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Exploiting rainy season potential from the onset of rains in the Sahelian zone of West Africa

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ABSTRACT

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Field studies were conducted at the ICRISAT Sahelian Center, Niamey, Niger, during 1986 and 1987 to test the methodology described earlier by Sivakumar (1988) that the potential of the rainy season in the Sahelian zone of West Africa can be determined from the date of onset of rains. We tested an early onset of rains treatment (imposed with supplemental irrigations) with the natural onset of rains. In 1986, natural onset was early while in 1987 it was considerably late. In both the seasons, dry matter production of millet (*Pennisetum glaucum* (L.) R. Br.) in the early onset of rains treatment reached 7 t ha^{-1} while late onset of rains resulted in only 3 t ha^{-1}. Data on soil water profiles showed that at the time of the millet harvest in the early rains treatment, profile soil water is adequate to establish a second crop of cowpea (*Vigna unguiculata* (L.) Walp.) for hay. This enables efficient exploitation of soil moisture. In addition, the combined water use of the two crops in the early rains treatment was much higher. Results of this study suggest that by tailoring management tactics to weather conditions, in years with early onset of rains it is possible to establish a second crop of cowpea for hay in the Sahelian zone where the farmers traditionally grow only millet. The implications of the suggested methodology for other climatic zones in West Africa and its limitations are discussed.

INTRODUCTION

The declining per capita food production in the Sahelian zone of West Africa over the past two decades has been a subject of major concern. Many reports concerning components or whole packages of technology to increase food production have addressed this problem (Ohm and Nagy, 1985; Mokwunye and Vlek, 1986; ICRISAT, 1989). Yield increases still depend on the subtle interaction between soil, water, seeds and sunlight. However the process is not as well understood under rainfed conditions as it is with irrigated land (World Bank, 1982). Even under rainfed conditions, years with a more favourable rainfall distribution do occur and it is necessary to strive for prod-

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uct-maximizing strategies in such years. Hence early identification of the "potential" for a given year is a very important step in designing appropriate strategies for increased food production in the Sahelian region of West Africa. Such a task is complicated by the unpredictable rainfall patterns in West Africa (Cocheme and Franquin, 1967; Nicholson, 1982; Sivakumar, 1989).

However, recent analyses of the daily rainfall data for 58 locations in Niger and Burkina Faso suggest that prediction of the rainy season potential may be possible (Sivakumar, 1988). The analysis consists of three parameters computed from the daily rainfall data: the date of onset and of ending of rains, and the length of the growing season for each year. A discussion of the definition of each of these terms was presented by Sivakumar (1988). All the three parameters followed the normal distribution. Probabilities of growing season lengths for variable onset of rains were computed from these data.

Average date of onset of rains in the Sahelian zone is much more variable than the date of ending of rains. At Niamey, Niger, standard deviation (SD) for the average date of onset of rains (12 June) is 18 days while the SD for the average date of ending of rains (27 September) is 12 days. Therefore at Niamey, an early onset of rains offers the probability of a longer growing season while delayed onset results in a considerably shorter growing season. For example, when the onset of rains at Niamey occurs 20 days earlier than the average, there is a 71% probability that the growing season will exceed 120 days. On the other hand, if the rains are delayed until the beginning of July, there is only a 15% probability that the growing season will exceed 100 days.

The above analysis suggests that agricultural planning in the Sahelian region should be formulated from alternatives that can be offered to the farmer, based on the agrometeorological relationship between the date of onset of rains and the length of the growing season. The objective of this study was to test whether crop management tactics could be based on the date of onset of rains in the Sahelian zone.

MATERIALS AND METHODS

Average growing season length at Niamey is 107 days whereas the locally recommended improved cultivar of millet (cv. CIVT) matures in 90–95 days. From the analyses described earlier, two hypotheses were used for the field test.

(1) Early onset: If the rains start early, i.e. 15–20 days before the average date of onset, the growing season length could exceed 120 days and could even be 140 days. This would then provide an opportunity to establish a second crop of cowpea for hay in order to exploit the long growing season. This cropping system of millet–cowpea could be considered appropriate if it does not significantly reduce the stored water in the soil profile at the time of cowpea harvest relative to the sole millet situation.

(2) Late onset: If the rains are delayed until 15–20 days after the average date of onset, the growing season may be too short for even cv. CIVT to attain physiological maturity. This assumes that the rains end around the average date of ending of rains at Niamey.

