 4	Achslastverteilung % 3.Achse (%)					40			40
Befahrung 4	Reifendurchmesser 1.Achse (m)	1,79		1,34		1,34			1,34
Befahrung 4	Reifendurchmesser 2.Achse (m)	1,36		1,72		1,72			1,72
Befahrung 4	Reifendurchmesser 3.Achse (m)					1,31			1,31
Befahrung 4	Reifenbreite 1.Achse (m)	0,70		0,50		0,50			0,50
Befahrung 4	Reifenbreite 2.Achse (m)	0,50		0,60		0,60			0,60
Befahrung 4	Reifenbreite 3.Achse (m)					0,65			0,65
Befahrung 4	Arbeitsbreite (m)	12,3		8,0		8,0			8,0
Befahrung 4	Lockerungsgrad Boden (fest / abgesetzt / locker; s. Tabelle Befahrung)	abgesetzt		abgesetzt		abgesetzt			abgesetzt
Befahrung 4	Bodentiefe (m)	0,35		0,35		0,35			0,35
	Befahrung 5:								
Befahrung 5	Bezeichnung (z.B. Grundbodenbearbeitung, org. Düngen, Saat, Ernte)			**Ernten**		**Kalken**			**Kalken**
Befahrung 5	Maschinentyp			Allradtraktor 110 kW (150 P		Allradtraktor 160 kW (218 PS), Großraumst			Allradtraktor 16
Befahrung 5	Datum (Monat, Zahl)			8		4			4
Befahrung 5	Arbeitsgewicht (75 % Maximalgewicht falls Gewichtsveränderung) (kg)			7900		18520			18520
Befahrung 5	Achslastverteilung % 1.Achse (%)			34		21			21
Befahrung 5	Achslastverteilung % 2.Achse (%)			66		39			39
Befahrung 5	Achslastverteilung % 3.Achse (%)					40			40

Befahrung 5	Reifendurchmesser 1.Achse (m)			1,34		1,34			1,34
Befahrung 5	Reifendurchmesser 2.Achse (m)			1,72		1,72			1,72
Befahrung 5	Reifendurchmesser 3.Achse (m)					1,31			1,31
Befahrung 5	Reifenbreite 1.Achse (m)			0,50		0,50			0,50
Befahrung 5	Reifenbreite 2.Achse (m)			0,60		0,60			0,60
Befahrung 5	Reifenbreite 3.Achse (m)					0,65			0,65
Befahrung 5	Arbeitsbreite (m)			8,0		8,0			8,0
Befahrung 5	Lockerungsgrad Boden (fest / abgesetzt / locker; s. Tabelle Befahrung)			abgesetzt		abgesetzt			abgesetzt
Befahrung 5	Bodentiefe (m)			0,35		0,35			0,35
	Befahrung 6:								
Befahrung 6	Bezeichnung (z.B. Grundbodenbearbeitung, org. Düngen, Saat, Ernte)					**Ernten**			**Ernten**
Befahrung 6	Maschinentyp					Allradtraktor 85 kW (116 PS), Mähdrescher			Allradtraktor 85
Befahrung 6	Datum (Monat, Zahl)					10			10
Befahrung 6	Arbeitsgewicht (75 % Maximalgewicht falls Gewichtsveränderung) (kg)					15120			15120
Befahrung 6	Achslastverteilung % 1.Achse (%)					73			73
Befahrung 6	Achslastverteilung % 2.Achse (%)					27			27
Befahrung 6	Achslastverteilung % 3.Achse (%)								
Befahrung 6	Reifendurchmesser 1.Achse (m)					1,79			1,79
Befahrung 6	Reifendurchmesser 2.Achse (m)					1,36			1,36
Befahrung 6	Reifendurchmesser 3.Achse (m)								
Befahrung 6	Reifenbreite 1.Achse (m)					0,70			0,70
Befahrung 6	Reifenbreite 2.Achse (m)					0,50			0,50
Befahrung 6	Reifenbreite 3.Achse (m)								
Befahrung 6	Arbeitsbreite (m)					12,3			12,3
Befahrung 6	Lockerungsgrad Boden (fest / abgesetzt / locker; s. Tabelle Befahrung)					abgesetzt			abgesetzt
Befahrung 6	Bodentiefe (m)					0,35			0,35

