Journal of Cleaner Production 261 (2020) 121191

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Crop straw utilization and field burning in Northern region of Ghana

Patience Afi Seglah [a], Yajing Wang [a, *], Hongyan Wang [b], Yuyun Bi [a], Ke Zhou [a], Ying Wang [a], Huan Wang [a], Xinxin Feng [a]

[a] Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences, Beijing, 100081, China
[b] Agricultural Information Institute, Chinese Academy of Agricultural Sciences, Beijing, 100081, China

ARTICLE INFO

Article history:
Received 11 September 2019
Received in revised form
16 March 2020
Accepted 16 March 2020
Available online 18 March 2020

Handling editor: CT Lee

Keywords:
Crop straw
Utilization
Sustainable
Field burning
Cleaner production
Ghana

ABSTRACT

Efficient utilization of crop straw is a determining factor for cleaner production and sustainable development in Ghana's agricultural sector. However, extensive field burning of crops straw is hampering the effective utilization of straw resources in the Northern region of Ghana. The aim of this research was to identify rural households' crops straw utilization methods and investigate the occurrence as well as effects of crops straw burning. Cross-sectional data collected from 384 farmer households' in Yendi municipality, Saboba and Tatale-Sanguli districts in the Northern region of Ghana were analyzed with Statistical Package of Social Sciences (SPSS). The total crop yield for major cereals and legumes produced was 1.29 kton with a total crop straw yield of 3.05 kton. Cereals straw contributed the highest yield percentage of 56.4% while legume straw contribution was 43.6%. About 1.23kton (40.3%) of straws from major cereals and legumes were utilized for different purposes such as returning to the field to enrich the soil, fodder for livestock, cooking fuel, sale and other traditional purposes. The remaining 1.82kton (59.7%) of crop straws were burnt on the field. The percentages of straw burnt on the field for each crop were 77.6% for maize, 58.6% for sorghum, 56.5% groundnut, 49.7% for millet, 47.4% cowpea, 42.2% for rice and 41.4% for soybean. Farming and farm size are the key influencing factors that affect straw burning. Open field burning of straws caused a decline in yield for about 65.7% of respondents. The present findings indicates that utilization of crop straw in the Northern region of Ghana is poorly practiced and needs to be encouraged because of its associated benefits. Government of Ghana needs to develop appropriate policies and legislative measures to encourage effective utilization of straw and prohibit field burning of straws.

1. Introduction

Crop and livestock productions dominate Ghana's agricultural system. The Northern region is one of the top five regions in Ghana which produces cereals and legumes in high quantities. Some of the major cereals and legumes cultivated in Ghana are maize, rice, millet, sorghum, cowpea, groundnut and soybeans (MoFA, 2017). Utilization of biomass such as straw is important for Ghana's development (Präger et al., 2019). Crops straw are important resources with economic and environmental consequences (Lal, 2005). It also serves as an important biomass resource with energy potential and the generation of biofuels from crops straw promote second generation of biofuels (Ayamga et al., 2015).

Albeit challenges such as bulky nature of straw, high transportation cost and field burning affects straw management. Burning is the cheapest method of removing straw (Long et al., 2016) in order to prepare land after harvesting crops (Cassou, 2018). Large amounts of crop straw are normally destroyed on the farm by bush burning (Quartey and Chýlková, 2012). Research on crops straw utilization in Ghana has received less attention and its documentation is inadequate. Crops straw utilization in Ghana is mostly at the traditional stage whilst large quantities ends up burnt on farms. A research by Ansong Omari et al. (2018) indicated that some farmers deliberately burn straw to prepare the farm for the next planting season. In Ghana, a total of 36, 099, 878 tons of maize and rice straws were burnt from 1961 to 2017 (Fig. 1) (FAOSTAT, 2018). There has been an increasing trend in the burning of maize straw as compared to rice straw. The quantity of maize straw burnt was the highest (32, 891, 495.8 tons) followed by rice straw (3,208,382.3 tons). This indicates that cereal straws particularly maize straws are highly burnt in Ghana.

* Corresponding author.
E-mail address: wangyajing@caas.cn (Y. Wang).

https://doi.org/10.1016/j.jclepro.2020.121191
0959-6526/

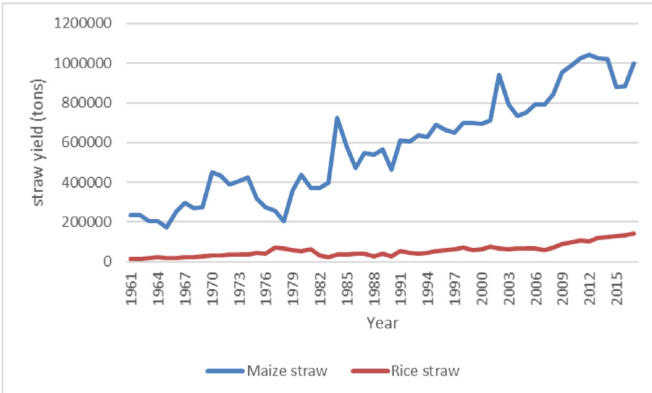

Fig. 1. Trend of burning maize and rice straws in Ghana from 1961 to 2017. Data source: FAOSTAT, 2018.

Field burning and decomposition of straw are considered as waste of valuable resources and often result in environmental degradation and pollution to humans (Aruya et al., 2016). Heat generated from straw burning has a significant negative impact on soil nutrients which increases erosion and renders the soil infertile (Smith et al., 2015). The emissions from field burning impacts negatively on the atmosphere (Azhar et al., 2019) which contributes immensely to particulate matter (PM) in the atmosphere (Shi et al., 2014). Thus, affecting human health, global climate change (Chen et al., 2019) and contributes to global warming through greenhouse gas emissions (Romasanta et al., 2017).

Field burning of straw is both a regional and global environmental burden (Long et al., 2016). In the 1980s, about 600,000 ha of crop straw was burnt annually in the United Kingdom (UK) (Prew et al., 1995). Crop straw burning was popular in the Great Plains of the United States of America (USA) (Jenkins et al., 1992). From the year 2000–2004, crop straw burning in southeastern USA occurred annually and it was the major cause of fire activities (McCarty et al., 2007). In Australia, rice straw generated in summer were burnt on the field to make way for winter rice production (Vagg, 2015). In addition, field burning of rice straw contributed to increase PM_{10} concentrations in eastern Spain (Viana et al., 2008). Straw is often burnt on farms in countries like China, Thailand and northern India (Bakker et al., 2013). In china, consistent increase in straw over the years made farmers resort to burning. According to Cao et al. (2008), the total amount of straws burnt in China was about $140*10^6$ tons per year, this contributes to 86.02–97.58% of atmospheric pollution (Zhou et al., 2017).