Field tests were conducted on a sandy soil at the ICRISAT Sahelian Center located at Sadore (13° 06′ N, 2° 21′ E), 40 km south of Niamey, Niger during the rainy seasons of 1986 and 1987. Rainfall patterns during the two seasons are shown in Fig. 1. The first hypothesis was tested in 1986 when an early onset of rains occurred by day of year (DOY) 143 in comparison with the average of DOY 163. The second hypothesis was tested during the 1987 rainy season when the onset of rains was very late and sowing rains did not arrive until 15 July (DOY 196), a delay of 33 days compared with the average date of onset. In 1987, the early onset of rains treatment was imposed using supplementary irrigations. Experimental treatments during the 2 years are given in Table 1. A sole millet treatment was included in the 1986 rainy season as a control to determine whether profile soil water contents in this system differ significantly from those in the millet–cowpea system.

The experimental design was a randomized block with four replications. Individual plots were 30×30 m which allowed sufficient border between the irrigated and rainfed plots.

For the simulation of the early onset of rains, long-term rainfall data avail-

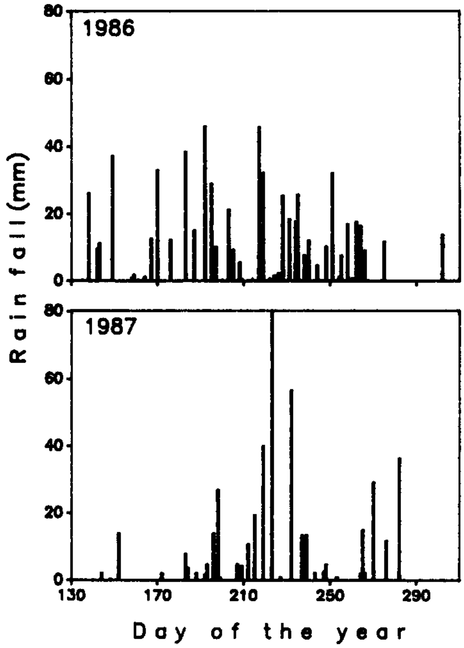

Fig. 1. Rainfall patterns during the 1986 and 1987 rainy seasons at ISC, Niger.

TABLE 1

Experimental treatments imposed for the field tests

Year	Treatment	Description	Crop(s)
1986	Early rains (irrigated)	Supplemental irrigations to follow average rainfall distribution each week	Millet–cowpea
	Early rains (rainfed)	Actual rainfall distribution each week	Millet–cowpea Millet–fallow
1987	Early rains (irrigated)	Supplemental irrigations to follow average rainfall distribution each week	Millet–cowpea
	Late rains	Actual rainfall distribution each week	Millet

able for Niamey (from 1905 to 1985) were used to compute the average rainfall for each calendar week. If the actual rainfall for a given week in 1986 and 1987 fell below the computed average, a supplemental irrigation was given at the end of the week to compensate for the deficit. On the other hand, if the difference between the actual and average rainfall indicated a surplus, that amount was carried forward into the calculations for the next week. Rainfall during 1986 was received at frequent intervals (Fig. 1) and only two supplemental irrigations of 10.2 and 20.8 mm were given on 6 and 16 June respectively. During the 1987 rainy season, rainfall frequency in the beginning was irregular (Fig. 1) and several supplemental irrigations were given until the end of July (Table 2). The irrigations were given using a sprinkler system and the amount of irrigation was monitored at several places in each plot using Diem type raingages (Wilh-Lambrecht Gmbh, Gottingen, West Germany) to ensure that the average depth of applied water corresponded to the calculated supplemental irrigation amount.

During the 1986 rainy season, millet (cv. CIVT) was sown with the early rains on 23 May in pockets spaced at 80 cm on ridges formed 75 cm apart. The pockets were thinned to two plants to give a final plant population of 33 333 plants ha^{-1}. Actual rainfall during the season fell below the average for only 2 weeks (31 May–6 June and 7–13 June). Two supplemental irrigations were given in the early rains (irrigated) treatment 1 on 6 and 14 June. Millet was harvested on 3 September. An early maturing, erect cowpea cv. IT84E1-108 (maturity duration 52 days) was sown on 8 September. Cowpea in early rains (irrigated) treatment received only one supplemental irrigation of 40 mm on 12 October. To conserve the soil water during the early stages of cowpea growth, millet stalks were spread between the ridges as a mulch. Cowpea was harvested on 12 November.