8.5 SALCA Outputs and In-Field Measurements of Field Trials

Ackerbau					
	Bewertung				
Direkte Indikatoren	**--**	**-**	**0**	**+**	**++**
pflanzennutzbare Gründigkeit			0		
Grobporenvolumen			0		
Aggregatstabilität			0		
Corg-Gehalt			0		
Schwermetallgehalt (Cd, Cr, Cu, Pb, Hg, Ni, (Zn))			0		
Organische Schadstoffe			0		
Regenwurmbiomasse		-			
Mikrobielle Biomasse			0		
Mikrobielle Aktivität			0		

Gesamtergebnis SALCA-Bodenqualität Ackerfläche:	-1
Gesamtergebnis SALCA-Bodenqualität Grünlandfläche:	0
Gesamtergebnis SALCA-Bodenqualität:	**-1**

Figure 13. SQ Assessment of DS-T1 (CT).

Ackerbau					
	Bewertung				
Direkte Indikatoren	**--**	**-**	**0**	**+**	**++**
pflanzennutzbare Gründigkeit			0		
Grobporenvolumen				+	
Aggregatstabilität				+	
Corg-Gehalt			0		
Schwermetallgehalt (Cd, Cr, Cu, Pb, Hg, Ni, (Zn))			0		
Organische Schadstoffe			0		
Regenwurmbiomasse			0		
Mikrobielle Biomasse			0		
Mikrobielle Aktivität			0		

Gesamtergebnis SALCA-Bodenqualität Ackerfläche:	1
Gesamtergebnis SALCA-Bodenqualität Grünlandfläche:	0
Gesamtergebnis SALCA-Bodenqualität:	**1**

Figure 14. SQ Assessment of DS-T2 (RT).

Ackerbau					
	Bewertung				
Direkte Indikatoren	--	-	0	+	++
pflanzennutzbare Gründigkeit			0		
Grobporenvolumen				+	
Aggregatstabilität				+	
Corg-Gehalt			0		
Schwermetallgehalt (Cd, Cr, Cu, Pb, Hg, Ni, (Zn))			0		
Organische Schadstoffe			0		
Regenwurmbiomasse			0		
Mikrobielle Biomasse			0		
Mikrobielle Aktivität			0		

Gesamtergebnis SALCA-Bodenqualität Ackerfläche:	1
Gesamtergebnis SALCA-Bodenqualität Grünlandfläche:	0
Gesamtergebnis SALCA-Bodenqualität:	**1**

Figure 15. SQ Assessment of DS-T3 (MT).

Table 10. Comparison of DSs-T1-T3 with direct SQ indicators measured in-field.

	CT	RT	MT
Aggregatstabilität [%]	10,40	12,77	25,11
Regenwurmbiomasse [g/m2]			
Corg [%]	1,74	1,75	1,88
Pflanzennutzbare Gründigkeit [cm]	60cm - >100cm	60cm - >100cm	60cm - >100cm
Grobporenvolumen [Vol %]	14,1	13,4	15,8
Schwermetallgehalt [mg/kg]			
org. Schadstoffe [mg PAK/kg]			
mikrobielle Biomasse [mg Corg/kg]			
mikrobielle Biomasse [mg Corg/100 g]			
mikrobielle Aktivität [mg CO2-C/h*kg]	8,5	9,5	10,5
mikrobielle Aktivität [mg CO2-C/24h*g]			

Ackerbau					
	Bewertung				
Direkte Indikatoren	--	-	0	+	++
pflanzennutzbare Gründigkeit			0		
Grobporenvolumen			0		
Aggregatstabilität			0		
Corg-Gehalt			0		
Schwermetallgehalt (Cd, Cr, Cu, Pb, Hg, Ni, (Zn))			0		
Organische Schadstoffe			0		
Regenwurmbiomasse			0		
Mikrobielle Biomasse			0		
Mikrobielle Aktivität			0		

Gesamtergebnis SALCA-Bodenqualität Ackerfläche:	0
Gesamtergebnis SALCA-Bodenqualität Grünlandfläche:	0
Gesamtergebnis SALCA-Bodenqualität:	**0**

Figure 16. SQ Assessment of DS-T4 (CT).

