EIP-AGRI Focus Group

Water & agriculture: adaptive strategies at farm level

MINIPAPER: Soil management for improved water availability

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1. Summarizing problems / solutions

The soil water content is a dynamic parameter. At the farm scale, it results from the balance between "gain" (precipitation, irrigation, run-on, capillary rise) and "loss" (evapo-transpiration, run-off, percolation) of water (fig. 1). The storage capacity of a soil is ultimately a function of its depth and texture, but can be reduced by problems such as poor structure. However, the soil water availability for a crop depends on the root system depth and soil porosity and both parameters do change at the farm scale. If adequate soil management practices are adopted, the amount of water stored in the soil profile can be increased and water losses reduced. The main issue remains soil porosity: the shape and size distribution of pores along the profile. The key solution lies in applying management practices which improve soil structure, reduce compaction and preserve and enhance soil organic matter (OM) levels. Over time this will rebuild the soil ability to capture and store water.

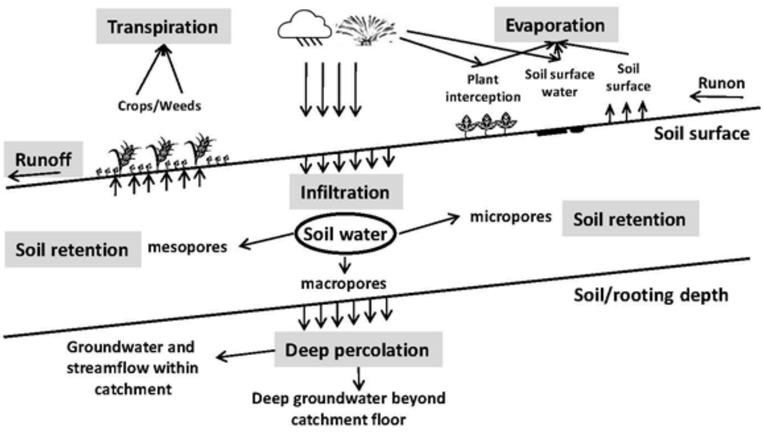

Figure 1: Water fluxes over a landscape or watershed and destinations of rain and irrigation water

2. Taking stock of the state of the art

There are several options available to improve water availability for crop growth. Within the limits imposed by each environment (soil properties and climatic characteristics are the main physical constraints), the good agro-practices become suitable tools for ameliorating the capacity of soils in storing water for feeding crops. The good practices are aiming at increasing infiltration, reducing runoff, soil evaporation and drainage, and optimizing the crop transpiration. Through good agronomic practices, farmers modify the parameters which affect the soil water content (fig. 2).

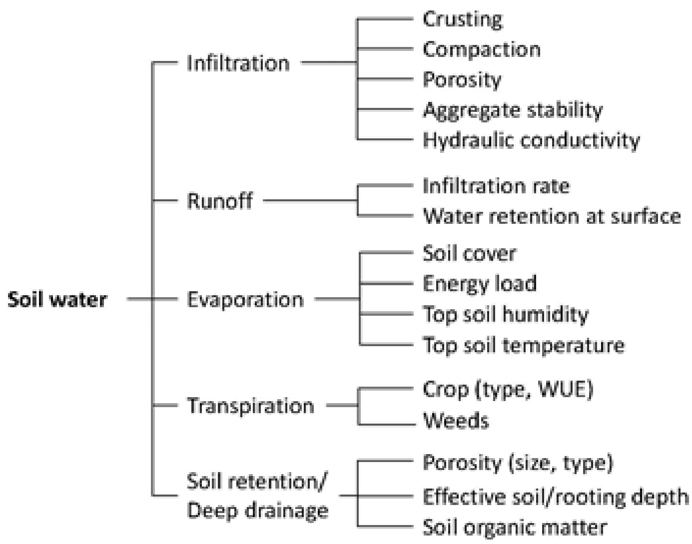

Figure 2: Processes and parameters affecting soil water

3. Developing new perspectives

Apart from vegetation canopies, the way soil is managed is the key to influence the processes that govern both the water fluxes over a watershed or landscape (fig. 1) and the parameters or processes affecting soil water (fig. 2). Although contributing to the recharge of surface water bodies (blue water, which is potentially reused for irrigation), or to the removal of excess water from agricultural fields, uncontrolled runoff is not desirable from the viewpoint of soil and water conservation. Therefore soil management practices should aim at improving the potential infiltration rate or

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'infiltrability'. For that purpose, it is necessary to distinguish whether infiltration is controlled by soil surface or by soil profile. At the soil surface the control of infiltrability is possible if water is supplied by irrigation (by regulating amount and intensity). Under rainfed conditions, the infiltrability (at the soil surface layer and in subsurface) is controlled by the hydraulic conductivity of the soil profile. This parameter can be modified by soil management practices.