During the 1987 rainy season, onset of rains was considerably delayed (Fig. 1) and did not occur until 15 July. Early rains treatment was simulated by

TABLE 2

Scheme for supplemental irrigations for simulating an average rainy season with early onset of rains during the 1987 rainy season, ISC, Niger

Week No.	Dates	Average rainfall (mm)	Actual rainfall (mm)	Deficit/surplus (mm)	Irrigation (mm)
1	2– 8 May	5.1	0.0	−5.1	–
2	9–15 May	12.5	0.0	−17.6	18.0
3	16–22 May	10.4	0.0	−10.4	11.0
4	23–29 May	13.2	2.4	−10.8	11.0
5	30 May– 5 Jun	16.9	13.9	−3.0	3.0
6	6–12 Jun	20.0	0.0	−20.0	20.0
7	13–19 Jun	17.9	0.0	−17.9	18.0
8	20–26 Jun	24.0	2.0	−22.0	22.0
9	27 Jun– 3 Jul	21.1	11.6	−9.5	10.0
10	4–10 Jul	30.0	2.1	−27.9	28.0
11	11–17 Jul	40.7	48.3	7.6	–
12	18–24 Jul	37.7	0.8	−36.9	30.0
13	25–31 Jul	42.0	19.6	−22.4	23.0
14	1– 7 Aug	44.7	59.3	14.6	–
15	8–14 Aug	44.5	79.5	49.6	–
16	15–21 Aug	34.9	57.5	72.2	–
17	22–28 Aug	38.7	26.7	60.2	–
18	29 Aug– 4 Sep	29.0	4.6	35.8	–
19	5–11 Sep	23.0	5.6	18.4	–
20	12–18 Sep	16.3	0.0	2.1	–
21	19–25 Sep	13.7	19.0	7.4	–
22	26 Sep– 2 Oct	8.8	29.2	27.8	–
23	3– 9 Oct	3.8	48.0	72.0	–
24	10–16 Oct	3.0	0.0	69.0	–
25	17–23 Oct	1.2	0.0	67.8	–

giving supplemental irrigations from 15 May onwards until the end of July after which actual rainfall was consistently above the computed average. With the first supplemental irrigation of 18 mm on 16 May, the field was cultivated and ridged and millet cv. CIVT was sown on 22 May; millet was harvested on 28 August. Cowpea (cv. IT84E1-108) was sown 2 weeks before millet harvest as a relay crop and harvested on 23 October. In the late rains treatment, millet was sown on 15 July and harvested on 23 October.

In both seasons, a basal application of 45 kg ha^{-1} of P_2O_5, as single superphosphate, was made at land preparation before the millet sowings. Calcium ammonium nitrate was applied to millet only at 21 and 45 days after planting to supply a total of 45 kg ha^{-1} of nitrogen. This schedule of fertilizer application was recommended for the millet and cowpea crops for the sandy soils of the Sahelian region (Fussell et al., 1987).

Soil moisture measurements were made in all the plots with a Troxler* neu-

*(Mention of a proprietary product does not imply endorsement or preference by ICRISAT over another product of similar nature.)

tron probe (Troxler Electronic Laboratories Inc., Research Triangle Park, NC 27709) at 7–10 day intervals throughout the growing season from 30 to 210 cm soil depth at 15-cm intervals. Soil water in the top 30 cm was measured gravimetrically. Soil water contents are presented as average values over the four replications. Total water use was computed with a water balance equation (Jensen, 1973). Water use efficiency (WUE) was computed as

$$\mathrm{WUE} = \frac{\text{Total dry matter or grain yield (kg ha}^{-1}\text{)}}{\text{Total water use (mm)}}$$

Growth measurements in the millet crop were made by sampling whole plants at 7–10-day intervals in a 3-m^2 area in each replicate while ensuring that enough guard area is left around the sampling area. Growth measurements in cowpea were made only during the 1987 rainy season at 7–10 day intervals by harvesting whole plants in a 1-m^2 area in each plot. Plants were separated into individual components i.e. leaves, stems, and heads. Leaf area was measured with a leaf area meter (LI-COR Ltd., Lincoln, NB). Plant components were dried to constant weight at 65°C and then weighed. Final yields were obtained from an area of 25 m^2.