Ackerbau					
	Bewertung				
Direkte Indikatoren	--	-	0	+	++
pflanzennutzbare Gründigkeit			0		
Grobporenvolumen			0		
Aggregatstabilität			0		
Corg-Gehalt			0		
Schwermetallgehalt (Cd, Cr, Cu, Pb, Hg, Ni, (Zn))			0		
Organische Schadstoffe			0		
Regenwurmbiomasse			0		
Mikrobielle Biomasse			0		
Mikrobielle Aktivität			0		

Gesamtergebnis SALCA-Bodenqualität Ackerfläche:	0
Gesamtergebnis SALCA-Bodenqualität Grünlandfläche:	0
Gesamtergebnis SALCA-Bodenqualität:	**0**

Figure 17. SQ Assessment of DS-T5 (RT).

Ackerbau					
	Bewertung				
Direkte Indikatoren	--	-	0	+	++
pflanzennutzbare Gründigkeit			0		
Grobporenvolumen			0		
Aggregatstabilität			0		
Corg-Gehalt			0		
Schwermetallgehalt (Cd, Cr, Cu, Pb, Hg, Ni, (Zn))			0		
Organische Schadstoffe			0		
Regenwurmbiomasse			0		
Mikrobielle Biomasse			0		
Mikrobielle Aktivität			0		

Gesamtergebnis SALCA-Bodenqualität Ackerfläche:	0
Gesamtergebnis SALCA-Bodenqualität Grünlandfläche:	0
Gesamtergebnis SALCA-Bodenqualität:	**0**

Figure 18. SQ Assessment of DS-T6 (MT).

Ackerbau					
	Bewertung				
Direkte Indikatoren	--	-	0	+	++
pflanzennutzbare Gründigkeit			0		
Grobporenvolumen			0		
Aggregatstabilität			0		
Corg-Gehalt			0		
Schwermetallgehalt (Cd, Cr, Cu, Pb, Hg, Ni, (Zn))			0		
Organische Schadstoffe			0		
Regenwurmbiomasse			0		
Mikrobielle Biomasse			0		
Mikrobielle Aktivität			0		

Gesamtergebnis SALCA-Bodenqualität Ackerfläche:	0
Gesamtergebnis SALCA-Bodenqualität Grünlandfläche:	0
Gesamtergebnis SALCA-Bodenqualität:	**0**

Figure 19. SQ Assessment of DS-T7 (NT).

Table 11. Comparison of DSs-T4-T7 with direct SQ indicators measured in-field.

	CT	RT	MT	NT
Aggregatstabilität [%]	37	41	41	43
Regenwurmbiomasse [g/m2]				
Corg [%]	0,88	0,94	0,94	0,83
Pflanzennutzbare Gründigkeit [cm]				
Grobporenvolumen [Vol %]				
Schwermetallgehalt [mg/kg]				
org. Schadstoffe [mg PAK/kg]				
mikrobielle Biomasse [mg Corg/kg]				
mikrobielle Biomasse [mg Corg/100 g]				
mikrobielle Aktivität [mg CO2-C/h*kg]				
mikrobielle Aktivität [mg CO2-C/24h*g]				

Ackerbau					
	Bewertung				
Direkte Indikatoren	**--**	**-**	**0**	**+**	**++**
pflanzennutzbare Gründigkeit			0		
Grobporenvolumen			0		
Aggregatstabilität			0		
Corg-Gehalt			0		
Schwermetallgehalt (Cd, Cr, Cu, Pb, Hg, Ni, (Zn))			0		
Organische Schadstoffe			0		
Regenwurmbiomasse	--				
Mikrobielle Biomasse			0		
Mikrobielle Aktivität			0		

Gesamtergebnis SALCA-Bodenqualität Ackerfläche:	-2
Gesamtergebnis SALCA-Bodenqualität Grünlandfläche:	0
Gesamtergebnis SALCA-Bodenqualität:	**-2**

Figure 20. SQ Assessment of DS-T8 (CT).

