TECHNICAL NOTE

FiBL

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Weeds as soil bioindicators: How to sample and use data

In brief

This technical note shows how weed species can be used as indicators of soil conditions that are either linked to soil characteristics (such as soil pH or texture) or to soil management (such as water logging, lack or excess of nutrients, compaction).

It should be stressed that (i) this kind of analysis does not always provide consistent results, because the relationship between weed species and soil conditions is not always clear cut and that (ii) the suggested sampling methodology requires some basic botanical skills for weed identification.

Wild plants as bioindicators

The aim of this method is to gain information on soil conditions in an agroecosystem using wild plants ('weeds') as bioindicators.

Many weeds can grow in different soils and environments, but each species has an optimum range of conditions under which it can be found [1,2]. According to Grime's plant strategy classification [3], weeds are usually characterised by a competitive or ruderal strategy, and only a few have the capacity to adapt to very extreme conditions (stress-tolerant species). At any abundance rate, some weed species can be typically found under specific soil conditions. Knowing which species can be associated with which soil condition is the basis for using them as bioindicators.

Weeds as bioindicators have been known for a long time. In this regard, the authors started by analysing the old, mainly anecdotal literature [4,5] and integrated more modern, scientifically-based evidence, which is still rather sparse. Finally, species were clustered into two groups based on the number of records clearly associating them with a given soil characteristic.

Weed species for which the same type of association with a given soil characteristic was reported in three or more different sources were defined as 'highly reliable' indicators. Weed species for which an association was reported in two different sources were defined as 'medium reliable' indicators. Weed species are listed in the 'Bioindicator species tables' shown in the appendix.

The second step was to develop a methodology that allows farmers and agroecosystem managers to extract the best information on weeds as bioindicators of soil conditions from dedicated field sampling. The sampling strategy suggested here cannot be considered exhaustive, but it represents a good compromise between sampling effort and data accuracy. In order to gain more precise information on soil conditions, the use of conventional soil testing techniques is recommended.

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Investigation method

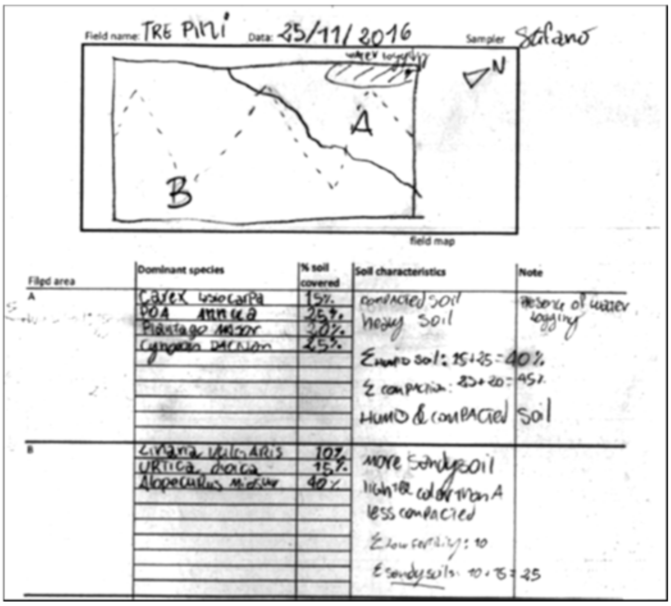
Identifying weed species is not always an easy task, but the species selected here as soil bioindicators are quite different from one another, which should reduce the risk of misclassification. The correct identification of weed species is a prerequisite for using this method.

When to sample

When the purpose of sampling is to make decisions on which control measure to apply, weeds are usually identified at an early developmental stage. However, sampling for weeds as soil bioindicators can be done at a later growth stage (e.g. flowering), when species are easier to identify. In temperate environments, it is advisable to take a sample more than once per year, for example, in spring before the application of weed control techniques, in summer before crop harvest, and in autumn before soil tillage (if any occurs). By combining the information of these three sampling periods, it is possible to form a clear picture of the most important weed species present in the agroecosystem while minimising the risk of missing some seasonally important, short-cycled species.

