

Impact of sugarcane bagasse mulching boards on soil erosion and carrot productivity

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ABSTRACT

Sustainable crop production depends primarily on water and nutrients among other inputs. Mulching improves soil moisture and nutrient conservation as well as ameliorates soil erosion. We conducted two different experiments to examine the impact of mulch on soil erosion and the productivity of carrot (*Daucus carota* L.). Mulch used were sugarcane bagasse boards (SBB) and sugarcane bagasse chips (SBC). Each experiment consisted of three treatments in a completely randomized design with three replications. The first experiment under rainfall simulation consisted of 2 SBB and 4 SBB representing 25 and 50% soil surface coverage and no sugarcane bagasse (NSB) represented the control. Treatments in the second experiment were SBB, SBC, and NSB. The 4 SBB and 2 SBB significantly decreased ($p < 0.05$) erosion by 1.74 Mg ha^{-1} and 1.57 Mg ha^{-1} . However, there was no significant difference in mitigating erosion between the 4 SBB and 2 SBB. Compared to NSB, 4 SBB and 2 SBB again decreased runoff rate by 223 and 23%. There was no significant improvement in soil moisture retention, temperature, carrot yield, and water productivity under either mulch. Weed growth was significantly reduced at 104 and 72% by SBB and SBC. The yield gap between SBB and SBC was only 18.75%. Unlike the particulate SBC which is susceptible to erosion during runoff, the bulky SBB cannot easily be eroded by runoff. Hence the SBB was recommended for farmers due to its significant impact on ameliorating runoff and erosion, as well as curtailing weed growth under carrot production.

1. Introduction

Soil is the basic source of farmer's wealth (Bahadur, 2000). However, the adverse impact of erosion could deny sustainable production of most crops thereby making it difficult for farmers to realize their wealth. Soil erosion defined as the removal of topsoil from the surface of the earth (FAO, 2015) could be caused by wind, tillage, water (rain or irrigation), unscrupulous land preparation methods for crop farming, and so on. Soil erosion has been the principal cause of soil degradation (Lal, 2001). In some parts of the globe e.g. Ghana where cultivated lands are gradually degrading, soil erosion is a threat to food security (García-Ruiz et al., 2017).

While Civil Engineers are challenged with the impact of soil erosion

on structural failure in built environments, Agriculturists on the other hand are increasingly concerned with the vital soil nutrients loss through erosion resulting from runoff. Nonetheless, the topsoils containing soil biota, organic matter, and vital nutrients within the plow layer (20 to 30 cm depth) are most susceptible to erosion (Balasubramanian, 2017; Martínez-Mena et al., 2020).

Soil erosion is observed during Aeolian dust displacement, runoff from high precipitation, and or excessive irrigation. Although the degree of erosion could be delineated to soil type, land gradient, runoff rate, and recreational activities among others (Quan et al., 2020; Salesa and Cerdà, 2020), the impending challenge lies in its contribution to soil mining leaving agricultural soils infertile and degraded. Studies also showed that eroded sediments containing materials such as heavy

Abbreviations: SBB, sugarcane bagasse board; SBC, sugarcane bagasse chips; NSB, no sugarcane bagasse; Q, runoff rate; S₁, S₂, S₃, S₄, and S₅, first, second, third, fourth, and fifth rainfall simulation event; Y_{ABM}, aboveground biomass yield; Y_{BBM}, belowground biomass yield; Y_{TBM}, total biomass yield; Y_W, weed yield; WP_{TBM}, water productivity of total biomass.

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metals and chemical fertilizer constituents are major pollutants to a nearby surface and underground water resources (Lal, 2001; Plambeck, 2020).

Some of the principles developed by scientists to control erosion were reported in (Felix-Henningsen et al., 1997; Martínez-Mena et al., 2020; Xiong et al., 2018a). To withstand the threat posed by erosion, mulching was a key concept adopted to address soil erosion and its impact on crop production.

In addition to sunlight, nutrient, and aeration, plants need water for efficient growth and to produce high yields. But the impact of climate change has made it difficult to solely rely on seasonal rainfall for crop production. Meanwhile, rainfall variability has been predicted to increase in the future and that could greatly affect basic crop productivities (Thornton et al., 2014). It was therefore inevitable to incorporate irrigation in most crop production to supplement and ameliorate the adverse impact of recent unpredictable seasonal rainfalls. Similar to the natural rainfall, irrigation when applied beyond a threshold can equally contribute to erosion as a result of runoff.

Mulching involves covering the soil with any solid material to reduce soil surface exposed to the environment. In addition to reducing erosion, mulching was observed to be sustainable in managing agricultural water in crop production especially during drought seasons (Chen et al., 2019; Xiong et al., 2018b). Soil mulching in any crop production gained attention due to its effectiveness in controlling weed growth (Campiglia et al., 2010; Taak et al., 2020; Thankamani et al., 2016), harnessing soil moisture and nutrient retention (Gicheru, 1994; Martínez-Mena et al., 2020), regulating soil temperature (Chen et al., 2019; Pavlu et al., 2020), and reducing erosion (Nyawade et al., 2019), etc. In the past, much emphasis was laid on supplemental nutrient application to improve soil fertility for crop production (Jayne et al., 2015). Meanwhile, less attention was given to the crop's nutrient use efficiency, i.e. the amount of yield produced per unit amount of nutrient applied. This was because less account was rendered on the impact of erosion on nutrients leachate and losses in the soil.

Two main sources of mulch material are synthetic e.g. polythene sheet and organic sources e.g. biomass residue (Agro Eco, 2008). Polythene sheet widely used in the pineapple growing industry (Kleemann, 2011) for instance has an adverse residual impact on soil health. It doesn't undergo easy decomposition, neither is it easily removed from the crop field after usage. Most farmers are therefore compelled to resort to onsite burning practices, which do not only pose a serious threat to the environment but also aggravates global warming. Serrano-ruiz et al. (2020) reported that plastic mulching contaminates agricultural soils thereby contributing to global plastic pollution.

To minimize worldwide polyethylene pollution caused by plastic mulch, degradable (biodegradable and photodegradable) plastic sheets were produced as an alternative to the non-degradable plastic mulch (Serrano-ruiz et al., 2020). On the contrary, small to medium holder farmers could not advance utilizing the in situ degradable plastic mulch due to financial constraints. Regardless of the type, the increased application of plastics in modern agriculture is threatening to the natural ecosystem due to its residual deposits in aquatic and terrestrial habitats (Shah and Wu, 2020). There is therefore the need to practice organic mulching that seeks to utilize cheap and readily available raw material to curtail erosion and improve crop productivity. Biomass boards among other organic mulch materials incontrovertibly serve to propagate a win-win characteristic in this context, i.e. reducing erosion as well as improving soil health for sustainable crop production.

Globally, it was estimated that 87.94 megatons of biomass residues were produced annually from crops (Honorato-salazar and Sadhukhan, 2019). Biomass residue accounted for about 64% of Ghana's primary source of energy supply (Duku et al., 2011). The Mexican energy sector also explored residue from sugarcane in generating electricity and heat (Islas et al., 2007). Furthermore, in Ghana, Yakubu et al. (2020) observed aggravation in environmental pollution as an appreciable amount of crop residues were either burnt off or abandoned onsite.

