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1 **Reducing soil erosion in smallholder farming systems in east Africa**
2 **through the introduction of different crop types**

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29 **Abstract**

30 On low-input smallholder farms of Kenyan upland landscapes, erosion of nutrient rich topsoil
31 strongly affects crop yields. Where maize (*Zea mays*) is intercropped on erosion-prone slopes,
32 intercropping can potentially reduce soil erosion. The objective of this research was to quantify
33 the contribution of crops and crop mixtures of different growth habits to erosion control and their
34 influence on above ground biomass and earthworm abundance as indicators of soil function in
35 smallholder farming systems under a bimodal rainfall pattern in Western Kenya. The experiment
36 involved five treatments, namely maize (*Zea mays*)/common bean (*Phaseolus vulgaris*) intercrop
37 (maize intercrop), maize/common bean intercrop plus Calliandra (*Calliandra calothyrsus*)
38 hedgerows and Calliandra mulch (Calliandra), sole Lablab (*Lablab purpureus*), sole Mucuna
39 (*Mucuna pruriens*) and groundnut (*Arachis hypogaea*) intercropped with maize (during the short
40 rains). The experiment was conducted over three consecutive cropping seasons and the cropping
41 system had significant effects on soil loss, runoff, water infiltration, earthworm abundance and
42 above ground biomass and crop grain yield. The Calliandra treatment had the lowest runoff (11.6
43 – 17.2 mm ha⁻¹) and soil erosion (31– 446 kg ha⁻¹, per season) in all the seasons, followed by the
44 Mucuna treatment. Lablab was affected by disease and showed the highest soil erosion in the last
45 two seasons. Infiltration was highest in Calliandra treatment, and earthworm abundance was
46 higher under Mucuna and Calliandra treatments (229 and 165 earthworms m⁻², respectively) than
47 under other crops. Our results suggest that including sole crops of herbaceous species such as
48 Mucuna, or tree hedgerows with mixtures of maize and grain legumes has the potential to reduce

49 runoff and soil erosion in smallholder farming. Additionally, these species provide a suitable
50 habitat for earthworms which stabilize soil structure and macropores and thus potentially
51 increase infiltration, further reducing soil erosion.

52

53 **Key words:** Calliandra, infiltration, intercropping, legumes, Mucuna, runoff

54

55 **1. Introduction**

56 Land degradation is a major problem in sub-Saharan Africa (SSA) leading to low agricultural
57 productivity and a need for increased inputs and ultimately leading to land abandonment and loss
58 of land for food production (FAO, 2010). It has been estimated that approximately 30 % of land
59 in SSA is degraded due to erosion, nutrient mining, overgrazing and deforestation (Bindraban et
60 al. 2012). Apart from being a threat to food security and human nutrition, surface runoff and soil
61 erosion are major environmental concerns (Fenta et al., 2017). Estimates of crop yield loss
62 caused by erosion in SSA vary but may be substantial on severely eroded soils. For example,
63 maize (*Zea mays*) yield reductions related to erosion have been estimated at up to 59 and 66 % in
64 Tanzania and Kenya, respectively (Okoba and Sterk, 2010). Yield losses result not only from
65 loss of soil organic matter and nutrients but also reductions in moisture availability and rooting
66 depth. The rate of erosion from conventionally ploughed land has been estimated to be 1 to 2
67 orders of magnitude greater than both rates of erosion under native vegetation and rates of soil
68 formation (Montgomery, 2007) suggesting an urgent need to look for alternative practices that
69 reduce erosion rates. Rates of soil erosion depend on the interaction of several variables

70 (Verheijen et al., 2009), such as erosivity or energy of the eroding agent (wind and water),
71 ground cover and management, slope characteristics and soil properties (erodibility). Control
72 methods for water-induced erosion therefore aim to manipulate both ground cover and soil
73 structure to reduce surface-water flow rates and increase infiltration rates. Methods include
74 covering the soil as much as possible, minimum tillage, contour ploughing, use of grass strips
75 planted on contours, inclusion of shrubs/trees (agroforestry) and use of cover crops (Salako et al.,
76 2006).

77 In much of east Africa, effective erosion control practices have been poorly implemented (Okoba
78 and Sterk, 2010). Two reasons for poor implementation of erosion control measures in Kenya are
79 lack of evidence of their technical efficiency and social acceptability in different areas (Sigunga
80 and Wandahwa, 2015). Another suggested reason for low uptake of erosion control measures is
81 high initial costs relative to economically beneficial yield gains in the short term (Nyangena and
82 Köhlin 2008). One method of erosion control, which does not require large investments, is
83 increasing crop diversity potentially through utilizing species mixtures within a single growing
84 season and in increasing diversity within crop rotations. Legume species (herbaceous, grain and
85 tree legumes) are among candidates for increasing crop diversity due to their high nutritional
86 value as food and fodder and their ability to biologically fix nitrogen. Herbaceous legumes are
87 plants with non-woody stems above ground (Mongkhonsin et al., 2019) and in this paper we
88 refer to them as crops mainly used as cover crops and/or fodder crops. Farmers in east Africa
89 generally practice intercropping e.g. maize (*Zea mays*) and common bean (*Phaseolus vulgaris*),
90 which increases soil cover and improves resource use efficiency compared to sole cropped maize
91 (Himmelstein et al. 2017). Herbaceous and tree legumes may also be incorporated into cropping
92 systems to reduce soil erosion while also providing other products and services. They have the

93 potential to contribute to soil erosion control because they have fast growth rates, high biomass
94 production and some of them are drought tolerant (Kaspar et al., 2011). Rapid growth rates
95 provide groundcover that helps reduce the impact of raindrops and direct sunlight hence
96 improving soil and water conservation (Kaspar et al., 2011). High biomass productivity also
97 increases soil organic matter content which improves soil structure as well as earthworm density,
98 which contributes to water infiltration and holding capacity (Jordán et al., 2010). Additionally,
99 legumes provide a series of other functions potentially useful to smallholder farmers including
100 provision of food, livestock feed, income and soil fertility improvement through biological
101 nitrogen fixation (BNF) and addition of organic matter. Tree legumes also have other purposes
102 within smallholder farms including providing a source of fuel or construction material.
103 Different legume types can be incorporated into smallholder farming systems through
104 intercropping, in crop rotations, and planted on farm boundaries and as hedgerows. Livestock is
105 important in east Africa and contributes 20–30 % of national gross domestic product, hence they
106 play a significant a role in farming livelihoods (EAFF, 2012). The use of herbaceous legume
107 species such as Mucuna (*Mucuna pruriens*) and Lablab (*Lablab purpureus*) and grain legumes
108 such as cowpea (*Vigna unguiculata*) and groundnut (*Arachis hypogaea*) could thus play a useful
109 role as providing fodder, as well as improving and protecting the soil.

