Cowpea Living Mulch Effect on Soil Quality and Grain Yield in Smallholder Maize-Based Cropping System of Northern Ghana

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Abstract
Low soil fertility is a major constraint for maize production in West Africa, the use of legumes as living mulch improves soil fertility and yield of main crops. However, there is limited literature on the appropriate time to plant living mulch in maize-based cropping system in West Africa. A 2-year (2017–2018) study was conducted to determine the effect of cowpea living mulch (CPLM) on soil quality and grain yield of maize-based cropping system of northern Ghana. A factorial treatment combination of three maize maturity types (extra-early, early and medium) and four CPLM methods (control, CPLM with maize planted on the same day, CPLM planted 1 week after maize and CPLM planted 2 weeks after maize) was laid out in a randomized complete block design with four replications in Northern and Upper East regions of Ghana. Principal component and correlation matrix analyses were used to select minimum data set for soil quality index (SQI) calculation. The SQI for CPLM improved by 50–100% relative to that of the control in both seasons and regions. The CPLM significantly increased maize grain by 34–37% during both seasons in Northern Region and 84% during 2017 in the Upper East Region compared with that of the control. The effect of time of planting CPLM on grain yield showed negative correlation with amount of rainfall received during vegetative growth of CPLM. The results suggest that smallholder maize-based farmers in northern Ghana and similar agro-ecologies in West Africa can plant CPLM 1–2 weeks after planting maize to improve soil quality and increase maize grain yield.

Keywords Maize · Cowpea · Living mulch · Soil quality · Savanna

1 Introduction
Maize (Zea mays L.) is among the major cereal crops in the world and accounts for more than 20% of food calories in most parts of Africa and Mesoamerica (Shiferaw et al. 2011). It is mostly produced by smallholder farmers under rain-fed conditions in Ghana with an average grain yield of less than 1990 kg ha⁻¹ from farmers’ fields compared with a potential of 5500 kg ha⁻¹ (MoFA 2017). The yield gap is caused by several biophysical factors including erratic rainfall patterns due to climate change and short duration of cropping season coupled with the use of medium to late maturing maize varieties (Sallah et al. 2003; Bawayelaa-Nyuor et al. 2016). Another reason for the yield gap is the low and diminishing fertility status of soils in northern Ghana which are generally shallow with low total nitrogen (<0.02 g kg⁻¹), organic matter (<20 g kg⁻¹) and available phosphorus (<10 mg kg⁻¹) (Tetteh et al. 2016). Maize is a heavy nutrient feeder with adequate water requirement for growth especially from vegetative through flowering and grain filling stages (Dugje et al. 2014). Therefore, there is the need to develop cropping systems such as living mulch that improves soil fertility, conserve soil moisture and increase yield.

Living mulch is a cover crop planted either before, same day with or after the main crop and maintain as ground cover throughout the cropping season or longer (Hartwig and Ammon 2002). Living mulch provides good soil ecosystem conditions for main crops to thrive well. However, the
type of crop used as living mulch affects soil quality. Food and feed legume living mulches improve soil organic carbon (OC), total nitrogen (TN), available phosphorus (AP), microbial biomass and soil bacterial structure and function better than non-legume living mulches (Duda et al. 2003; Qian et al. 2015). They also improve soil moisture, infiltration, soil bulk density, temperature and erosion relative to non-living mulch plots (Sharma et al. 2010; Wiggans et al. 2012; DeVetter et al. 2015; Qu et al. 2019).

Despite the importance of living mulch in improving soil properties, there are conflicting reports in the literature on the effect of living mulches on the grain yield of main crops. Some studies have reported a decreased or no difference in the yield of main crops (Jędrzeczyk et al. 2005; Radicetti et al. 2018). Others have also reported an increase in crop yields (Jamshidi et al. 2013; Trail et al. 2016; Bhaskar et al. 2018). These conflicting reports could be due to several factors, key among them is the type of crop grown as the mulch and the time of planting the mulch vis-a-vis the main crop (Afshar et al. 2018). For example, some studies have reported a reduction in the yield of main crops when the living mulch was planted before the main crop (Jędrzeczyk et al. 2005; Afshar et al. 2018). Other studies reported an increase in the grain yield of main crops when the main crop was planted either before or on the same day with the living mulch (Jamshidi et al. 2013; Trail et al. 2016; Bhaskar et al. 2018).

Quantitative data is limited on the effect of legume living mulch on maize grain yield and soil quality in the smallholder maize-based cropping systems in West Africa. This study reports the results of an on-farm study on the effects of time of planting CPLM on soil quality and grain yield of extra-early, early and medium maize maturity types in northern Ghana. Such information is needed to give an advantage for the use of resources (nutrient, water and light) to the maize crop which is more susceptible to competition at the early growth stage (vegetative) and in turn increase the grain yield of maize in the smallholder maize-based cropping systems. It will also contribute to the literature on the effect of time of planting of a legume living mulch on maize grain yield and soil quality in West Africa.

2 Materials and Method

2.1 Study Area

The experiment was conducted in Cheyohi No. 2, Tingoli, Duko and Tibali communities of the Northern Region, and Sambolongo, Nyangua, Gia and Bonia communities in the Upper East Region of northern Ghana during the 2017 and 2018 cropping seasons (Fig. 1). WatchDog 2900ET (Spectrum Technologies, USA) weather gauge was installed in Tingoli community (Northern Region) and Bonia community (Upper East Region) to measure daily rainfall (mm) and temperature (℃) for each region during June–October of 2017 and 2018 cropping seasons. The WatchDog 2900ET runs on AA dry cell batteries, therefore, weather data gaps were filled by data from the nearest gauge stations thus Savanna Agricultural Research Institute gauge station about 5 km from Tingoli community in the Northern Region and Ghana Meteorological Agency gauge station about 8 km from Bonia community in the Upper East Region. In the Northern Region, the total amount of rainfall recorded during 2017 was 692.4 mm and in 2018 was 850.5 mm (Fig. 2a and b), and the mean temperatures for 2017 and 2018 were 27.2 ℃ and 26.9 ℃ respectively (Fig. 2a and b). In the Upper East Region, the total amount of rainfall received during 2017 and 2018 was 565.5 and 796.3 mm respectively (Fig. 2c and d), whilst the mean temperatures were 27.1 ℃ in 2017 and 27.3 ℃ in 2018 (Fig. 2c and d).