Infiltration can be improved by either increasing its rate or by extending the time water has to infiltrate. Whereas the former is strongly enhanced in the presence of continuous macroporosity (mainly biopores created by macrofauna activity and former root channels), the latter depends on the soil surface roughness and the slope of the field. An increase of roughness is often attained unintentionally through any form of soil tillage, or intentionally achieved through tillage operations along contour lines or by creating "pockets" or "basins" or "terraces" over the soil surface. The infiltration rate, however, can only be improved where soil management contributes to:

a) surface aggregate stability, avoiding aggregates to breakdown by the kinetic impact of raindrops (or overhead or furrow irrigation) or the mechanical impact of soil tillage or wheeling, and consequently particle detachment, sealing and crusting;
b) maintain the soil covered permanently to dissipate the energy load of raindrops before they reach the soil surface.

Fig. 3: Infiltration under two tillage systems

Thus management practices which contribute to improving the infiltrability (fig. 3) aim at:

- minimizing soil disturbance (aggregate disruption)
- increasing soil OM content
- applying soil amendments that enhance aggregate stability
- maintaining crop residues or establishing cover crops

Regarding profile-controlled infiltration limitations (occurring in layered soil profiles or in the presence of compacted layers), subsoiling breaks restrictive soil layers (fig. 4). As long term strategy only the promotion of the development of vertically oriented macropores through earthworm and other macrofauna activities and/or the maintenance of former root channels, both achieved through the absence of soil disturbance, is able to improve profile-restricted infiltration rates.

Fig. 4: Vertical tillage or subsoiling

After water infiltrates the soil, its movement in or through the soil is mainly influenced by gravitational forces and suction gradients. The amount of soil water available to the plant depends on the porosity (amount and pore size distribution) and on the soil volume explored by roots. While pore size distribution is strongly affected by soil properties such as texture, structure and soil OM, the total pore volume from which plants may extract water depends on the effective rooting depth. Thus, in order to increase the amount of plant available soil water, specific soil management practices can be adopted. They aim to increase:

1) rooting depth. Vertical tillage is capable to break compacted soil layers (hard pans), frequently originated by heavy machine load under moist soil conditions or previous tillage operations (fig. 5). Although effective in breaking physical subsoil constraints (from natural or anthropogenic origin), deep-loosening effects are often of short duration, especially if not accompanied by additional measures, such as subsoil conditioners (i.e. gypsum), installation of primer crops or reduced or controlled traffic.

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2) percentage meso-macropores. Tillage in moist soil (near the field capacity) is the first cause of soil compaction (and losing meso-macroporosity). In the absence of soil disturbance (no-till systems) biological macropores, earthworm micro-galleries, former root channels, and voids between soil structural units are preserved. In that conditions effective deep percolation is allowed. However, tillage treatments alone make little difference to deep drainage. Though, the higher drainage losses in soil conservation systems can mainly be attributed to greater water intake and soil water storage where residues are maintained at the soil surface.

Fig. 5: Examples for tillage induced subsoil compaction

Unproductive soil water losses through evaporation, especially under high evaporative demand conditions, can affect crop available water considerably. Evaporative water losses are enhanced immediately after any form of soil tillage. At a later stage, however, the superficial layer of dry soil creates a barrier ("soil mulch") for the further rise and consequent evaporation of subsurface soil water. Under no-till conditions this process is not interrupted unless soil cover provides this barrier.

In summary, improving water availability through soil management, whether under rainfed or irrigated conditions, must always aim at the reduction of runoff and evaporation, and the enhancement of the volume of plant available water (rooting depth and pore size). Apart from chemical amendments to increase water infiltration and retention, tillage operations, either to retain rain or irrigation water for a longer time at the soil surface or to break surface crusts or compacted subsoil layers are widely used to reduce these losses and to allow roots to access deeper soil layers. Conservation Agriculture principles (mainly minimum soil disturbance and permanent soil cover) have shown to improve soil water availability considerably both through higher infiltration rates (intake) and reduced evaporation losses, and an enhanced water holding capacity as a result of an increase in the volume of mesopores and soil organic matter. Comparing the different options, the Conservation Agriculture approach appears to be the most cost-effective way of soil management to improve water availability at farm level.