110 There is little research that has focused on the ability of different legume types to contribute
111 to the control of soil erosion in smallholder farming systems in east Africa. Thus, the main
112 objective of this study was to assess the efficiency of integration of different crop types
113 (represented by herbaceous, grain or woody legumes) in preventing surface runoff and soil
114 erosion compared to maize-common bean intercropping that represents the typical cropping
115 system in the region. Soil erosion measurements using runoff plots have been successfully

116 used in several recent papers and that method was applied in this study (e.g. Thierfelder and
117 Wall, 2009). We also assessed the effect of different crop types and crop mixtures (with
118 legumes) on water infiltration and earthworm abundance as indicators of soil function, and
119 total above-ground biomass produced. The hypotheses tested were i) the introduction of
120 herbaceous or woody species can reduce soil erosion compared to maize-common bean
121 intercropping, and ii) herbaceous species and mulching enhance water infiltration and
122 earthworm populations compared to annual grain legumes intercropped with maize.

123

124 **2. Materials and methods**

125 ***2.1 Site description***

126 The experiment was conducted on-farm in Rongo district, Migori County (00°77' S, 34°60' E;
127 1474 meters above sea level), in western Kenya. The area is characterized by a sub-humid
128 climate and receives rainfall in a bimodal pattern, with approximately 1000 mm per annum (Fig.
129 1). In general, the rainy seasons last from March to July (LR) and from September to December
130 (SR). Annual average temperature is about 20 °C. Predominant soils are *Acrisols* according to
131 FAO classification and the land is generally sloping. The soil at the experimental site is a sandy
132 clay loam (Table 1) and the slope is around 20 %. Common crops in the region include maize
133 (*Zea mays L.*), sugarcane (*Saccharum officinarum*), tea (*Camellia sinensis*), coffee (*Coffea*
134 *arabica*), banana (*Musa L.*) groundnut and common bean (Rapsomanikis, 2015). The main
135 livestock species are cattle, goats, sheep and chickens. Farmers utilize both cropping seasons and
136 generally prefer to intercrop maize and common bean for food security and efficient land
137 utilization, and the average farm size is approximately two ha (Rapsomanikis, 2015). Land

138 preparation and weed management are usually done with ox-drawn mouldboard plough or hand
139 hoes (Rapsomanikis, 2015). The study farm had been cultivated for more than 10 years with
140 mainly cassava, maize, common bean and groundnuts.

141

142 **2.2 Experimental design**

143 The experiment was established early in 2016 during the long rain (LR 2016) season and was
144 continued during the subsequent 2016 short rain (SR 2016) and long rain (LR 2017) cropping
145 seasons. It was arranged according to a randomized complete block design (RCBD) with five
146 treatments and three replicates.

147 The treatments were as follows, maize/common bean intercrop (maize intercrop); groundnut, as
148 sole crop during LR and intercropped with maize during SR (groundnut) (following farmer
149 practice); Lablab (*Lablab purpureus*) as a sole crop (Lablab); Mucuna (*Mucuna pruriens*) as a
150 sole crop (Mucuna) and maize/common bean intercrop plus *Calliandra calothyrsus* hedgerow
151 and leaf mulch (Calliandra).

152 Soil samples were collected with a soil auger (internal diameters 7 cm) at two depths (0-20 cm
153 and 20-40 cm) just before planting in April 2016. Ten soil samples from each depth were bulked
154 to give one sample per block and sub-samples of 500 g were saved for further analysis. Soil pH
155 was determined in 1:2.5 soil and 0.01 M CaCl₂ suspension using a Labor-pH-meter (WTW
156 GmbH). Total N and C were analysed using dry combustion (Flash EA 1112 Elemental
157 Analyser). Soil texture was determined using the pipette method, after having removed the
158 organic matter using 35 % hydrogen peroxide. Available K was extracted using Calcium-

159 Acetate-Lactate solution and measured by Inductively Coupled Plasma Optical Emission
160 Spectrometry (Agilent 5100 ICP-OES). Available P was extracted using Bray No 1 extractant
161 and analysed on spectrophotometer (Bechman UV/Vis Spectrophotometer DU ®-640). For bulk
162 density determination, 110 cm³ undisturbed cylinder cores were taken, the soil oven dried at 105
163 °C, and the bulk density calculated using the volume of the core.

164 The crops were sown after the first effective rains in all seasons, except for the LR 2016 season
165 when crops were established a bit later. Establishment was delayed by a long dry spell after the
166 runoff plot structures were constructed (at the beginning of the rainy season). Land was prepared
167 using an ox-drawn mouldboard plough to a depth of approximately 20 cm, at the onset of the
168 experiment to remove *Cynodon nlemfuensis* Vanderyst (African Bermuda-grass) which was
169 common on the site and to loosen the soil for improved seed establishment. In the following
170 seasons (September 2016 SR and March 2017 LR), land preparation was carried out with hand
171 hoes (tilling depth approximately 20 cm) 2 weeks after harvesting the preceding crops. From the
172 SR 2016 cropping season, 50 % of the harvested leaf and stem biomass in all treatments was
173 retained in the respective plots and was uniformly spread soon after sowing the following crop,
174 following recommendations from Mupangwa and Thierfelder (2014) and allowing the remaining
175 crop residues to be used for feeding livestock or other purposes. Each main plot measured 12 m
176 × 6 m (72 m²) and consisted of a bounded runoff plot measuring 12 m × 4 m (48 m²) in the
177 centre with a 1 m buffer zone on both sides of the aluminium sheets (Muoni et al., 2018). At the
178 start of the experiment, aluminium sheet boundaries were buried 0.20 m into the soil around the
179 runoff plots to prevent water flow from adjacent plots or outside of the experimental area. At the
180 bottom of each runoff plot, a triangular cross-section was constructed with a 5-cm diameter iron

181 pipe outlet connected to two 100 L tanks to collect runoff and soil sediments. The first tank had 6
182 equidistant levelled splitter outlets. One splitter outlet was then connected to a second tank
183 (splitter tank), to account for the overflowing water from the splitter on the first tank.