The soils of the study areas in the Northern Region were developed from sandstones and shale with topsoil (0–20 cm) properties of pH (5.6–6.4, 1:2.5 soil: H2O), OC (5.5–9.5 g k−1), TN (0.5–0.9 g k−1), AP (6.8–11 mg k−1), available potassium (51–109.6 mg k−1) and soil texture of loam-sandy loam (Tetteh et al. 2016). The same authors reported that the soils of the study areas in the Upper East Region were developed from granite and the Upper Birimian phylite with topsoil (0–20 cm) properties of pH (5.3–6.4, 1:2.5 soil: H2O), OC (4.1–7.5 g k−1), TN (0.3–0.4 g k−1), AP (1.8–9.7 mg k−1), available potassium (52.8–62.6 mg k−1) and soil texture of sandy loam to loamy sand.

2.2 Experimental Design

In each region, a 3 × 4 factorial treatment combination of maize maturity type and CPLM laid out in a randomized complete block design with four replications was used. The maize maturity types were extra-early: Abontem, early: Omankwa and medium: Obatanpa. The physiological maturity periods for the maize maturity types were 80 days for Abontem, 95 days for Omankwa and 105 days for Obatanpa (Adu et al. 2014). The maize maturity types used in this study were open pollinated and quality protein maize whilst the Abontem and Omankwa maize were drought and Striga tolerant in addition to their earlier qualities (Adu et al. 2014). The CPLM included no mulch (control), CPLM with maize planted on the same day, CPLM planted 1 week after maize and CPLM planted 2 weeks after maize. The cowpea variety used as a living mulch was a local variety called “Nandambaya”; it is a spreading cowpea type and had a physiological maturity period of 65 days. The use of cowpea as living mulch in smallholder maize-based cropping system provides food in addition to the soil cover and this has the potential to
make the technology more attractive to smallholder farmers especially in northern Ghana.

The experiment was conducted in four communities in the Northern Region and four communities in the Upper East Region (Fig. 1). These communities were selected because they were part of the 25 intervention communities for Africa Research In Sustainable Intensification for the Next Generation (Africa RISING) project in three regions of northern Ghana. Each community was used as a block at the regional level where the experiment was established as a technology park for farmers to participate in, observe and learn about the technology. Therefore, the experiment was replicated four times in each region. The plot size for a block was 23 m × 15.5 m and that of a treatment was 5 m × 4.5 m.

2.3 Agronomic Practice

The experimental fields in the Northern Region were ploughed with tractors in line with the common land preparation practice of the region. The maize plants were planted at a spacing of 75 cm × 40 cm at three seeds per hill and thinned to two stands per hill after 14 days to achieve a plant density of 66,667 plants ha⁻¹. The cowpea plants were planted in the middle of maize rows at an intra-spacing of 20 cm and two seeds per hill to attain a plant density of 133,333 plants ha⁻¹. The maize plants were planted on 20th–30th June in the 2017 cropping season and on 25th June–6th July in the 2018 cropping season. The planting of the maize and cowpea was done manually with a wooden dibbler and garden line. A compound NPK (15–15-15 N-P-K) fertilizer was applied 14 days after planting to the maize plants at 40 kg ha⁻¹ NPK. The maize plants were top dressed at 21 days after application of compound fertilizer with sulphate of ammonia at 20 kg ha⁻¹ N. Hoe weeding was done once at 14 days after planting in all the treatment plots and 21 days after first weeding in the control plots.

In the Upper East Region, the experimental fields were prepared with bullock plough in line with the conventional land preparation practice of the region. The maize and cowpea plants were planted using the same approach (spacing and number of seeds per hill) as described for the Northern Region. The maize plants were planted on 30th June–10th July in the 2017 cropping season and on 4th–13th July in the 2018 cropping season. The fertilizer type and time of its application, method of weeding and time of weeding were also done as described for the Northern Region.
minimum data set: principal component (PC) and correlation

We calculated SQI using three key steps: (1) selection of

matrix analyses were used as data reduction tools to select
the minimum data set from the total data set (Andrews et al. 2002). Eigenvalue-one-criterion and proportion of variation
accounted for criteria were used to determine the number
of components to be retained for rotation and interpreta-
tion. For the eigenvalue-one-criterion, we selected PC with
eigenvalues of greater than one whereas for the proportion
of variation accounted for, we selected PC that accounted
for at least 10% of the total variation. Under a selected PC,
soil indicators with high eigenvector were selected as part of
the minimum data set. When soil indicators were less fitted, they were all
indicator may be retained or eliminated from the minimum
data set. When soil indicators were less fitted, they were all
retained in the minimum data sets, whilst when they were
best fitted, the soil indicator with the highest eigenvector
was retained in the minimum data set. (2) Transformation
of indicators of minimum data set into scores: a linear scor-
ing function of more is better or less is better method was
used to convert actual values of selected soil indicators as
minimum data set into unitless scores (Andrews et al. 2002).
(3) Integration of these scored indicators into an index: the
scored values ranged from 0 to 1 with 0 as the least and 1
as the highest indicator strength. Considering soil chemical,

2.4 Soil Sampling and Measurement

A soil thermometer (HI 98,501, Hanna Instrument Inc.,
USA) was placed randomly at five different spots along the
diagonals of each treatment plot to measure soil tempera-
ture at vegetative, tasseling and harvest stages of maize. A
galvanized iron cores of 4.5 cm inner diameter and 25 cm
high were used to take five core samples along the diago-
nals of each treatment plot to measure soil bulk density and
moisture content at vegetative, tasseling and harvest stages
of maize (Anderson and Ingram 1993). After harvesting the
maize crops in each cropping season, composite surface soil
(0–15 cm depth) samples were taken at five different spots
along the diagonals of each plot. The composite soil samples
were air dried, ground, sieved and analyzed for pH (1:2.5
H₂O: Soil), TN (Kjeldahl distillation and titration method),
AP (Bray 1 extraction solution and colorimetric method),
OC (titration method), microbial biomass carbon (MBC) and
nitrogen (MBN) (chloroform fumigation method) outlined
by Anderson and Ingram (1993). The soil microbial quotient
(SMQ) was calculated as the ratio of MBC and OC (Paz-
Ferreiro and Fu 2016).

2.5 Soil Quality Index

We calculated SQI using three key steps: (1) selection of
minimum data set: principal component (PC) and correlation

Fig. 2 Daily rainfall and temperature of experimental areas in the Northern Region a 2017, b 2018 and Upper East Region c 2017, d 2018 of
Ghana
biological and physical properties as soil quality subindices at the edge of a triangle, we used the arithmetic mean approach to sum the scores of the soil indicators under each of the subindices and calculated the SQI using the geometric rules of a triangle (Kang et al. 2005; Abdul Rahman et al. 2019).

2.6 Grain and Stover Yields

Maize cobs from the two middle rows of each treatment plot were harvested at physiological maturity, dehusked, shelled, oven dried at 65°C to a moisture content of 13% and weighed as grain yield. Similarly, the maize plants in the two middle rows from which the cobs were harvested were cut at ground level, oven dried at 65°C to a constant weight and measured as stover yield.

