

Soil Water Conservation: Dynamics and Impact

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Abstract: Human needs like food and clean water are directly related to good maintenance of healthy and productive soils. A good understanding of human impact on the natural environment is therefore necessary to preserve and manage soil and water resources. This knowledge is particularly important in semi-arid and arid regions, where the increasing demands on limited water supplies require urgent efforts to improve water quality and water use efficiency. It is important to keep in mind that both soil and water are limited resources. Thus, wise use of these natural resources is a fundamental prerequisite for the sustainability of human societies. This Special Issue collects 15 original contributions addressing the state of the art of soil and water conservation research. Contributions cover a wide range of topics, including (1) recovery of soil hydraulic properties; (2) erosion risk; (3) novel modeling, monitoring and experimental approaches for soil hydraulic characterization; (4) improvement of crop yields; (5) water availability; and (6) soil salinity. The collection of manuscripts presented in this Special Issue provides more insights into conservation strategies for effective and sustainable soil and water management.

Keywords: water and soil conservation; sustainable land management; soil erosion; soil water storage; water infiltration; water availability; crop yields

1. Introduction

To meet the needs of the increasing world population is one of the major challenges of our time [1]. At the same time, the high demands for food production have major impacts on soil and water resources [2]. Scarcity of water has been universally recognized as a global issue [3]. Moreover, climatic change has profound effects on the hydrological cycle, thus reducing the availability of water resources in many environments [4]. Basic human needs like food and clean water are strictly related to the maintenance of healthy and productive soils [5]. An improved understanding of human impact on the environment is therefore necessary to preserve and manage soil and water resources. This knowledge is particularly important in semi-arid and arid regions, where the increasing demands on limited water supplies require urgent efforts to improve water quality and water use efficiency [6]. It must be kept in mind that both soil and water are limited resources. Thus, the wise use of these natural resources is a fundamental prerequisite for the sustainability of human societies [7]. Soil erosion is well known to be a major cause of soil degradation. Many studies have highlighted that soil erosion involves a number of processes, including land levelling, gully erosion, piping and tillage erosion [8]. Human activities, such as deforestation, overgrazing, road construction and infrastructure development, have accelerated the erosion processes, causing grave negative effects over large areas [9]. Conservation strategies are

therefore essential to prevent soil degradation. Facing the problem of soil degradation also means implementing restorative measures of soil and crop management [10]. It is now widely recognized that strategies such as zero or reduced tillage, contour farming, mulches, and cover crops may improve soil and water conservation [2]. The development of proper conservation strategies also requires more information on how to interpret and model soil hydrological processes, such as aquifer recharge, rainfall partition into rainfall infiltration and excess runoff, and the associated transport of solutes and contaminants through the soil profile (such as nutrients, pesticides, heavy metals, radionuclides, and pathogenic microorganisms). Interpreting and modeling these processes needs the determination of the soil hydraulic characteristic curves, i.e., the relationships between volumetric soil water content, pressure head, and hydraulic conductivity [11–13]. Knowledge of these properties is therefore a necessity for sustainable management of soil and water resources. Despite the extensive literature on conservative strategies, the need for site-specific studies in different environments and socio-economic contexts still remains high. The aim of this Special Issue is to enhance our understanding on conservation strategies for effective and sustainable soil and water management. Contributions focus on: recovery of soil hydraulic properties [14–16]; erosion risk [17–19]; novel modeling [20–22], monitoring [23] and experimental [24] approaches for soil hydraulic characterization; improvement of crop yields [25,26]; water availability and food security [27]; and soil salinity [28]. In the following section we resume all the contributions of this Special Issue.

2. Overview of this Special Issue

This Special Issue collects 15 original contributions addressing the state of the art of soil and water conservation research. Three studies use infiltration experiments in order to assess the recovery of soil hydraulic properties after vineyard plantation [29], fire [15] and forest restoration [16]. With the aim of detecting the temporal variability of soil compaction and infiltration rates, Alagna et al. [29] carried out ring infiltrometer experiments in a Mediterranean vineyard planted with vines of different ages. According to these authors, planting operations caused soil compaction, which reduced the hydraulic conductivity. These modifications in the soil hydrological properties were reversed in the 24 years following planting. The rate of soil recovery was most profound immediately following the disturbance and declined thereafter, demonstrating the resilience of the considered soil to the stress induced by planting works.