184 All crops and the Calliandra hedgerows were planted across the slope. Maize was sown at 0.75 m
185 \times 0.30 m to achieve 44 444 plants ha⁻¹. Common bean was sown in-between the maize rows,
186 spaced at 0.20m between plants giving 66 666 plants ha⁻¹. Mucuna and Lablab were sown at 0.50
187 m between rows and 0.20 m between plants (100 000 plants ha⁻¹). Sole groundnut was spaced
188 0.45 m \times 0.15 m to achieve 148 148 plants ha⁻¹, for intercropping they were sown between the
189 maize rows at the same in-row spacing (74 074 plants ha⁻¹). Fertilizer applications in all crops
190 followed the recommended application rates in the region. All maize plots received 100 kg ha⁻¹
191 of Diammonium Phosphate (DAP) (18 kg N: 46 kg P₂O₅ (20 kg P) ha⁻¹) fertilizer at sowing. Sole
192 legumes received 45 kg ha⁻¹ of DAP (8 kg N: 21 kg P₂O₅ (9 kg P) ha⁻¹). Thus, intercrops
193 received 145 kg ha⁻¹ DAP. Reseeding in places of poor germination ('gap filling') was done
194 approximately 2 weeks after initial sowing. All maize crops were top dressed, at four and seven
195 weeks after sowing in two equal splits, using calcium ammonium nitrate fertilizer (26 kg N ha⁻¹).
196 Hand weeding was carried out at least twice in each cropping season and the first and second
197 weeding was carried out at four and seven weeks after sowing in each season followed by a third
198 weeding when deemed necessary. Aphids and leaf eating caterpillars were controlled using
199 Karate (active ingredient (a.i) Lambda-cyhalothrin), and fungal diseases on legumes were
200 controlled using Redomil (a.i. metalaxyl-M plus mancozeb) at recommended application rates.

201 The Calliandra hedgerows were established using small seedlings spaced at 4 m \times 0.50 m (19
202 August 2016) in the beginning of the SR 2016 cropping season (seedlings were not available LR

203 2016). Each plot had three hedgerows that were placed at the top, middle and bottom of the plot.
204 The seedlings received supplementary watering for the first three weeks to prevent wilting. The
205 seedlings grew naturally until the end of the LR 2017 when they were cut at 0.60 m height.
206 Calliandra mulch was imported from the nearby farms in the LR2016 before the hedgerows were
207 established, and also in the following seasons because the seedlings in the plots were too small to
208 provide sufficient quantities of plant material. The mulch was applied at 5 Mg ha⁻¹ soon after
209 sowing in all seasons.

210

211 ***2.3 Field measurements***

212

213 ***2.3.1 Runoff and soil erosion***

214 Runoff and soil erosion measurements were carried out after each rainfall event that resulted in
215 accumulation of water in the tanks. The second tank accounted 1/6 of the overflow from first
216 tank. The total overflow was then added to the volume of water in the first tank. The total
217 volume from all the rain events was added and converted to give runoff in m³ ha⁻¹.

218 All soil sediments collected from each tank were weighed on each sampling occasion.
219 Thoroughly mixed soil sediments subsamples weighing approximately 500 g were collected
220 from both tanks for oven drying. In cases where the soil sediments collected were below 500 g
221 the whole sample was used. Soil sediments subsamples were oven dried at 105 °C until a
222 constant weight was reached. The quantity of soil sediments from the splitter tank was also
223 multiplied by 6 as in the case of runoff. Soil erosion is reported on a dry weight basis in kg ha⁻¹.

224

225 2.3.2 *Water infiltration*

226 Infiltration measurements were carried out during the SR 2016 and LR 2017. Water infiltration
227 was measured on 14 November 2016 (67 days after planting) and 5 May 2017 (65 days after
228 planting) during the SR and LR respectively, using a single ring infiltrometer measuring 5.08 cm
229 in diameter and 12.70 cm depth. The ring was driven 5 cm into the soil in an area cleared of plant
230 material. The infiltration was measured by pouring 107 mL of water into the ring and recording
231 the time taken for the water to infiltrate the soil. The procedure was repeated at three random
232 positions in each plot.

233

234 2.3.3 *Earthworms*

235 Sampling of earthworms was carried out at three sampling points in each plot on two occasions,
236 in November 2016 (SR 2016) and May 2017 (LR 2017), i.e. approximately 60 days after sowing
237 when there was adequate soil moisture. The sampling was done in the buffer zone outside the
238 main runoff plot to avoid soil disturbance that may have affected soil loss results. A metal frame
239 measuring 0.25 m × 0.25 m was randomly placed in the plot and all crop residues in the area
240 were removed. The soil was extracted to a depth of 10 cm and hand sorted for earthworms. Both
241 earthworms and soil were returned to the sampling point after counting the earthworms.

242

243 2.3.4 *Above ground biomass and crop grain yield*

244 Biomass data were collected from eight central rows \times 3 m long, of each crop. The total fresh
245 weight of biomass from the net plot was weighed and a subsample (500 g) was oven dried at 80
246 °C for 48 hours. The subsample dry weight and fresh weight ratio was used to determine biomass
247 dry weight in kg ha^{-1} . All three Calliandra hedgerows were pruned during the LR 2017 season at
248 0.60 m from soil surface in each plot and the leaves and stems in each plot were weighed
249 separately. The average weight of leaves and stems in the three rows were calculated to give
250 fresh weights of each plot. Stems and leaves sub samples of approximately 200 g were collected
251 at each weighing. The sub-samples were oven dried at 80 °C for 48 hours. In intercropping
252 treatments, total biomass included all harvested crop material including Calliandra in the
253 appropriate treatment.

254 The maize grain yield was harvested on 8 central rows, each measuring 3 m. The fresh weight of
255 all cobs in the 8 rows was measured immediately after harvesting and a sub-sample of 10
256 randomly selected cobs was taken for air-drying. The fresh and air-dry weights of the sub-
257 samples were measured and grain yield was calculated at the recommended 12 % moisture
258 content. For common bean and groundnut intercropped with maize, the crops were harvested
259 between 8 central maize rows, also measuring 3 m each. Total fresh weight of the pods was
260 measured in the field and a pod sub-sample of approximately 500 g was collected for air-drying.
261 The grain yield for legumes was calculated at 9 % moisture basis. Sole Mucuna and Lablab grain
262 data was collected using the same procedure as for common bean and groundnuts.

263

264 *2.4 Statistical analysis*

265 All data collected was subjected to heterogeneity of variance and normality tests and then the
266 analysis of variance (ANOVA) was carried out, using Statistix 9 statistical package for personal
267 computers, to assess the treatment effects on soil loss, runoff, water infiltration, earthworm
268 populations, and total above ground biomass and grain yield (both maize and legumes) produced.
269 The means of the three sampling points for earthworms and infiltration per plot were used in
270 statistical analysis. Mean separation was carried out using the least significance difference (LSD)
271 test at $P \leq 0.05$ on all significant data.