Ackerbau					
	Bewertung				
Direkte Indikatoren	**--**	**-**	**0**	**+**	**++**
pflanzennutzbare Gründigkeit			0		
Grobporenvolumen			0		
Aggregatstabilität				+	
Corg-Gehalt			0		
Schwermetallgehalt (Cd, Cr, Cu, Pb, Hg, Ni, (Zn))			0		
Organische Schadstoffe			0		
Regenwurmbiomasse			0		
Mikrobielle Biomasse			0		
Mikrobielle Aktivität			0		

Gesamtergebnis SALCA-Bodenqualität Ackerfläche:	0
Gesamtergebnis SALCA-Bodenqualität Grünlandfläche:	0
Gesamtergebnis SALCA-Bodenqualität:	**0**

Figure 21. SQ Assessment of DS-T9 (RT).

Ackerbau					
	Bewertung				
Direkte Indikatoren	--	-	0	+	++
pflanzennutzbare Gründigkeit			0		
Grobporenvolumen			0		
Aggregatstabilität				+	
Corg-Gehalt			0		
Schwermetallgehalt (Cd, Cr, Cu, Pb, Hg, Ni, (Zn))			0		
Organische Schadstoffe			0		
Regenwurmbiomasse			0		
Mikrobielle Biomasse			0		
Mikrobielle Aktivität			0		

Gesamtergebnis SALCA-Bodenqualität Ackerfläche:	0
Gesamtergebnis SALCA-Bodenqualität Grünlandfläche:	0
Gesamtergebnis SALCA-Bodenqualität:	**0**

Figure 22. SQ Assessment of DS-T10 (MT).

Ackerbau					
	Bewertung				
Direkte Indikatoren	--	-	0	+	++
pflanzennutzbare Gründigkeit			0		
Grobporenvolumen			0		
Aggregatstabilität				+	
Corg-Gehalt			0		
Schwermetallgehalt (Cd, Cr, Cu, Pb, Hg, Ni, (Zn))			0		
Organische Schadstoffe			0		
Regenwurmbiomasse			0		
Mikrobielle Biomasse			0		
Mikrobielle Aktivität			0		

Gesamtergebnis SALCA-Bodenqualität Ackerfläche:	0
Gesamtergebnis SALCA-Bodenqualität Grünlandfläche:	0
Gesamtergebnis SALCA-Bodenqualität:	**0**

Figure 23. SQ Assessment of DS-T11 (NT).

Table 12. Comparison of DSs-T8-T11 with direct SQ indicators measured in-field.

	CT	RT	MT	NT
Aggregatstabilität [%]				
Regenwurmbiomasse [g/m2]				
Corg [%]	1,72	1,8	1,8	1,86
Pflanzennutzbare Gründigkeit [cm]				
Grobporenvolumen [Vol %]				
Schwermetallgehalt [mg/kg]				
org. Schadstoffe [mg PAK/kg]				
mikrobielle Biomasse [mg Corg/kg]	2,5	2,6	2,6	2,6
mikrobielle Biomasse [mg Corg/100 g]	0,25	0,26	0,26	0,26
mikrobielle Aktivität [mg CO2-C/h*kg]	8,75	10,42	10,42	10
mikrobielle Aktivität [mg CO2-C/24h*g]	0,21	0,25	0,25	0,24

Ackerbau					
	Bewertung				
Direkte Indikatoren	--	-	0	+	++
pflanzennutzbare Gründigkeit	--				
Grobporenvolumen			0		
Aggregatstabilität			0		
Corg-Gehalt			0		
Schwermetallgehalt (Cd, Cr, Cu, Pb, Hg, Ni, (Zn))			0		
Organische Schadstoffe			0		
Regenwurmbiomasse			0		
Mikrobielle Biomasse			0		
Mikrobielle Aktivität			0		

Gesamtergebnis SALCA-Bodenqualität Ackerfläche:	-2
Gesamtergebnis SALCA-Bodenqualität Grünlandfläche:	0
Gesamtergebnis SALCA-Bodenqualität:	**-2**

Figure 24. SQ Assessment of DS-T12 (CT).