2.7 Statistical Analysis

The soil and yield (grain and stover) data were analyzed on a cropping season basis using Statistical Analysis System (SAS Institute 2015) package. The soil data was analyzed with emphasis on the effect of CPLM on soil properties using the model in Eq. 1 and that of maize yield was analyzed with emphasis on the effect of maize maturity type and CPLM using Eq. 2.

\[
Y_{ijk} = \mu + B_i + C_j + e_{ijk}
\]

where \(Y_{ijk}\) is an observation, \(\mu\) is the experimental mean, \(B_i\) is the block (community) effect, \(C_j\) is the CPLM effect and \(e_{ijk}\) is the error.

\[
Y_{ijk} = \mu + B_i + M_j + C_k + MC_{jk} + e_{ijk}
\]

where \(Y_{ijk}\) is an observation, \(\mu\) is the experimental mean, \(B_i\) is the block (community) effect, \(M_j\) is the maize maturity type effect, \(C_k\) is the CPLM effect, \(MC_{jk}\) is the maize maturity type and CPLM interaction effect and \(e_{ijk}\) is the error. Treatment means of significant difference were separated using the least significant difference (LSD) test at a probability level of 0.05. Pearson’s correlation was used to establish the relationship between grain yield and other measured variables. We also calculated the square of the correlation coefficient and multiplied it by 100 to determine the proportion of variation of \(Y\) variables attributed to \(X\) (Armstrong 2019).

3 Results

3.1 Soil Physical Properties

The soil temperature at vegetative, tasseling and harvest growths of maize for CPLM were significantly lower relative to that of the control treatment during 2017 and 2018 in both regions (Table 1). The soil temperature for CPLM with maize planted on the same day declined \((p<0.05)\) at all growth stages of maize compared with that of the CPLM planted 2 weeks after maize during 2017 in both regions (Table 1). In 2018, the soil temperature for CPLM with maize planted on the same day reduced significantly relative to that of CPLM planted 2 weeks after maize at vegetative growth of maize in both regions and at tasseling growth of maize in Northern Region (Table 1). However, during 2018 in the Northern Region, the soil temperature at harvest growth of maize for CPLM with maize planted on the same day increased \((p<0.01)\) compared with that of CPLM planted 2 weeks after maize (Table 1). The soil bulk density at tasseling growth of maize for CPLM with maize planted on the same day declined significantly relative to that of the other CPLM and the control treatment during 2017 in the Northern Region (Table 1). Similarly, the soil bulk density at tasseling (2018) and harvest (2017) growths of maize were not significantly different among the CPLM in both regions (Table 1).

3.2 Soil Chemical Properties

The CPLM had a significant effect on soil pH, OC, TN and AP during the 2017 and 2018 seasons in both regions (Table 2). In the Upper East Region during 2017, the soil pH for CPLM planted 2 weeks after maize was higher \((p<0.05)\) than that of the other CPLM and the control treatment (Table 2). The soil OC increased significantly with CPLM relative to the control treatment but was not statistically different among the CPLM in the Upper East Region (Table 1). The soil moisture at vegetative, tasseling and harvest growths of maize for CPLM increased significantly compared with that of control treatment but were not significantly different among CPLM in both regions (Table 1).

3.3 Soil Biological Properties

The CPLM showed a significant effect on MBC, MBN and SMQ during 2017 and 2018 in both regions (Table 3). The MBC of the CPLM increased \((p<0.01)\) by 13–51% during...
| Cowpea living mulch | Vegetative 2017 | Vegetative 2018 | Tasseling 2017 | Tasseling 2018 | Harvest 2017 | Harvest 2018 |
|---------------------|-----------------|-----------------|-----------------|-----------------|---------------|---------------|
| No mulch (control)  | 29.1 ± 0.37A    | 29.1 ± 0.44A    | 28.2 ± 0.18A    | 29.4 ± 0.41A    | 30.9 ± 0.57A  | 33.1 ± 0.71A  |
| CSDM                | 28.0 ± 0.26C    | 27.8 ± 0.20C    | 27.1 ± 0.06C    | 28.3 ± 0.32C    | 29.5 ± 0.40C  | 32.6 ± 0.69A  |
| C1WAM               | 28.3 ± 0.26BC   | 28.4 ± 0.22B    | 27.6 ± 0.19B    | 28.6 ± 0.43BC   | 29.8 ± 0.56BC | 31.4 ± 0.37B  |
| C2WAM               | 28.6 ± 0.35B    | 28.8 ± 0.31A    | 28.0 ± 0.19A    | 28.9 ± 0.39B    | 30.1 ± 0.51B  | 31.3 ± 0.42B  |

*Vegetative and Tasseling* are **precipitation events** in the <country>, as recorded in the *Vegetative and Tasseling* table. *Harvest* is the period in which planting occurred. *Vegetative* is the period in which cowpea living mulch was planted. *Tasseling* is the period in which cowpea living mulch was planted 1 week after maize. *CSDM* cowpea living mulch was planted 1 week after maize; *C1WAM* cowpea living mulch was planted 1 week after maize; *C2WAM* cowpea living mulch was planted 2 weeks after maize; *p* > 0.05; *p* ≤ 0.05 and **p** ≤ 0.01

| Cowpea living mulch | Soil temperature (°C) | Soil moisture (cm^3^-1 × 10^2) |
|---------------------|------------------------|-------------------------------|
| No mulch (control)  | 13.2 ± 0.02A           | 8.3 ± 0.80A                   |
| CSDM                | 13.3 ± 0.02A           | 8.6 ± 0.70A                   |
| C1WAM               | 13.2 ± 0.02A           | 8.4 ± 0.80A                   |
| C2WAM               | 13.2 ± 0.02A           | 8.8 ± 0.80A                   |

| Cowpea living mulch | Soil bulk density (g cm^-3) | Soil moisture (cm^3^-1 × 10^2) |
|---------------------|-------------------------------|-------------------------------|
| No mulch (control)  | 1.3 ± 0.04A                  | 5.0 ± 0.30B                   |
| CSDM                | 1.6 ± 0.02A                  | 5.6 ± 0.60A                   |
| C1WAM               | 1.6 ± 0.03A                  | 5.2 ± 0.50A                   |
| C2WAM               | 1.6 ± 0.03A                  | 5.5 ± 0.60A                   |

