



# KEY INDICATORS AND MANAGEMENT STRATEGIES FOR PRIMARY PRODUCTIVITY

D 3.1



LANDMARK














## KEY INDICATORS AND MANAGEMENT STRATEGIES FOR PRIMARY PRODUCTIVITY

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## PROJECT DETAILS

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### Abstract

LANDMARK is a pan-European multi-actor consortium of leading academic and applied research institutes, chambers of agriculture and policy makers that will develop a coherent framework for soil management aimed at sustainable food production across Europe. The LANDMARK proposal builds on the concept that soils are a finite resource that provides a range of ecosystem services known as "soil functions". Functions relating to agriculture include: primary productivity, water regulation and purification, carbon-sequestration and regulation, habitat for biodiversity and nutrient provision and cycling (Schulte *et al.*, 2014). Trade-offs between these functions may occur: for example, management aimed at maximising primary production may inadvertently affect the 'water purification' or 'habitat' functions. This has led to conflicting management recommendations and policy initiatives. There is now an urgent need to develop a coherent scientific and practical framework for the sustainable management of soils. LANDMARK will uniquely respond to the breadth of this challenge by delivering (through multi-actor development):

1. **LOCAL SCALE:** A toolkit for farmers with cost-effective, practical measures for sustainable (and context specific) soil management.
2. **REGIONAL SCALE:** A blueprint for a soil monitoring scheme, using harmonised indicators: this will facilitate the assessment of soil functions for different soil types and land-uses for all major EU climatic zones.
3. **EU SCALE:** An assessment of EU policy instruments for incentivising sustainable land management.

There have been many individual research initiatives that either address the management and assessment of individual soil functions, or address multiple soil functions, but only at local scales. LANDMARK will build on these existing R&D initiatives: the consortium partners bring together a wide range of significant national and EU datasets, with the ambition of developing an interdisciplinary scientific framework for sustainable soil management (O'Sullivan *et al.*, 2015; Schulte *et al.* 2015; Coyle *et al.*, 2016; Valujeva *et al.*, 2016).





## OBJECTIVES OF THE TASKS SUPPORTING THE DELIVERABLE

This deliverable relates to Task 3.2 *Primary Productivity*. The task aims to understand which attributes and diagnostic features regulate primary productivity and facilitate its utilisation by grazing livestock or harvested cropping and how biomass production and its utilisation interacts with other soil functions.

This report is one of the five “Key indicators and management strategies” outcomes of Work Package 3 (WP3) - *Understanding soil functions: from data and knowledge to proxy-indicators* of the LANDMARK project. The work done relied on the activities undertaken under Task 3.1- *From data and knowledge to proxy-indicators and management information* which aims to:

1. produce a working protocol for the LANDMARK project for harmonisation analysis of the available data-sets ultimately leading to proxy-indicator systems and integrated management decision-support tool for simultaneously optimization of five predetermined soil functions;
2. add new knowledge to still existing data gaps and disclosing patterns in existing datasets for information on soil functioning at different spatial and temporal scales;
3. apply data mining and in particular machine learning methods to discover potentially new patterns and knowledge about predetermined soil functions, from data on soil properties, soil management and climate. This is first done separately for each of the five different soil functions, as well as for all of the above soil functions simultaneously;
4. formulate existing knowledge of soil processes for the relevant soil functions and use it, together with measured data, as input to machine learning approaches for equation discovery.

Public deliverables are available at [www.landmark2020.eu](http://www.landmark2020.eu).

## ACTIVITIES UNDERTAKEN

The task 3.2 working group has experience in the relationship between soil physicochemical properties and arable biomass production based on a strong experimental focus and in the biogeochemical links between soil types and primary productivity. This was the starting point of the work.

All of the authors contributed to the report that was jointly coordinated by Taru Sandén (AGES).