Although biomass residue is noted for bioenergy production, a substantial amount abandoned onsite can exacerbate aquatic ecosystem pollution through erosion. Meanwhile, epidemiological studies (Mugica-Alvarez et al., 2018) revealed the impacts of emissions from sugarcane bagasse used as a biofuel on human health including respiratory challenges. Nonetheless, more sugarcane bagasse would be generated as the government of Ghana revamps a sugar factory that would use sugarcane as feedstock. It, therefore, remained unaddressed and a challenge on how the crop residue following sugar production would be disposed of without polluting the environment. Producing biomass mulching boards from sugarcane bagasse would otherwise reduce the pollution potential of the crop residue on the environment. Also promoting biomass mulch as a substitute for plastic mulch could alleviate global polyethylene pollution and the associated soil health threats.

Biomass residue generation has increased (Prasad et al., 2020) with global production estimated at 5010 Mt, and sugarcane accounted for 563 Mt in 2013 (Cherubin et al., 2018). Biomass residue such as dry grass and crop litter are commonly used in mulching to reduce erosion, weed growth, and to conserve soil nutrient and moisture. But when these biomass residues decompose or are wiped off the soil surface by runoff or strong winds, the topsoils are suddenly exposed to erosion. In that regard, reinforcing the given biomass residue into solid layers to form bulk boards could render the resulted mulch material durable and sustainable. These boards produced from crop residue are known as biomass boards. Sample biomass boards include bio-residue boards, fertilizer-impregnated boards, and compressed biomass (Onwona-Agyeman et al., 2002; Onwona-Agyeman et al., 2007; Onwona-Agyeman et al., 2015). Other biomass boards were produced from corn residue (Wu et al., 2015), sorghum bagasse (Kusumah et al., 2016), and sugarcane bagasse (Noor et al., 2020) as used in our study. Besides the agricultural perspective, similar sugarcane bagasse boards have been produced and explored as building materials (Yogitha et al., 2020) especially for indoor application (Nadhari et al., 2020). Sugarcane accounts for 80% of sugar production and the second largest crop for worldwide bioenergy production (Yang et al., 2020). Its residue availability for biomass mulching board production is therefore promising.

Given the challenge of erosion, a rainfall simulation experiment was conducted to elucidate the effect of sugarcane bagasse mulching board on runoff and soil erosion. A second experiment was conducted alongside to compare the effectiveness of sugarcane bagasse boards and their equivalent bagasse chips on improving soil health for carrot productivity.

The objectives of the study were to; (i) determine the quantity of sugarcane bagasse boards required to significantly reduce sediment transport under runoff, (ii) determine the comparative effects of sugarcane bagasse boards and sugarcane bagasse chips on soil temperature and moisture conservation, and (iii) determine the effect of sugarcane bagasse board and sugarcane bagasse chips on weed growth and carrot yield. It was hypothesized that regardless of percentage area mulched, sugarcane bagasse mulching board would minimize runoff and erosion rate. Also under an equal irrigation rate, carrot yield would be improved by sugarcane bagasse boards more than its equivalent bagasse chips.

2. Materials and methods

2.1. Experimental site description

The research was conducted in Accra, Ghana during the dry season on two different fields (Field A and B). Field A and B were located 300 m apart on a site (latitude 5.6506° N and longitude 0.1962° W) at the University of Ghana, Legon campus in Accra, Ghana. The experimental site lies at 61 m above sea level with an annual rainfall range of 800–1000 mm and an average daily temperature of 26.9 °C. The study area has two rainfall seasons and a dry season annually. A major rainy season starts in April and ends in July. The months of September to October mark the minor rainfall season while the dry season starts from

December and ends in March.

2.2. Experimental soils characteristics

The experimental area consists of savannah ochrosol (Yanquoi, 2014). Textural classification of soils on both fields A and B were sandy loam based on the USDA soil textural triangle chart (FAO, 2006). Characteristics of the experimental soils used are given in Table 1.

2.3. Field preparation and layout

Two different fields with regular slope profiles were selected for the sugarcane bagasse mulching board experiment. An experiment on field A was conducted to determine the effect of SBB on erosion. The second experiment on field B was a comparative study of SBB and SBC's impact on carrot productivity. The SBB was sourced from Japan and fabricated by Oshima et al. (2020). Both fields were grassland with limited to no stumps and shrubs. Weeds were initially brushed using a machete followed by herbicide application to obtain a weed-free soil surface. Finally, plots on both fields were demarcated.

2.3.1. Layout of field A

An area of 20 m × 15 m on a steep slope of 6.13° (10.74%) was demarcated for field A. There were nine mini-plots demarcated for treatment application. Each plot measured 200 cm × 50 cm (10,000 cm²). A walking space of 2 m was allowed between plots and 3 m between replicates.

Given each plot size, i.e. 200 cm × 50 cm, corrugated aluminum sheets were cut into equal dimensions (200 cm) as that of the length of the plots. As the experiment aimed at working on in situ field soil conditions, a thin shallow trench was carefully created to erect each of the aluminum sheets with minimal to no disturbance of topsoil within the respective plots. This was done to minimize any eventual loose soils adding up to transported sediments during runoff under simulated rainfall. The height of each erected aluminum sheet was 15 cm above the ground surface. The parallel erected aluminum sheets formed confinement that was used to house the SBBs along the slope of each plot on the field. With a final thin sheet installed upstream and perpendicular to the two parallel sheets, the base was left open to direct runoff into a catch can downslope.

The installation of aluminum sheets was done on all nine plots. The configuration of a plot following the aluminum sheets installation assumed the shape of a hollow cuboid with an opening at one end. The opening at the base of the aluminum sheet housing served as an exit for runoff. A galvanized metallic tray molded into H-flume was fixed at the base opening of the plot to direct runoff through its orifice into a catch can. A diagram of one replicate containing three plots with the respective SBB treatments on Field A is given in Fig. 1.

Sample runoff harvested in each catch was stored overnight for eroded sediments to settle. It was followed by filtration to separate sediments from the filtrate.

The actual runoff rate, R (m³ s⁻¹) was determined by measuring the volume of filtrate (m³) per unit time (sec) of simulated rain. It was then validated by comparing to estimated runoff rate using the Rational method (Eq. (1)).

$$Q = \frac{1}{360} \times C \times I \times A \quad (1)$$

where; Q (m³ s⁻¹) is the peak rate of runoff, I (mm h⁻¹) is the intensity of rainfall given as simulated rain intensity, i.e. 65 mm h⁻¹, C is the runoff coefficient adjusted as 0.25 (Table 2) based on Thompson (2006), and A (ha) is the catchment area given as the area of plot under simulated rainfall.

Inferred from literature, the runoff coefficient was selected based on similarities between current experimental site descriptions, i.e. slope (steep) and soil type (heavy soils), and that reported in Table 1 of Thompson (2006).

2.3.2. Layout of field B

The second experiment on field B constituted a comparative study of SBB and its equivalent SBC impact on carrot productivity. It was carried out on a 6 m × 7 m land area with a 1.37° slope. Again there were three replicates with three plots in each replicate. Each plot measured 115 cm × 80 cm with 1 m spacing serving as a walkway between plots and 2 m between replicates. The plots were tilled and beds were raised at 10 cm above the ground surface. Four crops (carrot) rows at 30 cm apart were obtained on each plot. A diagram of one replicate with all treatments (SBB, SBC, and NSB) of the experimental setup on field B is given in Fig. 2.