Data are mean ± standard error of mean. Values with the same letters in a column under a parameter are not significantly different from each other according to the LSD test. *CSDM* cowpea living mulch with maize planted on the same day; *C1WAM* cowpea living mulch planted 1 week after maize; *C2WAM* cowpea living mulch planted 2 weeks after maize; *p* > 0.05; *p* ≤ 0.05 and **p** ≤ 0.01
### Table 2  Soil chemical properties affected by cowpea living mulch in the Northern and Upper East regions of Ghana, 2017 and 2018 cropping seasons

|                      | pH (1:2.5, Soil: H₂O) | Organic carbon (g kg⁻¹) | Total nitrogen (g kg⁻¹) | Available phosphorus (mg kg⁻¹) |
|----------------------|------------------------|-------------------------|-------------------------|-------------------------------|
|                      | 2017       | 2018       | 2017       | 2018       | 2017       | 2018       | 2017       | 2018       |
| **Cowpea living mulch** |           |            |            |            |            |            |            |            |
| Northern Region      |           |            |            |            |            |            |            |            |
| No mulch (control)   | 5.9 ± 0.05A | 5.7 ± 0.16A | 4.8 ± 0.28B | 5.5 ± 0.28B | 0.5 ± 0.02B | 0.6 ± 0.03B | 4.6 ± 0.30B | 5.0 ± 0.42B |
| CSDM                 | 5.7 ± 0.06A | 5.7 ± 0.15A | 6.2 ± 0.44A | 6.5 ± 0.30A | 0.7 ± 0.05A | 0.7 ± 0.05A | 6.5 ± 0.60A | 9.4 ± 0.71A |
| C1WAM                | 5.8 ± 0.05A | 5.8 ± 0.11A | 5.9 ± 0.43A | 7.1 ± 0.25A | 0.7 ± 0.04A | 0.7 ± 0.07A | 6.5 ± 0.51A | 10.2 ± 0.55A |
| C2WAM                | 5.7 ± 0.07A | 5.7 ± 0.15A | 6.1 ± 0.39A | 6.9 ± 0.39A | 0.6 ± 0.02A | 0.7 ± 0.04A | 6.8 ± 0.54A | 9.2 ± 0.74A |
| **p-value**          | ns         | ns         | *          | **         | *          | **         | *          | **         |
| Upper East Region    |           |            |            |            |            |            |            |            |
| No mulch (control)   | 5.2 ± 0.22B | 5.1 ± 0.12A | 4.5 ± 0.27B | 4.4 ± 0.15B | 0.6 ± 0.07B | 0.6 ± 0.06C | 4.2 ± 0.61B | 5.5 ± 0.57B |
| CSDM                 | 5.3 ± 0.27B | 5.1 ± 0.16A | 5.4 ± 0.48A | 5.3 ± 0.25A | 0.7 ± 0.09A | 0.7 ± 0.07B | 9.1 ± 0.78A | 9.4 ± 1.01A |
| C1WAM                | 5.2 ± 0.30B | 5.2 ± 0.14A | 5.6 ± 0.50A | 5.5 ± 0.26A | 0.8 ± 0.09A | 0.7 ± 0.06B | 8.2 ± 1.27A | 10.3 ± 0.81A |
| C2WAM                | 5.5 ± 0.32A | 5.0 ± 0.14A | 5.5 ± 0.51A | 5.1 ± 0.37A | 0.7 ± 0.07A | 0.8 ± 0.06A | 8.8 ± 1.01A | 10.2 ± 1.10A |
| **p-value**          | *          | ns         | **         | **         | **         | **         | **         | **         |

Data are mean ± standard error of mean. Values with the same letters in a column under a parameter are not significantly different from each other according to the LSD test. CSDM cowpea living mulch with maize planted on the same day; C1WAM cowpea living mulch planted 1 week after maize; C2WAM cowpea living mulch planted 2 weeks after maize; *p > 0.05; **p ≤ 0.05 and ***p ≤ 0.01
Table 3  Soil biological properties affected by cowpea living mulch in the Northern and Upper East regions of Ghana, 2017 and 2018 cropping seasons

| Cowpea living mulch | Microbial biomass (g kg⁻¹) | Microbial quotient (%) |
|---------------------|-----------------------------|------------------------|
|                     | Carbon                      | Nitrogen               | 2017  | 2018  | 2017  | 2018  |
| Northern Region     |                             |                        |       |       |       |       |
| No mulch (control)  | 111.3±1.93B                 | 117.5±3.23B            | 12.0±1.82B | 19.6±5.66B | 2.4±0.12B | 2.2±0.13C |
| CSDM                | 162.5±7.26A                 | 169.4±15.71A           | 25.4±5.48A | 36.1±3.91A | 2.7±0.16AB | 2.6±0.16AB |
| C1WAM               | 174.5±7.69A                 | 173.1±9.13A            | 31.8±5.57A | 49.1±5.81A | 3.1±0.21A  | 2.4±0.10BC |
| C2WAM               | 168.2±8.48A                 | 192.9±8.93A            | 29.9±4.50A | 44.5±6.28A | 2.9±0.22AB | 2.8±0.15A  |
| p-value             |                             |                        | **     | **    |     * |     ** |
| Upper East Region   |                             |                        |         |       |       |       |
| No mulch (control)  | 87.4±2.34B                  | 88.1±2.76C             | 17.2±1.43B | 12.6±1.83B | 2.0±0.08B  | 2.0±0.07C  |
| CSDM                | 132.6±2.54A                 | 135.0±3.76B            | 23.7±2.27A | 27.0±5.43A | 2.6±0.20A  | 2.6±0.08BC |
| C1WAM               | 133.8±6.17A                 | 149.3±6.02AB           | 22.8±2.28AB | 31.1±4.58A | 2.6±0.31A  | 2.8±0.15B  |
| C2WAM               | 135.1±3.00A                 | 163.1±15.51A           | 28.5±2.39A | 22.9±3.25A | 2.7±0.28A  | 3.4±0.48A  |
| p-value             |                             |                        | **     | **    |     * |     ** |

Data are mean± standard error of mean. Values with the same letters in a column under a parameter are not significantly different from each other according to the LSD test. CSDM cowpea living mulch with maize planted on the same day; C1WAM cowpea living mulch planted 1 week after maize; C2WAM cowpea living mulch planted 2 weeks after maize; *p > 0.05; *p ≤ 0.05 and **p ≤ 0.01

2017 and 52–69% during 2018 compared with that of the control treatment in both regions (Table 3). During 2018 in the Upper East Region, the MBC of CPLM with maize planted on the same day decreased (p < 0.05) relative to that of CPLM planted 2 weeks after maize (Table 3). The MBN of the CPLM increased (p < 0.01) by 45–142% relative to that of the control treatment but was not significantly different among the CPLM during 2017 and 2018 in both regions (Table 3). The SMQ of the CPLM increased (p < 0.05) by 21–30% during 2017 and 18–45% during 2018 relative to that of the control treatment in both regions (Table 3). During 2018, the SMQ of CPLM planted 2 weeks after maize increased significantly compared with that of CPLM planted 1 week after maize in both regions and CPLM with maize planted on the same day in the Upper East Region (Table 3).