RESULTS AND DISCUSSION

Crop growth and yield

Dry matter distribution in millet in different plant components during the 1986 rainy season is shown in Fig. 2. Total dry matter produced by millet in that year was 7 t ha^{-1} for both irrigated and rainfed treatments. In the early rains (rainfed) treatment, millet growth pattern early in the season was slow due to infrequent rains (Fig. 1) in contrast with the irrigated treatment.

During the 1987 rainy season, dry matter distribution in different plant

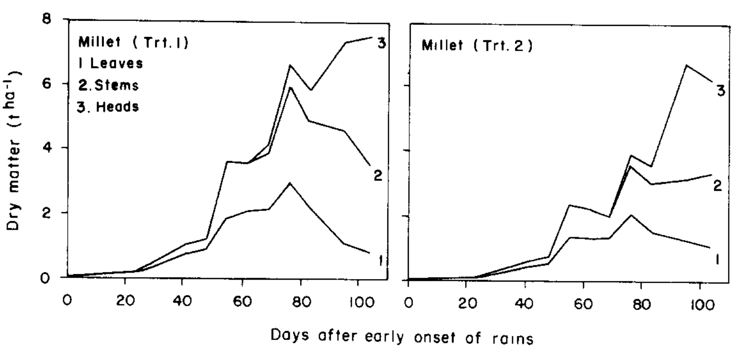

Fig. 2. Dry matter distribution in different plant components of millet in Treatments 1 and 2 during the 1986 rainy season, ISC, Niger.

components for the early and late onset treatments (Fig. 3) presented a distinct contrast. With the early onset, the growing season stretched over 140 days as opposed to 100 days for the late onset. Pearl millet dry matter production in the early onset treatment was 7 t ha^{-1} (as in 1986) but only 3 t ha^{-1} for the late onset treatment. The relay crop of cowpea produced 2 t ha^{-1}.

Leaf area index data (Fig. 4) showed that the millet–cowpea relay crop provided a good ground cover which could have contributed to smaller evaporative losses from the soil and a better light use efficiency. In the late onset of rains treatment, millet achieved a leaf area index of only 1.3.

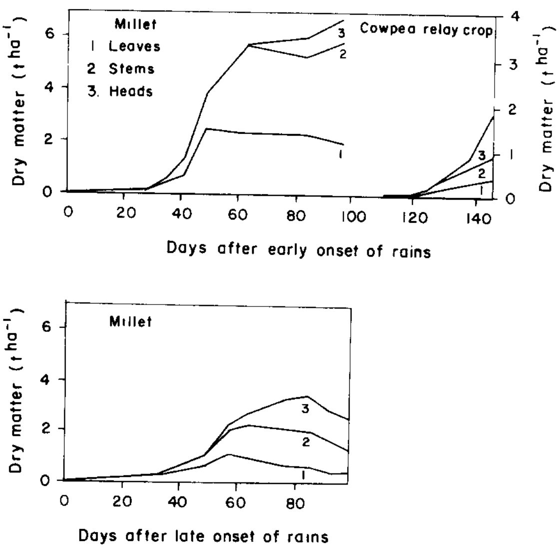

Fig. 3. Dry matter distribution in different plant components of millet and relay crop of cowpea in the early and late onset of rains treatments during the 1987 rainy season, ISC, Niger.

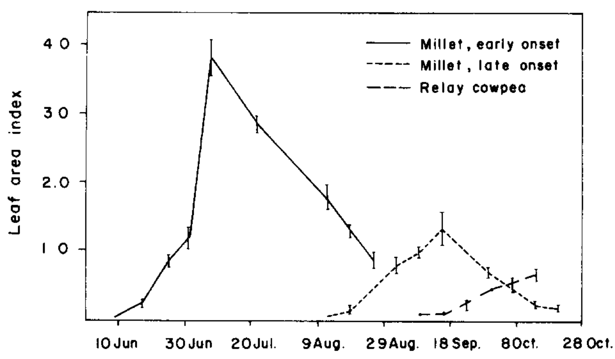

Fig. 4. Leaf area index of millet and relay crop of cowpea in the early and late onset of rains treatments during the 1987 rainy season, ISC, Niger.