Ackerbau					
	Bewertung				
Direkte Indikatoren	--	-	0	+	++
pflanzennutzbare Gründigkeit	--				
Grobporenvolumen				+	
Aggregatstabilität				+	
Corg-Gehalt			0		
Schwermetallgehalt (Cd, Cr, Cu, Pb, Hg, Ni, (Zn))			0		
Organische Schadstoffe			0		
Regenwurmbiomasse			0		
Mikrobielle Biomasse			0		
Mikrobielle Aktivität			0		

Gesamtergebnis SALCA-Bodenqualität Ackerfläche:	-1
Gesamtergebnis SALCA-Bodenqualität Grünlandfläche:	0
Gesamtergebnis SALCA-Bodenqualität:	**-1**

Figure 25. SQ Assessment of DS-T13 (RT).

Ackerbau					
	Bewertung				
Direkte Indikatoren	--	-	0	+	++
pflanzennutzbare Gründigkeit	--				
Grobporenvolumen				+	
Aggregatstabilität				+	
Corg-Gehalt			0		
Schwermetallgehalt (Cd, Cr, Cu, Pb, Hg, Ni, (Zn))			0		
Organische Schadstoffe			0		
Regenwurmbiomasse			0		
Mikrobielle Biomasse			0		
Mikrobielle Aktivität			0		

Gesamtergebnis SALCA-Bodenqualität Ackerfläche:	-1
Gesamtergebnis SALCA-Bodenqualität Grünlandfläche:	0
Gesamtergebnis SALCA-Bodenqualität:	**-1**

Figure 26. SQ Assessment of DS-T14 (MT).

Ackerbau					
	Bewertung				
Direkte Indikatoren	--	-	0	+	++
pflanzennutzbare Gründigkeit	--				
Grobporenvolumen				+	
Aggregatstabilität				+	
Corg-Gehalt			0		
Schwermetallgehalt (Cd, Cr, Cu, Pb, Hg, Ni, (Zn))			0		
Organische Schadstoffe			0		
Regenwurmbiomasse			0		
Mikrobielle Biomasse			0		
Mikrobielle Aktivität			0		

Gesamtergebnis SALCA-Bodenqualität Ackerfläche:	-1
Gesamtergebnis SALCA-Bodenqualität Grünlandfläche:	0
Gesamtergebnis SALCA-Bodenqualität:	**-1**

Figure 27. SQ Assessment of DS-T15 (NT).

Table 13. Comparison of DSs-T12-T15 with direct SQ indicators measured in-field.

	CT	RT	MT	NT
Aggregatstabilität [%]	34	45	45	55
Regenwurmbiomasse [g/m2]				
Corg [%]	1,44	1,4	1,4	1,42
Pflanzennutzbare Gründigkeit [cm]				
Grobporenvolumen [Vol %]	16	11	11	12
Schwermetallgehalt [mg/kg]				
org. Schadstoffe [mg PAK/kg]				
mikrobielle Biomasse [mg Corg/kg]	1,9	2,1	2,1	2
mikrobielle Biomasse [mg Corg/100 g]	0,19	0,21	0,21	0,2
mikrobielle Aktivität [mg CO2-C/h*kg]	4,17	4,58	4,58	4,58
mikrobielle Aktivität [mg CO2-C/24h*g]	0,1	0,11	0,11	0,11

Ackerbau					
	Bewertung				
Direkte Indikatoren	--	-	0	+	++
pflanzennutzbare Gründigkeit			0		
Grobporenvolumen			0		
Aggregatstabilität			0		
Corg-Gehalt			0		
Schwermetallgehalt (Cd, Cr, Cu, Pb, Hg, Ni, (Zn))			0		
Organische Schadstoffe			0		
Regenwurmbiomasse			0		
Mikrobielle Biomasse			0		
Mikrobielle Aktivität			0		

Gesamtergebnis SALCA-Bodenqualität Ackerfläche:	0
Gesamtergebnis SALCA-Bodenqualität Grünlandfläche:	0
Gesamtergebnis SALCA-Bodenqualität:	**0**

Figure 28. SQ Assessment of DS-T16 (2004-WG).