However, these countries have taken measures to help stop or reduce the state of straw burning. Field burning of crop straw was banned in the UK in 1992 (Tomlinson et al., 2017). Currently in the UK, straws are mainly used as fertilizer, feed and bedding in the livestock sector, power generation, fuel and mushroom production (Townsend et al., 2018). Field burning of straw was banned in the USA and some European Union countries (Vagg, 2015). According to a recent economic and environmental evaluation of advanced energy technologies of rice straw in India, production of ethanol through integrated fermentation and anaerobic digestion was a preferred technology whiles integrated technique has environmental and economic benefits. In addition, gasification is the most preferred for electricity production. The authors indicated that, electricity and bioethanol production has the potential to reduce environmental pollution and plays a pivotal role in the economic development of India (Singh and Basak, 2019). Chinese government adopts practical approach and policies to manage its crop straw (Ren et al., 2019). Straw burning was banned in China coupled with the use of monitoring teams and remote sensing to track straw burning spots (Tian et al., 2011).

Effective utilization of crop straw must be affordable and suitable to the environment for sustainable cleaner production (Aruya et al., 2016). Cleaner production in this context means the effective utilization of straw resources without resorting to open field burning (Chen et al., 2019). This has potential environmental, health and economic benefits (Smith et al., 2015; Romasanta et al., 2017), hence the government of Ghana must prioritize efficient straw utilization. According to Badarinath et al. (2006) maintaining straws on farms after harvest is a sustainable and cleaner approach of managing it. In addition, practicing other utilization methods and prohibiting burning will help to promote an eco-friendly environment (Yodkhum et al., 2018). The efficient utilization of straw for energy generation is also a potential area which will help resolve energy crises and promote a cleaner environment (Ghaffar et al., 2015).

In Ghana, some efforts have been made towards promotion of cleaner production on the utilization of straw resources. Recent study by Seglah et al. (2019) focused on the estimation of straw resources based on secondary crop production data obtained from Food and Agriculture organization (FAO) and the Ministry of Food and Agriculture (MoFA). Investigation on the various utilization methods was not base on questionnaire survey but reviewed from literatures. In addition, the research focused on the broader context of straw utilization in Ghana without considering detailed research in the Northern region, which is a major producer of cereals and legumes. Previous studies conducted did not explore utilization of straw resources in a holistic form but rather focused on one or few utilization methods. The research conducted by Adjapong et al. (2015) focused on the use of crop straw as substrate for mushroom production while others were on generation of energy from crop straw (Arranz-Piera et al., 2016). Other research conducted focused on sale of crop straw as animal fodder (Konlan et al., 2015) and utilization of straw as soil management option (Ansong Omari et al., 2018). Field burning of straw is a major mitigating factor on crops straw utilization but earlier studies conducted (Ofosu et al., 2013) did not consider the major causes of open field burning of crop straw and its implication on crop productivity in the Northern region of Ghana. A study conducted in the coastal savannah zone of Ghana assessed the impact of straw burning on soil organic carbon and release of carbon dioxide (CO_2) in the atmosphere (Parker et al., 2010) but they however, did not include the Northern region of Ghana where agricultural straw burning is rampant. Even though straw resources are abundant in the Northern region of Ghana, research on the various straw utilization methods and effects of straw burning is minimal. Field burning of crop straws occurs often and detailed information is needed for policy makers to address it.

There is inadequate documentation on the proportion of households' who practice various straw utilization methods, reasons why straw is burnt and the type of government intervention farmers need to curtail the continuous burning of crop straw. The high diversity of smallholder farming systems makes it worthy to investigate the different straw utilization methods to establish realistic information on the value farmers place on crop straw in the Northern region of Ghana. Therefore, the current study was conducted to know the collective utilization methods of crop straw and field burning in the Northern region of Ghana. This research will provide relevant information on how farmers' utilize their straws and identify the proportion of households who practice it as well as ascertain the state of field burning of straw. The study will also help to predict the future occurrence of field burning of straw and suggest appropriate government interventions needed to curtail field burning and ensure effective utilization of straw. The aim of this research was to identify rural households' crops straw utilization methods and investigate the occurrence as well as effects of crops straw burning.

2. Methodology

2.1. Description of the study area

The study was conducted in Yendi municipality, Saboba and Tatale-Sanguli districts located in the Eastern corridor of the Northern region of Ghana (Fig. 2). ArcGIS was used to draw the map of the study area. The region has the highest land size of 29.5% compared to the other nine regions of Ghana. The Northern region is located at Latitude: 9° 29′ 59.99″ N and Longitude: 1° 00′ 0.00″ W. It is among the top five regions in Ghana that produces major starchy staples, cereals and legumes particularly for maize, rice, sorghum, cowpea, cassava and yam. A significant proportion of farmers in the region keep livestock and most of the farmers rely on rainfall for their agricultural activities (MoFA, 2015). About 81,490 agricultural households can be found in the three districts. The specific number of agricultural households in Yendi are 30,972, Saboba (25,547) and in Tatale-Sanguli 24,971 (MoFA, 2017). Yendi Municipality is located in the eastern corridor of the Northern Region and lies between Latitude 9^0—35^0 North and 0^0—30^0 West and 0^0—15^0 East. The Municipality cuts through the Greenwich Meridian and shares boundaries with six other districts including Saboba district to the east with Zabzugu and Tatale districts to the south. Its total land surface area of 5350 km^2 is ranked 6th in the Northern region (Abdulai and Al-hassan, 2016). Saboba district lies between Latitudes 24° and 25° north, Longitudes 27° and 13° east, covering a total land area of approximately 1751.2 km^2. Tatale -Sanguli to the south and Yendi municipal to the west surrounds the district. On the east is River Oti, which serves as the international boundary between Ghana and Togo. Tatale-Sanguli district covers an area of about 1090.47 km^2 and shares boundaries with Togo to the east, Zabzugu district to the south, Saboba districts to the north and Yendi Municipality to the west (Government of Ghana, 2013). From 2014 to 2016, Tatale-Sanguli and Saboba were the highest millet and sorghum producers among the top ten districts in Ghana whiles Tatale—Sanguli was also among the top 10 groundnut producers within the same period. Yendi was the second highest producer of cowpea and soybeans among the top ten districts in Ghana from 2014 to 2016. All three districts are among the leading maize producing districts in the Northern region of Ghana (MoFA, 2017). Even though the northern area supplies Ghana with major cereals and legumes, there is rampant burning of crop straw in the region during the dry season where Yendi, Saboba and Tatale-Sanguli are no exception. This leads to planting crops on bare soil (Kombiok et al., 2012).