Assessing the effects of fire on soil hydraulic properties in the Mediterranean area is crucial to evaluating the role of fire in land degradation and erosion processes. Among the soil hydraulic properties, field-saturated hydraulic conductivity, K_{fs} , exerts a key role in the partitioning of rainfall infiltration and excess runoff [14,30]. Therefore, estimates of K_{fs} are essential for evaluating the hydrological response of fire-affected soils. Di Prima et al. [15] determined the field-saturated soil hydraulic conductivity, K_{fs} , of an unmanaged field affected by fire by means of single-ring infiltrometer runs and the use of transient and steady-state data analysis procedures. Sampling and measurements were carried out in a fire-affected field (burnt site) and in a neighboring non-affected site (control site). The predictive potential of different data analysis procedures (i.e., transient and steady-state) to yield proper K_{fs} estimates was also investigated.

Forest cover may improve water infiltration and soil hydraulic properties, but little is known about the response and extent to which forest restoration can affect these properties. Knowledge of soil hydraulic properties after forest restoration is essential for understanding the recovery of hydrological processes, such as water infiltration. Lozano-Baez et al. [16] investigated the effect of forest restoration on surface-saturated soil hydraulic conductivity, K_s , and its recovery to the pre-disturbance soil conditions. These authors measured K_s data under three land-cover types, i.e., pasture, restored forest and a remnant forest patch. They used a simplified method based on the Beerkan infiltration experiment [31]. They found considerable differences in soil hydraulic properties between land-cover classes. The highest K_s values were observed in remnant forest sites and the lowest K_s were associated with pasture sites.

Two other papers focus on soil erosion, investigating the specific cases of tillage [18] and piping [19] erosion. In their study, Novák and Hůla [18] used aluminum cubes as tracers to investigate tillage erosion. The results demonstrated the effect of the slope gradient on the crosswise translocation of particles during secondary tillage of soil in the slope direction. The tillage equipment translocated particles in the fall line direction even if it passed along the contour line.

Many engineering geological disasters have direct relations to bimsoils (block-in-matrix-soils), which are characterized by extreme non-homogeneity, environmental sensitivity, and looseness. Piping is considered to be the main mechanism leading to the failure of hydraulic structures in bimsoils. Piping seepage failure in bimsoils was investigated by Wang et al. [19]. The authors evaluated in the laboratory the critical hydraulic gradient on cylindrical specimens. Four different parameters: rock block percentage, soil matrix density, confining pressure and block morphology were considered.

Three studies address water flow and storage modeling [20–22]. Modeling flow processes in unsaturated soils is usually based on the numerical solutions of the Richards equation. Meshless methods are emerging tools for solving problems on complex domains. Ku et al. [21] propose a novel meshless method based on the Trefftz method for the transient modeling of subsurface flow in unsaturated soils. These authors suggest that the proposed method could be easily applied both to one-dimensional and two-dimensional subsurface flow problems.

The understanding of the temporal and spatial dynamics of soil moisture and hydraulic property is crucial to interpret several hydrological and ecological processes. A model based on topography and soil properties is proposed by Xiang et al. [22]. The model was used to describe the site-specific soil storage capacity in a sub-basin, and to simulate spatial distribution of hydrological variables of runoff, soil moisture storage and actual evapotranspiration. The proposed model yielded satisfactory predictions of daily and hourly flow discharges, and reasonable spatial variations of the considered hydrological variables.

Delta plains require special attention given their vulnerability to flooding, climatic variation and water quality deterioration. Variation in soil water content in the delta plain has its own particularity. A three-dimensional numerical model based on the Richards equation was developed by Hua et al. [20] to investigate the temporal and vertical variation of soil water content in the Yangtze River Delta (East China). The model was calibrated and validated in an experimental plot. The authors show that the variation of soil water content was mainly dependent on the groundwater table due to the significant capillary action in the delta plain.

Three studies in Sub-Saharan region are included. Declining natural resources and climate change are the major challenges to crop production and food security in Sub-Saharan African countries [32]. Silungwe et al. [25] reviewed 187 papers focused on crop upgrading strategies (UPS) for improving rainfed cereals yields in semi-arid areas. They identified four different UPS, i.e., tied ridges, microdose fertilization, varying sowing/planting dates and field scattering, as the most promising strategies to improve rainfed cereal production and reduce the risks of cereal production failure under low rainfall, high spatiotemporal variability, and poor soil fertility conditions for poor farmers.

Management of erosion in rural landscapes needs specific strategies aimed at maintaining soil cover, reducing tillage, and enhancing soil nitrogen through legumes. This set of practices is known as conservation agriculture (CA). A study concerning the adoption of specific activities of CA in Malawi was carried out by Bell et al. [17].

Röschel et al. [27] conducted a household survey of 899 farmers in a semi-arid and a sub-humid region in Tanzania. The authors examine how smallholder farmers perceived climatic and environmental changes over the past 20 years and the resulting effects on water availability and food security.

Two other papers focus on novel monitoring [23] and experimental [24] approaches for soil hydraulic characterization. With the aim of measuring and mapping the fraction of transpirable soil water, Rallo et al. [23] compared the cumulative EM38 (Geonics Ltd., Mississauga, ON, Canada) response collected by placing the sensor above ground with the corresponding soil water content obtained by integrating the values measured with a frequency domain reflectometry sensor.