3.4 Soil Quality Index

The first three PCs had eigenvalues of above one and the individual PCs accounted for more than 10% of the total variation in the soil data set for both seasons in the Northern and Upper East regions (Table 4). In both regions, PC1 accounted for the highest (27–40%) total variation in the data set compared with the other two PCs (Table 4). In the Northern Region, a total of four out of the sixteen indicators were selected as minimum data set during 2017 whereas during 2018 five out of the sixteen indicators were selected as minimum data set (Tables 4 and 5). The minimum data set for 2017 included TN (PC1), soil moisture at vegetative and tasseling growths of maize (PC2) and MBC (PC3) (Table 5). The minimum data set for 2018 in the Northern Region were soil temperature at tasseling growth of maize (PC1), soil moisture at vegetative growth of maize and OC (PC2) and soil bulk density at vegetative growth of maize as well as MBC (PC3) (Table 5). In the Upper East Region, a total of four out of sixteen indicators were selected as minimum data during 2017 and 2018 (Tables 5 and 6). The minimum data set for 2017 included soil temperature at tasseling stage of maize (PC1), SMQ (PC2), soil bulk density at tasseling stage of maize and AP (PC3) (Table 5). That of 2018 were pH (PC1), MBC (PC2) and soil temperature at tasseling stage of maize as well as soil bulk density at vegetative growths of maize (PC3) (Table 5).

Figure 3 shows the effect of CPLM on soil biological, chemical and physical subquality indices and SQI during 2017 and 2018 in both regions. The soil biological subquality index of the CPLM was 43–80% higher than that of the control treatment during 2017 and 2018 in both regions. The soil chemical subquality index of the CPLM increased 25–38% compared with the control treatment during both years in the Northern Region whereas in the Upper East Region, it increased by 100% during 2017 (Fig. 3). The soil physical subquality index of the CPLM increased by 25% during both years in the Northern Region and 11% during 2017 in the Upper East Region compared with the that of the control (Fig. 3). The SQI of the CPLM
increased by 33–100% relative to that of the control during 2017 and 2018 in both regions (Fig. 3).

### 3.5 Grain and Stover Yields

Maize grain yield showed a significant response to CPLM during 2017 and 2018 in both regions (Table 7). Maize grain yield of the CPLM increased ($p < 0.05$) by 34% during 2017 and 37% during 2018 relative to the control treatment in the Northern Region (Table 7). In the Upper East Region during 2017, the grain yield of the CPLM increased ($p < 0.01$) by 84% compared with that of the control treatment (Table 7). During 2018 in the Upper East Region, grain yield decreased with CPLM, and the control treatment significantly increased grain yield relative to that of CPLM with maize planted on the same day but was not significantly different from that of CPLM planted 1 week and 2 weeks after maize (Table 7).

The maize maturity type had a significant effect on grain and stover yields during 2017 and 2018 in both regions (Table 7). The grain yield for the early maze increased ($p < 0.05$) relative to that of extra-early and medium maize during 2017 in the Northern Region (Table 7). The stover yield for medium maize increased significantly compared with that of the extra-early maize during 2017 in the Northern Region but a positive correlation between them in the Upper East Region.

The variation in soil physical properties between the two regions could be attributed to the difference in weather conditions, soil texture and OC content of the soils in both
Table 5  Coefficient of correlation (r) among soil physical, chemical and biological properties in the Northern Region of Ghana, 2017 and 2018 cropping seasons

