Geoderma 237–238 (2015) 283–297

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

Improving rainwater-use in Cabo Verde drylands by reducing runoff and erosion

I. Baptista [a,b,*], C. Ritsema [b], A. Querido [c], A.D. Ferreira [d], V. Geissen [b]

[a] Instituto Nacional de Investigação e Desenvolvimento Agrário, INIDA, CP 84 Praia, Cape Verde
[b] SLM Group Wageningen University (WUR), P.O. Box 47, 6700 AA Wageningen, The Netherlands
[c] Environment, Energy & Natural Disaster Prevention Unit, Office of United Nations, Praia, Cape Verde
[d] CERNAS, Escola Superior Agrária de Coimbra, Bencanta, P-3040-316 Coimbra, Portugal

ARTICLE INFO

Article history:
Received 3 July 2014
Received in revised form 22 August 2014
Accepted 16 September 2014
Available online 26 September 2014

Keywords:
Runoff
Erosion
Land management techniques
Rainwater-use
Dryland
Cabo Verde

ABSTRACT

Dryland agriculture in Cabo Verde copes with steep slopes, inadequate practices, irregular intense rain, recurrent droughts, high runoff rates, severe soil erosion and declining fertility, leading to the inefficient use of rainwater. Maize and beans occupy > 80% of the arable land in low-input, low-yielding subsistence farming. Three collaborative field trials were conducted in different agroecological zones to evaluate the effects of water-conservation techniques (mulching of crop residue, a soil surfactant and pigeon-pea hedges) combined with organic amendments (compost and animal or green manure) on runoff and soil loss. During the 2011 and 2012 rainy seasons, three treatments and one control (traditional practice) were applied to 44- and 24-m^2 field plots. A local maize variety and two types of beans were planted. Runoff and suspended sediments were collected and quantified after each daily erosive rainfall. Runoff occurred for rainfalls ≥ 50 mm (slope < 10%, loamy Kastanozem), ≥ 60 mm (slope ≤ 23%, silt–clay–loam Regosol) and ≥ 40 mm (slope ≤ 37%, sandy loam Cambisol). Runoff was significantly reduced only with the mulch treatment on the slope > 10% and in the treatment of surfactant with organic amendment on the slope < 10%. Soil loss reached 16.6, 5.1, 6.6 and 0.4 Mg ha^{-1} on the Regosol (≤ 23% slope) for the control, surfactant, pigeon-pea and mulch/pigeon-pea (with organic amendment) treatments, respectively; 3.2, 0.9, 1.3 and 0.1 Mg ha^{-1} on the Cambisol (≤ 37% slope) and < 0. 2 Mg ha^{-1} for all treatments and control on the Kastanozem (< 10% slope). Erosion was highly positively correlated with runoff. Mulch with pigeon-pea combined with an organic amendment significantly reduced runoff and erosion from agricultural fields on steep slopes, contributing to improved use of rainwater at the plot level. Sustainable land management techniques, such as mulching with pigeon-pea hedges and an organic amendment, should be advocated and promoted for the semiarid hillsides of Cabo Verde prone to erosion to increase rainwater-use and to prevent further soil degradation.

1. Introduction

A combination of harsh climatic conditions, human pressure on limited natural resources, nutrient depletion and geomorphologic and pedological factors has led to environmental degradation in semiarid sub-Saharan Africa (Smolikowski et al., 2001; Ryan and Spencer, 2001). Land degradation reduces water productivity at the field scale and affects water availability, quality and storage (Gao et al., 2014). The strong links between water use and land degradation and management allow the improvement of rainwater-use efficiency (RWUE) by properly managing the land through use of sustainable land management techniques and approaches (Bossio et al., 2010). RWUE is a measure of the biomass or grain yield produced per increment in precipitation (Hatfield et al., 2001). A wide range of land-management techniques is available to improve RWUE in dryland farming systems (Erenstein, 2003; Rockstrom et al., 2002, 2009; Stroosnijder, 2003, 2009; Stroosnijder et al., 2012; Turner, 2004; WOCAT, 2007).