272

273 **3. Results**

274 *3.1 Runoff, soil erosion and water infiltration*

275 Cropping season had a significant effect on runoff. Runoff was higher during the LR 2017 and
276 SR 2016 seasons than in the LR 2016 season (Fig 2). Also, runoff differed significantly between
277 crop treatments in all three cropping seasons (Fig 2). The treatment Calliandra showed the lowest
278 runoff in all seasons. Mucuna was the second most efficient crop in reducing surface runoff
279 across the seasons, while the effects of the other crops were inconsistent. During the LR 2016
280 cropping season, runoff from the groundnut treatment was as low as from the Calliandra
281 treatment whereas in SR 2016 and LR 2017 runoff under groundnuts was as high as with the
282 worst performing crops. In the LR 2016, Lablab and Mucuna treatments had similar and
283 intermediate runoff, whereas during the SR 2016 and LR 2017 Lablab was diseased and did not
284 differ significantly from the maize-common bean (control) and the groundnut treatments. Both
285 LR seasons had an extended mid-season dry spell when compared to the SR season (Fig 1).

286

287 Soil erosion differed by cropping season with SR 2016 having more soil erosion than LR 2016
288 and LR 2017 (Fig. 3). Soil erosion was also affected by treatments during the three cropping
289 seasons investigated in this study (Fig. 3). Soil erosion was lowest on the Calliandra treatment in
290 all three seasons, and the Mucuna treatment was similarly low during the first and the last
291 seasons ($<500 \text{ kg ha}^{-1}$). During the LR 2016, Lablab, Mucuna and Calliandra caused similar and
292 lowest soil erosion, while the maize intercrop led to the highest erosion. Overall, there was much
293 greater soil erosion in all treatments during SR 2016 (up to 6000 kg ha^{-1}) as compared to LR
294 2016 and LR 2017, except for Calliandra where erosion remained low. In the SR 2016 season,
295 maize intercrop, groundnut and Lablab had the highest soil loss, Mucuna caused intermediate
296 and caused Calliandra the lowest. During the LR 2017 season, soil erosion was relatively low
297 overall ($500\text{-}1500 \text{ kg ha}^{-1}$) and similar to LR 2016. Soil erosion was highest under Lablab
298 followed by maize intercrop. Calliandra, Mucuna and groundnut showed the lowest soil loss.

299

300 Treatments had a significant effect on water infiltration during the SR 2016 only (Table 2). The
301 highest water infiltration was observed under Calliandra and Mucuna treatments, while the
302 lowest was observed in Lablab treatment. Calliandra caused 154 % higher infiltration rate than
303 Lablab and 107 % higher than the maize intercrop treatment.

304

305 *3.2 Earthworm population*

306 The treatments had a significant effect on earthworm populations during the LR 2017 season
307 only (Fig. 4). Mucuna and Calliandra caused similar, large earthworm populations compared to
308 other treatments. The earthworm populations tended to be larger in Calliandra than in the other
309 treatments also in SR 2016 ($P = 0.28$). Treatments with low earthworm populations had high
310 surface runoff (Fig. 5a) and soil loss (Fig. 5b) during the SR 2016 and LR 2017 cropping
311 seasons.

312

313 *3.3 Above ground biomass and crop grain yield*

314 The total biomass produced was larger and more affected by treatment in the SR 2016 season
315 than in the LR 2016 (Table 3). In the SR 2016 season, the highest biomass was observed in
316 groundnut/maize intercrop, Mucuna and Calliandra treatments, while Lablab produced the
317 smallest biomass. In the LR 2017 season, Calliandra produced the largest total biomass followed
318 by maize intercrop.

319 Treatment had a significant effect on maize and legumes grain yields during the SR 2016, where
320 Calliandra treatment was larger than maize intercrop and groundnut treatments. Mucuna
321 treatment produced a higher grain yield than other legume treatments (Table 3). During the LR
322 2017 season, treatments had a significant effect on legume grain yields only and the same trend
323 was observed where Mucuna had the largest yield (Table 3). LR 2017 season had higher crop
324 yields than SR 2016 in all treatments except for Lablab.

325

326 **4. Discussion**

327 Soil erosion control is a critical issue in smallholder farming systems in SSA. The washing away
328 of organic matter and nutrient rich topsoil, accompanied by low fertilizer use, results in low crop
329 yields. The use of intercrops including different types of legumes has the potential to improve
330 soil fertility through reduction of soil erosion and addition of nitrogen through biological
331 nitrogen fixation.

332

333 *4.1 Runoff, soil erosion, water infiltration and abundance of earthworms*

334 Mucuna and Calliandra caused low soil erosion and runoff during the study period.
335 Although the first season trial was established late, this did not affect the results since the
336 same trend of less soil erosion was observed from Calliandra and Mucuna treatments as
337 from other treatments throughout the study period. Soil erosion observed during LR seasons
338 in this study was generally low when compared to other studies, e.g. 6.9 Mg ha⁻¹ recorded
339 under no-till plus legume intercrop in Zimbabwe 2005/06 cropping season (Thierfelder and
340 Wall, 2009), >2 Mg ha⁻¹ under different crop and tillage management in Western Kenya
341 (Ampofo et al., 2002) and 52 Mg ha⁻¹ year⁻¹ on bare soils during 2010/11 cropping season in
342 Southern Africa (Paterson et al., 2013). Since the general level of erosion was small
343 compared to other experiments conducted under similar conditions, the relatively small
344 differences found in the present experiment can be expected to be of greater importance in
345 situations as in the work referred to. Thus, the experiment supported the hypothesis that
346 herbaceous and woody species can reduce soil erosion compared to maize-common bean
347 intercropping. Increased infiltration was observed under Mucuna and Calliandra treatments,
348 which also supports the hypothesis that herbaceous legumes and tree legumes with mulching

349 enhance water infiltration and earthworm populations compared to intercropping of annual
350 crops and sole grain legumes.