|       | TV     | TT     | TH     | BV     | BT     | BH     | MV     | MT     | MH     | pH     | OC     | TN     | AP     | MBC    | MBN    | SMQ    |
|-------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
|       | 1      |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| 2017  |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| TV    |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| TT    | 0.01 ns| 1      |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| TH    | 0.31*  | 0.19 ns| 1      |        |        |        |        |        |        |        |        |        |        |        |        |        |
| BV    | 0.18 ns| 0.22 ns|        | 0.50** | 1      |        |        |        |        |        |        |        |        |        |        |        |
| BT    | 0.03 ns| 0.16 ns| 0.46** | 0.23 ns| 1      |        |        |        |        |        |        |        |        |        |        |        |
| BH    | 0.26 ns| 0.02 ns| 0.57** | 0.29*  | 0.52** | 1      |        |        |        |        |        |        |        |        |        |        |
| MV    | 0.57** | 0.16 ns| 0.02 ns| 0.21 ns| 0.08 ns| 0.05 ns| 1      |        |        |        |        |        |        |        |        |        |
| MT    | 0.17 ns| 0.05 ns| 0.44** | 0.35** | 0.56** | 0.11 ns| 0.24 ns| 1      |        |        |        |        |        |        |        |        |
| MH    | 0.01 ns| 0.19 ns| 0.45** | 0.29*  | 0.32*  | 0.17 ns| 0.21 ns| 0.51** | 1      |        |        |        |        |        |        |        |
| pH    | 0.07 ns| 0.02 ns| 0.39** | 0.13 ns| 0.18 ns| 0.17 ns| 0.36** | 0.25 ns| 1      |        |        |        |        |        |        |        |
| OC    | 0.12 ns| 0.27 ns| 0.07 ns| 0.09 ns| 0.15 ns| 0.19 ns| 0.15 ns| 0.1 ns | 1      |        |        |        |        |        |        |        |
| TN    | 0.17 ns| 0.30 ns| 0.52** | 0.35** | 0.30*  | 0.24 ns| 0.26 ns| 0.29*  | 0.47** | 0.32*  | 0.48** | 1      |        |        |        |        |
| AP    | 0.24 ns| 0.37** | 0.40** | 0.33*  | 0.21 ns| 0.14 ns| 0.38** | 0.36** | 0.32*  | 0.48** | 0.64** | 1      |        |        |        |        |
| MBC   | 0.20 ns| 0.14 ns| 0.02 ns| 0.16 ns| 0.04 ns| 0.40** | 0.11 ns| 0.14 ns| 0.48** | 0.28*  | 0.34** | 1      |        |        |        |        |
| MBN   | 0.30*  | 0.28*  | 0.35*  | 0.29** | 0.09 ns| 0.05 ns| 0.12 ns| 0.29*  | 0.15 ns| 0.48** | 0.07 ns| 1      |        |        |        |        |
| SMQ   | 0.35*  | 0.11 ns| 0.09 ns| 0.05 ns| 0.12 ns| 0.19 ns| 0.29*  | 0.15 ns| 0.04 ns| 0.27 ns| 0.50** | 0.21 ns| 0.50** | 0.07 ns| 1      |        |
| 2018  |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| TV    | 0.87** | 1      |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| TT    |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| TH    | 0.38** | 0.35*  | 1      |        |        |        |        |        |        |        |        |        |        |        |        |        |
| BV    | 0.35*  | 0.34*  | 0.10 ns| 1      |        |        |        |        |        |        |        |        |        |        |        |        |
| BT    | 0.43** | 0.45** | 0.62** | 0.06 ns| 1      |        |        |        |        |        |        |        |        |        |        |        |
| BH    | 0.13 ns| 0.25 ns| 0.09 ns| 0.03 ns| 0.01 ns| 1      |        |        |        |        |        |        |        |        |        |        |
| MV    | 0.06 ns| 0.01 ns| 0.59** | 0.12 ns| 0.47** | 0.27 ns| 1      |        |        |        |        |        |        |        |        |        |
| MT    | 0.54** | 0.63** | 0.24 ns| 0.04 ns| 0.43** | 0.16 ns| 0.07 ns| 1      |        |        |        |        |        |        |        |        |
| MH    | 0.69** | 0.74** | 0.01 ns| 0.54** | 0.01 ns| 0.26 ns| 0.30*  | 0.55** | 1      |        |        |        |        |        |        |        |
| pH    | 0.65** | 0.69** | 0.52** | 0.23 ns| 0.48** | 0.08 ns| 0.36** | 0.46** | 0.42** | 1      |        |        |        |        |        |        |
| OC    | 0.05 ns| 0.11 ns| 0.20 ns| 0.26 ns| 0.05 ns| 0.23 ns| 0.29*  | 0.12 ns| 0.11 ns| 0.08 ns| 1      |        |        |        |        |        |
| TN    | 0.10 ns| 0.21 ns| 0.10 ns| 0.25 ns| 0.10 ns| 0.28 ns| 0.21 ns| 0.11 ns| 0.31*  | 0.20 ns| 0.04 ns| 0.24 ns| 0.30** | 1      |        |        |
| AP    | 0.10 ns| 0.10 ns| 0.22 ns| 0.09 ns| 0.03 ns| 0.12 ns| 0.34*  | 0.36** | 0.11 ns| 0.04 ns| 0.24 ns| 0.30** | 1      |        |        |        |
| MBC   | 0.12 ns| 0.14 ns| 0.02 ns| 0.19 ns| 0.21 ns| 0.21 ns| 0.34*  | 0.05 ns| 0.12 ns| 0.68** | 0.36** | 0.28*  | 1      |        |        |        |
| MBN   | 0.14 ns| 0.20 ns| 0.19 ns| 0.01 ns| 0.25 ns| 0.40** | 0.44** | 0.33*  | 0.32*  | 0.36** | 0.29*  | 0.28*  | 0.28 ns| 1      |        |        |
| SMQ   | 0.22 ns| 0.29** | 0.19 ns| 0.01 ns| 0.38** | 0.07 ns| 0.12 ns| 0.34*  | 0.17 ns| 0.24 ns| 0.09 ns| 0.08 ns| 0.18 ns| 0.65** | 0.00 ns| 1      |

*a*Temperature at vegetative stage of maize, *b*temperature at tasseling of maize, *c*temperature at harvest of maize, *d*bulk density at vegetative stage of maize, *e*bulk density at tasseling of maize, *f*bulk density at harvest of maize, *g*möisure at vegetative stage of maize, *h*möisure at tasseling of maize, *i*möisure at harvest of maize, *j*organic carbon, *k*total nitrogen, *l*available phosphorus, *m*microbial biomass carbon, *n*microbial biomass nitrogen, *o*soil microbial quotient. **p > 0.05, *p ≤ 0.05 and **p ≤ 0.01
|     | TV   | TT   | TH   | BV   | BT   | BH   | MV   | MT   | MH   | pH   | OC   | TN   | AP   | MBC  | MBN  | SMQ  |
|-----|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| 2017|      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| TV  | 1    |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| TT  | 0.08 | 1    |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| TH  | -0.07| 0.73 | 1    |      |      |      |      |      |      |      |      |      |      |      |      |      |
| BV  | 0.10 | 0.62 | 0.35 | 1    |      |      |      |      |      |      |      |      |      |      |      |      |
| BT  | 0.40 | 0.42 | 0.09 | 0.45 | 1    |      |      |      |      |      |      |      |      |      |      |      |
| BH  | -0.17| 0.65 | 0.60 | 0.44 | 0.07 | 1    |      |      |      |      |      |      |      |      |      |      |
| MV  | -0.36| -0.52| -0.38| -0.40| -0.51| -0.36| 1    |      |      |      |      |      |      |      |      |      |
| MT  | -0.15| -0.28| -0.31| -0.31| -0.27| -0.13| 0.47| 1    |      |      |      |      |      |      |      |      |
| MH  | -0.17| -0.36| -0.19| -0.53| -0.05| -0.58| 0.40| 0.31| 1    |      |      |      |      |      |      |      |
| pH  | 0.03 | -0.80| -0.53| -0.67| -0.52| -0.61| 0.52| 0.23| 0.37| 1    |      |      |      |      |      |      |
| OC  | 0.08 | -0.70| -0.77| -0.37| -0.31| -0.68| 0.42| 0.25| 0.25| 0.75| 1    |      |      |      |      |      |
| TN  | -0.03| -0.76| -0.71| -0.61| -0.49| -0.64| 0.31| 0.29| 0.19| 0.31| 0.80| 0.82| 1    |      |      |      |
| AP  | -0.12| -0.29| -0.47| -0.06| 0.05| -0.46| 0.21| 0.28| 0.29| 0.11| 0.44| 0.29| 1    |      |      |      |
| MBC | -0.51| -0.32| -0.46| -0.00| 0.18| -0.29| 0.52| 0.45| 0.26| 0.07| 0.26| 0.26| 0.53| 1    |      |      |
| MBN | -0.20| 0.15 | 0.24 | 0.08 | 0.04 | 0.34 | 0.31| 0.20| 0.39| 0.10| 0.27| 0.11| 0.51| 0.59| 1    |
| SMQ | -0.48| 0.33 | 0.33 | 0.22 | 0.07 | 0.35 | 0.06| 0.15| 0.01| -0.54| -0.67| -0.48| -0.07| 0.50| 0.12| 1    |
| 2018|      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| TV  | 1    |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
| TT  | 0.13 | 0.33 | 1    |      |      |      |      |      |      |      |      |      |      |      |      |      |
| TH  | 0.81 | 0.23 | 0.42 | 1    |      |      |      |      |      |      |      |      |      |      |      |      |
| BV  | -0.53| 0.11 | 0.51 | 1    |      |      |      |      |      |      |      |      |      |      |      |      |
| BT  | -0.45| -0.22| 0.16 | 0.43 | 0.16 | 0.33 | 1    |      |      |      |      |      |      |      |      |      |
| BH  | -0.16| 0.04 | 0.18 | 1    |      |      |      |      |      |      |      |      |      |      |      |      |
| MV  | -0.32| -0.26| 0.15 | 0.38 | 0.21 | 0.08 | 0.33 | 1    |      |      |      |      |      |      |      |      |
| MT  | -0.19| -0.34| -0.24| 0.06 | -0.37| -0.24| 0.32 | 0.32| 1    |      |      |      |      |      |      |      |
| MH  | -0.24| -0.27| 0.40 | 0.21 | -0.38| 0.26 | 0.04 | 1    |      |      |      |      |      |      |      |      |
| pH  | 0.39 | 0.37 | -0.35| -0.36| 0.09 | -0.40| -0.13| 0.46| 1    |      |      |      |      |      |      |      |
| OC  | 0.16 | 0.10 | 0.34 | -0.43 | 0.27 | -0.13| 0.20 | 0.09 | 0.50| 1    |      |      |      |      |      |      |
| TN  | 0.13 | 0.15 | -0.06| -0.37| 0.27 | -0.37| 0.32 | 0.33| 0.64| 0.54| 1    |      |      |      |      |      |
| AP  | -0.43| -0.34| 0.15 | 0.01 | 0.21 | 0.31 | 0.21 | -0.40| -0.03| -0.03| 1    |      |      |      |      |      |
| MBC | -0.37| -0.03| 0.11 | 0.00 | 0.35 | 0.27 | 0.11 | 0.32| 0.44| 0.10| 1    |      |      |      |      |      |
| MBN | -0.16| 0.28 | -0.23| 0.04 | -0.06| 0.31 | 0.10 | 0.24| 0.39| 0.38| 0.60| 0.49| 1    |      |      |      |
| SMQ | -0.45| 0.08 | 0.49 | 0.35 | 0.22 | -0.07| 0.10 | 0.23| 0.30| -0.18| -0.31| 0.10 | 0.78| 0.22| 1    |