2.4. Treatment and experimental design

The two different experiments on fields A and B were conducted concurrently in the dry season from January to March. While the erosion control experiment on field A lasted for five weeks, the carrot productivity experiment on field B lasted for twelve weeks.

The initial experiment carried out on field A consisted of three treatments, i.e. by varying the quantity of SBB for erosion control. Thus, the treatments were 4 SBB (four sugarcane bagasse boards), 2 SBB designating two sugarcane bagasse boards, and NSB (no sugarcane bagasse) designating the control treatment. The 2 cm thick SBB used in each of the two experiments had a cross-sectional area of 50 cm × 25 cm and weighed 584 g.

On the other hand, the second experiment on field B also consisted of three different treatments, i.e. by varying sugarcane bagasse. Thus, the first treatment was assigned SBB followed by SBC while the third, NSB served as the control.

2.5. Biomass board application on field A

The biomass boards, SBBs were placed on the soil surface and in the confinement of the erected aluminum sheet along the length of each given plot. The SBBs were aligned on the soil surface from the base along the upslope of each respective plot. This was done to achieve trapping upslope sediment without it exiting the plot's boundaries. Thus, the first SBB was placed at the base end area of the plot and at the peripheral of the H-flume, followed by the second in that order leaving no gap between the SBBs. The biomass boards again were positioned with no intervals between individual SBB to assess the effect of the multiple SBBs on erosion control assuming it was combined as one SBB. Based on the soil surface area covered by SBB under any given treatment, the

Table 1
Characteristics of experimental soil (0–30 cm)^a

Field	Sand	Silt	Clay	OM	TN	TP	K	pH(H ₂ O)	ρ _b	EC
(%)							(mg g ⁻¹)		(g cm ⁻³)	(mS cm ⁻¹)
A	73	15	13	*	*	*	*	7.9	1.14	0.19
B	78	12	10	1.7	0.1	0.8	0.5	7.6	1.17	0.32

^a OM, organic matter; TN, total nitrogen; TP, total phosphorus; ρ_b, dry bulk density; EC, electrical conductivity;

* unavailable due to field A not used for crop productivity experiment.

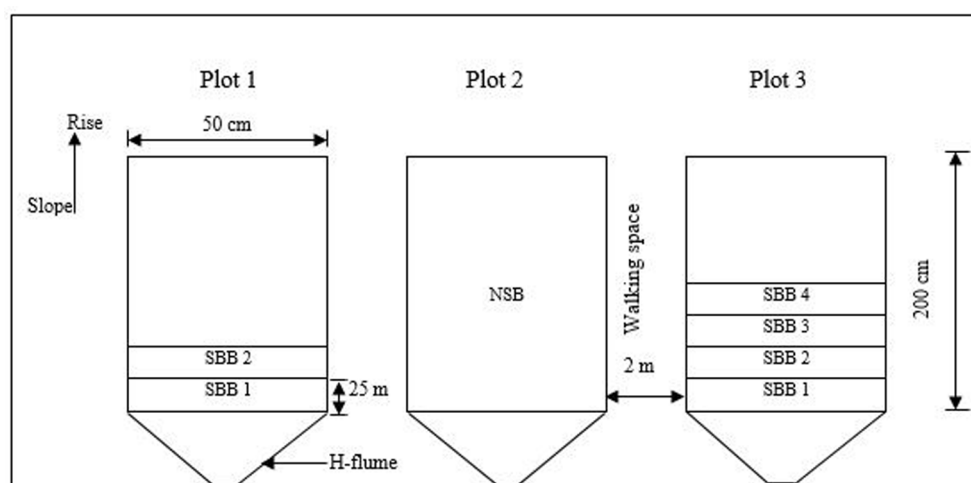


Fig. 1. Sugarcane bagasse mulching board impact on erosion. Note: Fig. 1 represents one replicate with all treatments (2 SBB, 4 SBB, and NSB).

Table 2

Selected runoff coefficients for the Rational method.

Slope	Runoff Coefficient	
	Lawns; sandy soils	Lawns; heavy soils
Flat (2%)	0.05–0.10	0.13–0.17
Average (2–7%)	0.10–0.15	0.18–0.22
Steep (7%)	0.15–0.20	0.25–0.35 ^c

^c is the range of runoff coefficient selected for runoff estimation under Rational method based on similar description of slope and soil type under lawns. [Extracted from Thompson (2006)].

remainder of the soil surface area within the plot's confinement was bare and exposed to erosion. The percentage of ground surface area exposed to runoff was therefore determined by the number of SBB covering the soil surface. Hence 4 SBB constituted 50% soil surface coverage and 2 SBB represented 25% soil surface coverage respectively. Where there was NSB as in the control, the percentage ground surface coverage was nil leaving the whole plot surface area bare and exposed to runoff.

2.5.1. Rainfall simulation and sediment trapping

Rainfall simulation was done once a week for five weeks to determine runoff and the amount of sediment transported under the influence of biomass boards. The low-cost portable rainfall simulator (Tecnocore, Saitama, Japan) also reported by Boulange et al. (2019) was only used for the erosion control experiment on field A. It consisted of a gang baring drip nozzles with emitters. The gang was horizontally supported on two tripod stands with adjustable elevations. The rainfall simulator was powered by an electric pump that supplied pressurized water from a reservoir through a one-inch (25.4 mm) water hose to the emitters. A pressure regulator mounted on the pump was used to regulate the intensity of the simulated rainfall. The rainfall simulator was set to operate at an intensity of 65 mm h^{-1} by setting the pump pressure to 0.2 MPa for 30 min. Each of the treatments received an equal amount of simulated rainfall throughout the experiment. To operate at the same intensity, i.e. 65 mm h^{-1} , the simulator was calibrated before used on each plot. The calibration involved covering with a plastic sheet and allowing sagging on each given plot. The sagging in the plastic sheet serves to trap and convey the simulated rainwater into a catch can for simulated rainfall intensity determination. Throughout the experiment, the simulator was

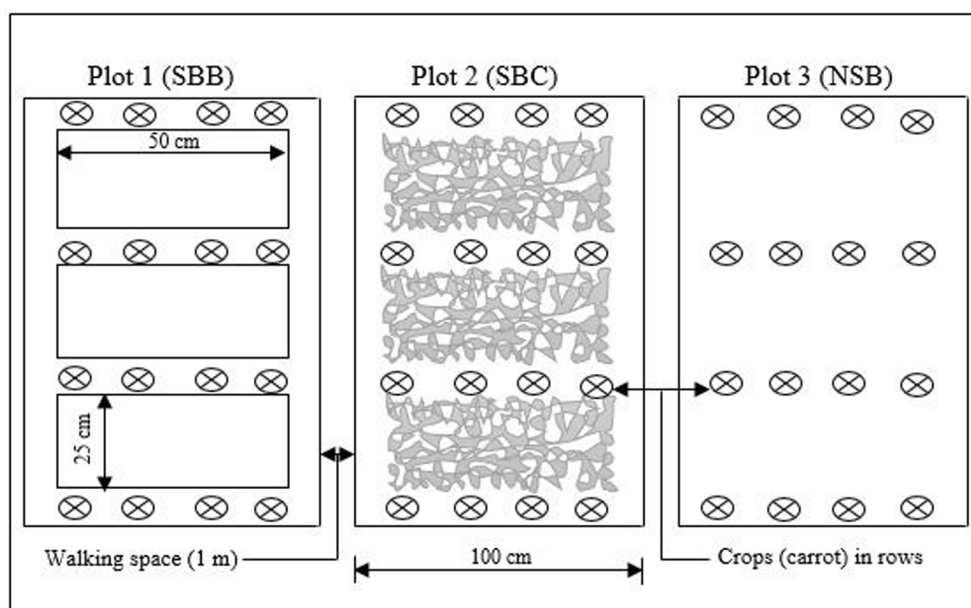


Fig. 2. Effect of sugarcane bagasse mulch on carrot productivity.