Pirastru et al. [24] developed a field technique to determine spatially representative lateral saturated hydraulic conductivity, $K_{s,l}$, values of soil horizons of an experimental hillslope. Drainage experiments were performed on soil monoliths of about 0.12 m³ volume, encased in situ with polyurethane foam. The $K_{s,l}$ from the monoliths were in line with large spatial-scale $K_{s,l}$ values reported for the experimental hillslope in a prior investigation based on drain data analysis. This indicated that the large-scale hydrological effects of the macropore network were well represented in the investigated soil blocks.

The remaining two investigations in the thematic issue focus on improvement of crop yields [26] and soil salinity [28]. Trinchera and Baratella [26] investigated the use of an innovative non-ionic surfactant to fertigation water in *Lactuca sativa* (var. Iceberg) production to increase water and nutrient use efficiency. Finally, Akramkhanov et al. [28] discuss the process of testing and validation of an electromagnetic induction meter, a tool for rapid salinity assessment.

3. Conclusions

The 15 manuscripts presented in this Special Issue contribute to enhancing our understanding of conservation strategies for effective and sustainable soil and water management. Three studies use infiltration experiments in order to assess the recovery of soil hydraulic properties. Alagna et al. [29] highlight the need to adopt effective strategies to reduce soil compaction during vineyard establishment in order to maintain the soil infiltration capacity and reducing erosion potential. Di Prima et al. [15] show a certain degree of soil degradation at the burnt site with an immediate reduction of soil organic matter and a progressive increase of soil bulk density during the five years following the fire. This general impoverishment resulted in a slight but significant decrease in the field-saturated soil hydraulic conductivity. These authors also conclude that steady-state methods are more appropriate for detecting slight changes of K_f in post-fire soil hydraulic characterizations. Lozano-Baez et al. [16] suggest that soil properties and K_s recovery are affected by prior land use, and this should be taken in due account in forest management.

Two other papers focus on soil erosion. Novák and Hůla [18] show that the effect of the equipment on crosswise translocation increased with the increasing intensity of passes. Moreover, during the secondary tillage, the working tools of the equipment had an erosive effect even when the equipment moves along the contour line. Wang et al. [19] contributes to the assessment in the laboratory of the critical hydraulic gradient of bimsoils, concluding that it was mainly sensitive to the percentage of rock blocks.

Novel models are proposed by Ku et al. [21], Xiang et al. [22] and Hua et al. [20]. These contributions allow us to simulate water flow and storage in different environments.

Three studies in Sub-Saharan region are included. The conclusion drawn by Silungwe et al. [25] from the examined literature was that the most suitable models to simulate the considered UPS were the Decision Support System for Agrotechnology Transfer (DSSAT), the Agricultural Production Systems Simulator (APSIM), and the AquaCrop model. Bell et al. [17] found that farmer decisions in Malawi followed a dynamic of peer influence, with neighbors' adoption as the most effective factor. This finding might have significant implications for the overall cost of encouraging conservation agriculture as it is taken up across a landscape. Röschel et al. [27] conclude that the specific environment paired with socio-economic factors can severely increase the negative effects of water scarcity for rural farmers in Tanzania.

Two other papers focus on novel monitoring and experimental approaches for soil hydraulic characterization. The methodology proposed by Rallo et al. [23] appears usable to monitor the variations in soil water content in response to irrigation and root water uptake. Moreover, it has the practical potential to be flexible in terms of spatial and temporal sampling resolution. Pirastru et al. [24] suggest that performing drainage experiments on large-volume monoliths is a promising method for characterizing lateral conductivities over large spatial scales. This information could improve the understanding of hydrological processes and could be used to parameterize runoff-generation models at hillslope and catchment scales [33].

The remaining two investigations in the thematic issue focus on improvement of crop yields and soil salinity. Trinchera and Baratella [26] found a positive physiological response by more expanded and less thick leaves in lettuce. This finding corresponded to the lowest leaf nitrate content, indicating an improvement of the crop quality while maintaining crop production. Finally, Akramkhanov et al. [28] involved local stakeholders in Uzbekistan in a transdisciplinary and participatory approach for innovation development. From a methodological point of view, the contributions involve both field [15,16,18,23,24,29] and laboratory [19] experiments, and modeling [20–22], survey [17,27,28] and review [25] studies. The Special Issue includes studies carried out at different spatial scales, from field- to regional-scales. A wide range of geographic regions are also covered, including Brazil [16], Mediterranean basin [15,23,24,26,29], central Europe [18], China [20–22], Sub-Saharan Africa [17,25,27], and central Asia [28].

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