*Temperature at vegetative stage of maize, "temperature at tasseling of maize, ⁃temperature at harvest of maize, ⁴bulk density at vegetative stage of maize, ⁵bulk density at tasseling of maize, ⁶bulk density at harvest of maize, ⁷moisture at vegetative stage of maize, ⁸moisture at tasseling of maize, ⁹moisture at harvest of maize, ¹⁰organic carbon, ¹¹total nitrogen, ¹²available phosphorus, ¹³microbial biomass carbon, ¹⁴microbial biomass nitrogen, ¹⁵soil microbial quotient. ²p > 0.05, ³p ≤ 0.05 and ⁴⁴p ≤ 0.01
regions (Tetteh et al. 2016). The significant response of soil temperature, bulk density and moisture to the CPLM could be explained by the presence of the cowpea as a living mulch. The canopy cover of the cowpea reduces the direct intensity of the sunlight to the surface of the soil which affects soil temperature. The variation in soil temperature among the CPLM might be attributed to the effect of time of planting CPLM on the growth of the cowpea canopy. The results support earlier findings that mulched fields reduce soil temperature relative to non-mulched fields (Yin et al. 2016; Chang et al. 2020). The cowpea canopy cover on the soil surface reduces evaporation from the soil which affects soil moisture. Our results support earlier findings that living mulch fields increase soil moisture content relative to that of control fields (Sharma et al. 2010; Wiggans et al. 2012; Trail et al. 2016; Qu et al. 2019). The variation in soil moisture between CPLM planted 1 week and 2 weeks after maize in the Upper East Region could be explained by the difference in the establishment and growth of the CPLM. The CPLM planted 1 week after maize recorded a higher amount of rainfall at vegetative growth of cowpea than the other CPLM in the region. A higher amount of rainfall received at vegetative growth of cowpea results in poor seedling establishment and growth (Abdul Rahman et al. 2021).

The difference in soil chemical properties between the two regions could be explained by the difference in the parent material of the soils in the two regions (Tetteh et al. 2016). The significant increase in soil pH for CPLM planted 2 weeks after maize in the Upper East Region could be explained by the relationship between soil pH and moisture content at harvest of maize. The soil pH was positively correlated with soil moisture content at harvest growth of maize. The soil moisture content at harvest growth of maize for CPLM planted 2 weeks after maize was significantly higher than that of the control and CPLM planted 1 week after maize. This supports the finding that an increase in soil moisture content corresponds to an increase in soil pH (Zárate-Valdez et al. 2006). However, this result is in contrast with findings of other studies that reported no significant difference in the soil pH of a living mulch or cover crop.
Table 7  Maize grain and stover yields affected by cowpea living mulch and maize maturity type in the Northern and Upper East regions of Ghana, 2017 and 2018 cropping seasons

| Cowpea living mulch | Grain yield (kg ha⁻¹) | Stover yield (kg ha⁻¹) |
|---------------------|----------------------|-----------------------|
|                     | Upper East 2017 2018 | Upper East 2017 2018 |
| No mulch (control)  | 1605.6 ± 199.54B     | 4027.2 ± 376.75A      |
| CSDM                | 2223.3 ± 123.93A     | 4406.1 ± 412.46A      |
| C1WAM               | 2277.8 ± 174.51A     | 4217.1 ± 461.75A      |
| C2WAM               | 1946.7 ± 148.95AB    | 4382.8 ± 362.70A      |

| p-value             | ns                   | ns                    |

| Maize maturity type | Grain yield (kg ha⁻¹) | Stover yield (kg ha⁻¹) |
|---------------------|----------------------|-----------------------|
| Abontem (extra-early) | 1788.3 ± 131.36B     | 3531.2 ± 187.90B      |
| Omankwa (early)     | 2241.7 ± 184.70A     | 3737.1 ± 268.61B      |
| Obatanpa (medium)   | 2010 ± 123.77AB      | 5547.5 ± 306.90A      |

| p-value             | ns                   | ns                    |

Data are mean ± standard error of mean. Values with the same letters in a column under a parameter are not significantly different from each other according to the LSD test. CSDM cowpea living mulch with maize planted on the same day; C1WAM cowpea living mulch planted 1 week after maize; C2WAM cowpea living mulch planted 2 weeks after maize; *p > 0.05; **p ≤ 0.05 and ***p ≤ 0.01.
difference in soil AP content between living mulch system and non-living mulch system.