351 Soil erosion, runoff and infiltration were probably reduced by the high soil cover provided
352 by the crop canopies and residues (Montgomery, 2007; Thierfelder and Wall, 2009). Retention
353 of crop residues increased soil cover at the onset of the season before crop establishment,
354 which reduced raindrop impact, soil erosion and runoff. Raindrop energy loosens and
355 displaces soil particles and this energy is dissipated by ground cover (Kaspar et al., 2011).
356 Living and non-living mulch also diminishes the velocity of runoff which reduces the
357 dispersion of soil particles from their original source thus reducing erosion (Kaspar et al.,
358 2011). Mulching also increases surface roughness and thus reduces runoff velocity and increases
359 ponding, giving the opportunity for increased water infiltration (Jordán et al., 2010). The greater
360 above ground biomass production in treatments with *Mucuna* and *Calliandra* also increases litter
361 and organic material in the soil, which improves aggregation of soil particles. The addition of
362 mulch favored earthworm population build up, and the *Calliandra* leaves dropping during the
363 season increased litter which may have improved moisture retention and feed availability for
364 earthworms (Buchholz et al., 2017). More soil cover protects soil from direct sunlight and thus
365 evaporation of surface water. This improves the retention of soil moisture, which is important for
366 earthworm survival (Ivask et al., 2006). Both mulching and earthworm buildup contribute to
367 more water infiltration (Jordán et al., 2010). As the *Calliandra* hedgerows grew, they provided
368 additional ground cover which helped reduce runoff and soil loss. This could be the effect of
369 changes in microtopography of the hedgerows (Lin et al., 2009) and earlier development of
370 leaves at the beginning of the season, when the existing shrub roots can make use of residual soil
371 moisture.

372 Establishing and pruning legume hedgerows for high quantities of fodder (or mulch) is labor
373 intensive. Although tree and herbaceous legumes are valuable feed sources for animals and have
374 been shown to increase milk production (Paterson et al., 2013), farmers are less willing to
375 incorporate them because they lack experience in growing these crops. There is a very low
376 interest in herbaceous legumes since farmers prefer growing grain legumes to provide food
377 security for their families (Muoni et al., 2019). One way to increase interest in the inclusion of
378 herbaceous or tree legumes would be to stress its usefulness as fodder in addition to the soil
379 fertility enhancing and soil conservation aspects, but adoption is more likely in cases where
380 livestock play an important role in income generation.

381 The maize intercrop had higher runoff and soil erosion than the other treatments during the LR
382 2016 cropping season, probably due to the long dry spell. Due to late establishment in that
383 season, both maize and common bean suffered during the long dry spell and the vegetative
384 growth period and thus produced little groundcover that could prevent runoff and soil erosion.
385 Maize and common bean were more affected by moisture stress than Mucuna, Lablab and
386 groundnut. More soil erosion and runoff were observed when the sole crop was in poor
387 health, as we observed with Lablab in the seasons with pest issues. In such situations, crop
388 mixtures will generally perform better than sole crops, because it is less likely that two or
389 more crops will fail simultaneously, and the additional crop helps maintain groundcover
390 (Rapsomanikis, 2015). In addition, crops such as Mucuna, Lablab and groundnut are all
391 relatively drought tolerant and can provide ground cover even under harsh conditions.

392

393 *4.2 Above ground biomass and crop grain yield*

394 Crop biomass is crucial in smallholder farms for livestock feed, soil improvement, fuel and
395 construction. Incorporating different crop types e.g. legumes in smallholder farms helps provide
396 soil cover and livestock feed of better quality that helps improve soil fertility and livestock
397 productivity. Groundnut intercropped with maize produced the largest biomass in SR 2016
398 season while Calliandra (with maize and common beans) produced the largest biomass in LR
399 2017 season. Although the Calliandra treatment produced high biomass, farmers need to be
400 aware of the potential yield penalty resulting from competition for water, nutrients, light and
401 space between crops and hedgerows, which can be reduced by regular pruning of hedgerows (De
402 Costa and Surethran, 2005). Biomass during the LR 2016 was lower than during other seasons
403 because of late planting, and a long dry spell during the vegetative growth stage. When crop
404 residues remain in the field soil organic matter can increase (Jordán et al., 2010) and this can
405 increase biological activity and soil aggregate formation. Thus, legume crops that produce high
406 biomass enable dual benefits of livestock feed and soil improvement, which improve farm
407 productivity.

408 The maize intercrops produced high grain yields that may help farmers remain food secure. The
409 Calliandra treatment had the largest maize yield during SR 2016 season due to the additional
410 organic matter that was added by leaf mulch from the previous season. However, the Calliandra
411 treatment had lower maize yield in the final season than maize intercrop treatment which may
412 have been due to increased competition with Calliandra hedgerows and subsequent yield loss
413 (De Costa and Surethran, 2005). Competitive crops such as Mucuna, may be rotated with
414 maize, which can help control soil erosion, improve soil fertility, provide livestock feed and
415 provide food for farmers (Bonsu and Asibuo, 2013).

416

417 **5.0 Conclusions**

418 Incorporating a mixture of crop types in cropping systems has the potential to reduce runoff and
419 soil loss, increase earthworm populations and infiltration in smallholder farms. Based on the
420 results from this study, we conclude the following; use of a mixture of crop types including
421 herbaceous and woody species in cropping systems increases soil cover, which reduces the
422 impact of raindrops, as well as runoff and soil erosion. High soil cover can be attained in various
423 ways including intercropping (for example establishing Calliandra hedgerows in maize/common
424 bean intercrop) or crop rotations with herbaceous legumes that produce large amounts of
425 biomass (for example Mucuna). By including a mixture of crop types water infiltration can be
426 improved through increased soil cover and soil organic matter. Mucuna and Calliandra
427 treatments produced both high soil cover and above ground biomass than treatments with only
428 grain crops, which resulted in high infiltration rates and numbers of earthworms. Large
429 earthworm populations contribute to increase water infiltration through soil aggregate formation
430 and increased porosity. Inclusion of legume crops with high biomass production allows farmers
431 to use some biomass for protein rich livestock feed in integrated crop-livestock systems while
432 improving soil fertility.

