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21st century hydrological modeling for optimizing traditional soil and water conservation practices

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In order to increase dryland productivity, soil and water conservation practices have received renewed attention, leading to their massive implementation in marginal drylands. However, versatile tools to evaluate their efficiency under a wide range of conditions are often lacking. This study focuses on semi-arid Niger, where as a result of growing population pressure and severe soil erosion, farmers increasingly rely on degraded lands for millet production. The adverse rainfall distribution and imbalanced rainfall partitioning over the rootzone of these degraded lands calls for sustainable land management strategies that are water resource efficient. We therefore evaluated the soil-water balance of promising Nigerien Water and Soil Conservation (WSC) techniques (i.e. zaï pits, demi-lune microcatchments and scarification with standing crop residue) and their impact on millet yield by means of an in-situ field experiment on degraded laterite soil classified as Plinthosol with a 1% slope. We also applied a fully coupled 3D surface-subsurface hydrological model based on the Richards' and the Saint Venant equations to further improve promising WSC techniques.
All WSC practices received the same amount of fertilizer and were compared to two control practices, one with and one without fertilizer. Soil-water content was recorded with a neutron probe till 105 cm depth and runoff by means of a cemented gutter directing runoff water with a multi-pipe divisor into a collector drum.
WSC techniques proved to significantly reduce runoff with overall runoff coefficients being reduced from 25% (control practice) to 5-10%. Consequently, significantly more water was stored inside the catchments of the zaï pits and demi-lunes. With the scarification treatment, no considerable differences in soil-water storage were found with the control. On the other hand, WSC practices had little impact on soil evaporation, which was only 12% of rainfall by the self-mulching soil. Crop transpiration increased with WSC and highest millet yields were found with zaï pits (4 to 5 times higher than under the fertilized control). Although rainwater was better partitioned in case of demi-lune microcatchments resulting in highest amounts of water stored in the soil, yield was only 40-60% of that with zaï pits. This was due to a higher plant density within each demi-lune microcatchment in an attempt to attain similar plant densities at field scale across the treatments.
An optimized design for demi-lune microcatchments, in which the number of catchments per surface area is increased while reducing plant density per catchment, is therefore suggested. This was demonstrated using the fully coupled surface–subsurface process-based model that enabled to simulate at field scale overland and soil-water flow in 3D under various WSC designs. The model would also allow to evaluate the effect of WSC practices at catchment scale.