The World Overview of Conservation Approaches and Technologies (WOCAT, 2007) defines land-management technologies or soil- and water-conservation (SWC) techniques as "agronomic, vegetative, structural and/or management measures that prevent and control land degradation and enhance productivity in the field". These solutions may include: mechanical structures (e.g. terraces, check dams, contour stone walls and contour ridges), biological structures (e.g. afforestation and strips of vegetation), manipulation of the surface soil (e.g. tillage, mulching and soil amendments such as surfactants, compost and animal and green manure), rainwater harvesting (e.g. reservoirs and retaining dams) and agronomic measures (e.g. drought-resistant species and varieties, short-cycle varieties, crop rotation, animal and green manures, appropriate fertilizer use, compost and weed control). These SWC practices improve soil quality (Araya and Stroosnijder, 2010; Tesfaye et al., 2014), decrease erosion (less runoff and nutrient

* Corresponding author at: Instituto Nacional de Investigação e Desenvolvimento Agrário, INIDA, CP 84 Praia, Cape Verde.
E-mail addresses: isaurinda.baptista@wur.nl, ibaptista@inida.gov.cv, zau.baptista@gmail.com (I. Baptista).

http://dx.doi.org/10.1016/j.geoderma.2014.09.015
0016-7061/

losses) and increase infiltration (less surface evaporation) (Xu et al., 2012; Zhao et al., 2013) and the efficient use of green water, i.e. the fraction of rainwater used for biomass production (Stroosnijder, 2003). Some of these measures succeed under certain combinations of conditions but may fail in other settings, so they require testing under specific conditions, taking into account the perception and knowledge of the farmers.

Land degradation is a major environmental issue in Cabo Verde, an island country off the western coast of Africa. The degradation has been associated with prolonged droughts and inadequate dryland agricultural practices such as the cultivation of steep slopes and bare soils (Langworthy and Finan, 1997; Mannaerts, 1993; Tavares et al., 2013). Both a lack of rain, through drought, and excess rain, through erosion and runoff, are drivers of land degradation. Paradoxically, rain in this semiarid Sahelian country is both responsible for land degradation and the limiting factor determining dryland yields.

Though dryland farming is a subsistence activity, it is very important for the livelihoods of smallholder farmers that rely on it for food production. Farmers must have a selection of integrated management options (Stroosnijder, 2003) that would provide sufficient benefits against reasonable costs and simultaneously reduce dryland degradation and maintain sustainable yields, as the application of conservation strategies depends on the farmers (Huenchuleo et al., 2012; Thapa and Yila, 2012).

Dryland farming in Cabo Verde is dominated by a continuous cultivation of maize intercropped with beans and occupies over 80% of the arable land. This farming system must cope with steep slopes, short and irregular rains, recurrent droughts, severe storms, water losses through rapid runoff and high rates of evaporation and increasing land degradation due to erosion and declining fertility, leading to an inefficient use of rainwater. To stop land degradation and desertification, successive governments since Cabo Verde's independence in 1975 have supported a long-term program of soil and resource conservation as a centerpiece of their agricultural policy (NAPA, 2007). The predominant strategies of SWC have focused on the construction of rural structures that retard sedimentation flow and increase infiltration and the widespread reforestation of marginal soils (steep slopes and semiarid rangeland). These strategies have included the implementation of a series of measures, both mechanical and biological with the most common ones in hillslopes being: a. terraces which are structures comprising leveled strips running across the slope at vertical intervals that potentially reduce erosion and sediment transport up to 50%; b. contour stone walls which are slope stabilizing structures built along a contour line, using on-site stones that slow down runoff, promote infiltration and trap sediment; c. vegetation barriers which consist in planting lines of species, such as *Aloe vera*, *Leucaena leucocephala* and *Fucraea gigantean*, particularly in places without stones, impeding the erosion processes and allowing accumulation of sediments behind the vegetation barriers; d. vegetation surface cover which consists in the use of plants such as thorn shrubs to protect sensitive areas from overland flow; and reforestation which consists in the plantation of drought-resistant species, both as SCW measure and strategy against desertification (INIDA/DESIRE, 2008; Ferreira et al., 2012; Tavares et al., 2013). The implemented strategies do not include agronomic measures or soil surface manipulation such as mulching and soil amendments that prevent and control land degradation and enhance productivity at field scale. Thus, despite the governmental efforts to reverse the processes at the watershed scale, soil erosion, low rainwater use efficiency and land degradation are still very problematic (Tavares et al., 2013), and dryland yields remain low (FAO, 2003, 2014), even in years of sufficient annual rainfall.