## LANDMARK Report 3.1

# KEY INDICATORS AND MANAGEMENT STRATEGIES FOR PRIMARY PRODUCTIVITY

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## LANDMARK

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Website [www.landmark2020.eu](http://www.landmark2020.eu)

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## EXECUTIVE SUMMARY

### KEY INDICATORS AND MANAGEMENT STRATEGIES FOR PRIMARY PRODUCTIVITY

According to predictions by the United Nations global agricultural production must grow by 60% to feed the world population. Soil is one of the key natural resources that enable us to manage this challenge. Primary productivity is one out of five soil functions (water purification, carbon sequestration, habitat for biodiversity, recycling of nutrients/agro-chemicals) and it is defined as the capacity of soil to supply nutrients and water and to produce plant biomass for human use. If soils are not managed sustainably they lose their productivity function for the long-term, if not permanently. It is estimated that about a quarter of all agricultural soils are degraded, therefore their future potential for biomass productivity decreases. Primary productivity depends on many factors. The main factors are geographic location as well as land and soil management. The LANDMARK primary productivity model considers additionally inherent soil attributes (physical, chemical, biological). Agricultural soils do not only need to fulfil their primary productivity function but at the same time sustain other soil functions such as water regulation and purification as well as carbon sequestration and climate regulation. To maintain all functions simultaneously is difficult and depends on the agronomical and environmental interests. Abiotic (e.g. climate) and biotic (e.g. soil organisms) factors have an influence on primary productivity. Therefore, land use management and agricultural management are important. Crop rotation and cover crops can have a positive effect on primary productivity. Also, the preceding crop and type, rate, timing and placement of fertiliser applied have an impact on the primary productivity of the crop being cultivated. For grassland soils, soil N mineralisation potential, soil fertility, nutrient application, soil structural quality and trafficability, grazing animal stocking rate and grazing management are important. On each level (local, regional and European) different tasks must be fulfilled. Farmers have to be aware about the impacts of agricultural practices on soil functions. Possible recommendations for soil and land management with regards to primary productivity are:

- Well-tailored crop rotations,
- Inclusion of precision farming,
- Integrated farming systems, and
- Sustainable intensification.



Facing the future resource limitation, monitoring and sustainable intensification of primary productivity are needed, and here different scales (local, regional, European, global) have to be considered. As far as monitoring systems are concerned, a harmonisation in measures and analyses is crucial on national, regional and European level. Further, long-term experiments should be supported to investigate the influence of agricultural practices on soil functions. At a policy level, there is no legislation in the European Union that focusses on soil only; nonetheless many countries have policies that indirectly have an impact on some of the soil functions. To implement an adequate policy for soil functions, reliable measurement and assessment schemes are needed and it is a requirement to link different scales (field, local, regional, European). However, in order to manage soil functions sustainably, cooperation and integration of knowledge and technologies between socio-economic and environmental interests are required. It is therefore crucial to interlink scientists, policy-makers, advisors, land managers and farmers to create an active network to maintain multifunctional soil landscapes into the future.



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## 1/ FROM FUNCTION TO PROCESSES

The Human society is facing multiple challenges, including an estimated population increase by 2.5 billion from 2015 to 2050, increased energy consumption, a combination of expanding agricultural land use on the one hand and loss of most productive agricultural land to non-food production land use types on the other hand, while furthermore, facing increased climate variability and global warming (Blum, 2006, Valujeva *et al.*, 2016). According to a prediction done by the United Nations the global agricultural production must grow by 60% to feed the world population (WWDR, 2015). Soil is one of the key resources that help society to face these challenges, while being itself under heavy pressure (Blum, 2006). It is estimated that about a quarter of all agricultural soils are degraded, therefore their future potential for biomass productivity has decreased and still decreases (Conijn *et al.*, 2013). Soil provides several ecological and social functions (ecosystem services); one of which is productivity (Schulte *et al.*, 2014).

The primary productivity function is “the capacity of a soil to supply nutrients and water and to produce plant biomass for human use, providing food, feed, fibre and fuel within natural or managed ecosystem boundaries” (Schulte *et al.*, 2014; Schröder *et al.*, 2016). It is the productivity function of soils that delivers an economical basis for farmers and all connected sectors, and thereby is directly linked to humans (Tóth *et al.*, 2013, Schulte *et al.*, 2014;). Soils play a unique role for agriculture and forestry. If soils are not managed sustainably they lose their productivity function in the longer-term, if not permanently (Mueller *et al.*, 2010). Moreover, agricultural soils do not only need to fulfil their primary productivity function but at the same time sustain other soil functions such as water regulation and purification, carbon sequestration and climate regulation, provision of functional and intrinsic biodiversity as well as provision and cycling of nutrients (Mueller *et al.*, 2010; Schulte *et al.*, 2014). The influence of climate, hydrology, topography and human activities need to be considered when assessing the capacity of soils to produce biomass. On a continental scale, climate is a major factor for the production of biomass. Human activities that transform land to an arable area and other land uses, directed to a greater utilisation of the productive capacity, are equally important. Since primary productivity is the main interest of the agricultural sector, there are several methods to evaluate the potential for productivity of soils. Methods including land capability and agro-ecological zoning have been used to evaluate the capacity of a soil to produce biomass (Mueller *et al.*, 2010). According to Haberl *et al.* (2007) the influence of human activities on the net primary production (NPP), defined as the biomass that will reign with no human interactions, can be described as the “human appropriation of net primary production” (HNPP). The HNPP shows