4. Collecting relevant examples of good practice

The good practices can be divided in two categories:
A) those for <u>increasing the volume of water stored in the soil profile</u>:
- Ripper subsoiling (non-inversion tillage). Deep tillage (fig. 4) is necessary wherever a hard pan is present for breaking up hard layers and increasing available soil depth (by slicing thinly through the pan vertically, while lifting and then dropping the soil). Moreover it allows the root growth into deeper layers, particularly where reduced tillage is practiced, but ripping is not well-suited in tree stands. However, it is an expensive operation (requiring high energy and specific machineries) and should be repeated whenever a hard layer appears into the soil profile.

Fig. 6: Soils having different OM contents

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- Increasing soil OM (fig. 6). The soil water holding capacity is a direct function of the porosity and it depends on the soil structure, which in turn is the result of the OM contained in the soil. Apart from the traditional sources (livestock or green manure), compost, cover crops, vegetal mulch, digestate, sewage sludge and municipal wastes are becoming "alternative" organic materials. The limits of the application of external OM sources consist in the effective nutrient content and C/N ratio (changing with the origin of the organic material and the processing treatments), risk of contamination (heavy metals, organic pollutants, pesticides, heavy metals, antibiotics). Most of the alternative sources of organic amendments require high volumes (due to the relative high water content, especially in non-dried materials), as a consequence the constraint of transport costs must be considered. T
- Preserve soil OM. Notwithstanding the origin of the supplied organic matter, the soil management strategy for avoiding the mineralization of the organic matter contained in the soil profile consists in the minimization of soil disturbance (in particular, no-till). The technique lowers machinery and labour costs, but requires alternative, integrated weed control management. Moreover, pedo-climatic conditions are determining factors. Excess of water prevents from humification and favours anaerobic process. Drought and high temperatures accelerate the aerobic decomposition and CO_2 fluxes from the soil to the atmosphere. In practice, external input of organic matter can be "burnt" (at least partially) when the conditions for mineralization are enhanced (consciously or unconsciously) by soil tillage under warm and moist conditions.
- Controlled traffic. Machinery seeks to create permanent tracks in the field so that all vehicles which access the soil use the same tracks. Whilst this makes these areas more compacted the soil structure improves in the rest of the filed. In most systems the target is to limit track to 20% or less of the soil surface thus allowing more than 80% of the field area to have uncompacted soil. The benefits of Controlled Traffic Farming increase as time progresses and so they require time to develop. Reported benefits include soil structure improvement (fig. 7), better nutrient retention, less soil erosion and ultimately higher yields. To obtain less compaction - and favoring water storage and root growth - farm machinery should be adapted so that all the wheels follow the same tracks by standardising machine widths and wheel spacings and then using GPS guidance to ensure all vehicles follow the same tracks. The practice starts to be applied in farms and it could be largely adopted if farmers are assisted in optimizing plot design and sustained in purchasing new machineries or adapting the existing ones.

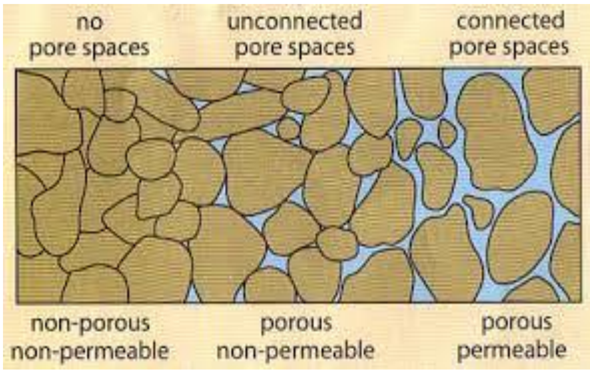

Fig.7: Effect of compaction on soil porosity

B) those for <u>regulating the soil water balance</u>

- Conservation Agriculture. It results as the combination of a series of practices (minimum soil disturbance - reduced/zero tillage, sod seeding, residues retention, crop rotation) which improves water infiltration (fig. 3) and reduces evaporation losses and runoff. The main advantage for farmers derives from a quite yield stability (less variability among years) and lower costs (for machinery and labor). Farmers are aware of this practice (as demonstrated by a series of active farmers' associations), nevertheless it slows to spread because it requires specific machinery and an integrated weed management. Moreover this technique may pose problems to crop establishment on heavy clay soils under wet conditions and high amounts of crop residues. Example of success are in olive groves or cereal farming systems.
- Soil mulching. Reduces soil evaporation and speeds up the first growth stages (due to higher soil temperature and moisture below the mulching sheet). Plastic mulches are used in irrigated cropping systems (mainly for horticultural species), if the incomes compensate the high costs of application, while the mulch layers obtained by vegetal materials are becoming popular. These mulches can be

either impervious plastic applied to the soil to keep water in the soil or floating pervious mulches which allow rainfall to pass through.
- Choice of cultivated species. Crops (cultivars / rootstocks) having a deep (vigorous and well-developed) root system which explores more soil. The main advantage for farmers is that it does not require additional costs after planting.