433

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441

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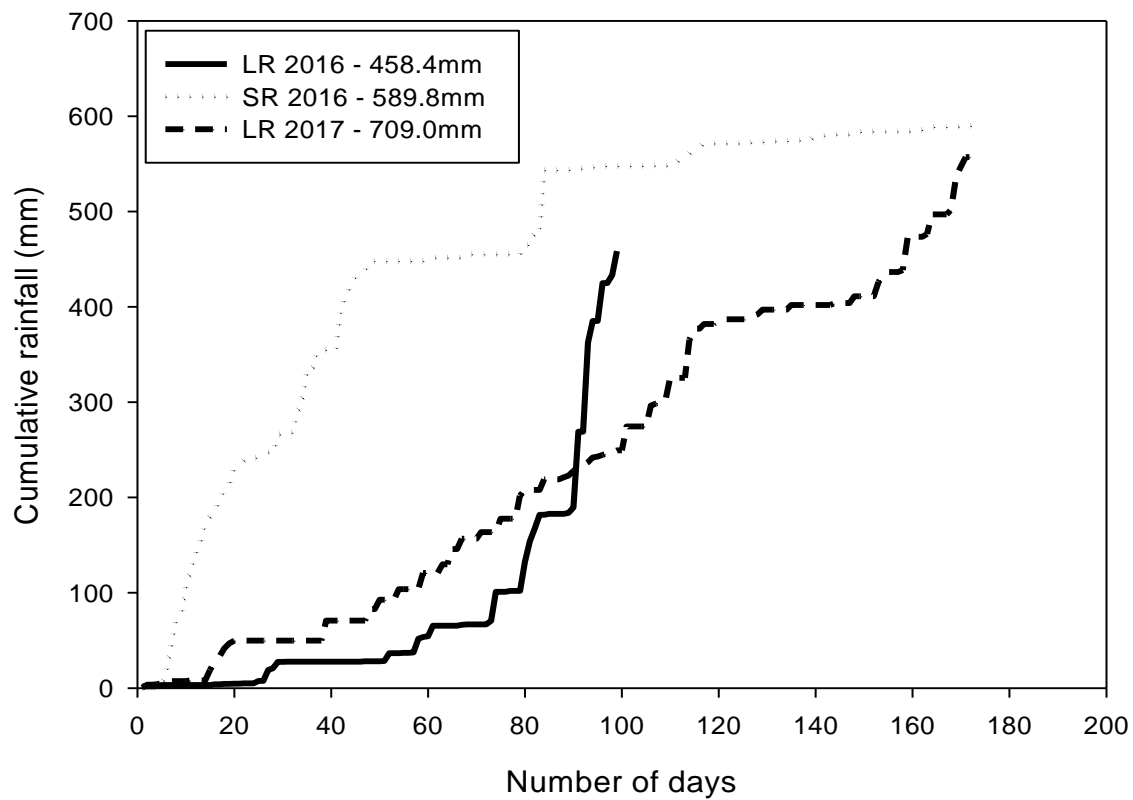
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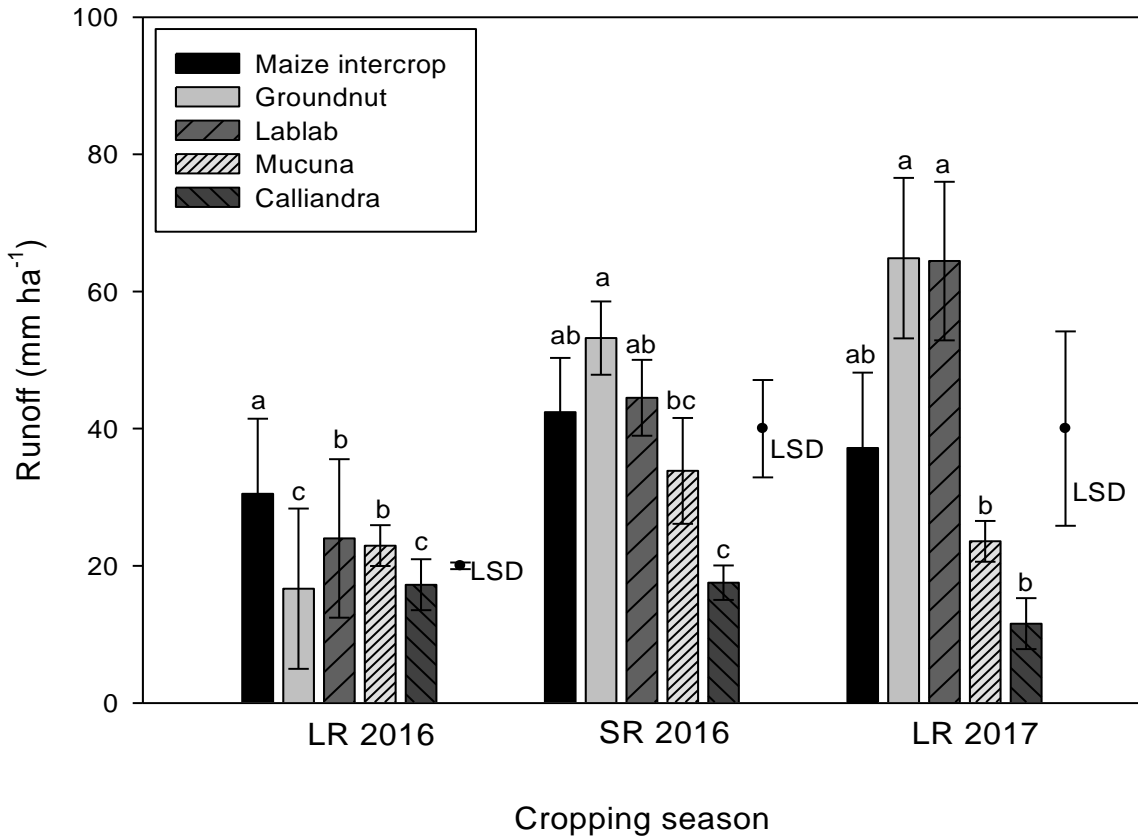


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2 Figure 1. Cumulative rainfall for all cropping seasons. LR 2016 x-axis is in days after
3 planting (25 May 2016), for SR 2016 (planted 8 September 2016) and LR 2017 (planted 1
4 March 2017) its days after the first day of the month when season starts.

5

6



7

8 Figure 2. Effect of treatments on runoff during the 2016 long rains (LR 2016) and short rains
9 (SR 2016), and the LR 2017 in Rongo district, Migori County, in Western Kenya. Groundnut
10 was intercropped with maize during the SR 2016 season. Means with different letters in the
11 same cropping season are significantly different from each other. Error bars are standard error
12 of mean. LSD means least significant differences.