2.2. Sampling and data collection

A multistage sampling technique was adopted in choosing the communities for the study putting into consideration the geographical, socioeconomic and demographic profiles of the households in Yendi, Saboba and Tatale - Sanguli districts. The socio-economic and demographic profiles were based on population trend, housing structures, family size, ethnic composition, employment rate, land use characteristics, major source of income

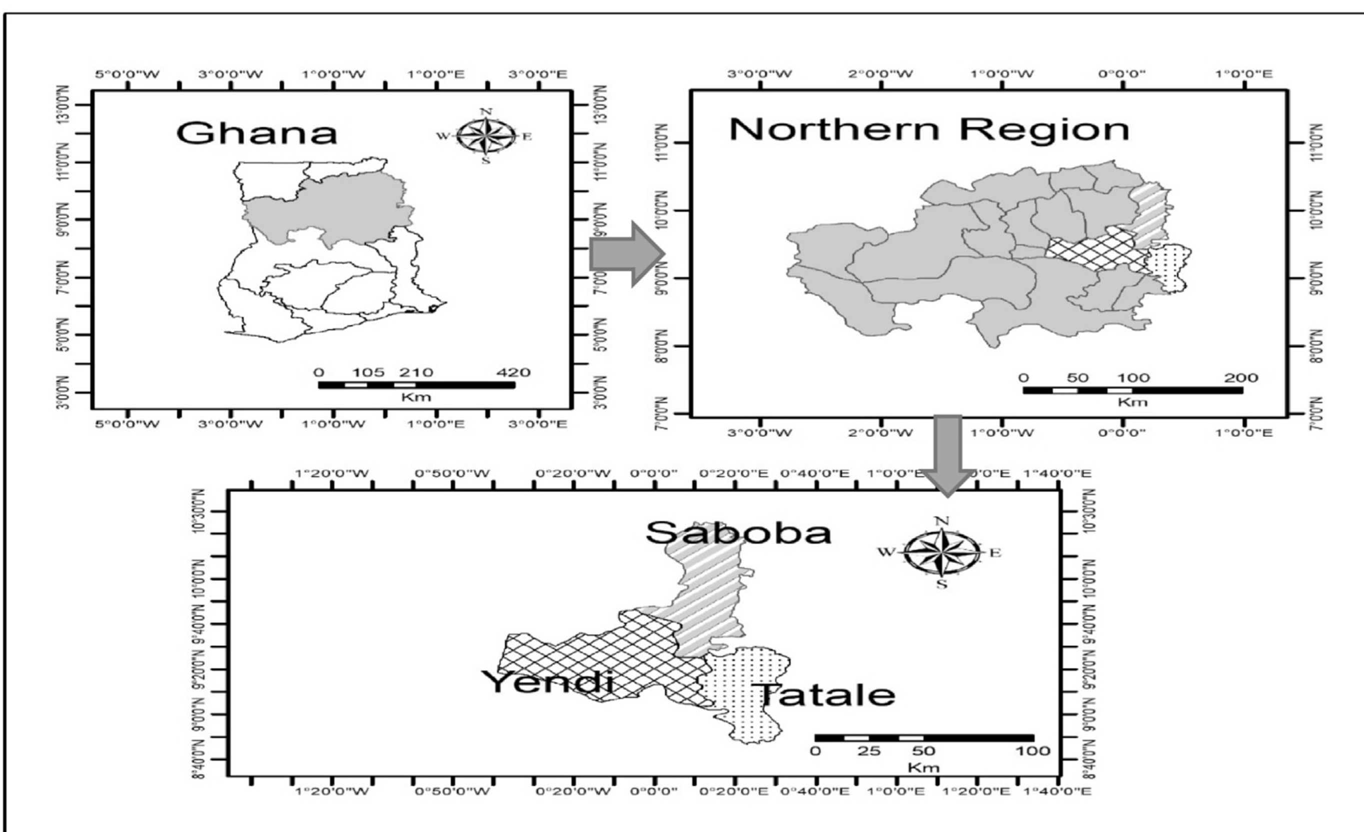

Fig. 2. Map of the study area.

and poverty rate of households. Ten communities were randomly selected from each district making 30 communities for the survey. The research targets were mainly farming households. The questionnaire was designed based on review of literatures and consultations with experts in the field of agricultural resource utilization. A semi-structured questionnaire was used to gather both quantitative and qualitative data. However to ensure the quality of the data to be gathered, after the first draft of questionnaire was developed, we did a pretest with some selected farmers in ten communities in two districts (Yendi and Saboba) of the study area to modify the questionnaire before the final draft was used. Face-to-face interaction interviews with 384 households represented by the household heads were conducted from January to February 2019. For a fair representation of gender, special attention was made to include women to ensure the sample size had a good representation of women respondents. All information gathered on households was based on demographic characteristics, crop and ruminant production information, methods of crop straw utilization and field burning of crop straw. The survey focused on the quantity of crop straw produced, how they utilize the straw and the state of straw field burning in the area.

2.3. Estimation of crop straw yield

Straw yield was calculated with Residue to Product Ratio (RPR) or Straw to Grain Ratio (SG) value from Kemausuor et al. (2014). We used the formula by Bi et al. (2009) shown in Eq. (1) to estimate yield for each separate straw type (maize stalks, husks and cobs; rice stalks and husks; millet straw; sorghum straw; groundnut stalks and husks; cowpea straw as well as soybeans stalks and pods).

$$W_S = W_P * S_G \tag{1}$$

Where W_S= crop straw yield, W_P= Crop yield, S_G= Straw to Grain Ratio/Residue to Product Ratio.

The total straw yields of maize (stalks, husks and cobs) were calculated in Eq. (2). Total rice straw yield (stalks and husks) was calculated using Eq. (3). Straw yield for groundnut stalks and shells were used to calculate the total groundnut straw yield shown in Eq. (4).

$$W_{STM} = W_{SMS} + W_{SMH} + W_{SMC} \tag{2}$$

Where W_{STM} = total maize straw yield, W_{SMS} = maize stalks yield, W_{SMH} = maize husk yield, WSMC = maize cobs yield

$$W_{STR} = W_{SRS} + W_{SRH} \tag{3}$$

Where W_{STR} = total rice straw yield, W_{SRS} = rice stalks yield, W_{SRH} = rice husks yield

$$W_{STG} = W_{SGS} + W_{SGSh} \tag{4}$$

Where W_{STG} = total groundnut straw yield, W_{SGS} = groundnut stalks yield, W_{SGSh} = groundnut shell yield.

We calculated the grand total straw yield of all the major cereals (maize, rice, millet, sorghum) and legumes produced (groundnut, cowpea, soybeans) based on Eq. (5).

$$W_{SGT} = W_{STC} + W_{STL} \tag{5}$$

Where W_{SGT} = grand total straw yield, W_{STC} = total cereal straw yield, W_{STL} = total legume straw yield.

2.4. Data analysis

The questionnaire data was analyzed with IBM Statistical Package for Social Sciences (SPSS version 22). The data was subjected to descriptive and bivariate statistics. The descriptive statistics tools included frequencies, percentages and proportions of the information gathered. The data was also subjected to cross tabulation and correlation analysis. A linear regression analysis was done as shown in Eq. (6) to analyze factors that determine continuous straw burning in Ghana using the major crops, cereals and legumes cultivated. Statistical test for significance was at 5% confidence level.

$$Y = \alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \ldots + \beta_n X_n + \varepsilon \tag{6}$$

Where Y = dependent variable, α = Intercept, β1-n = Coefficients of the dependent variables.

$X_{1\text{-}n}$ = Independent variables that affect straw burning, ε = Residual term.