always mounted and operated on the upslope of each plot to allow for runoff. Sediments were eroded into the catch cans as a result of runoff from the confined plots. Transported sediments due to runoff were mainly soil particles. Whatman filter paper (Qualitative 1) with medium to fast filtering speed was used in filtering sediment from harvested runoff samples. Filtered sediments were oven-dried to constant weight for estimating erosion rate. The volume of runoff water was also measured under each treatment to determine the effect of SBB on infiltration. The rate of sediment transport in any given rainfall simulation event was estimated using Eq. (2).

$$E_r = \frac{W_s}{A} \quad (2)$$

where; E_r (Mg ha^{-1}) is the rate of erosion, W_s (Mg) is the weight of sediment trapped, and A (ha) is an area of a plot under simulated rainfall.

2.6. Carrot sowing and mulching

Soil mulching using SBB and SBC was applied to the carrot productivity experiment. One of the treatments involved placing three SBB and spaced at 2 cm on the given plots. The second treatment consisted of 584 g of SBC representing an equivalent weight of an SBB. Therefore, three sampled SBC at 584 g each were also placed and spaced at 2 cm on the respective plots. Finally, the control treatment contained no mulch material on the plots. The 2 cm spacing between the SBBs and SBCs in each case served as row spacing for sowing carrot seeds in drills. However, equal row spacing and planting distance were observed under all the treatments to secure an equal plant population. The control treatment, therefore, had the largest surface area exposed to weed growth. The SBB was less porous compared to the SBC.

2.7. Soil moisture and temperature conservation under carrot production

Irrigation was the only resort for the dry season carrot production. Each plot received 0.013 m^3 of water using a watering can at three days intervals. Soil temperature and moisture content were measured and logged on Em50 meter (Decagon Devices, Inc., USA). Considering the soil textural characteristic (sandy loam) and gradient (1.37°) of field B, the volume of water used for irrigation could not induce surface runoff and erosion.

2.8. Weed growth, crop yield, and water productivity

After carrot germination, the effect of mulch type on weed growth was determined by estimating weed yield at two weeks intervals. There was no fertilizer application and the test crop (carrot) competed with the weeds for moisture and nutrient. The carrot was harvested 75 days after planting.

The total biomass yield of carrot consisting of aboveground biomass (vegetative) and the belowground biomass (edible root) was determined by weighing the freshly harvested produce. Water productivity was estimated for total biomass using Eq. (3).

$$WP_{TBM} = \frac{Y_{TBM}}{\sum I_w} \quad (3)$$

where; WP_{TBM} (kg m^{-3}) is water productivity of carrot total biomass, Y_{TBM} (kg m^{-2}) is total biomass yield, and I_w (mm or m) is the amount of water used in irrigation.

2.9. Statistical analysis

Experimental treatments were applied in a completely randomized design with three replications on each field. Before statistical analysis, data were subjected to normality test using Shapiro - Wilk's test ($P =$

0.05) to ascertain normally distributed sample population for analysis of variance (ANOVA) test. Abnormal characteristics are subjected to transformation. Statistical software, GenStat (11th edition) was used for the ANOVA test to measure any significant difference between means of treatments using Duncan's least significant difference (LSD) test at a 95% confidence level ($p < 0.05$).

3. Results and discussion

3.1. Effect of sugarcane bagasse mulching board on infiltration and runoff

At the initial stage of each simulated rainfall, SBB facilitated infiltration while surface runoff was reduced until the soil reached its field capacity. Beyond field capacity, topsoils were subjected to erosion caused by the runoff. Just as the SBB served as a mulch covering the soil surface, Wu et al. (2016) also observed infiltration being facilitated by vegetation cover. Compared to the vegetation cover in literature, sugarcane biomass residue mulch had merit in limiting soil moisture and nutrient competition with a given experimental crop. Where there was more SBB mulch such as 4 SBB, there was a corresponding decrease in soil surface sealing that could have resulted from the splash of simulated raindrops. That scenario enhanced the soil porosity for infiltration (Chen et al., 2013). On the contrary, infiltration was minimal on the control treatment, NSB and that resulted in runoff shortly after initiating the simulated rain. The SBB served as a barrier in shielding soil surface from the direct impact of the simulated raindrops thereby reducing surface runoff in turn. Consequently, the SBB helped in mitigating erosion by trapping a substantial amount of sediment that could have been transported downslope through runoff.

Generally, the percentage area of soil surface mulched with SBB influenced infiltration and runoff rates. Thus, the runoff rate under the various mulch treatments was in the order $4 \text{ SBB} < 2 \text{ SBB} < \text{NSB}$ (Table 3). The results, therefore, indicated that the quantity of SBB directly determined the amount of erosion reduced. In other words, the more SBB covering the soil surface, the lesser the erosion. This was because less runoff yielded less transported sediments and hence less soil was eroded. Pan et al. (2019) carried out a similar experiment but varied both the soil cover (vegetation type, clipping) and rainfall intensity (60 and 90 mm h^{-1}) and found out that irrespective of the rainfall intensity, bare soil treatment which is similar to NSB in our study produced the largest runoff (Table 3).

Peak runoff rate (Q) was estimated as $4.4766 \times 10^{-6} \text{ m}^3 \text{ s}^{-1}$ using the Rational method (Eq. (1)) and compared to actual runoff values in the

Table 3
Sugarcane bagasse board impact on infiltration and runoff rate.

Mulch	Filtrate Volume				
	S_1	S_2	S_3	S_4	S_5
m^3					
NSB	0.0048	0.0046	0.0095	0.0010	0.0134
	a	a	a	a	a
2 SBB	0.0034	0.0024b	0.0063b	0.0107	0.0113
	ab			a	a
4 SBB	0.0007	0.0013b	0.0025c	0.0040b	0.0047b
	bc				
LSD	0.0037	0.0017	0.0023	0.0047	0.0029
$\text{Runoff rate } (10^{-6} \text{ m}^3 \text{ s}^{-1})$					
NSB	2.6851	2.5314	5.2833	5.53	7.4166
2 SBB	1.9074	1.351	3.4842	5.95	6.2888
4 SBB	0.3740	0.6988	1.3851	2.22	2.5888
					LSD .05
					0.8560

^k Mean values within columns not sharing a common letter are significantly different at $p \leq 0.05$ according to LSD test ($n = 3$). S_1 , S_2 , S_3 , S_4 , S_5 , are first, second, third, fourth, and fifth simulated rainfall events.

current study, it was observed that the control, NSB recorded the closest runoff ($4.6887 \times 10^{-6} \text{ m}^3 \text{ s}^{-1}$) to the estimated runoff value. That was because the NSB treatment depicted in situ field conditions as used in the rational equation. However, we attributed the slight difference between experimental to estimated runoff rate to the difference in runoff coefficient. While the Rational method assumed 0.25 as a coefficient of runoff (Thompson, 2006) based on lawns as soil cover, our experimental soil cover was biomass boards with different surface resistance. Hence the variation in runoff coefficient was due to the difference in soil surface cover. Validating the actual runoff rate (Table 3) with the Rational method, it was observed that the more SBB used, the higher the infiltration and less runoff rate. On the other hand, less SBB promoted runoff and with values closer to the estimated value in the Rational method.