Ackerbau					
	Bewertung				
Direkte Indikatoren	**--**	**-**	**0**	**+**	**++**
pflanzennutzbare Gründigkeit			0		
Grobporenvolumen					++
Aggregatstabilität				+	
Corg-Gehalt			0		
Schwermetallgehalt (Cd, Cr, Cu, Pb, Hg, Ni, (Zn))			0		
Organische Schadstoffe			0		
Regenwurmbiomasse				+	
Mikrobielle Biomasse			0		
Mikrobielle Aktivität			0		

Gesamtergebnis SALCA-Bodenqualität Ackerfläche:	1
Gesamtergebnis SALCA-Bodenqualität Grünlandfläche:	0
Gesamtergebnis SALCA-Bodenqualität:	**1**

Figure 29. SQ Assessment of DS-T17 (2005-KW).

Ackerbau					
	Bewertung				
Direkte Indikatoren	**--**	**-**	**0**	**+**	**++**
pflanzennutzbare Gründigkeit			0		
Grobporenvolumen		-			
Aggregatstabilität		-			
Corg-Gehalt			0		
Schwermetallgehalt (Cd, Cr, Cu, Pb, Hg, Ni, (Zn))			0		
Organische Schadstoffe			0		
Regenwurmbiomasse				+	
Mikrobielle Biomasse		-			
Mikrobielle Aktivität		-			

Gesamtergebnis SALCA-Bodenqualität Ackerfläche:	-2
Gesamtergebnis SALCA-Bodenqualität Grünlandfläche:	0
Gesamtergebnis SALCA-Bodenqualität:	**-2**

Figure 30. SQ Assessment of DS-T18 (2010-SEE).

Ackerbau					
	Bewertung				
Direkte Indikatoren	--	-	0	+	++
pflanzennutzbare Gründigkeit			0		
Grobporenvolumen		-			
Aggregatstabilität		-			
Corg-Gehalt			0		
Schwermetallgehalt (Cd, Cr, Cu, Pb, Hg, Ni, (Zn))			0		
Organische Schadstoffe			0		
Regenwurmbiomasse		-			
Mikrobielle Biomasse		-			
Mikrobielle Aktivität		-			

Gesamtergebnis SALCA-Bodenqualität Ackerfläche:	-2
Gesamtergebnis SALCA-Bodenqualität Grünlandfläche:	0
Gesamtergebnis SALCA-Bodenqualität:	**-2**

Figure 31. SQ Assessment of DS-T19 (2012-WR).

Ackerbau					
	Bewertung				
Direkte Indikatoren	--	-	0	+	++
pflanzennutzbare Gründigkeit			0		
Grobporenvolumen			0		
Aggregatstabilität			0		
Corg-Gehalt			0		
Schwermetallgehalt (Cd, Cr, Cu, Pb, Hg, Ni, (Zn))			0		
Organische Schadstoffe			0		
Regenwurmbiomasse				+	
Mikrobielle Biomasse			0		
Mikrobielle Aktivität			0		

Gesamtergebnis SALCA-Bodenqualität Ackerfläche:	1
Gesamtergebnis SALCA-Bodenqualität Grünlandfläche:	0
Gesamtergebnis SALCA-Bodenqualität:	**1**

Figure 32. SQ Assessment of DS-T20 (2013-KW).

Table 14. Comparison of DSs-T16-T20 with direct SQ indicators measured in-field.