Where to sample

Weed sampling should be performed in one or more target fields, typically in those frequently showing abnormal soil conditions. Since the evaluation is based on weed community composition and not just on the presence of some individual weeds, the whole target field should be sampled. Considering that the weed community can strongly vary from the field margin to the centre of the field, it is suggested to walk along and across the field before starting the sampling, take note of any areas where the weed composition abruptly changes, and decide whether or not to include outer field areas (e.g. margins) in the sampling.



Example of sampling sheet filled in with the collected information. Photo: Stefano Carlesi

Materials needed

- Weed identification book
- Clipboard, pad and pencil
- Sampling sheet (see example below, appendix & website)
- Bioindicator species table (see appendix & website)
- Newspaper sheets

Field work

1. Observe the overall field or area that you are going to sample. Walk along and across the whole field to get an idea of whether the sampling area is homogeneous in terms of weed community composition. If it is not, identify the sub-areas that have a clearly different weed composition. If the field margin vegetation is very different from field vegetation (e.g. due to the presence of ditches, shrubs, fences or other structural elements) exclude it from the sampling.

2. From one side, walk inside the field following a zigzag pattern. Take note of the main weed species present, and visually estimate the percentage of soil cover for each of them. In the sampling sheet, write down the main species encountered in the first sampled sub-area (e.g. 'A'). Repeat this procedure for the second (e.g. 'B') and any other sampling sub-areas.

Wet soil showing a high presence of *Poa annua* and *Ranunculus repens.* Photo: Stefano Carlesi

3. SAMPLING NOTES:

3.1 Focus your survey on the overall weed species composition and on the dominant species. Single occurrences and rare species may be of high botanical interest but cannot be considered trustable indicators for soil conditions, especially in highly disturbed situations like agroecosystems.

3.2 In case you cannot identify some of the main species present, take some individual specimens to identify them later. In that case, remove the plant from soil and include part of the root system. The best individuals to be sampled are those with flowers and fruits. If they are too large, you can bend the plant or sample part of it. Then assign it a provisional name based on main plant features (e.g. 'grass with hairy reddish leaves' or 'dicot with purple flowers and long ovary') and record the species as such on the sampling sheet. Next, conserve the plant between two newspaper sheets after flattening and opening leaves. Afterwards, put some weight on the newspaper sheets. This will keep the features of the specimen as close as possible to those of the live plant.

4. In the sampling sheet, annotate the soil conditions in each sub-area. Focus on differences between sub-areas for these features:

- Soil texture (e.g. in which sub-area is it sandier? In which is it more clayey?)
- Soil compaction (how difficult is it to put a stick into the soil?)
- Soil colour (e.g. which one is darker?)
- Soil moisture

5. Check if the main species found in the sub-areas are annual or perennial. If you are uncertain, use the following simple test: try to uproot a plant of the target species; if you can easily uproot it including a large amount of the root system it is an annual; if the plant breaks when trying to uproot it is likely a perennial.

6. Now, for each sub-sample, you have a description of the main weed species present as well as of the main soil characteristics.

Out-of-field work

1. Identify the unknown species using the pressed specimens taken in the field and update the sampling sheet accordingly. If you cannot identify these species on your own, seek help from a more experienced colleague.

2. Check which species recorded as dominant in the sampling sheet are present in the 'Bioindicator species table' (see Annex I).

3. Add up the soil cover value of each species belonging to the same bioindicator typology that is present in each sampled sub-area.

4. In case species that are considered bioindicators of opposite soil characteristics (e.g. dry *vs* wet soil, acidic *vs* alkaline soil) appear in the same sub-area, discard these characteristics: in this case, the bioindicator(s) would be of low reliability.

5. If dominant weed species belonging to different bioindicator typology are not conflicting, the characteristics described in the 'Bioindicator species table' can be checked against the actual soil characteristics to verify whether or not the indication given by the table is consistent.

6. Now, for each sampled sub-area in your field, you have a more detailed description of the main soil characteristics based on the weed species present.

Plant conservation

If you want to conserve the specimens collected in the field keep them in newspaper sheets until the plant is completely dry. Then remove the sheets and attach the specimen to a thick white A3-sized paper sheet using pins. Add information like the species' Latin name, the date and place of collection, etc.