A higher runoff rate produced a correspondent larger volume of suspended sediment solution and as a result, large filtrate volume was obtained in that order. Under each simulation event, filtrate volume increased from the 4 SBB through 2 SBB to NSB just as the runoff rate except in the fourth simulation event where the NSB produced less filtrate than both the 2 SBB and 4 SBB (Table 3). This could have been caused by a slight fluctuation in the pump pressure that probably tempered with the given 65 mm h^{-1} simulated rainfall intensity during the fourth simulation event. The portable rainfall simulator used in the current study made it possible for real-time in situ determination of runoff and erosion. Similarly, Abudi et al. (2012) observed and described the rainfall simulator as a powerful tool for studies of infiltration, soil crusting, and erosion on the field.

The SBB in this regard intercepted with simulated raindrops from splashing the soil surface as well as trapped upslope sediments during surface runoff. There was a significant difference in runoff rate among all biomass boards' treatments (2 SBB, 4 SBB) and the control (Table 3).

3.2. Biomass board impact on soil erosion

It is of great importance to conserve topsoils in crop production as it contains vital soil nutrients and biota for supporting plant growth (Martínez-Mena et al., 2020). The least erosion rate (0.003 Mg ha^{-1}) was recorded under 4 SBB in the first simulation event, S_1 while the highest erosion rate (4.4 Mg ha^{-1}) was recorded under NSB, i.e. the control treatment during the fifth rain simulation event, S_5 (Fig. 3).

Generally, the rate of erosion increased from the first to fifth simulated rain event and in the order $\text{NSB} > 2 \text{ SBB} > 4 \text{ SBB}$ (Fig. 3). Thus,

erosion started on the topsoil which was more resistant to displacement by runoff due to higher compaction compared to the subsoils. Hence less erosion was recorded at the initial stage because of the topsoil compaction. But with subsequent simulated rain events, it was easier for the same rainfall intensity to displace more subsoil particles under less compaction. This scenario was responsible for the increase in erosion rate from the first to fifth simulated rainfall events. Under each of the five simulation events, there was a significant decrease in erosion rate between the control and both the 2 and 4 SBB treatments. The 4 SBB constantly recorded the least erosion rate throughout the experiment. However, there was no significant reduction in erosion between 4 SBB and the 2 SBB.

There were differences in erosion rate among the different events of simulated rainfalls under each given treatment, i.e. NSB, 2SBB, and 4 SBB (Table 4). The highest erosion rate (Table 4) under NSB for instance was recorded under the difference between S_1 – S_5 and that of 2 SBB occurred during S_2 – S_5 while 4 SBB was recorded under S_1 – S_4 .

Compared to control treatment on average, 2 SBB significantly decreased erosion by 1.571 Mg ha^{-1} while the 4 SBB significantly decreased erosion by 1.739 Mg ha^{-1} . The 4 SBB as compared to the 2 SBB decreased erosion by 0.168 Mg ha^{-1} but insignificant at the end of the fifth simulated rainfall.

The rate at which topsoils were eroded under any given simulated rainfall event increased from S_1 to S_2 for all treatments except under 2 SBB where erosion decreased from S_1 (0.068 Mg ha^{-1}) to S_2 (0.050 Mg ha^{-1}) but increased again from S_3 through S_4 to S_5 (Fig. 3).

As the field was subjected to subsequent runoffs, the top soils gradually eroded until living soil organisms e.g. earthworms were visible in the harvested runoff during the fourth and fifth rainfall simulation. This suggests that as erosion prevails on any given fertile soil, the loss in soil biological species is equally inevitable as that of the chemical constituents of the soil.

Error bars represent the standard error of the mean ($n = 3$). NSB is control treatment; 2 SBB and 4 SBB are two and four sugarcane bagasse boards respectively; S_1 to S_5 is the first to fifth rainfall simulation event. Mean values of treatments within the same simulation event not sharing a common letter are significantly different at $p \leq 0.05$ according to the LSD test.

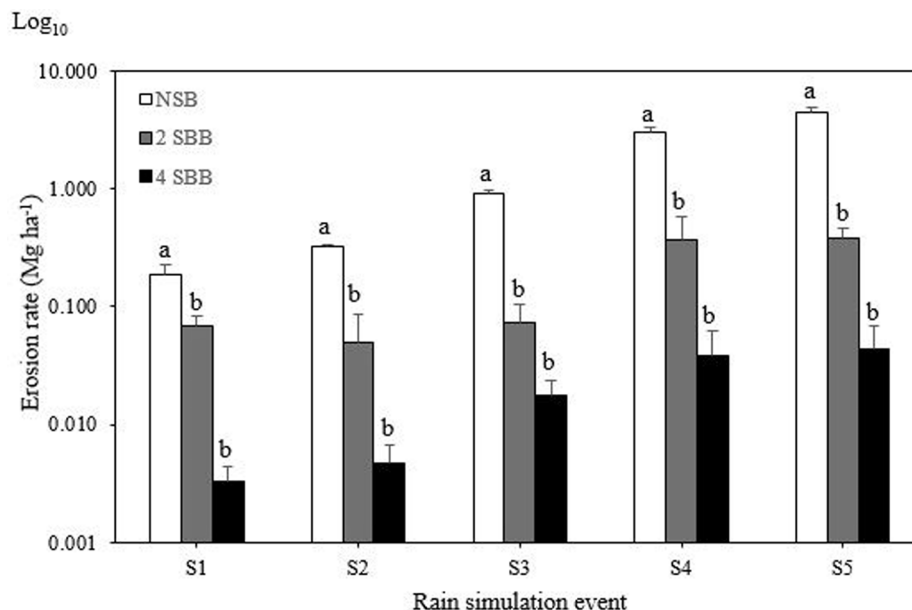


Fig. 3. Effect of biomass boards on soil erosion.

Table 4

Erosion rate between different simulated rain events under similar mulch treatment.

Mulch	Difference in Erosion rate (Mg ha ⁻¹)									
	S ₁ -S ₂	S ₁ -S ₃	S ₁ -S ₄	S ₁ -S ₅	S ₂ -S ₃	S ₂ -S ₄	S ₂ -S ₅	S ₃ -S ₄	S ₃ -S ₅	S ₄ -S ₅
NSB	0.138	0.72	2.801	4.213	0.582	2.663	4.075	2.081	3.493	1.412
2 SBB	-0.018*	0.006	0.303	0.317	0.024	0.321	0.335	0.297	0.311	0.014
4 SBB	0.002	0.015	0.377	0.041	0.013	0.033	0.039	0.02	0.026	0.006

S₁-S₂ to S₄-S₅, difference between the first and second to the fourth and fifth rainfall simulation events;

* is erosion lagged with rainfall simulation events under 2 SBB.