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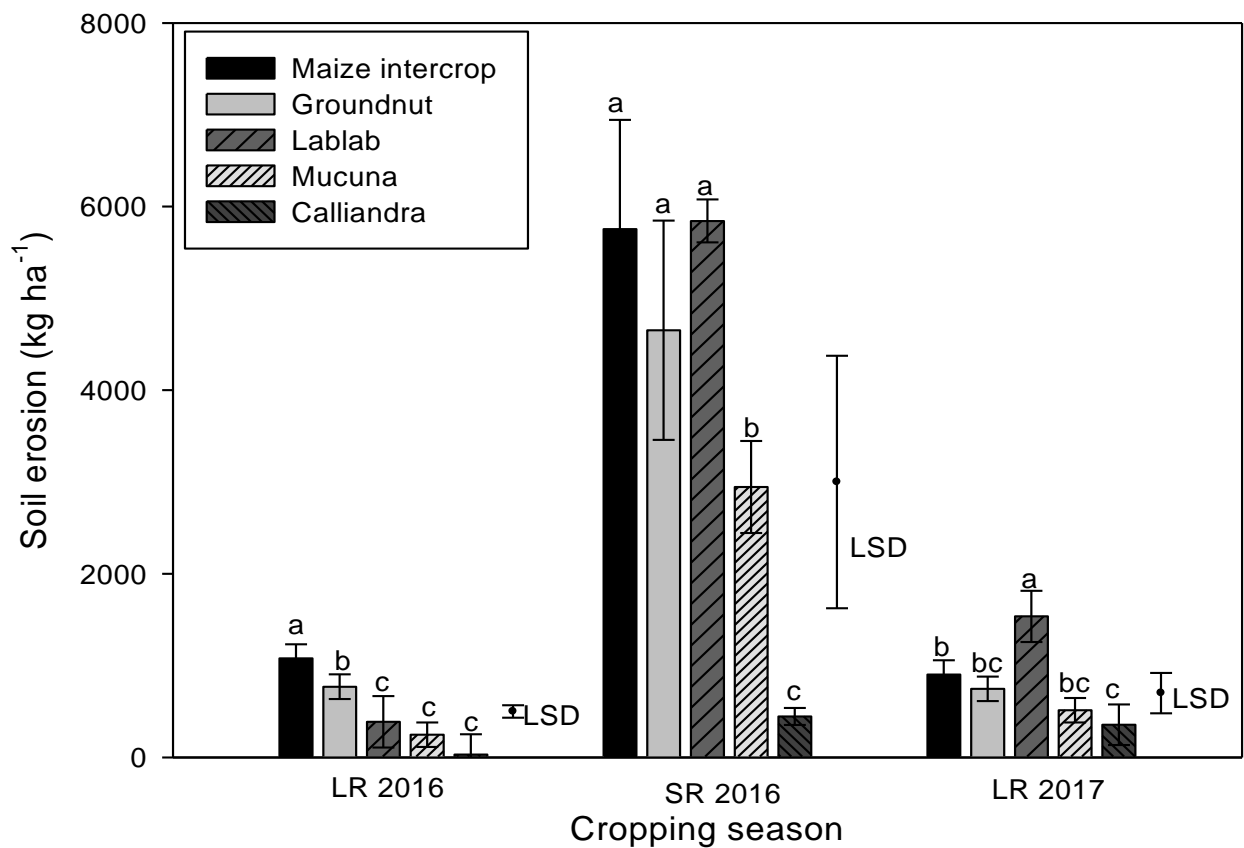
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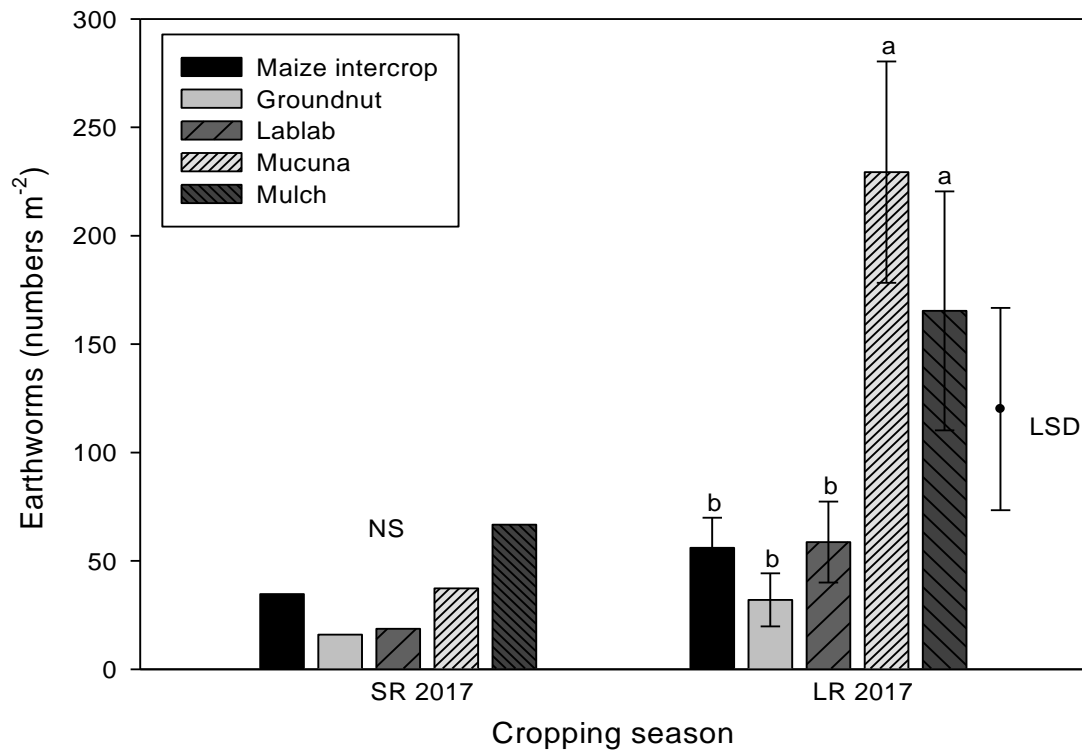
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25 Figure 3. Effect of treatments on soil loss during the LR 2016, SR 2016 and LR 2017
26 cropping seasons. Groundnut was intercropped with maize during the SR 2016 season. Means
27 with different letters in the same cropping season are significantly different from each other.
28 Error bars are standard error of mean. LSD means least significant differences.



30

31 Figure 4. Effect of treatments on earthworm population during the 2016 short rains (SR 2016)
 32 and 2017 long rains (LR 2017) cropping seasons in Rongo. Groundnut was intercropped with
 33 maize during the SR 2016 season. Means with different letters in the same cropping season are
 34 significantly different from each other. Error bars are standard error of mean. LSD means least
 35 significant differences.