Yield data for the two growing seasons are shown in Table 3. In the early rains treatments (irrigated or rainfed), the second crop of cowpea made effective use of the residual soil water. Sequential cowpea in 1986 did not produce much grain because the stored soil water was not adequate during the seed filling stage. The switch from a millet–cowpea sequential crop to a relay crop system of millet/cowpea for the early rains treatment in 1987 proved to be a better strategy since it gave pod yield in addition to hay. Although the dry matter production of millet in the early rains treatment was higher in 1987 than in 1986, grain yields in 1987 were lower because most of the filled heads were damaged by birds and insects.

Soil water profiles

During 1986, rainfall occurred at regular intervals during the season and the growth of millet was excellent. Millet was harvested on 3 September and stored soil water in the 210 cm soil water profile was 190 mm in the irrigated treatment and 183 mm in the rainfed early rains treatment. Volumetric water contents at different soil depths at the time of millet harvest (Fig. 5) showed adequate water throughout the soil profile and there were no significant differences between the two treatments. Residual soil water at the time of cowpea harvest (12 November) was slightly higher, but not significant, in the sole millet treatment (114 mm) in comparison with the two sequential cow-

TABLE 3

Grain and hay yields (kg ha^{-1}), water use (mm) and water use efficiency (WUE) (kg ha^{-1} mm^{-1}) of cropping systems during the 1986 and 1987 rainy seasons

Treatment	Millet					Cowpea				
	Grain	Straw	Water use	WUE		Seed	Hay	Water use	WUE	
				Grain	Straw				Seed	Hay
1986 rainy season										
Early rains (irrigated)	1730	4100	398	4.4	10.3	50	680	237	0.2	2.9
Early rains (rainfed)	1210	3650	374	3.2	9.8	–	420	223	–	1.9
SE (±)	100	410	7	0.31	1.2	–	10	4		0.05
CV (%)	10	15	3	12	17	50	3	3		3
1987 rainy season										
Early rains (irrigated)	1050	5370	398	2.7	13.7	480	380	187	2.6	2.0
Late rains	810	3780	316	2.6	12.1	–	–	–	–	–
SE (±)	90	420	16	0.29	1.69	68	67	5	0.33	0.32
CV (%)	19	18	9	22	26	29	35	6	26	30

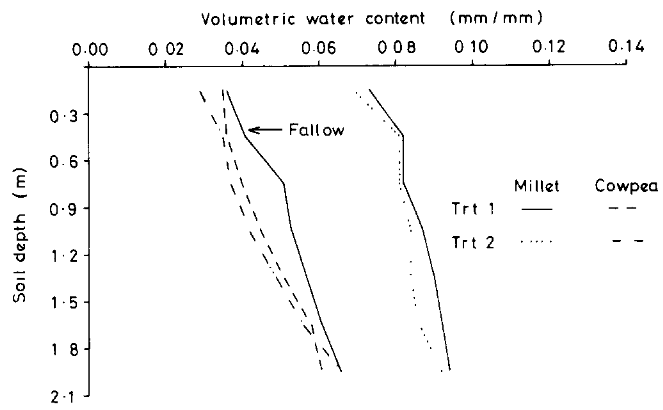

Fig. 5. Soil water profiles at the time of millet and sequential cowpea harvests and in the millet–fallow during the 1986 rainy season, ISC, Niger.

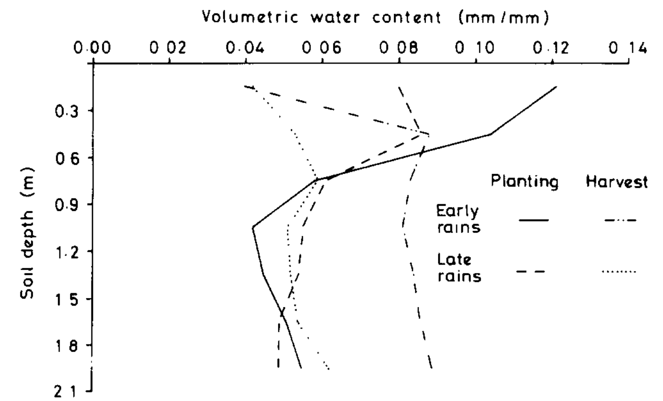

Fig. 6. Soil water profiles at the time of planting and harvesting of millet in the early and late onset of rains treatments during the 1987 rainy season, ISC, Niger.

pea treatments (103 mm in irrigated treatment and 99 mm in the rainfed treatment).

