Agricultural Water Management 119 (2013) 89–99

Contents lists available at SciVerse ScienceDirect

Agricultural Water Management

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

Wet years and farmers' practices may offset the benefits of residue retention on runoff and yield in cotton fields in the Sudan–Sahelian zone

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ARTICLE INFO

Article history:
Received 21 June 2012
Received in revised form 8 December 2012
Accepted 11 December 2012
Available online 17 January 2013

Keywords:
Cropping systems
Crop residues management
Runoff
Africa

ABSTRACT

Cotton (*Gossypium hirsutum* L.) is sensitive to water shortage during its establishment phase. In the Sudan–Sahelian zone, a significant part of rainfall events can be lost through runoff, particularly as the rainy season begins. Using residues from previous crops as soil cover is expected to reduce runoff and thus improve water availability to young cotton plants. To test this hypothesis, we set up a trial in Sikasso, Southern Mali, with a two-year rotation of cotton and sorghum (*Sorghum bicolor* L.). The conventional cropping system (CS) was compared with two no-tillage, mulch-based cropping systems, where cotton was grown on straw residues of a sorghum crop (DMC1) or sorghum/brachiaria *(Brachiaria ruziziensis)* intercropping (DMC2). Soils in this region are classified as ferruginous types with hydromorphic characteristics at depths below 0.7 m (Plinthic Haplustalfs). Measurements included runoff, soil water content, biomass, cotton yield, and soil surface status (i.e. covered, open with visible macropores, or closed with no visible macropores). On DMC systems, the amounts of residues from the preceding crop kept on the soil surface at the beginning of the cotton cycle ranged from 4.4 to 9.3×10^3 kg ha^{-1} of dry matter, depending on the year and preceding crop. The soil surface status was more open under DMC1 and DMC2 (38 and 62%, respectively) than under CS (30%). Crop residues reduced runoff at the beginning of the rainy season in both years (−26 and −56 mm between CS and DMC2 in 2006 and 2007, respectively) and increased soil water availability for cotton (+26 mm and +50 mm, respectively). This gain in soil water did not result in higher cotton yields, probably because 2006 and 2007 rainfall amounts were unusually high, with a low gap between water supply and cotton requirements. Row ridges made perpendicular to the slope and after sowing in CS, created an effective obstacle to runoff and increased soil water content. The effects of crop residues on rainwater infiltration accumulated over the entire growing season were minimal. In conclusion, during wetter periods, the potential benefit of DMC systems on water balance and cotton yield in these types of soil may be low when compared with conventional systems if ridging done perpendicular to the slope is added.

1. Introduction

The Malian cotton zone is located in the Sudan–Sahelian area between isohyets 800 and 1200 mm. Cotton (*Gossypium hirsutum* L.) is grown in rotation with food crops and is usually not irrigated. Under these conditions the crop water requirement for the whole cotton cycle were estimated at 600 mm (Albergel et al., 1985). Uneven repartition of rainfall during the growing season and variations between years increase the threshold in mean annual rainfall above which cotton can be grown. Thus, cotton area is decreasing in the northern part of this zone, where annual rainfall is below 900 mm, presumably due to yield limitation by drought.

The sensitivity of cotton to water stress varies across developmental stages. Cotton germination and emergence are slow, in comparison with other annual crops, making the period from sowing to emergence one of the most sensitive periods in cotton development (Bozbek et al., 2006; Wang et al., 2007). Poor soil moisture conditions at sowing induce poor emergence and consequently low stand densities. The subsequent stages of cotton plant development, until flowering, are less sensitive to water deficit. Lacape et al. (1998) showed that the major consequence of water deficit on cotton yield is premature growth cessation, inducing a reduction of the number of fruit-bearing nodes as well as the incapacity of the cotton plant to maintain sufficient carbon assimilation during the bolls formation phase.

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http://dx.doi.org/10.1016/j.agwat.2012.12.012

Runoff in the Malian cotton zone can reach up to 30% of the total annual rainfall in some parts of the region (Gigou et al., 2006). Runoff values up to 50% have even been measured in plowed fields (Diallo et al., 2004). At the end of the dry season, while fields are bare, not ridged, and before crop installation, intense rainfalls are often recorded. Casenave and Valentin (1989) estimated that rainfall intensity during this period can frequently reach 60–70 mm h^{-1} when measured over 30 min periods. To improve rainwater infiltration, the Textiles Development Company of Mali (CMDT) proposed three crop establishment strategies aimed to reduce runoff:

(i) Plowing along contour lines—expected to reduce runoff by approximately 10% of total annual rainfall (Gigou et al., 2006);
(ii) Anti-erosive bands—expected to reduce the superficial flows of water and sediments out of the cultivated field; and,
(iii) Stony cords—expected to reduce runoff by 5% with a distance between stony cords of 50 m, 12% with a distance of 33 m, and 23% with a distance of 25 m, compared with an unaltered field (Zougmoré et al., 2004).