the effect of harvest and productivity changes induced by the land use changes compared to the net primary production (Erb *et al.*, 2016).

## 2/ FROM PROCESSES TO ATTRIBUTES

Biomass production depends on many factors. Mueller *et al.* (2010) and Tóth *et al.* (2013) describe the main factors for primary production as the geographic location (climate, altitude, and slope degree, latitude and longitude) and the land management (land use types, soil management). The thermal and moisture regimes of most soils are directly linked to climate and location properties. Primary productivity is often limited by climatic parameters, like drought, wetness and length of growing season (Fischer *et al.*, 2002) and unfavourable soil properties. The LANDMARK Primary Productivity model considers attributes including climate (in the model termed “Environment”), land use management (in the model termed “Management”) as well as inherent soil attributes like physical (structure, groundwater table depth) and chemical (micro- and macro-elements) properties and parameters which influence the biological activity rate (pH, C/N ratio, soil organic matter) (Figure 1). The multi-attribute qualitative decision model for primary productivity soil function resulted in a hierarchical structure (Bohanec and Rajkovič, 1990; Bohanec, 2009). The top of the hierarchy represents an efficiency, i.e. capacity, of the primary productivity function; the intermediate levels represent attributes that integrate lower level attributes down to the basic input. Primary productivity is being determined by soil (S) properties (‘attributes’), environmental (E) attributes such as precipitation, temperature and orography, in interaction with crop (C) and management (M) decisions and practices. These S x E x C x M interactions determine whether the capacity of a soil to produce biomass is ‘low’, ‘medium’, or ‘high’ (Figure 2).