Which conclusions can be drawn?

To have clearer indications of soil characteristics, it is preferable to rely on soil analyses. However, the observation of wild plant ('weed') community composition present in a field represents a quick and cheap method to estimate soil characteristics and to draw inferences about the effects of agricultural practices. It should be kept in mind that weed community composition may be affected by several soil factors as well as by past and present management, which may interact at a very small scale. Therefore, the information resulting from using weeds as bioindicators should always be cross-checked with field records and soil assessments.

Different soil characteristics usually result in different weed species compositions. By focusing on dominant weed species that may be bioindicators, it is possible to extract useful information to tailor farming practices to the actual soil conditions and to improve them where needed. Aspects like soil texture and soil reaction (pH) are less likely to be improved, but others like excess water, soil compaction and reduced soil fertility can be improved by e.g. appropriate drainage, tillage and cover crop practices.

Interpretation of the findings

Observations	Possible conclusions and recommendations
Soil texture	▪ It is a very important agronomic characteristic, which usually drives the choice of main tillage, crop and cover crop and main agronomic practices (e.g. fertilisation, irrigation). To a certain extent, poor soil structure can be improved by enhancing humus content by soil organic matter enrichment. Adjust your crop choice, farm machinery and timing of tillage and fertilisation to soil structure.
Soil reaction (pH)	▪ It determines crop choice and fertilisation practices, and has a strong direct and indirect influence on soil chemical and biological quality. If weed bioindicators suggest acidic soil, validate it with pH measurement and take appropriate measures to increase soil pH, if necessary.
Soil water availability	▪ High values indicate the need to increase drainage system efficacy or to check for the presence of a tillage pan. In case of low values, where irrigation is not possible, careful choice of crop, cultivar and tillage/management practices (e.g. reduced tillage, water harvesting techniques) is a must.
Soil compaction	▪ It indicates the need for changing tillage practices (e.g. the application of reduced tillage and/or chiselling/subsoiling).
Soil fertility	▪ A high presence of species indicating fertile soil may be a sign of excessive use of fertilisers. As such, the crop fertilisation strategy may need to be changed. In contrast, a high presence of species that indicate poor soil suggests the need to increase soil organic matter, e.g. through the combination of reduced tillage and cover crops and/or manure and compost application. In this case, any detrimental practice (e.g. deep inversion tillage, stubble removal or burning) should be abandoned.

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Fertility Building Management Measures in Organic Cropping Systems – FertilCrop is a project funded by the CORE Organic Plus funding bodies, being partners of the FP7 ERA-Net project CORE Organic Plus. The overall aim of FertilCrop is to develop efficient and sustainable management techniques aimed at increasing crop productivity in organic farming systems. More information about FertilCrop is available at www.fertilcrop.net.