3.3. Effect of sugarcane bagasse board and bagasse chips on soil temperature and moisture

The SBB and its equivalent SBC used as mulch in the carrot productivity experiment did not show any major variation in soil temperature and moisture conservation. The average daily soil temperature was almost equal for SBB and SBC (30.66 and 30.67 °C) while that of the control recorded 31.18 °C. Thus the mulch materials, i.e. SBB and SBC reduced the direct impact of sunlight on the soil surface and hence minimized soil heat flux. The highest mean daily soil temperature was therefore recorded under the control treatment although insignificant compared to the SBB and SBC.

The volumetric water content of the soil was higher under SBC (0.30 m³ m⁻³) compared to the control (0.29 m³ m⁻³) and SBB (0.17 m³ m⁻³). Despite the variation, there were no significant differences in moisture conservation among all treatments. Soil moisture content under SBB was expected to be higher than that of SBC but that was not the case. We attributed the moisture conservation characteristic to the less porous nature of the SBB that did not fast-track infiltration in the crop root zone during irrigation. This was because the sprinkled water during irrigation splashed on the surface of the solid SBB thereby resulting in some amount of the water spilling off the plot's confinement. Secondly, due to its less porosity compared to the SBC, the SBB resulted in an appreciable amount of irrigated water runoff in the plot area. Variation in moisture content among treatments did not differ so much because irrigation was constantly applied at a three-day interval on the minimum. The irrigation schedule played a key role in eliminating water stress conditions in the soil thereby preventing root zone drought under each treatment. Significant variation in soil moisture content could have been observed among the different treatments if deficit irrigation was scheduled to allow root zone drying.

3.4. Crop yield and weed growth as influenced by mulch material

Carrot yield constituting aboveground and belowground biomass as well as yield of weeds were affected by the different sugarcane bagasse mulch materials (Table 5). Weeds under any crop production affect the interrelationship between the Soil-Plant-Atmosphere Continuum (SPAC) so long as they compete with the crop for soil moisture and sunlight for photosynthesis. Weeds also compete with crops for soil nutrients and hence it was of high expectation to obtain higher crop yield on treatments with low weed growth.

Table 5

Effect of sugarcane mulch on weed growth, carrot yield and water productivity.

Mulch	Y _{ABM} Mg ha ⁻¹	Y _{BBM}	Y _{TBM}	Y _W	WP _{TBM} kg m ⁻³
SBB	0.68	1.15	1.83	0.48 b ^k	0.52
SBC	0.75	2.22	2.97	0.57b	0.84
NSB	0.36	0.47	0.83	0.98 a	0.23
LSD ₀₅	0.65	2.94	3.52	0.31	0.99

^k Mean values within column not sharing a common letter are significantly different at $p \leq 0.05$ according to LSD test ($n = 3$). Y_{ABM}, aboveground biomass yield; Y_{BBM}, belowground biomass yield; Y_{TBM}, total biomass yield; Y_W, weed yield; WP_{TBM}, water productivity of total biomass.

Weeds harvested on the control treatment were always more than that of the SBC and SBB. This was because the control treatment (NSB) having no shield from a mulch material, exposed larger portions of the soil surface to weed growth. The mulch material, irrespective of its form, i.e. SBB or SBC, therefore, reduced weed growth compared to the control. Whereas the highest yield of weeds (Y_W) was recorded in the control treatment, the SBB recorded the least weed growth (0.48 Mg ha⁻¹) compared to the SBC (Table 5).

The SBB significantly reduced weed growth by 104% compared to the control. A significant reduction in weed growth at 72% by SBC compared to the control was also recorded. However, there was no significant difference in weed growth between the SBB and SBC. The impact of sugarcane bagasse mulch on curtailing weed growth was in the order SBB > SBC > NSB (Table 5). Although a significant reduction in weed growth was recorded among treatments, it could not correspond to an increase in carrot biomass yield.

In terms of the aboveground biomass yield of carrot (Y_{ABM}), the SBC recorded 10 and 108% more yield over the SBB and NSB. The SBB also recorded 89% more Y_{ABM} over the NSB but there were no significant differences in either case. Also, on the other hand, belowground biomass yield (Y_{BBM}) was not significantly impacted by the various sugarcane bagasse mulch materials. Therefore, the increase in Y_{TBM} of carrots under SBB and SBC compared to the control was also not significant.

Compared to SBB, the SBC being more porous enhanced infiltration, moisture retention as well as improved air circulation in the soil. That resulted in a higher yield under SBC. Since equal amounts of irrigation water were applied to the various treatments, the WP_{TBM} of each treatment followed the same trend in terms of significant effect as its Y_{TBM}. That means there was no significant increase in carrot water productivity among all treatments.

In general, the SBC improved carrot yield and water productivity more than the control and SBB although insignificant. It was as a result of the efficacy of SBC on porosity which in turn improved soil moisture retention. In the latter part of the growing season, the SBB having a significant effect on suppressing weed growth was found wholesome while portions of the SBC were degraded by termites. Therefore, when durability and sustainability were taken into consideration, the SBB was recommended over SBC as mulching material due to its significant suppressive effect on weed growth and resistance to degradation by termite.

Moisture retention and weed control by the sugarcane bagasse board and its equivalent bagasse chips were key to improving carrot yield. Meanwhile, crop growth and yield in any agrosystem depend tremendously on nutrients and water. The limitation of our study was the inability to investigate the efficacy of sugarcane bagasse mulching board on soil nutrient retention under carrot production. It would therefore be necessary to conduct a similar experiment where fertilizer would be applied prior to placing biomass boards to investigate nutrients retention ability of the biomass board following runoff and under carrot production.

4. Conclusions

It may take centuries for soil formation, therefore it worth preventing even a microgram of soil from erosion. Varied mulch quantity under the

same rainfall event increased infiltration while erosion decreased and was directly proportional to the number of biomass boards except for the fourth rainfall event (S_4). Under the same mulch quantity (2 SBB, 4 SBB, or NSB) but varied rainfall events, only 4 SBB recorded increased erosion with subsequent increased rainfall events (S_1 – S_5). Soil erosion reduction was directly proportional to the number of biomass boards used hence the 4 SBB was recommended. Under carrot production, biomass board and its equivalent biomass chips did not have any significant effect on soil moisture and temperature conservation. Biomass board did not influence carrot yield either, instead, it had a significant impact on weed control thereby making it desirable for ameliorating nutrient competition between weeds and the crop. Biomass board proved durable and was recommended as a promising material for mulching under carrot production while curtailing erosion and its consequent environmental pollution.