3. Results and discussion

3.1. Demographic characteristics of respondents

From the total respondents interviewed 33.1% were from Yendi municipal, 33.6% from Saboba and 33.3% from Tatale - Sanguli districts. Farming is the primary occupation for 99.7% of the respondents whiles 0.3% were employees of government and non - government organizations (Table 1). The higher proportion of farmers indicates agriculture is the major source of income and this helps to promote their economic livelihood. Gender representation of the respondents was more of males (54.4%) than females (45.6%) with the age of all the respondents ranging from 15 to above 50 years. Our conscious effort to engage women is to get a fair representation of straw utilization practices and field burning in the area since they play a major role in straw utilization.

A significant percentage (34.4%) of the respondents were between 36 and 45 years old. Household size for majority of respondents ranged from 3 to 10 (42.7%) and 11–20 (42.7%). The large family size observed was because majority of the households in the northern region practice extended family system (Ansah and Issaka, 2018). These large households support farm work, which helps to ease the burden of hiring farm laborers.

The common cropping systems in the study area are mixed cropping and crop rotation. The crops cultivated by the households are maize (98.7%), rice (54.8%), millet (68.2%), sorghum (79.4%), groundnut (84.9%), cowpea (68.8%) and soybeans (66.1%). Maize was the predominant crop cultivated by most households. The straws produced by these households are from cereals and legumes. Major cereal straws produced are from maize, rice, millet and sorghum while the major legume straws produced are from soybeans, groundnut and cowpea. Crop livestock system is a common practice where livestock rearing plays an important role in the agricultural system of the area. The farmers usually rear goats, sheep, cattle, pigs and poultry. All the surveyed households relied on rainfall as their main source of water for farming. From the results of the survey, about 92.7% of households rear goats, sheep and cattle as a source of generating extra income to meet family needs. The integration of crop and livestock production diversification can be viewed as a climate change mitigation strategy, which can help improve the sustainable livelihood of farm households. Ghana's farming systems is characterized by livestock production and rain fed agriculture (MoFA, 2007). Household's diversification into livestock production can influence the utilization of straw as feed for ruminants particularly in the dry season when there is scarcity of feed.

Table 1
Differences in Demographic characteristics.

Characteristics	Categories	Percentage (%) (n = 384)	*P value* based on mean
District	Yendi	33.1	
	Saboba	33.6	
	Tatale	33.3	
Gender	Male	54.4	0.294
	Female	45.6	
Age (years)	15–25	3.9	0.367
	26–35	19.0	
	36–45	34.4	
	46–55	21.9	
	Above 55	20.8	
Household size	3–10	42.7	0.066
	11–20	42.7	
	21–30	10.4	
	31–40	4.2	
Educational level	No education	82.0	0.508
	Primary education	4.7	
	Junior High School (J.S.S)	6.5	
	Secondary (S.H.S)	5.2	
	Tertiary	1.3	
	Adult Education	0.3	
Primary Occupation	Farming	99.7	
	Employee (Government or Non-Government Organizations)	0.3	
Ruminants reared	Yes	92.7	0.133
	No	7.3	
Main source of water for farming	Rainfall	100	
Main source of household energy	Firewood	100	

At 5% significant level.

A significant proportion (82%) of the household heads had no formal education. However, those who had primary, junior high, senior high and secondary education were 4.7%, 6.5%, 5.2% and 1.3% respectively whiles 0.3% had some form of adult education. Farmers educational level coupled with their indigenous knowledge can positively influence crop straw utilization. When farmers are educated, they tend to appreciate the need to practice sustainable methods of straw utilization and this helps to promote a cleaner environment. Major source of cooking fuel for all the households was firewood. However, some households use crop straw as cooking fuel when there is scarcity of firewood or to supplement firewood. There were similarities in gender, age distribution of household heads, household size, farmers' level of education and ruminants reared for the three districts indicating a demographic homogeneity. All the districts were considered as a uniform population in the analysis.

3.2. *Straw yield for major cereals and legumes*

Table 2 shows the total straw yield for the major cereals and legumes. From the results, the average farm size per household for crops cultivated were 4.5 acres (1.8 ha) for maize, 3 acres (1.2 ha) for rice, 5 acres (2 ha) for soybeans, 3 acres (1.2 ha) for groundnut, 2 acres (0.8 ha) each for millet, sorghum and cowpea. The findings of our results for farm sizes are similar to the report of Aruya et al. (2016) where they reported 87% of respondents used 1–5acres of farm size. Farm size can be associated with utilization of straws. A research done by Jaleta et al. (2015) showed that farm size positively influenced quantities of straw incorporated into the soil while it negatively affected the quantities of straw utilized for animal feed. Our results shows a total crop yield of 1.29 kton was produced in the study area for major cereals and legumes during the production season. Using the Residue to Product Ratio (RPR) or Straw to Grain Ratio (SG) values of Kemausuor et al. (2014), total crop straw yield produced was 3.05 kton with soybeans straws having higher yields of 1.04 kton than maize straw (0.97 kton) (Fig. 3). This shows that more maize and soybeans straws are been re-used compared to the other types of crop straws. These straw resources are less costly and readily available at the community levels. Crop straws are normally available immediately after harvest. The availability of abundant straw resources depends on numerous factors such as crop production and type of farming system practiced (Illo et al., 2018). Climatic factors also play a major role particularly when farmers solely rely on rainfall for their crop production.

Although, soybeans straw yield is higher than maize straw, the total cereal yield is 1.72kton whiles legume straw yield is 1.33kton. Cereal straw accounts for 56.4% of the total straw and 43.6% for legume straw. Our results partly confirm the findings of (Ansah and Issaka, 2018) who stated that the average straw yield per household produced for legumes were higher for soybeans followed by cowpea and groundnut. Lal (2005) discovered that total cereal straw produced by farmers constituted the highest percentage (75%) than other straw. The abundance of cereal straw was emphasized by Alkhtib et al. (2017) where 76.1% cereal straws and 23.9% legume straws were produced in part of Ethiopia. According to Seglah et al. (2019) cereal straw recorded 72.3% out of the total straw produced in Ghana from 2006 to 2016 whilst legume straw was 26.8%. Our results show that there are abundant of cereal straws produced than legume straws in the study area. Production of different types of straw has a close association with the abundance of straw resources. This promotes the alternative utilization of straw instead of focusing on only one re-use method. According to Jaleta et al. (2015) production of straw has close association with its effective utilization. Estimation of straw resources is necessary for the quantification of straw utilization methods. Prioritizing the use of these crop straws for different utilization methods such as returning to the field, animal fodder, cooking fuel and others will help reduce farmer's financial burden. In addition, managing these straws will satisfy long-term productivity needs of farmers however if not managed well can cause serious environmental problems.