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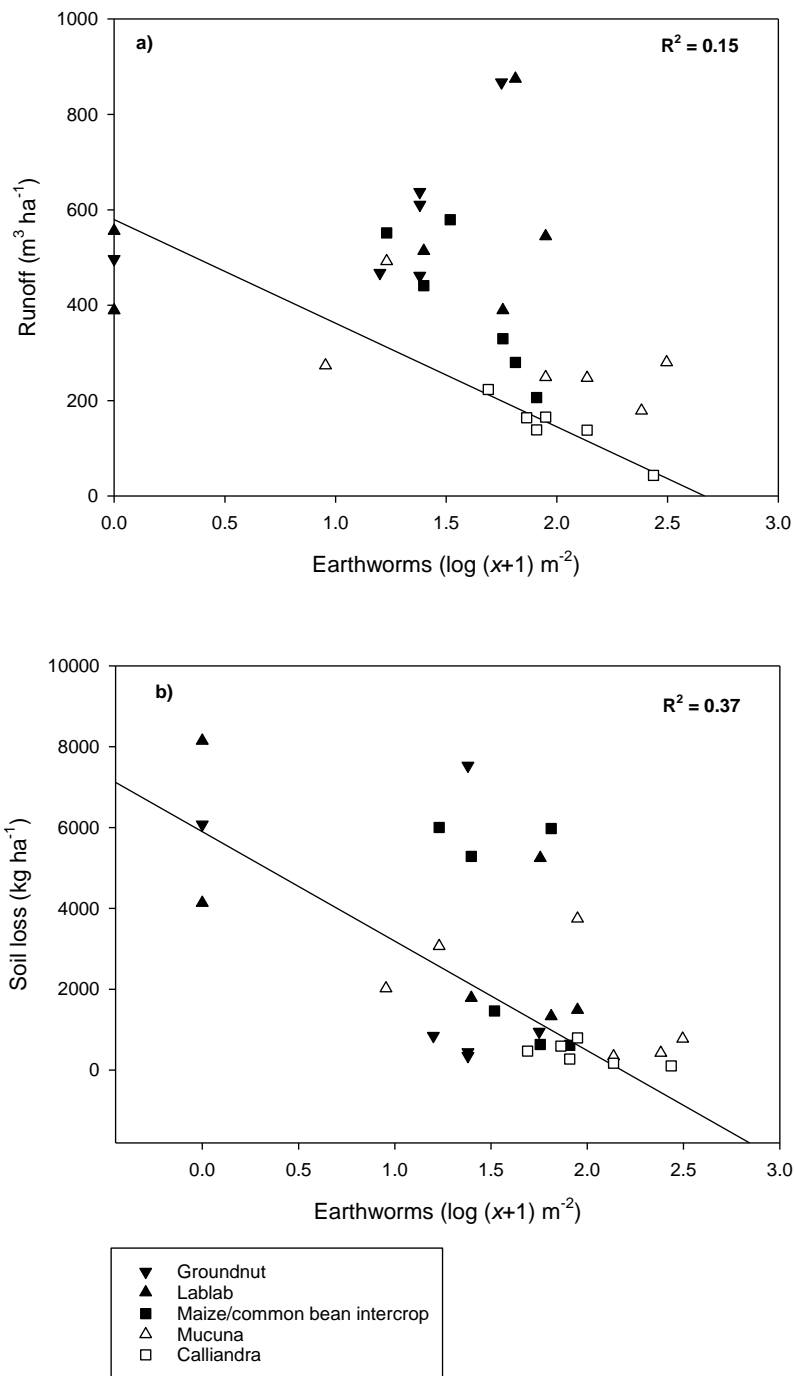
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45 Figure 5. Effect of earthworms in different treatments on a) runoff and b) soil loss during the SR
 46 2016 and LR 2017 season. Significance of the correlations was not tested because the data points
 47 in the regression were not independent. x- earthworms m^{-2} .

Table 1. Soil properties at the experimental site in Rongo district, Migori County, Western Kenya

Depth (cm)	pH	Org C (%)	Total N (%)	C/N ratio	BD (g cm ⁻³)	Avail P (mg kg ⁻¹)	Avail K (mg kg ⁻¹)	Sand (%)	Silt (%)	Clay (%)
0–20	4.8	1.0	0.1	9.9	1.3	0.9	61.0	63	12	25
20–40	4.9	0.9	0.1	10.0	1.4	0.1	77.0	56	13	31

pH (measured in 0.01M CaCl₂ extraction with soil to extraction solution ratio of 1:2.5); Org C = organic carbon, N = nitrogen, BD=bulk density, Available phosphorus (P) and potassium (K). Available P was determined by Bray 1 with Beckman coulter Du, UV – Du 640 spectrophotometers, USA. Available K was analyzed by Calcium–Acetate–Lactate–extraction method.

Table 2 Effect of treatments on infiltration in Rongo during the short rains in 2016 and long rains in 2017

Treatments	Short rains 2016	Long rains 2017
	Infiltration (mL second ⁻¹)	Infiltration (mL second ⁻¹)
Maize/Common bean intercrop	2.7 ^b	1.9
Groundnut*	3.0 ^b	2.0
Lablab	2.2 ^b	1.3
Mucuna	5.0 ^a	1.4
Calliandra	5.6 ^a	2.6
Least significant differences (LSD)	1.55	NS
P-Value	0.003	NS

*Groundnut was intercropped with maize during the SR 2016 season. Means with different letters are significantly different from each other.

Table 3 Crop grain and above ground biomass yield (kg ha⁻¹) during the short rains 2016 and long rains 2017 in Rongo. Statistical significances are indicated with different letters (p<0.05) for maize^(A, B) and legume^(a, b) grain yield. Above ground biomass yield is the total biomass of the treatment.

Treatments	Crops	SR 2016	LR 2017	LR 2016	SR 2016	LR 2017
		Grain yield (kg ha ⁻¹)		Above ground biomass yield (kg ha ⁻¹)		
Maize intercrop	Common bean	79 ^b	229 ^b	3192	4336 ^B	8532 ^A
	Maize	3071 ^B	7260			
Groundnut	Groundnut	73 ^b	418 ^b	2411	6592 ^A	3040 ^B
	Maize	3361 ^B	-			
Lablab	Lablab	209 ^b	80 ^b	2318	548 ^C	176 ^C
Mucuna	Mucuna	1626 ^a	3433 ^a	2963	6197 ^{AB}	5097 ^B
Calliandra	Common bean	108 ^b	240 ^b	3481	5257 ^{AB}	10426 ^A
	Maize	4339 ^A	4697			

‘LR 2016 has no grain yield data due to poor crops/crops not reaching maturity. Groundnut was intercropped with maize during the SR 2016 season and grown as sole crop LR 2017 (following farmer practice).