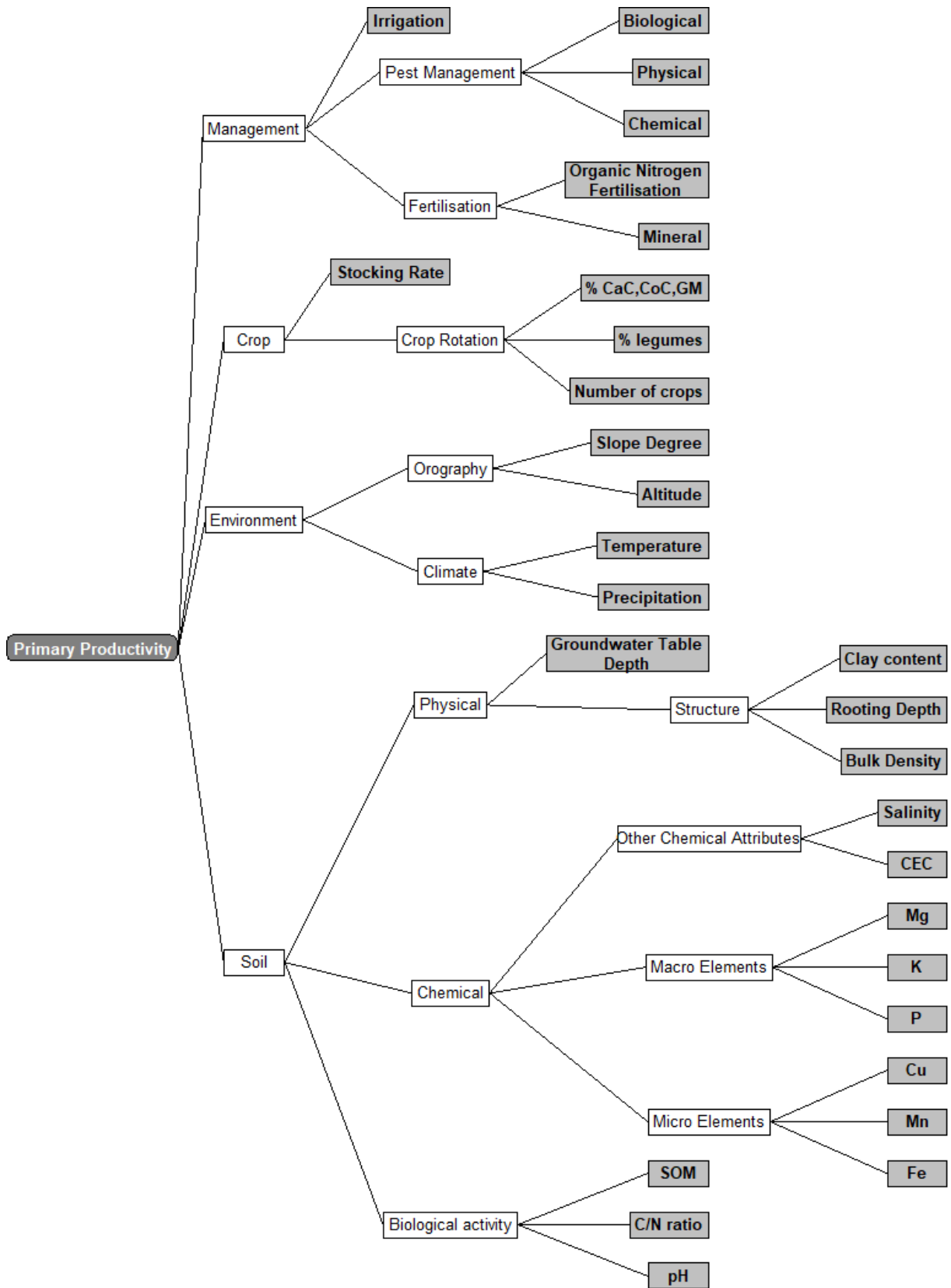


Figure 1 The decision model for Primary Productivity in LANDMARK: from basic attributes (grey boxes on the right) via aggregated attributes (e.g. Biological activity, Soil) to the ultimate soil function Primary Productivity.



Limiting factors for primary productivity, related to internal soil attributes, are suboptimal rooting and nutrition of plants. These factors include shallow soils, stoniness, hardpan, anaerobic conditions, salinity, sodicity, acidity, nutrient depletion and contamination (Louwagie *et al.*, 2009, Mueller *et al.*, 2010). In addition, the LANDMARK Primary Productivity model takes account of crop (C) specific properties like crop rotation, including the share of legumes and use of catch crops, and stocking rate (Figure 1). The model splits agricultural management (M) into fertilisation (mineral, organic nitrogen fertilisation), pest management (chemical, physical, biological) and irrigation. The aim of management is to improve soil fertility in order to overcome yield-limiting (e.g. soil moisture) and yield-reducing (e.g. pests) factors of soil productivity (Horton *et al.*, 2016). Cultivation of land has e.g. an influence on the soil structure (e.g. spatial arrangement of aggregates, porosity) (Scheffer and Schachtschabel, 2010, Mueller *et al.*, 2010). Unfavourable structure such as low aggregate stability can have negative effects on crop yields, for example due to greater leaching losses (Kavdir and Smucker, 2005). Each attribute in the Primary Productivity qualitative decision model can have one out of three (or two) values (e.g. 'high', 'medium', 'low' or 'yes', 'no'). Such values can be derived from real (measured) values by discretization based on pre-defined threshold values. Subsequently, values of a similar nature are assigned to the overarching process of each possible combination of two or three underlying attributes, until the ultimate function primary productivity (at the top) is reached (Figure 2).