3.3. *Farm households crop straw utilization*

Considering the total cereal and legume straw produced, only 1.23kton (40.3%) of straws were utilized. The utilization methods are returning to the field to enrich the soil, fodder for livestock, cooking fuel, for sale and other traditional uses. Out of the total straw (3.05kton) produced only 40.3% were utilized indicating that a larger proportion produced by households are considered as waste. Crop straw is re-use occasionally or every time by households. Table 3 shows the various straw utilization methods and proportion of households who practice these methods. 37.0% and 37.8% households returned rice and cowpea straws to the field (either used as mulch or incorporated into the soil). The proportion of farm households who return crop straws to the field was higher than all the other utilization methods. Using straw as mulch or incorporating it into soil helps in restoring the soil nutrient level for the next cropping season. Our results corroborates with Ansong Omari et al. (2018) whose research in the Guinea Savannah zone of Ghana revealed that a significant proportion of farmers return straw to the field. Kombiok et al. (2012) emphasized, straw is used as mulch in the Northern region of Ghana. Abukari (2014) showed that in Nyankpala, 28.5% and 15% of respondents return maize stover and cob to the field whiles 7.5% of respondents used maize

Table 2
Total straw yield for Major cereals and legumes.

Crop	Farm size cultivated (Acres)	Crop yield in kton (W_P)	Straw	S_G/RPR (g/g)	Straw yield in kton (w_s)	Total straw yield in kton (W_{ST})
Cereals straw						
Maize	1678.5	0.47	Stalks	1.59	0.74	0.97
			Husks	0.2	0.09	
			Cobs	0.29	0.14	
Rice	648	0.24	Stalks	1.66	0.39	0.45
			Husks	0.26	0.06	
Millet	597.5	0.08	Stalks	1.83	0.15	0.15
Sorghum	706	0.07	Straw	1.99	0.15	0.15
Total cereal straw (W_{STC})	3630	0.86				1.72
Legume straw						
Groundnut	1061.5	0.08	Stalks	2.15	0.18	0.21
			Shells	0.37	0.03	
Cowpea	478.8	0.05	Shells	1.75	0.08	0.08
Soybeans	1259	0.3	Stalks and Pods	3.5	1.04	1.04
Total legume straw (W_{STL})	2799.3	0.43				1.33
Grand total	6429.3	1.29				3.05

W_P = crop yield. S_G/RPR = Straw to grain ratio/residue to product ratio. W_S = straw yield. W_{ST} = total straw yield. Source: Residue to Product Ratio (RPR) from Kemausuor et al. (2014).

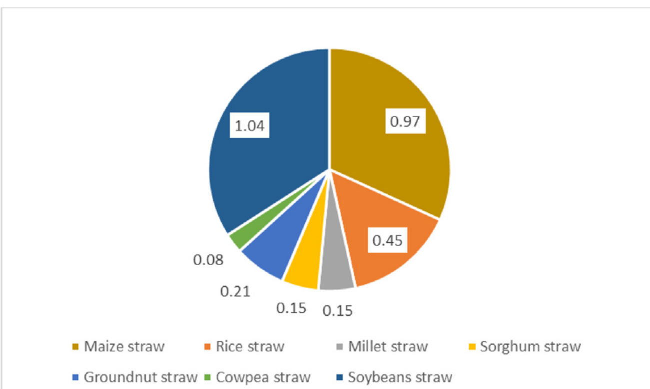

Fig. 3. Crop straw yield for major cereals and legumes (kton).

stover as compost. Returning straw to the field is a common straw utilization method (Huang et al., 2019). Based on our findings, a high proportion of households incorporate straw into the soil. This can be attributed to the fact that the practice is the cheapest way to utilize straw as a mitigation approach to field burning (Liu et al., 2019). This implies encouraging more farmers to return straw to the field might be much easier and a cheaper strategy to adopt. Soil fertility plays a significant role in increasing crop productivity. In Sub Saharan Africa, soil erosion is a major problem which affects plant growth (Yageta et al., 2019). Returning straws to field is an effective way to resolve soil erosion problems particularly when sufficient amounts are maintained on the farms after harvest (Karlen and Huggins, 2014). This helps to enrich the soil with nitrogen, phosphorous, potassium and sulphur (Gadde et al., 2009). It also improves the physical, chemical and biological properties of soil (Zhao et al., 2015) which have positive implications on crop productivity and livelihood of farmers (He and Zhuang, 2013). Returning straw to the field will help reduce the application of inorganic fertilizers and promote a cleaner environment (Yin et al., 2018). It can help farm households spend less in purchasing fertilizers and increase their income levels since the profitability rate of incorporating straw is higher (Uddin and Fatema, 2016). In addition, utilization of straw as a soil management option helps to mitigate climate change issues (Mohammadi et al., 2016).

In using straw as a fodder for livestock, straws from soybeans (9.3% of households), groundnut (7.6% of households) and cowpea (7.15% of households) were mainly used. This indicates that farmers prefer to feed their livestock with legume straws than cereal straws. The utilization of legume straws as fodder for livestock can be due to their palatability and high nutritional value when compared to cereals straws (Illo et al., 2018). In addition, legume straws have good level of digestibility (Ayatunde et al., 2019). Crops straw plays important role in crop-livestock farming systems (Teshager, 2019) and households with livestock are more likely to utilize crops straw as feed (Jaleta et al., 2015). Crop straws are main source of feed in the dry season (Ayatunde et al., 2019) due to their abundance after

Table 3
Straw utilization methods and proportion of farmer household practice.

Method of utilization	Type of straw and Percentage (%) utilization							
	Maize straw	Rice straw	Millet straw	Sorghum straw	Soybean straw	Groundnut straw	Cowpea straw	Other straw
No use	52.5	54.0	49.4	25.3	46.5	51.1	48.4	57.4
Returning to the field	24.8	37.0	36.4	25.0	29.1	32.4	37.8	26.6
Fodder	1.1	1.4	1.5	–	9.3	7.6	7.1	11.7
Fuel	6.3	–	4.6	14.9	–	–		
For sale	–	–	–	.3	–	–	–	1.1
Returning and Fodder	6.1	7.1	5.0	2.6	15.1	8.9	6.7	3.2
Returning and Fuel	3.7	–	2.7	9.4	–	–	–	–
Fodder and Fuel	1.1	.5		1.3	–	–	–	–
Other use	1.1	–	.4	18.8	–	–	–	–
Returning to field, fodder and fuel	3.4	–	–	2.3	–	–	–	–
Total	100	100	100	100	100	100	100	100

Note: The blank spaces shows farmers do not use the straw for that particular purpose.

harvest. Their nutritive value for ruminants (Haile et al., 2016) can help improve on meat and milk products. In addition, it enhances livestock productivity, which helps farmers generate more income. Growth in the livestock sector can serve as employment for people and income generated can be used to purchase more food and other family needs. This can serve as a driving force to achieve sustainable food security as well as improve on the standard of living of households (Smith et al., 2013). We found that 18.8% of households used sorghum straw for other purposes such as fencing, making soap, weaving of baskets and mats, albeit some households practice 2 or more utilization methods.