5. Identifying needs from practice and proposing directions for further research

The aforementioned soil management practices will affect soil-water balance and crop available water depending on agro-climatic conditions and intensity of their application. Modelling and validation efforts need therefore to be undertaken in different agro-climatic regions to estimate the degree of how the different management practices impact soil water availability and thus water scarcity resilience, and, ultimately, crop yields or irrigation water savings.
The research themes can be identified within two scientific domains: agronomy and agricultural engineering. All research on the scientific and technical aspects of soil and water management must also consider the economics for farmers of adopting the technology and any regulatory barriers they may face.
Agronomic research topics should address:
- the conditions for the success of conservation agriculture practices (from no-till to minimum tillage);
- the evaluation of the effect of alternative organic materials (digestate, compost from different sources, sewage sludge, reclaimed waters, beached algae) on the soil-water balance and crop available water;
- the comparison of new mulching materials, alternative to the plastic, and verifying the mulching effect of the cover crops;
- testing "on farm" devices for monitoring the input required by the soil-water balance equation or the soil water content.

Agricultural engineering research topics should address:
- relationship among reducing soil compaction, porosity, economic benefits;
- methods to avoid deep compaction as once this is present it is virtually impossible to remove;
- design of new ripper machines, adapted to small fields;
- the improvement of no-till drilling equipment, especially for high residue and wet or dry soil conditions

Moreover, following a multi-disciplinary approach, new research topics are required in domains associated to agronomy: chemistry (weed control, hydrogel materials) and genetics (early and deeply developing root systems suitable to no-tillage, and canopies fast growing in the early phenological stage to cover rapidly the soil).
Finally, farmers which improve the soil water availability in their farms, at the same time they produce a series of ecological services at the territorial scale:
- partition of rain water, while increasing the stored soil water it prevents from the risks connected to the excess of runoff;
- living windbreaks, while reducing evaporation they serve as ecological corridors;
- "protection" of soil OM, while improving soil structure it contributes to reduce CO_2 emissions and to increase microbial biodiversity recognized as important to crop health;
- cover crops, while increasing organic matter input they reduce soil erosion and nutrient leaching;
- fallow (green or set-aside) plots, while storing water in the soil profile it increases biodiversity.

These ecological services should be recognized by the society and adequately paid for. For quantifying the economic value of the ecological services new research topics should be addressed.

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6. Proposing priorities for innovative actions

There is a large body of scientific knowledge on soils collected over many decades. However, recent decades have seen a lack of investment in communicating this science to farmers and in adopting the principles of soil management to modern farming systems with larger machinery and information technologies. The priorities for soil management to improve the provision of water to plants are therefore to rebuild connections between practical farming and soil management research. This should include:

- Developing crop production techniques which integrate modern agronomic practice with methods of building long term soil fertility;
- "Translation" of soil science and agronomy to farmers by using ICT teaching methods;
- Building links between farmers and those with organic matter from other sources (from municipal waste companies, agro-industries, bio-refineries, biogas plants);
- Participative approach to design machineries and equipment for the application of "conservation agriculture" principles;
- Innovative demonstration and participatory approaches to effectively reach the end-users or beneficiaries of 'green water'.

7. Suggesting potential practical operational groups or other project formats to test solutions and opportunities

Operational groups are led by farmers to address their problems. This requires a focus on sharing ideas on the practical actions which farmers can take informed by science and research. Suitable topics include:

- Analyzing the long term experiences on "conservation agriculture" in different areas and cropping systems in order to demonstrate to farmers the importance of well-founded agronomic practices on soil fertility and yield stability over years
- The safe use of municipal waste streams to provide organic matter to build soil organic matter levels and fertility
- Production of compost on farm from either farm or other sources
- The economics of soil amendments by working with farmers to review which methods of soil amendment produce the best returns
- Reviewing on farm practices which enhance natural soil processes such as porosity or humus formation to increase water holding capacity and soil structure
- Developing innovative methods to reduce soil compaction in intensively managed soils (crops and livestock farming)

8. Ways to disseminate experience and practical knowledge

- Soils are a very visual and practical topic and thus where possible on farm events should be used as these allow farmers to see new ideas at first hand. This can be facilitated by developing local farmers' groups who meet to discuss soil management integrated into an on-farm visit;
- Videos of soil profile pits and soil management techniques would be valuable to allow wider dissemination including the exchange of ideas between countries;
- Online social networks between farmers and researchers can help to both spread the benefits of research whilst helping researchers appreciate the applicability of their new ideas on-farm.

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