Attribute	Scale
<b>Primary Productivity</b>	<b>Low</b> ; Medium; <b>High</b>
<b>Soil</b>	<b>Unsuitable</b> ; Neutral; <b>Suitable</b>
<b>Biological activity</b>	<b>Low</b> ; Medium; <b>High</b>
pH	<b>Low</b> ; High; <b>Medium</b>
C/N ratio	<b>High</b> ; Medium; <b>Low</b>
SOM	<b>Low</b> ; Medium; <b>High</b>
<b>Chemical</b>	<b>Unsuitable</b> ; Neutral; <b>Suitable</b>
<b>Micro Elements</b>	<b>Unsuitable</b> ; Neutral; <b>Suitable</b>
Fe	<b>High</b> ; <b>Medium</b> ; <b>Low</b>
Mn	<b>High</b> ; Medium; <b>Low</b>
Cu	<b>High</b> ; Low; <b>Medium</b>
<b>Macro Elements</b>	<b>Unsuitable</b> ; Neutral; <b>Suitable</b>
P	Low; <b>Medium</b> ; <b>High</b>
K	<b>Low</b> ; Medium; <b>High</b>
Mg	<b>Low</b> ; Medium; <b>High</b>
<b>Other Chemical Attributes</b>	<b>Unsuitable</b> ; <b>Suitable</b>
CEC	<b>High</b> ; Low; <b>Medium</b>
Salinity	<b>High</b> ; Medium; <b>Low</b>
<b>Physical</b>	<b>Unsuitable</b> ; <b>Suitable</b>
<b>Structure</b>	<b>Unsuitable</b> ; Neutral; <b>Suitable</b>
Bulk Density	<b>High</b> ; Medium; <b>Low</b>
Rooting Depth	<b>Low</b> ; Medium; <b>High</b>
Clay content	<b>Low</b> ; High; <b>Medium</b>
Groundwater Table Depth	<b>High</b> ; <b>Low</b> ; <b>Medium</b>
<b>Environment</b>	<b>Unsuitable</b> ; <b>Suitable</b>
<b>Climate</b>	<b>Unsuitable</b> ; Neutral; <b>Suitable</b>
Precipitation	<b>High</b> ; <b>Low</b> ; <b>Medium</b>
Temperature	<b>Low</b> ; Medium; <b>High</b>
<b>Orography</b>	<b>Unsuitable</b> ; Neutral; <b>Suitable</b>
Altitude	<b>High</b> ; <b>Medium</b> ; <b>Low</b>
Slope Degree	<b>High</b> ; Medium; <b>Low</b>
<b>Crop</b>	<b>Unsuitable</b> ; Neutral; <b>Suitable</b>
<b>Crop Rotation</b>	<b>Unsuitable</b> ; Neutral; <b>Suitable</b>
Number of crops	<b>Low</b> ; Medium; Permanent grassland; <b>High</b>
% legumes	<b>Low</b> ; <b>Medium</b> ; <b>High</b>
% CaC, CoC, GM	<b>Low</b> ; Medium; <b>High</b>
Stocking Rate	<b>High</b> ; Low; Stockless; <b>Medium</b>
<b>Management</b>	<b>Unsuitable</b> ; Neutral; <b>Suitable</b>
<b>Fertilisation</b>	<b>Low</b> ; Sufficient; <b>High</b>
Mineral	<b>Without</b> ; <b>Low</b> ; Medium; <b>High</b>
Organic Nitrogen Fertilisation	<b>Without</b> ; <b>Low</b> ; Medium; <b>High</b>
<b>Pest Management</b>	<b>Moderate</b> ; Without; <b>Sufficient</b>
Chemical	No; <b>Yes</b>
Physical	No; <b>Yes</b>
Biological	No; <b>Yes</b>
Irrigation	No; <b>Yes</b>

Figure 2 The scales of values being used for each attribute in the Primary Productivity decision model.