For the combined utilization of straws, returning straw to the field and fodder was high for soybeans straw (15.1% of households) followed by groundnut (8.9% of households), rice (7.1% of households), cowpea (6.7% of households), maize (6.1% of households), millet (5.0% of households), other crops (3.2% of households) and sorghum (2.6% of households) straws. The proportion of households that practice returning to the field plus fuel were 9.4% for sorghum straw, 3.7% for maize straw and 2.7% for millet straw (Table 3). Some households utilize straw as fodder and cooking fuel using sorghum (1.3% of households), maize (1.1% of households) and rice (0.5% households) straws. Simultaneous utilization of straw by returning to the field as fodder and fuel is common with maize (3.4% of households) and sorghum (2.3% households) straws. The adoption of more than one utilization method was emphasized by Berazneva (2013) where out of the 310 households interviewed, 143 re-used maize straw to enrich their lands, as livestock feed and cooking fuel. This indicates that adopting multiple uses of straw is a household decision. The various utilization methods practiced shows farmers might be aware of the benefits of straw utilization as a mitigation approach against open field burning which is an environmentally friendly approach (Silalertruksa and Gheewala, 2013). However, demand and utilization of straw resources are influenced by crop production, individuals' preferences and availability of alternative resources. Higher population and livestock densities can also influence straw use (Valbuena et al., 2015).

Adoption of straw management option is based on factors such as geographical location, educational level of farmers', farming experience, primary occupation and farm size (Ahmed and Ahmad, 2013). Even though straw utilization is being practice, the proportion of households that did not utilize straw was higher than those who re-use it. The households who did not utilize their straws were 54.0% (rice), 52.5% (maize), 51.1% (groundnut), 49.4% (millet), 48.4% (cowpea), 46.5% (soybeans) and 25.3% (sorghum). The high proportion of households that do not re-use crop straws is closely associated with high quantities of straws unutilized, which are considered as waste. When large quantities of straws are unutilized, its disadvantages override the benefits. According to Quartey and Chýlková (2012) large quantities of unused straw get burnt on the field. Effective straw utilization is unattainable if straws are considered as waste and abandoned. Even though crop straw is abundant in the area its utilization rate is minimal which can be attributed to the fact that farmers had little knowledge on the benefits of straw utilization while there are vast range of potential utilization methods which can be practiced effectively (Rosmiza et al., 2017).

3.4. Farmers' crop straw field burning practice

From our findings, farmers and hunters mainly burn straw on the field and in few instances by both (farmers and hunters). However, some households do not practice straw burning. Fig. 4 shows that 45% of farmers burn their own straw, 36% of households indicated their straw is burnt by hunters and 4% indicated both farmers and hunters burn. The combined burning (farmers and hunters) of straw occurs when hunters partly burns and the farmers burn the straw remains at the beginning of the farming season during land preparation. In total, 85% of the respondent's crop straws were burnt consciously or unconsciously whiles 15% practice no burning. The 15% of respondents normally re-use straw for three main purposes such as returning to the field, as animal fodder and cooking fuel. The annual occurrence of bush fires instigated by both hunters and farmers in the savannas (Yahaya and Amoah, 2013) can cause field burning of straws. The activities of hunters using fire as a way of getting more wild animals has a negative impact on crop straw, wildlife species, land and the vegetation. Based on field observations, burning crop straws and vegetation leaves the land bare, which causes land degradation. The quest of getting hunted species is a common practice in the area with severe environmental implications that needs to be banned. Our results shares similarities with Yang et al. (2014) where straw burning in Anhui province of China is still rampant. From our study, the high proportions can be attributed to the fact that straw burning is a demographic issue and low educational level of respondents makes burning a common phenomenon in the study area. Straw burning is a major obstacle in the utilization of straw which is caused by conscious or unconscious human factors (Shi et al., 2014).

Field burning of straw is done in the dry season, Table 4 shows that late dry season (February to April) records the highest period of straw burning by households (44% of household's) while the remaining straw are burnt in the early dry season (November to January) and early wet season (May–July). From our findings, field burning of straw is rampant during and after the harvest season. According to Saggu et al. (2018) straw burning is normally practiced after harvest. This can cause increasing trend in smoke related health problems, property loss and affect crop productivity. Kombiok et al. (2012) indicated that burning of crop straw is practiced in the dry season when the straws are prone to bushfire. Majority of farmers in the forest transition zone of Ghana burn in March and April and this agrees with our findings where most straw is burnt in the late dry season (February to April). Different geographical locations and harvesting seasons influence the time of straw burning. Rice and wheat straws were burnt in parts of Malwa region in Punjab (India) in October–November and April–May respectively (Saggu et al., 2018). The period of burning straws can vary depending on the harvesting period of the crop. In some parts of Northeast China, straw burning is practice in April, November, October and March (Fang et al., 2020). In addition, wheat, corn and rice straws were burnt in June, October and December in Tianjin (Guan et al., 2017). Emissions due to straw burning were observed in June whiles some farmers burnt straws at the beginning of the farming season in spring in other parts of China (Zhang et al., 2016).

3.4.1. Proportion of crop straw and farm size burnt

The amount of straw burnt in the field is about 1.82kton, which accounts for 59.7% of major cereals and legume straws burnt. From Table 5, large quantities of straw (82–100%) were burnt. The percentage of maize straw burnt was 77.6% while the percentages of other crops straw burnt are rice (42.2%), millet (49.7%), sorghum (58.6%), soybean (41.4%), cowpea (47.4%), groundnut (56.5%) and other crops (sesame, pigeon pea and Bambara beans, 16.9%) straws. In Malaysia, most straws particularly rice straw is often disposed by burning on the fields (Rosmiza et al., 2017). On average 23.0% of rice straw was burnt in Thailand (Junpen et al., 2018). Over half of the total straw for major cereals and legumes produced were burnt (59.4%). Maize straw is highly burnt because of its abundance in most of the households. Continuous burning of straw will have negative impact on agriculture and farmers livelihood (He and Zhuang, 2013). Burning of these straws leads to loss of valuable

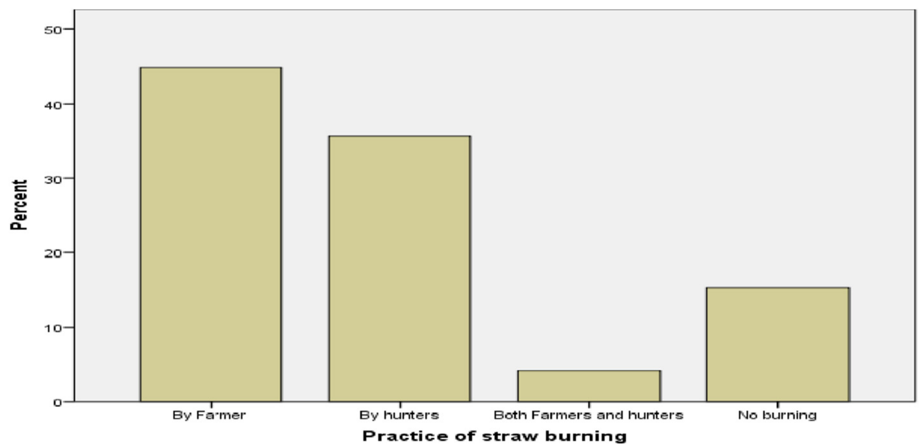

Fig. 4. State of field burning of crop straw.

Table 4
Season of field burning of crop straw.