	2004 Wintergerste	2005 Luzerne	2010 Körnererbse	2012 Winterroggen	2013 Luzerne
Aggregatstabilität [%]	25,5	17,5	31,5	27,0	30,5
Regenwurmbiomasse [g/m2]					
Corg [%]		2,3	2,3		2,3
Pflanzennutzbare Gründigkeit [cm]	70	70		94	94
Grobporenvolumen 0-30 cm [Vol %]	18	18		17	17
Schwermetallgehalt [mg/kg]					
org. Schadstoffe [mg PAK/kg]					
mikrobielle Biomasse [mg Corg/kg]					
mikrobielle Biomasse [mg Corg/100 g]					
mikrobielle Aktivität [mg CO2-C/h*kg]					
mikrobielle Aktivität [mg CO2-C/24h*g]					
(Porenanteil 0-90 cm [%])	46,4	46,4		49,8	49,8

8.6 Model Errors of SALCA-SQ (Version 4.1)

- **Worksheet 'Dateneingabe'**
  - Row 16 (Loss of soil due to erosion, Ger. *Bodenabtrag durch Erosion*): if there is more than one parcel examined, all values of soil erosion have to be equal, since only the value of column C is considered for the assessment of the rooting depth (worksheet 'Wirkungsabschätzung Grasland' / 'Wirkungsabschätzung Ackerbau', cell E5).
  - Rows 80, 83 and 86 always have to be filled, not only when mixed solid and liquid manure is applied. If there is no dilution of the organic fertiliser, '1' needs to be entered. Otherwise, the calculations on the input of organic substances (worksheet 'Hilfsvar', rows 70, 72, 74 and 76) cannot be done correctly.
  - For rows 151-121, it should be made more obvious that the required values are weights of heavy metals entering the parcels via organic fertilisers, and not the background values of heavy metals found in the corresponding soil.

- **Worksheet 'Ergebnis'**
  - Cells G21 and G22 should contain the formulas '=Hilfsvar!C6' and '=Hilfsvar!C5' instead of '=Hilfsvar!F6' and '=Hilfsvar!F5', respectively. Otherwise, the calculation cannot be done correctly for the assessment of three or less data sets (= columns C, D and E).
  - Cell B37 should contain the formula '='Wirkungsabschätzung Ackerbau'!G43' instead of '='Wirkungsabschätzung Ackerbau'!E43'.

- **Worksheet 'Wirkungsabschätzung Grasland' / 'Wirkungsabschätzung Ackerbau'**
  - The assessment of all direct SQ indicators should be based on column C of the worksheet 'Hilfsvar', since the other columns remain empty if there is only one parcel of land assessed. Therefore, for instance the formula in cell G5 for assessing the rooting depth should not be written as '=WENN(Hilfsvar!F5=0;0;E5*F5)' or '=WENN(Hilfsvar!F6=0;0;E5*F5)' but instead as '=WENN(Hilfsvar!C5=0;0;E5*F5)' and '=WENN(Hilfsvar!C6=0;0;E5*F5)', respectively.

- **Worksheet 'Hilfsvar'**
  - The formulas for calculating possible inflows of organic pollutants (rows 89, 90 and 91) need to be rephrased as they do not make sense. Currently, the code

number of the third organic fertiliser (Worksheet 'Dateneingabe' row 84) instead of the amount of the fertiliser which contains the pollutants is multiplied with concentration values entered in worksheet 'org.Schadstoffe' cells C4, C5 and C6.

- Care should be taken that the depth of sampling (Ger. *Beprobungstiefe*, row 120) is entered correctly – not for the first DS a depth of 0,2 m, for the second DS 1,2 m, for the third 2,2 m and so on (see file 'SALCA-BQ_V4.1_Beisp_Burgrain').

- **Worksheet 'KulturWert'**
    - Values for norm yields (Ger. *Normertrag*, column R) of 'natural pasture intensive' and 'natural pasture medium intensive' need to be checked – were they confused with each other? The same accounts for values of 'valley' and values of 'mountain'. Furthermore, the norm yield value ascribed to 'natural pasture little intensive mountain' (cell R59) should be reviewed.

Statutory Declaration

I, the author, herewith declare that this paper was written independent from any external influences and that no other sources or resources were used than the ones listed. All kinds of information which do not form part of the author's personal thoughts and assumptions but which were derived from other sources either literally or by content are clearly marked as such by referring to the used source. The paper has not been published previously in any other form.

Date, place

Arnoud Maaswinkel
(The author)