Author Contributions

The study concept was developed and partly funded by S. Onwona-Agyeman. H. Takada funded the transportation of the rainfall simulator and assisted in the revision of the manuscript. H. Watanabe contributed to the revision of the first manuscript draft. E. B. Sabi provided sugarcane bagasse chips, tools, and supervised field setup and experiment. A. Yakubu conducted the field experiments, drafted and revised the manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

- Abudi, I., Carmi, G., Berliner, P., 2012. Rainfall simulator for field runoff studies. *J. Hydrol.* 454–455, 76–81. <https://doi.org/10.1016/j.jhydrol.2012.05.056>.
- Agro Eco, 2008. Improve your sugarloaf pineapple production illustrated manual for organic farmers in Ghana. FAO Proj. GCP/RAF/404/GER report. FAO, Rome, Italy, pp. 1–23.
- Bahadur, P., 2000. What is Mulching? Farmers' Handbook. "Near House - 1" 16.
- Balasubramanian, A., 2017. Soil Erosion- Causes and Effects. *Cent. Adv. Stud. Earth Sci. Univ. Mysore* 7. <https://doi.org/10.13140/RG.2.2.26247.39841>.
- Boulange, J., Malhat, F., Jaikaew, P., Nanko, K., 2019. Portable rainfall simulator for plot-scale investigation of rainfall-runoff, and transport of sediment and pollutants. *Int. J. Sediment Res.* 34, 38–47. <https://doi.org/10.1016/j.ijsrc.2018.08.003>.
- Campiglia, E., Mancinelli, R., Radicetti, E., Caporali, F., 2010. Effect of cover crops and mulches on weed control and nitrogen fertilization in tomato (*Lycopersicon esculentum* Mill.). *Crop Prot.* 29, 354–363. <https://doi.org/10.1016/j.cropro.2009.12.001>.
- Chen, L., Sela, S., Svoray, T., Assouline, S., 2013. The role of soil-surface sealing, microtopography, and vegetation patches in rainfall-runoff processes in semiarid areas. *Water Resour. Res.* 49, 5585–5599.
- Chen, Z., Sun, S., Zhu, Z., Jiang, H., Zhang, X., 2019. Assessing the effects of plant density and plastic film mulch on maize evaporation and transpiration using dual crop coefficient approach. *Agric. Water Manag.* 225, 105765 <https://doi.org/10.1016/j.agwat.2019.105765>.
- Cherubin, M.R., Oliveira, D.M.D.S., Feigl, B.J., Pimentel, L.G., Lisboa, I.P., Gmach, M.R., Varanda, L.L., Moraes, M.C., Satrio, L.S., Popin, G.V., De Paiva, S.R., Dos Santos, A.K.B., De Vasconcelos, A.L.S., De Melo, P.L.A., Cerri, C.E.P., Cerri, C.C., 2018. Crop residue harvest for bioenergy production and its implications on soil functioning and plant growth: A review. *Sci. Agric.* 75, 255–272. <https://doi.org/10.1590/1678-992x-2016-0459>.
- Duku, M.H., Gu, S., Ben Hagan, E., 2011. A comprehensive review of biomass resources and biofuels potential in Ghana. *Renew. Sustain. Energy Rev.* 15, 404–415. <https://doi.org/10.1016/j.rser.2010.09.033>.
- FAO, 2015. World's Soil Resources, Status of the World's Soil Resources. <https://doi.org/10.1016/j.sci.2015.10.004>.
- FAO, 2006. Guidelines for soil description. Fourth Ed. Rome, Italy 1–109.
- Felix-Henningsen, P., Morgan, R.P.C., Mushala, H.M., Rickson, R.J., Scholten, T., 1997. Soil erosion in Swaziland: A synthesis. *Soil Technol.* 11, 319–329. [https://doi.org/10.1016/S0933-3630\(97\)00016-0](https://doi.org/10.1016/S0933-3630(97)00016-0).
- García-Ruiz, J.M., Beguería, S., Lana-Renault, N., Nadal-Romero, E., Cerdà, A., 2017. Ongoing and Emerging Questions in Water Erosion Studies. *L. Degrad. Dev.* 28, 5–21. <https://doi.org/10.1002/ldr.2641>.
- Gicheru, P.T., 1994. Effects of residue mulch and tillage on soil moisture conservation 3630.
- Honorato-salazar, J.A., Sadhukhan, J., 2019. Food and Bioproducts Processing Annual biomass variation of agriculture crops and forestry residues, and seasonality of crop residues for energy production in Mexico. *Food Bioprod. Process.* 119, 1–19. <https://doi.org/10.1016/j.fbp.2019.10.005>.
- Islas, J., Manzini, F., Masera, O., 2007. A prospective study of bioenergy use in Mexico. *Energy* 32, 2306–2320. <https://doi.org/10.1016/j.energy.2007.07.012>.
- Jayne, T., Kolavalli, S., Debrah, K., Ariga, J., Brunache, P., Kabaghe, C., Nunez-Rodriguez, W., Baah, K.O., Bationo, A., Huisin, E., Lambrecht, I., Diao, X., Yeboah, F., Benin, S., Andam, K., 2015. Towards a Sustainable Soil Fertility Strategy in Ghana. A Report submitted to the Ministry of Food and Agriculture of Government of Ghana, 1–30.
- Kleemann, L., 2011. Organic Pineapple Farming in Ghana - A Good Choice for Smallholders? *Kiel Inst. World Econ. Kiel Work. Pap.* 1671, 1–39.
- Kusumah, S.S., Umemura, K., Yoshioka, K., Miyafuji, H., Kanayama, K., 2016. Utilization of sweet sorghum bagasse and citric acid for manufacturing of particleboard I: Effects of pre-drying treatment and citric acid content on the board properties. *Ind. Crops Prod.* 84, 34–42. <https://doi.org/10.1016/j.indcrop.2016.01.042>.
- Lal, R., 2001. Soil degradation by erosion. *L. Degrad. Dev.* 12, 519–539. <https://doi.org/10.1002/ldr.472>.
- Martínez-Mena, M., Carrillo-López, E., Boix-Fayos, C., Almagro, M., García Franco, N., Díaz-Pereira, E., Montoya, I., de Vente, J., 2020. Long-term effectiveness of sustainable land management practices to control runoff, soil erosion, and nutrient loss and the role of rainfall intensity in Mediterranean rainfed agroecosystems. *Catena* 187, 104352. <https://doi.org/10.1016/j.catena.2019.104352>.
- Mugica-Álvarez, V., Hernández-Rosas, F., Magaña-Reyes, M., Herrera-Murillo, J., Santiago-De La Rosa, N., Gutiérrez-Arzaluz, M., de Jesús Figueroa-Lara, J., González-Cardoso, G., 2018. Sugarcane burning emissions: Characterization and emission factors. *Atmos. Environ.* 193, 262–272. <https://doi.org/10.1016/j.atmosenv.2018.09.013>.
- Nadhari, W.N.A.W., Karim, N.A., Boon, J.G., Salleh, K.M., Mustapha, A., Hashim, R., Sulaiman, O., Azni, M.E., 2020. Sugarcane (*Saccharum officinarum* L.) bagasse binderless particleboard: Effect of hot pressing time study. *Mater. Today Proc.* <https://doi.org/10.1016/j.matpr.2020.06.016>.
- Noor, W., Wan, A., Abd, N., Geng, J., Mohd, K., Mustapha, A., Hashim, R., Sulaiman, O., Edyazuan, M., 2020. Sugarcane (*Saccharum officinarum* L.) bagasse binderless particleboard: Effect of hot pressing time study. *Mater. Today Proc.* <https://doi.org/10.1016/j.matpr.2020.06.016>.
- Nyawade, S.O., Gachene, C.K.K., Karanja, N.N., Gitari, H.I., Schulte-geldermann, E., Parker, M.L., 2019. Geoderma Regional Controlling soil erosion in smallholder potato farming systems using legume intercrops. *Geoderma Reg.* 17, e00225 <https://doi.org/10.1016/j.geoder.2019.e00225>.
- Onwona-Agyeman, S., Fuke, M., Kawabata, M., Yamada, M., Tanahashi, M., 2015. Compressed Biomass as Mulches in No-till Farming. *J. Arid L. Stud.* 25, 253–256.
- Onwona-Agyeman, S., Kyomori, K., Shigematsu, M., Tanahashi, M., 2002. Bioresidue boards produced from agricultural residues and weeds. *Trans. Mater. Res. Soc. Japan* 645–647.
- Onwona-Agyeman, S., Hada, T., Sabi, E.B., Tanahashi, M., 2007. Fabrication of Fertilizer-Impregnated Boards from Low Quality Thinned logs using the High-Pressure Steam Method. *Trans. Mater. Res. Soc. Japan* 32, 1155–1158. <https://doi.org/10.14723/tmrj.32.1155>.
- Oshima, S., Onwona-Agyeman, S., Saho, N., Appiah, K.S., Fujii, Y., 2020. Development and Evaluation of Mulching Boards Fabricated from Bagasse. *Trans. Mater. Res. Soc. Japan* 45, 9–13. <https://doi.org/10.14723/tmrj.45.9>.
- Pan, D., Yang, S., Song, Y., Gao, X., Wu, P., Zhao, X., 2019. The tradeoff between soil erosion protection and water consumption in revegetation: Evaluation of new indicators and influencing factors. *Geoderma* 347, 32–39. <https://doi.org/10.1016/j.geoderma.2019.02.003>.
- Pavli, L., Kodešová, R., Fér, M., Nikodem, A., Némec, F., 2020. Soil & Tillage Research The impact of various mulch types on soil properties controlling water regime of the Haplic Fluvisol. *Soil Tillage Res.* 205, 104748 <https://doi.org/10.1016/j.still.2020.104748>.
- Plambeck, N.O., 2020. Reassessment of the potential risk of soil erosion by water on agricultural land in Germany: Setting the stage for site-appropriate decision-making in soil and water resources management. *Ecol. Indic.* 118, 106732 <https://doi.org/10.1016/j.ecolind.2020.106732>.
- Prasad, S., Singh, A., Korres, N.E., Rathore, D., Sevdá, S., Pant, D., 2020. Sustainable utilization of crop residues for energy generation: A life cycle assessment (LCA) perspective. *Bioresour. Technol.* 303, 122964 <https://doi.org/10.1016/j.biortech.2020.122964>.