In 1987, stored soil water in the early and late rains treatments at the time of millet planting differed in the upper 60 cm because of the two supplemental irrigations applied in the early rains treatment (Fig. 6). Soil water content at the time of millet harvest in the early rains treatment showed that below 45 cm soil depth, water content was much higher than at millet sowing (Fig. 6). This is an important factor for the subsequent growth of the relay-cropped cowpea which was established by that time. Stored soil water in the profile at the time of millet harvest in the late onset treatment (Fig. 6) was lower (119 mm) than at the time of harvest of relay-cropped cowpea (141 mm).

Water use and water use efficiency of millet and cowpea under conditions of early and late onset of rains

The advantage of the millet–cowpea system under the early rains treatment is reflected in the water use and the water use efficiency values (Table 3). In 1986 the two crops together used 597 mm as opposed to 374 mm for the sole crop of millet. During 1987, the total amount of water received by the early rains treatment of 624 mm was 64 mm above the long-term average rainfall of 560 mm, but still below the 655 mm of rainfall received during 1986. Total water use from the millet and cowpea during 1987 was 585 mm, in contrast to 398 mm of water used by the sole millet. Recent evidence from the ICRISAT Sahelian Center suggests that soil evaporation rates on a fallow soil could be large, especially after a rain (Wallace et al., 1988). In view of the poor water holding capacity of the sandy soils at Sadore, establishing a second crop of cowpea for hay after the first crop of millet could result in an efficient use of the September rains, a large part of which would otherwise have evaporated from the fallow soil.

IMPLICATIONS OF THE PROPOSED CROPPING STRATEGY

Results of the preliminary study reported here suggest that the potential of the rainy season in years with early onset of rains in the Sahelian zone can be exploited by establishing a second crop of cowpea for hay after the millet. Comparison of stored soil water at the time of cowpea harvest with that in the fallow plots after millet, revealed no significant difference. The second crop of cowpea effectively uses September rains and provides valuable hay (and possibly grain if rains continue into October) to the farmer.

Sahelian farmers over the years have evolved a mechanism for exploiting good years by intercropping long season millet with cowpea. The strategy of millet–cowpea relay crop suggested here should be viewed as a complementary system to this traditional practice. Studies in the Sahel reported yields of millet in the intercropping system to be less than the sole millet yields since they were affected by factors such as planting density, plant population, planting dates, and spatial arrangement of both the component crops (Fussell and Serafini, 1985; Ntare et al., 1989). Hence, where the farmers' aim is to harvest a full crop of millet and any additional cowpea hay, the millet–cowpea relay crop may offer some possibilities.

In the millet–cowpea system, one could attempt to establish a sole crop density of cowpea for the purpose of increased hay yield. The success of the second crop would depend upon the intra-seasonal rainfall distribution and the timely establishment of cowpea well before the end of August to take full advantage of September rains. Analysis of the relationship between onset of rains and rainfall amounts showed that, in general, early onset is associated with higher rainfall amounts. If the intra-seasonal rainfall distribution is not favourable, despite the early onset of rains, one need not plant cowpea. Hence the decision to plant cowpea could be made by mid-August depending on the rainfall distribution and soil moisture conditions at that point. This process is the central theme of Weather-responsive Crop Management tactics described by Sivakumar (1988).

It is also necessary to examine some of the constraints posed by the millet–cowpea relay crop. Planting cowpea between rows of full-grown millet and spreading the millet stalks between cowpea rows after millet harvest is labour intensive and may present a bottleneck. Despite the advantages such as water conservation, improved organic matter, etc., offered by the millet mulch in the cowpea crop, the alternative use of millet stalks for livestock feed and construction is a real concern in the Sahelian region. However with the increased stover production (of around 7 t ha^{-1} as obtained in the present study) under conditions of early onset of rains, this may not pose a big problem.

The relay crop is a possibility only when the farmers adopt the improved short duration millet cultivars that mature in 90 days as opposed to the traditional cultivars that mature in 110–120 days. Short duration millet cultivars may be prone to insect attack and bird damage. However, a relay crop of cowpea faces fewer problems with diseases and pests because of clear skies, reduced relative humidity and fewer insects in September.

For reasons discussed above, the field test reported here should be viewed as an exploratory study. The potential of the system suggested here needs more intensive studies by agronomists, soil scientists and economists. The potential of the growing season with early onset of rains is much higher in the Sudanian climatic zone than in the Sahelian zone (Sivakumar, 1988) and the relay cropping system of millet–cowpea could be attempted for both grain and hay of cowpea in the Sudanian zone.

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