In addition to these field management proposals, several cropping techniques (plowing, weeding and ridging) have a well-established reputation among farmers, to temporarily improve the crops water status.

Sowing through mulch could represent a way to further improve cotton yield by way of increased water availability. Indeed, several studies have demonstrated that straw mulches strongly reduce runoff (Adekalu et al., 2007; Dahiya et al., 2007; Scopel et al., 2004, 2005) and soil evaporation (Bristow et al., 1986; Parker et al., 1992) when compared to bare soil. This may or may not induce higher soil water availability for crops, depending on the particular way mulching is combined with other components of the cropping system, and on the characteristics of soil and climate. For example, Scopel et al. (2004) compared the effects of mulch introduced in mechanized maize systems in two locations of Latin America: mulch induced similar reductions of runoff and evaporation in both locations. However, it induced an increase in transpiration and yields only in one location. In the other locations most of the water saved from runoff and evaporation was added to drainage below the root zone and not transpired by the plants.

Sowing on mulch or standing residues of the preceding crops has also been studied in cotton, mainly in the US where this practice is widespread. Mulch-based cropping system usually produce higher cotton lint yields, although it is sometimes necessary to wait after 4–6 years of continuous no-till to observe these positive effects (Brown et al., 1985). A significant part of the yield increase with mulching is attributed to reduced soil evaporation (Lascano et al., 1994) and increased rainfall infiltration into the soil, although this last factor has not been frequently measured on cotton cropping systems. Some experiments have even shown no effect of mulch on water infiltration (Baumhardt et al., 1993). It is frequently observed that the effects of no-till, mulch based cropping systems are mostly positive in rainfed conditions, dry years (Bauer et al., 2010) or water constrained cotton producing regions (Naudin et al., 2010).

The objective of the present study was to analyze, in a two years experiment, the impacts of soil and residue management on runoff, water balance and yield of a cotton crop in cropping systems conditions representative of farmers' fields in West Africa.

2. Materials and methods

2.1. Design of the experiment

The experiment was conducted in 2006 and 2007 at the Finkolo Agronomic Research Station located in the Sudan–Sahelian zone in southeast Mali (11°16.4′N, 5°30.8′W).

2.1.1. Climate and soil

The average annual rainfall over a 16-year period (1992–2007) was 1042 mm with a standard deviation of 220 mm. Rainfalls recorded during the two years of experiment (1230 mm in 2006 and 1323 mm in 2007) were unusually abundant, belonging to the higher quartile of the distribution.

The soil of the experimental site was of tropical ferruginous type with visible signs of hydromorphy below 0.7 m depth (Plinthic Haplustalfs, Doumbia et al., 1993). Field slope, measured with a theodolite, was 1.2%. Soil texture was sandy-silt in the upper layer (Table 1). The percentage of clay increased with depth, while the percentage of sand decreased and the percentage of silt remained stable at approximately 25% throughout the profile. Mean soil pH and organic matter content in the upper soil layer were 5.4 (±0.3) and 7.8 g kg^{-1} (±0.3), respectively, both values acceptable for growing cotton in Africa (Pieri, 1989).

2.1.2. Cropping systems

In order to study the effects of crop residue under conditions of actual cropping systems in the region, cotton was placed in a two-year rotation, one year with a cotton crop and the following year with sorghum (*Sorghum bicolor* L.). A conventional cropping system (CS) was compared with two no-tillage, mulch-based cropping systems, where cotton was grown on straw residues of a sorghum crop (DMC1) or sorghum/brachiaria (*Brachiaria ruziziensis*) intercropping (DMC2).

Table 1
Soil characteristics in the experimental fields (mean values and standard errors around the mean when replicates where taken).

Depth (cm)	Clay (g kg^{-1})	Silt (g kg^{-1})	Sand (g kg^{-1})	pH water	Organic matter (g kg^{-1})
Field A					
0–20	96 ± 31	236 ± 41	688 ± 79	5.5 ± 0.1	8.0 ± 0.9
20–40	128 ± 14	229 ± 46	642 ± 58	5.2 ± 0.2	6.0 ± 0.8
40–70	172 ± 10	247 ± 43	580 ± 51	5.2 ± 0.2	4.7 ± 0.5
70–100	236 ± 61	251 ± 74	513 ± 110	5.2 ± 0.1	4.0 ± 0.3
100–130	335	300	365	5.2	4.4
130–160	402	299	298	5.3	4.0
160–190	406	332	262	5.1	4.2
Field B					
0–20	151 ± 25	218 ± 19	631 ± 10	5.2 ± 0.5	7.5 ± 0.7
20–40	210 ± 83	198 ± 19	592 ± 67	5.4 ± 0.7	6.4 ± 0.8
40–70	311 ± 74	197 ± 25	492 ± 98	5.2 ± 0.1	5.3 ± 0.3
70–100	398 ± 44	222 ± 27	380 ± 70	5.2 ± 0.2	4.4 ± 0.2
100–130	443	231	326	5.4	4.2
130–160	400	228	373	5.1	2.7
160–190	412	250	339	5.1	2.1