### 3/ ADOPTION

In general, the effects of agricultural management practices can be assessed best in long-term field experiments. Small changes in the soil can accumulate over several years until they become detectable, and interactions with meteorological variabilities can more easily be assessed in an experimental setting (Zavattaro *et al.*, 2015, Sandén *et al.*, 2018, Johnston and Poulton, 2018). Zavattaro *et al.* (2015) analysed the long-term effects of management practices on crop yields, testing practices like crop rotation, cover crops, no and minimum tillage, fertilisation with compost, manure, slurry and incorporation of residues. The yields gained with those management practices were always compared with yields of fields on which the practices were not applied (e.g. conventional tillage, mineral fertilisation etc.). The study observed that especially crop rotation and cover crops had positive effects on crop yields. In more than 80% of the examined cases the yield of a crop grown in a rotation practice was larger than the yield of a monoculture (Zavattaro *et al.*, 2015). Crop rotation worked well on sandy and loamy soils in Western Europe, whereas clayey soils have unfavourable conditions for a rotation system (Zavattaro *et al.*, 2015). Also cover/catch crops had positive effects on the yields of the main crops in 60% of the cases. It was of minor importance which cover crop was grown (leguminous, non-leguminous). Here the best results were detected in Eastern Europe, in soils other than silty ones (Zavattaro *et al.*, 2015). The positive effects of crop rotation and catch crops on the primary productivity were confirmed by the study of Sandén *et al.* (2018). Sandén *et al.* (2018) analysed different European long-term experiments and reported an increase in yields of about 5% and 4%, when crop rotation and catch crops were applied, respectively. A slight reduction in yields could be seen in applying organic amendments, including farmyard manure and incorporation of crop residues. Sandén *et al.* (2018) concluded that no-tillage had no significant influence on primary productivity, whereas they indicated a decrease of primary productivity when non-inversion tillage was applied compared to conventional tillage practices. Although on average non-inversion tillage had no beneficial effect on the yield, these practices worked best on silty soils (Zavattaro *et al.*, 2015). It was also shown that the climate type and therefore the geographical location were the main factors determining whether a specific management practice had beneficial effects on primary productivity. Zavattaro *et al.* (2015) showed that the performance of organic fertilisers depended on the climate (the colder the better), the soil type (best positive impact on coarse-textured soils) and the duration of application (longer than 5 years).

Trajanov *et al.* (2018) modelled the long-term influence of different management practices like tillage, crop residue incorporation and compost amendments on primary productivity in Austria. Data mining methodology was applied for analysis of the long-term monitoring data from the

experimental sites. The analysis showed that the preceding crop, plant-available Mg and the crop of the growing year for the tillage long-term experiment were the most important factors for primary productivity (Trajanov *et al.*, 2018). Considering the preceding crop, it turned out that cereal yields were significantly lower when sugar beet, or winter wheat were preceding crops in contrast to soybean and spring wheat. Moreover, preceding yields, C/N ratio, preceding cation exchange capacity (CEC) and plant-available phosphorus were important for predicting yields (Trajanov *et al.*, 2018). This knowledge can help farmers in their decision making processes for field management. The data analysis showed that the influence of soil tillage was less important for primary productivity than assumed. In the case of crop residue incorporation, the plant-available Mg contributed the most to primary productivity. In which amount and how easy magnesium is available for plants, depend on several circumstances like soil pH, soil moisture, weathering and microbial activity (Senbayram *et al.*, 2015, Trajanov *et al.*, 2018). Magnesium may play a crucial role in intensively farmed land due to rapid Mg depletion (Cakmak, 2013, Trajanov *et al.*, 2018). However, when analysing data from 21 different long-term experiments with crop residue incorporation, Sandén *et al.* (2018) showed a significant negative effect of crop residue incorporation on primary productivity. A positive effect could only be recognized in badly structured silty soils according to Zavattaro *et al.* (2015), when investigating nearly the same dataset. Considering compost amendments, the data mining analysis showed that the crop grown and the treatment applied had major effects on primary productivity. It was important which fertilisation was applied, so higher yields were achieved when sufficient mineral or a combination of compost and mineral fertilisation was applied compared to the application of compost amendments only (Trajanov *et al.*, 2018). This is in agreement with previous work from the same site (Lehtinen *et al.*, 2017).

In countries where animal production is based on grassland, increasing early and late season grass growth increases the production efficiencies of farms (O'Donovan *et al.*, 2011). Parsons (1988) demonstrated that although a grass sward initially produces the equivalent of 65 t/ha day matter (DM) per annum, because of losses in the system, only some 20% of this is eventually harvested. An average annual DM yield of 14.0 t/ha was recorded in long term grass experiments between 1982 and 2009 (range 11.0 to 18.6 t/ha among years). However, grass DM production on intensive dairy farms can be more variable and ranged from 9.2 to 14.4 t/ha in 2009 (Shalloo *et al.*, 2011). In temperate grassland soils significant differences in soil N mineralization potential have been shown to be closely linked with grass production (McDonald *et al.*, 2014). Various management factors such as soil fertility, nutrient application, soil structural quality and trafficability, coupled with grazing animal stocking rate and grazing management have been shown to affect



primary productivity and other functions performed by grassland soils (Greenwood and McKenzie, 2001; Bondi *et al.*, 2018).