Season when burning is normally done					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Early dry season (Nov–Jan)	72	18.8	22.4	22.4
	Late dry season(Feb–April)	169	44.0	52.5	74.8
	Early wet season (May–July)	67	17.4	20.8	95.7
	Late dry season and Early wet season (Feb–July)	14	3.6	4.3	100.0
	Total	322	83.9	100.0	
Missing	System	62	16.1		
Total		384	100.0		

resources and nutrients, which can be used to fertilize farmlands and improve on farmers' livelihood. Frequent burning of straw increases farmers cost of production since they will spend more in purchasing fertilizers. Farmers in the study area complained of low crop yields and this could be because of large quantities of straw burnt instead of incorporating into the soil. These fires can spread to other areas and destroy farm and forest vegetation (Kumar et al., 2015). Burning of straws pollutes the atmosphere, which can release toxic emissions like Methane, Carbon dioxide (CO_2) and Volatile organic compounds (VOC). Continuous release of CO_2 will diminish the oxygen level and greenhouse emissions (Gadde et al., 2009). When straw burning increases, the higher the probability of rise in pollution (Wu et al., 2018). These harmful pollutants can affect both human and animal health. Emissions from straw burning affect the health of children by decreasing the function of their lungs (Saggu et al., 2018). Farmers might have to spend more money to alleviate the health problems associated with field burning of straw particularly during the months when pollution is high. Straw burning causes a reduction in working days of farmers as well as increase their medical cost. In addition, farmers might spend more on buying agro inputs such as fertilizers and pesticides. This can negatively affect the finances of households (Kumar and Kumar, 2016).

The size of farmland burnt for majority of respondents was 0.1–2.0 acres (Table 6). When households heap crop straws on parts of the farm to burn they end up burning on small pieces of lands. This was confirmed by Domínguez-Escribà and Porcar (2010) who indicated that straw is often piled up on some portions of the land for burning which is likely to cause the accumulation of ash at some parts of the farm. In addition, these households are mostly smallholder farmers who farm on small portions of land. The size of farms burnt between 0.1 and 2 acres are as follows maize straw (60.1%), rice straw (80.9%), millet straw (90.6%) sorghum straw (90.7%), soybean straw (49.7%) groundnut straw (94.5%) and cowpea straw (77.4%). Even though the higher proportion of farmlands burnt were between 0.1 and 2 acres, there were instances where larger farm size between 40 and 50 acres were equally burnt. Our findings show that farm size plays an important

Table 5
Proportion of crop straw burnt.

Proportion Burnt	Type of crop straw burnt (%)							
	Maize straw	Rice straw	Millet straw	Sorghum straw	Soybean	cowpea	Groundnut straw	Other straw
1–15%	9.1	6.5	9.4	9.9	2.9	9.1	16.1	1.0
16%–30%	18.2	13.3	15.4	18.0	5.7	14.1	10.7	.8
31%–45%	5.2	3.1	2.6	3.1	2.1	2.6	.5	–
46%–60%	6.3	3.1	4.4	9.4	3.1	4.4	4.4	1.3
61%–81%	6.0	1.0	2.9	4.2	3.4	1.0	1.3	–
82%–100%	32.8	15.1	15.1	14.1	24.2	16.2	23.4	13.5
Total	77.6	42.2	49.7	58.6	41.4	47.4	56.5	16.9

Note: The blank spaces shows crop straw was not burnt at that proportion. Other straws include pigeon pea, sesame and Bambara beans straw.

role in determining the quantity of straw burnt. The size of land cultivated is closely associated with the size of land burnt. According to McCarty et al. (2007) an average of 40 acres of farm size were burnt in Arkansas (U.S.A) from 2001 to 2004. In other research Badarinath et al. (2006) stated that 5504 Km^2 and 12,685 km^2 under wheat and rice cultivation were burnt respectively. Farmland is a principal resource for farming activities but straw burning cause damaging effect on soil organic carbon. The top soil becomes dark in colour and easily heats up. Burning can increase the soil temperature to about 33.8 °C to 42.2 °C, this heat penetrates into the soil and causes negative effects on soil quality which affects plant growth particularly shallow rooted crops (Parker et al., 2010).

Straw burning exposes the land to high erosion (Hesammi et al., 2014), and continuous erosion degrades the soil which might affect crop yield. The negative effect of erosion on food supply is a global issue (Sartori et al., 2019). Parker et al. (2010) highlighted that, field burning of straw is not a sustainable approach since it was observed that there was a 21% reduction in soil organic carbon which caused release of 1446 CO_2 kg ha^{-1}. The Northern region is agriculturally driven, and the study area is ranked among the top districts that provide food in the region. Hence, a reduction in food from these areas will negatively affect Ghana's food supply that will be a threat to food security, increase hunger and poverty levels of farm households.

3.4.2. Reasons for burning crop straw

Field burning of straw is practiced for numerous reasons, in Table 7, 154 farm households indicated the essential reason for burning straw is that, it saves time for them to work on the farm. The practice also makes ploughing and working on the farm easy after planting. Other respondents (28) indicated they burn to reduce pests infestation, increase soil fertility and sometimes because there is no alternative for utilizing straw after harvest. Farmers opt to burn straw to reduce the high incidence of scorpions, snakes, rabbits and rats, which harm them and destroy their crops. Some of the reasons for burning straw were lack of training from extension officers and government support. Lack of government support to prohibit field burning of straw influenced the continuous burning of straw in the area. Our results agrees with Ahmed et al. (2015) who reported that farmers completely or partly burns straw to ease farm machinery usage, time saving, increases yield and improvement of soil quality. In addition, straw burning helps to reduce pest and rat infestation as well as the spread of diseases (Rosmiza et al., 2014). According to Aruya et al. (2016) lack of ignorance on efficient management of straw resources caused poor management of straw in part of Kaduna state in Nigeria. This reason might be that farmers do not get access to agricultural extension trainings on the efficient re-use of straw resources. Farmers have numerous reasons for practicing field burning of straw although most of these reasons have negative effect on the environment. Their reasons were based on immediate benefits but they do not consider the long-term effects of their actions.