Annex I: Bioindicator species tables

Ordered by soil characteristic

Species	Botanical family	Typology	Trustability
Soil reaction			
Chrysanthemum leucanthemum* syn. *Leucanthemum vulgare	Asteraceae	Acidic soil	M
Gnaphalium uliginosum	Asteraceae	Acidic soil	M
Hieracium aurantiacum* syn. *Pilosella aurantiaca	Asteraceae	Acidic soil	H
Hieriacium pratense* syn. *H. caespitosum, Pilosella caespitosa	Asteraceae	Acidic soil	H
Polygonum aviculare	Polygonaceae	Acidic soil	M
Polygonum persicaria* syn. *Persicaria maculosa	Polygonaceae	Acidic soil	M
Portulaca oleracea	Portulacaceae	Acidic soil	M
Potentilla argentea	Rosaceace	Acidic soil	M
Potentilla monspeliensis	Rosaceace	Acidic soil	M
Rumex acetosella	Polygonaceae	Acidic soil	H
Rumex crispus	Polygonaceae	Acidic soil	M
***Sonchus* spp.**	Asteraceae	Acidic soil	H
Spergula arvensis	Caryophyllaceae	Acidic soil	H
***Verbascum* spp.**	Scrophulariaceae	Acidic soil	M
Viola arvensis	Violaceae	Acidic soil	H
Anagallis arvensis	Primulaceae	Alkaline soil	H
Anthemis nobilis* syn. *Chamaemelum nobilis	Asteraceae	Alkaline soil	M
***Chenopodium* spp.**	Chenopodiaceae	Alkaline soil	M
Daucus carota	Apiaceae	Alkaline soil	M
Lepidium virginicum	Brassicaceae	Alkaline soil	M
Water availability			
Amaranthus retroflexus	Amaranthaceae	Dry soil	M
Euphorbia maculata	Euphorbiaceae	Dry soil	M
Medicago lupulina	Fabaceae	Dry soil	M
Althaea officinalis	Malvaceae	Humid soil	M
Apios americana	Fabaceae	Humid soil	M
Carex lasiocarpa	Cyperaceae	Humid soil	H
Echinochloa crus-galli	Graminaceae	Humid soil	M
Equisetum arvense	Equisetaceae	Humid soil	H
Impatiens pallida	Balsaminaceae	Humid soil	M
Lychnis flos-cuculi	Caryophyllaceae	Humid soil	M
Poa annua	Graminaceae	Humid soil	H
Podophyllum peltatum	Berberidaceae	Humid soil	M
Polygonum pensylvanicum	Polygonaceae	Humid soil	M
Polygonum persicaria* syn. *Persicaria maculosa	Polygonaceae	Humid soil	H
***Ranunculus* spp.**	Ranunculaceae	Humid soil	H
Rumex acetosella	Polygonaceae	Humid soil	M
Tussilago farfara	Asteraceae	Humid soil	H
Typha latifolia	Typhaceae	Humid soil	M
Soil compaction			
Euphorbia maculata	Euphorbiaceae	Compaction	H
Galium aparine	Rubiaceae	Compaction	H
Plantago major	Plantaginaceae	Compaction	H
Poa annua	Graminaceae	Compaction	H
Polygonum aviculare	Polygonaceae	Compaction	H

Species	Botanical family	Typology	Trustabil-ity
Soil texture			
Allium vineale	Liliaceae	Clayey soil	M
Bellis perennis	Asteraceae	Clayey soil	M
Plantago major	Plantaginaceae	Clayey soil	H
***Ranunculus* spp.**	Ranunculaceae	Clayey soil	M
Ranunculus repens	Ranunculaceae	Clayey soil	M
Rumex obtusifolius	Polygonaceae	Clayey soil	H
Taraxacum officinale	Asteraceae	Clayey soil	M
Centaurea cyanus	Asteraceae	Sandy soil	M
Centaurea melitensis	Asteraceae	Sandy soil	M
Convolvulus arvensis	Convolvulaceae	Sandy soil	M
Eupatorium capillifolium	Asteraceae	Sandy soil	M
Lactuca tatarica* var. *pulchella	Asteraceae	Sandy soil	M
Linaria vulgaris	Scrophulariaceae	Sandy soil	M
Urtica dioica	Urticaceae	Sandy soil	H
Viola arvensis	Violaceae	Sandy soil	H
Soil fertility			
Arctium minus	Asteraceae	High fertility	M
Chenopodium album	Chenopodiaceae	High fertility	H
Phytolacca americana	Phytolaccaceae	High fertility	M
Poa annua	Graminaceae	High fertility	M
Portulaca oleracea	Portulacaceae	High fertility	M
Stellaria media	Caryophyllaceae	High fertility	H
Taraxacum officinale	Asteraceae	High fertility	H
***Andropogon* spp.**	Graminaceae	Low fertility	M
Linaria vulgaris	Scrophulariaceae	Low fertility	M
Lotus corniculatus	Fabaceae	Low fertility	M
Rumex acetosella	Polygonaceae	Low fertility	M
***Verbascum* spp.**	Scrophulariaceae	Low fertility	M

H: high reliability (information from > 3 bibliographic sources)
M: medium reliability (information from at least 2 sources)

Annex II: Sampling sheet

Field name: Data: Sampler:

Field map

Field sub-area	**Dominant species**	**% soil cover**	**Soil characteristics**	**Note**
A				
B				
C				

Annex III: References

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