Facing the future resource limitation, monitoring and sustainable intensification of primary productivity are needed, not only at local level but also in a global context. Considering different scales (local, regional, European, global) is important because soil functions can operate at different spatial scales (Schulte *et al.*, 2015, Valujeva *et al.*, 2016). It must also be kept in mind that not all attributes that influence primary productivity have the same relevance, or the same level of influence, on every scale. The differences between local, regional, European and global scales must be distinguished and evaluated when scaling up (Schulte *et al.*, 2015). Most attributes work on a local scale. Factors like climate work on a larger scale, from local to regional to European and to global scales (Mueller *et al.*, 2010). Valujeva *et al.* (2016) give the example that the demand for increased primary productivity specified on national level also is of interest at the local level, because it is linked to the economic output of each individual farm. Global scales must be considered, when generalisations are made and when overall assumptions are of interest. In addition, the evaluation should take into account the main European agricultural land uses such as arable land, grassland and forestry (EuroStat, 2015). A comprehensive assessment could help to create reliable attributes for farm- and forestland quality (Mueller *et al.*, 2010), given that land and soil are set under diverging pressure to meet both agronomic and environmental targets by the respective countries' policies (Valujeva *et al.*, 2016). For these reasons it is of pivotal importance to get a better understanding of how soil functions work, how they interact with one another and to what extent the soil functions can work simultaneously. At the same time an enabling environment for the political targets to be achieved, should be created (Valujeva *et al.*, 2016).



## 4/ RECOMMENDATIONS

Although farmers, researchers and policy makers have already implemented strategies, management recommendations and soil monitoring systems, there are still gaps between the existing knowledge and its implementation in practice. These gaps have to be overcome, because soil management is one of the key actions to shape future quantity and quality of primary productivity and to meet the demand for a soil to sustain multiple soil functions simultaneously (Techen and Helming, 2017). In the next part, recommendations on practices and strategies at different levels, for farmers and farm advisors (local), for monitoring (country/regional) and for policy makers (EU), are given.

### 4.1/ FOR FARMERS AND FARM ADVISORS

This report summarises the effects of different agricultural management practices on primary productivity. Crop rotation, catch/cover crops and mineral fertilisers were observed to have positive effect on primary productivity. No-tillage or non-inversion tillage was shown to have no beneficial impact on primary productivity and neither had the incorporation of crop residues, however, it is site-specific. The importance of the previous crops on the field was shown to be crucial. Further, C/N ratio, preceding CEC and plant-available phosphorus were important predictors of yields. In order to support primary productivity and to deliver 2 or more soil functions simultaneously, the following can be recommended:

- > Soil management including precision farming for larger farms in order to reach better external resource management, introduction of field margins and field transition zones, implementation of intercropping systems, application of different crop varieties (adapted to new climate conditions) and crop rotation management systems (Techen and Helming, 2017).
- > An integrated farming system: combines practices from conventional, organic and conservation agriculture systems, e.g. in nutrient and pest management. In the case of integrated nutrient management, it would mean a combination of chemical and organic fertilisers (Stavi *et al.*, 2016).
- > Sustainable intensification: Garnett *et al.* (2013) defined sustainable intensification as increasing food production from existing farmland in ways that place far less pressure on the environment and that do not undermine the capacity to continue producing food into the future. The long-term productivity of the soil is the main focus and as such the interaction with other soil functions becomes very important. Farmers and advisors should therefore seek to deliver 2 or more soil functions simultaneously to optimise primary productivity in the long-term.



Independent from the chosen management practices farm management options are often site-specific and should therefore be tailored to local conditions ('supply') and requirements ('demands'). Thus, what counts for one farm does not automatically count for a different one. This should be taken into account in the decision making process (Stavi *et al.*, 2016).

## 4.2/ FOR REGIONAL MONITORING AND ASSESSMENT

Soil protection is one of the objectives of the agenda of the European Commission (EU Soil Thematic Strategy and the 7<sup>th</sup> Environment Action Programme), soil monitoring systems exist on a national level for some countries and also on a European level through the Land Use and Coverage Area frame Survey (LUCAS, Orgiazzi *et al.*, 2018). However, there is no national or European monitoring system which has the capacity to quantify all five soil functions (van Leeuwen *et al.*, 2017), as they tend to focus on soil chemical attributes, with few soil biological and physical attributes.