This study evaluates the effects of selected soil- and water-conservation techniques in Cabo Verde dryland for improving the efficiency of rainwater through the reduction of runoff and soil loss from rain-fed agricultural fields. More specifically, we test the effectiveness of residue mulching, soil surfactant and pigeon pea barriers combined with organic amendments (i.e. compost, animal manure and green manure) on surface runoff and soil loss. The selection of the techniques combined traditional and scientific knowledge in a field-based participatory approach, with the perceptions and contributions of the farmers playing a major role.

2. Materials and methods

2.1. Study site characterization and soil properties

This study was conducted in three sites (S. Jorge — site I; Serrado — site II; and Órgãos Pequenos — site III) of the Ribeira Seca watershed, which is the largest watershed in Santiago, the main agricultural island of Cabo Verde (Fig. 1). The watershed has a drainage surface of approximately 72 km^2 and extends across four agro-ecological zones of the Cabo Verde classification: semiarid (49%), arid (20%), subhumid (20%) and humid (11%) (Diniz and Matos, 1986).

The climate is characterized by a dry season of 8–9 months (November–June) and a short, humid season of 3–4 months (July–October). Rainfall is extremely heterogeneous and has an irregular spatiotemporal distribution, with annual precipitation varying from <200 mm downstream to 650 mm upstream of the watershed. The 30-year mean annual rainfall (1980–2010) was 437, 300 and 310 mm at experimental sites I, II and III, respectively, with most of the rain falling in August and September (INMG, 2010). The predominant land use is rain-fed (i.e. dryland) agriculture covering >83% of the area, comprising maize, several varieties of beans and groundnuts.

The sites were selected based on their specific characteristics of soil, agro-ecological zone (AEZ), slope and agricultural practices present. Site I is characterized by a low slope (<10%) and loamy Kastanozem on a terraced field at a research station in the subhumid to humid zone (351 m a.s.l. and mean annual rainfall of AEZ of 437 mm). Site II is characterized by a steep slope (37%), a sandy loam Cambisol and marked symptom rill erosion on a farm, in the semiarid zone (183 m a.s.l. and mean annual rainfall of AEZ of 300 mm). Site III is characterized by moderate to steep slopes (23%) and a silt–clay–loam Regosol subject to erosion by mass flow in which the soil is protected with stone and plant barriers at field edges and is located on a farm at the junction of the semiarid and subhumid zones (204 m a.s.l and mean annual rainfall of AEZ of 310 mm).

The initial physical and chemical properties of the soil varied among the three sites but were homogeneous within the sites (Table 1) in texture, bulk density, slope and total N and extractable-P contents. The soils at sites I, II and III had loam, sandy loam and silt–clay–loam textures, respectively. Organic-matter content was low at sites II and III and average at site I (INIDA, 1997). All sites were low in total N, particularly sites II and III with <10 mg N g^{-1} and the extractable-P content was average to high. Bulk density varied from 1.16 g cm^{-3} at site III to 1.42 g cm^{-3} at site I. The soil pH was neutral to slightly alkaline. The slope was gentle at site I (8%), moderate at site III (23%) and steep at site II (37%). The infiltration rate was highest at site II, followed by site I and site III, which had the lowest water infiltration.

2.2. Selection of technologies and treatments

We based our selection of treatments on a comprehensive review of the literature of land-management technologies in drylands and on one workshop for stakeholders. We prepared a list of ten techniques with the potential to increase the efficiency of rainwater within the Ribeira Seca watershed, taking into account the biophysical characteristics of the study area, the socioeconomic conditions of the farmers, the cost of the techniques and their applicability in the watershed. Most of these techniques were selected from the WOCAT database (WOCAT, 2007).

Twenty-two farmers of the Ribeira Seca watershed participated in a local workshop for stakeholders in March 2011, before the start of the field experiments. The farmers were asked to: (1) identify and group the primary constraints of dryland production, (2) discuss the list of potential technologies for addressing the primary constraints, (3) select and rank these technologies and (4) group these technologies into