The lower values of soil biological properties recorded in the Upper East Region could be explained by the lower values of soil chemical properties especially OC. The response of soil MBC to the CPLM could be partly explained by the positive correlation between the soil MBC and OC. This is in line with the findings that living mulch systems increase soil MBC relative to that of non-living mulch systems (Duda et al. 2003; Rabary et al. 2008; Gattullo et al. 2020). The difference in MBC between CPLM with maize planted on the same day and CPLM planted 2 weeks after maize in Upper East Region could be explained by the positive and significant correlation between the MBC and TN. Moore et al. (2000) reported a positive and significant correlation between TN and MBC from a cropping systems study conducted in Iowa state in the USA. The significant increase in soil MBN between CPLM and the control treatment could be partly attributed to the increase in soil OC, TN and MBC of the CPLM system. The soil TN, OC and MBC were positively correlated with the soil MBN. This result agrees with earlier reports that living mulch systems increase soil MBN relative to non-living systems (Duda et al. 2003; Kaneda et al. 2012). The SMQ which is the ratio of soil MBC and OC indicates the availability of substrate to soil microbes and the SMQ values recorded in this study are within the range of the SMQ values of agricultural land (Anderson 2003; Paz-Ferreiro and Fu 2016). The variation in SMQ between CPLM and the control treatment could be due to the significant differences in the soil MBC values recorded by the CPLM and the control treatment. The SMQ was positively correlated with the MBC, meaning as the MBC increases, SMQ also increases. The results of the SMQ in this study are in line with the finding that the long-term intercropping (rotation) field recorded a higher SMQ value than that of a monocropping field (Anderson 2003). Similarly, the variation in SMQ among the CPLM in both regions could be explained by the effect of the time of planting the CPLM on MBC and its relationship with SMQ.

The results of the correlation matrix analyses followed a similar trend to other studies that used PC and correlation matrix analyses to select minimum data set for soil quality assessment (Andrews et al. 2002; Abdul Rahman et al. 2019). The higher percentage variation recorded by PC1 in both regions could be due to the correlation among most of the indicators selected as a minimum data set. The inclusion of soil temperature, moisture and bulk density in the minimum data set supports earlier reports that soil moisture conservation and temperature reduction are among key features of mulching effects on soil physical properties (Wiggans et al. 2012; Trail et al. 2016; Chang et al. 2020). The selection of soil chemical properties such as pH, OC, TN and AP as part of the minimum data set is in line with minimum data set indicators reported by other studies (Andrews et al. 2002; Abdul Rahman et al. 2019). The inclusion of MBC as well as SMQ in the minimum data confirms the importance of these biological properties as key soil quality indicators (Anderson 2003; Paz-Ferreiro and Fu 2016).

The increase in soil chemical and biological subquality indices for the CPLM in both regions could be due to the presence of the cowpea as living mulch. The CPLM significantly improved the content of selected indicators as minimum data set through cowpea leaf litter for nutrient cycling and biological nitrogen fixation. In line with our results, several authors have reported a significant increase in the selected chemical and biological indicators as minimum data set in living mulch cropping systems especially with the use of leguminous crops (King and Berry 2005; Qian et al. 2015; Gattullo et al. 2020). The increase in SQI for the CPLM in both regions could be attributed to the higher physical, chemical and biological subquality indices scored by the CPLM system. The result of the SQI agrees with the findings that living mulch cropping systems improve soil properties relative to non-living mulch systems (King and Berry 2005; Qian et al. 2015; Gattullo et al. 2020). Given that a decade (2001–2011) average of land area cultivated with maize is 97016 ha in the Northern Region and 77% of this land area is cultivated by households with <2 ha of land, then the CPLM technology has the potential to improve the soil quality of 74,702 ha of land area under cultivation of maize in the region (Amanor-Boadu et al. 2015; CountrySTAT 2021). Similarly, in the Upper East Region, given that the 10-year average of land area cultivated with maize is 20439 ha and 94% of the land is cultivated by households with <2 ha of land, then the CPLM technology has the potential for soil fertility amelioration for 19,213 ha of land area under cultivation of maize in the region (Amanor-Boadu et al. 2015; CountrySTAT 2021).

The difference in grain and stover yields between the two regions could be due to the variation in soil properties and rainfall patterns of both regions. In line with our findings, other authors have reported higher maize grain yield for the Northern Region relative to the Upper East Region (Amanor-Boadu et al. 2015; MoFA 2017). The significant response of maize grain yield to CPLM in both regions could be partly explained by the positive correlation between grain yield and SQI in both regions. The relationship shows that about 26–40% variation in grain yield could be explained by the difference in the SQI of the CPLM in both regions. This result is in consonance with other reports that living mulch systems increase the grain yield of main crops relative to that of non-living systems (Jamshidi et al. 2013; Trail et al. 2016; Bhaskar et al. 2018). The variation in grain yield between CPLM planted 2 weeks after maize and CPLM with maize planted on the same day in Upper East Region may be due to poor establishment and growth of the CPLM which
might result in competition for nutrients and light between
the maize and cowpea. The grain yield showed a negative
correlation with the amount of rainfall received at vegeta-
tive growth of the CPLM and this relationship contributed
about 85% of the variation in grain yield. Other studies
have also attributed the reduction in grain yield of living
mulch systems to competition for nutrients, light and water
(Jędrszczyk et al. 2005; Radicetti et al. 2018). The variation
in maize grain and stover yields among the maize maturity
types in both regions could be explained by differences in
the days to physiological maturity as well as the amount of
rainfall received at vegetative and reproductive growths of
the maize maturity type. In line with our results, other stud-
ies have reported how the distribution pattern of rainfall at
vegetative and reproductive growths of maize affect yield
(Waddington et al. 2007; Abdul Rahman et al. 2021).

5 Conclusion

Cowpea living mulch (CPLM) improved soil properties,
soil quality index and maize grain yield relative to that of
the control treatment in both regions. The effect of time of
planting CPLM on maize grain yield showed a negative
relationship with the amount of rainfall received during
the vegetative growth of the CPLM in both regions. Maize
maturity type did not affect ($p > 0.05$) grain yield but showed
a significant effect on stover. The results suggest that small-
holder maize-based farmers in northern Ghana and simi-
lar agro-ecologies in West Africa can intercrop cowpea as
living mulch especially 1–2 weeks after planting maize to
improve soil quality and increase maize grain yield. Depend-
ing on the calendar days of the cropping season in northern
Ghana, smallholder maize farmers can plant the different
maize maturity types particularly the early maturing type
for better and stable yields.

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Declarations

Conflict of Interest The authors declare no competing interests.

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