- > In order to link primary productivity to other soil functions, especially the habitat function, more biological (e.g. bacterial community) and physical (e.g. soil moisture, bulk density, texture and soil slope) attributes should be integrated into monitoring efforts (van Leeuwen *et al.*, 2017).
- > Harmonisation in measures and analyses is crucial on a national level as well as on European scale (van Leeuwen *et al.*, 2017).
- > Long-term experiments are important living laboratories for productivity monitoring (Johnston and Poulton, 2018, Sandén *et al.*, 2018). For many potentially beneficial management practices (e.g. intercropping and agroforestry), there is very little scientific evidence about their effects on soil processes and functions and field experiments could be an adequate vehicle to conduct these tasks (Techen and Helming, 2017). The longer the field long-term experiment runs, the higher its value gets. Cost effectiveness of an experiment can be increased when it serves more than one objective (Johnston and Poulton, 2018).



### 4.3/ FOR POLICY MAKERS

Environmental awareness among the general public has increased and soil related topics are on the European agenda, especially after the International Year of Soil in 2015. The European Union's Common Agricultural Policy (CAP) includes regulations related to soil management. Further to the CAP, several other political instruments exist on a European level (e.g. Nitrates Directive, Water Framework Directive, and Landfill Directive), affecting directly and indirectly soil management and are linked under the umbrella of the UN Sustainable Development Goals (SDGs). Soils are mentioned in nine out of 17 SDGs (Techen and Helming 2017, Vrebos *et al.*, 2017).

- > However, there is no legislation in the European Union that focusses on soil only. Some countries have at least policies that indirectly have an impact on soil functions (Vrebos *et al.*, 2017). Examples for country specific solution are the Rural Development Plan of the Italian region Emilia-Romagna which is part of the European Agricultural Fund for Rural Development and the Upper-Austrian Regional Spatial Development Program in Austria (Haslmayr et al, 2016, Vrebos *et al.*, 2017).
- > Policy targets should be harmonized and monitoring and evaluation methods should be developed which are applicable across the entire European Union (Vrebos *et al.*, 2017). The future CAP should enable multifunctionality of soils and not only focus on individual soil functions (Sandén and Spiegel, 2017).
- > To implement an adequate policy for soil functions, reliable measurement and assessment schemes are needed and it is a requirement to link different scales (Valujeva *et al.*, 2016, Vrebos *et al.*, 2017).

A reorganization of the political-economic landscape is needed in order to reach a change in soil management in favour of the soil (Godfrey and Garnett, 2014). Further, political actions have to be implemented to not only consider soil directly, but also to modify population growth, resource intensive consumption patterns, waste reduction to improve the system of governance. Further, an integration of and communication between soil management, policy and land planning is required.



## 5/ CONCLUSIONS

On the one hand, land take and soil degradation processes present urgent challenges for long-term primary productivity, while on the other hand farm and soil management tries to compensate for this lost soil quality by higher input of external resources to the detriment of other soil functions and the state of the environmental quality. One of society's and especially policy makers' main tasks is to support all soil functions and to bridge the conflicting issues between agronomical and environmental interests.

Farmers can optimise productivity by applying smart farming, integrated farming systems and sustainable intensification. In order to link productivity to other soil functions the monitoring systems (regional, national, European) should include more biological and physical factors. Further, standardized procedures for soil data collection and management should be defined and a harmonisation of the data collecting and analysing should be done over all monitoring scales. Long-term field experiments are a good possibility to monitor long-term effects on productivity under controlled conditions and to gather more knowledge about soil functions. In the case of policy, a European legislation for soil is needed. Policy targets should be harmonized and monitoring and evaluation methods should be developed which are applicable across the entire European Union. Therefore, reliable measurement and assessment schemes are needed and it is a requirement to link different scales.

Soils are a finite natural resource which should be used as a means to generate quantitatively and qualitatively fair agricultural and wood products but with sustaining environmental quality for the next generations. Soil processes are complex and to manage the soil functions sustainably, cooperation and integration of knowledge and technologies between economic and environmental interests are required. It is crucial to interlink scientists, policy-makers, advisors, land managers and farmers to create an active network to maintain all soil functions.



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