- Quan, X., He, J., Cai, Q., Sun, L., Li, X., Wang, S., 2020. Soil & Tillage Research Soil erosion and deposition characteristics of slope surfaces for two loess soils using indoor simulated rainfall experiment. *Soil Tillage Res.* 204, 104714 <https://doi.org/10.1016/j.still.2020.104714>.
- Salesa, D., Cerdà, A., 2020. Soil erosion on mountain trails as a consequence of recreational activities. A comprehensive review of the scientific literature. *J. Environ. Manage.* 271 <https://doi.org/10.1016/j.jenvman.2020.110990>.
- Serrano-ruiz, H., Martin-closas, L., Pelacho, A.M., 2020. Review: Biodegradable plastic mulches : Impact on the agricultural biotic environment. *Sci. Total Environ.* 750, 141228 <https://doi.org/10.1016/j.scitotenv.2020.141228>.
- Shah, F., Wu, W., 2020. Use of plastic mulch in agriculture and strategies to mitigate the associated environmental concerns, 1st ed., *Advances in Agronomy*. Elsevier Inc. <https://doi.org/10.1016/bs.agron.2020.06.005>.
- Taak, P., Koul, B., Chopra, M., Sharma, K., 2020. Comparative assessment of mulching and herbicide treatments for weed management in *Stevia rebaudiana* (Bertoni) cultivation. *South African J. Bot.* 000 <https://doi.org/10.1016/j.sajb.2020.05.016>.
- Thankamani, C.K., Kandiannan, K., Hamza, S., Saji, K.V., 2016. *Scientia Horticulturae* Effect of mulches on weed suppression and yield of ginger (*Zingiber officinale* Roscoe). *Sci. Hortic. (Amsterdam)* 207, 125–130. <https://doi.org/10.1016/j.scienta.2016.05.010>.
- Thompson, D.B., 2006. *The Rational Method*. *Eng. Hydrol.* 1–7.
- Thornton, P.K., Erickson, P.J., Herrero, M., Challinor, A.J., 2014. Climate variability and vulnerability to climate change : a review. *Glob. Chang. Biol.* 20, 3313–3328. <https://doi.org/10.1111/gcb.12581>.
- Wu, G., Yang, Z., Cui, Z., Liu, Y., Fang, N., Shi, Z., 2016. Mixed artificial grasslands with more roots improved mine soil infiltration capacity. *J. Hydrol.* 535, 54–60.
- Wu, T., Wang, X., Kito, K., 2015. Effects of pressures on the mechanical properties of corn straw bio-board. *Eng. Agric. Environ. Food* 8, 123–129. <https://doi.org/10.1016/j.eaef.2015.07.003>.
- Xiong, M., Sun, R., Chen, L., 2018a. Effects of soil conservation techniques on water erosion control: A global analysis. *Sci. Total Environ.* 645, 753–760. <https://doi.org/10.1016/j.scitotenv.2018.07.124>.
- Xiong, M., Sun, R., Chen, L., 2018b. Science of the Total Environment Effects of soil conservation techniques on water erosion control: A global analysis. *Sci. Total Environ.* 645, 753–760. <https://doi.org/10.1016/j.scitotenv.2018.07.124>.
- Yakubu, A., Danso, E.O., Arthur, E., Kugblenu-Darrah, Y.O., Sabi, E.B., Abenney-Mickson, S., Ofori, K., Andersen, M.N., 2020. Rice straw biochar and irrigation effect on yield and water productivity of okra. *Agron. J.* <https://doi.org/10.1002/agj2.20230>.
- Yang, L., Deng, Y., Wang, X., Zhang, W., Shi, X., Chen, X., Lakshmanan, P., Zhang, F., 2020. Science of the Total Environment Global direct nitrous oxide emissions from the bioenergy crop sugarcane (*Saccharum* spp. inter-specific hybrids). *Sci. Total Environ.* 752, 1–12. <https://doi.org/10.1016/j.scitotenv.2020.141795>.
- Yanquoi, H., 2014. The effect of phosphorus sources on nodulation and dry matter yield of pigeon pea (*Cajanus cajan*). MSc. thesis. University of Ghana, Legon, Accra.
- Yogitha, B., Karthikeyan, M., Reddy, M.G.M., 2020. Progress of sugarcane bagasse ash applications in production of Eco-Friendly concrete - Review. *Today Proc. Mater.* <https://doi.org/10.1016/j.matpr.2020.05.814>.