3.4.3. Negative effects of straw burning

The proportion of respondents who incurred injury or health issues in the process of burning or trying to quench field fire are 4.2%. The types of injuries were body burns, severe foot injury, high body temperatures and coughs. However, a larger section of households did not experience any form of injury. This value is far below the findings of Yang et al. (2018) where 36% of farmers indicated they experienced health issues due to open field burning in China. The low proportion of farm households who experienced some form of injury may be because some farmers did not directly burn their straws but rather by hunters. About 82% of respondents were aware of the bad effects of smoke on human health. Although high proportion of households indicated they were aware of the health hazards of burning, they did not have any measures in place to prevent themselves from any smoke related illness (Kumar et al., 2015). During straw burning periods, the levels of particulate matter (PM) are higher (Gupta, 2016). The emissions from straw burning have negative impact on household health, climate and crop yield (Lohan et al., 2018). Health problems associated with straw burning can be cough, skin disorders, pulmonary illnesses, irritation and dryness of the eyes (Singh, 2018). In some cases, it can cause asthma and lung cancer (Batra, 2017). In addition, smoke related issues can affect farmers' active working time. Farmers' health and lives are important for the continuous production of food to satisfy the needs of citizens (Gadde et al., 2009). Pregnant women and children are more at risk to health problems of straw burning (Singh, 2018), with severe pulmonary problems experienced by girls than boys (Gupta, 2016). People who experience severe illness might even die prematurely in the process. Rampant straw burning can affect visibility and cause road accidents (Singh, 2018). Pollution from straw burning affect both people within and far away from the burning sites (Batra, 2017) which can affect the general population. Even though few households did encounter severe health issues, continuous burning of straw in the area might cause severe illnesses in the future. Government needs to formulate policies to help reduce continues burning of straw (Ravindra et al., 2019) and its negative effects on human. About 8.3% of the households' lost their properties due to activities of hunters. Some of the properties lost were bags of cereals and legumes and harvested tubers of yams stored in barns on the farm. In one instance, a farmer lost his motorbike. According to Raza et al. (2019), field burning of crop straw causes loss of property and can cause conflict among farmers. It also decreases agricultural productivity. The households indicated that field burning of straws affects crop productivity both negatively and positively. Most of the households

Table 6
Farm size burnt.

Farm size in Acres	Maize Straw	Rice straw	Millet straw	Sorghum straw	Soybean straw	Groundnut straw	Cowpea straw	Other straw
0.1–2.0	60.1	80.9	90.6	90.7	49.7	94.5	77.4	95.4
2.1–5.0	25.5	10.5	7.8	8.4	32.1	3.8	17.1	4.6
5.5–10	9.4	4.3	.5	.9	11.9	1.6	4.6	–
10.5–15	3.0	1.9	.5		5.0	–	.5	–
15.5–20	.3	1.2	–	–	–	–	.5	–
20.5–25	.7	.6	–	–	–	–	–	–
25.5–30		–	–	–	.6	–	–	–
30.5–40	.3	–	–	–	.6	–	–	–
40.5–50	.3	–	–	–	–	–	–	–

Note: The blank spaces shows that farm size was not burnt. Other straws include pigeon pea, sesame and Bambara beans straw.

Table 7
Reasons for burning crop straw.

No.	Reasons	Proportion of households in terms of 'Order of Priority' base on reasons for burning				
		Not a priority	Low priority	Medium priority	High priority	Essential
1	Saves time to work on the farm	51	77	8	32	154
2	Saves money	173	139	6	4	–
3	Lack of machines for straw returning to the field	285	37	–	–	–
4	Lack of machines for collecting straw	286	35	1	–	–
5	No alternative method for straw utilization after harvesting	64	56	172	28	2
6	Labour was not available	256	58	6	2	
7	No time to remove straw from field before next farming season	88	58	51	102	23
8	Decreases pests infestation	86	81	98	49	8
9	Easy for ploughing	73	88	50	89	22
10	Ease of post planting operations	67	73	47	111	23
11	Increases soil fertility	227	55	23	14	3
12	Lack of training from Agriculture Extension Officers	16	12	212	81	1
13	Lack of government support to ban straw burning	9	3	174	123	13

(65.7%) indicated field burning of straw decreases their yield while 11.2% said it increases their yield and 6.8% of the respondents stated they did not observe any change in yield. Our results corresponds with Ansong Omari et al. (2018) who reported farmers were aware of changes in crop yield as a result of field burning, there was decrease (39.5%), increase (37.7%) and no change (10.5%) in yield. The high proportion of farmers who experience reduction in straw yield implies that field burning of straw negatively affects crop yield. The continuous burning of straw will affect crop productivity, which can lead to a threat on food security at the study area. This may cause shortage in food supply particularly cereals and legumes which will affect both producers (farmers) and consumers. The negative effects of burning which farmers usually experience calls for the sustainable utilization of straw resources (Cardoen et al., 2015).

3.4.4. Determinants of future burning and interventions to reduce straw burning

A linear regression analysis based on educational level, primary occupation, farm distance, farm size of major crops harvested, age, years of farming, farm size of cereals and legumes shows the main factors that can influence the future occurrence of field burning of straw. Primary occupation of respondents, farm size of major crops harvested and major legumes are key influencing factors that affect farmers' practice of burning straw at a significance level of 0.27, 0.38 and 0.45 respectively (Table 8). Since primary occupation of majority (99.7%) of respondents is farming, our results show that farming activities are more likely to increase the state of burning crop straw. In addition, expansion in area of major crop harvested or legume straw farm size can influence the state of burning. This may be because legumes straws are re-use as livestock feed instead of multiple utilization methods. This renders majority of legume straws to be abandoned on the farm for animals to graze on or left on the field to be burnt. Increase in farm size can cause abundance of straw resources which will be difficult for farmers to manage hence they might resort to straw burning.

This agrees with Ahmed et al. (2015) who indicated that farm size has a negative effect on field burning of straw. According to the authors farm size plays an important role in affecting how farmers manage straw. They hypothesized that the larger the farm the more likely straw will be burnt. Straw field burning increases with farm size (Ahmed and Ahmad, 2013). Findings from Junpen et al. (2018) showed that burning of rice straw by farmers increased from 284,000 ha in 2011 to 465,000 ha in 2012. In addition, Wu et al. (2018) indicated that there were records of high straw burning emissions in some provinces in China due to vast farm sizes. Farm size has a relationship with farm household's decision to practice field burning of straw (Haider, 2013) which has a negative impact on the environment and its inhabitants. In England, farm size is a determinant for farmers to incorporate straw into the soil. Which implies that increase in farm size positively influence farmers returning straw to the field (Townsend et al., 2018). This contrast can be due to the policies and measures various governments have put in place towards field burning of straw. From our findings majority of households (99%) indicated they were not aware of government intervention to prohibit burning. Only 1% of the total respondents were aware of government's intervention against field burning. This indicates that, government intervention towards field burning have future implications. Large farm size can positively influence the availability of straw resources (Iye and Bilsborrow, 2013). In addition, increase in crop productivity will lead to increase in the total straw burnt (Arai et al., 2015). If appropriate measures are not enforced, crops straw burning will increase over time (Jin et al., 2018) specially when farmers continue to expand their farmlands.

The households indicated the need for government and individuals to play their role to stop field burning of straw. About 18.2% of farmers stated they will stop field burning of straw while 20.3% indicated they will decrease the rate of field burning. Their decision to stop straw burning can be because of their attitude and experience over the years. Farmers' attitude can be linked to their long time experience of field burning and the alternative methods of straw utilization available. Those who experience negative effects of straw burning are more likely to stop and practice straw utilization (Raza et al., 2019).

Field burning of straw is difficult to stop over a short time (Wu et al., 2018). From our research, even though some farmers agreed they will stop burning, Cassou (2018) emphasized that farmers always procrastinate hence their intention to stop field burning of straw is never accomplished. Some farmers (10.2%) also indicated they would need education/trainings on straw utilization methods whiles 6.5% iterated they would create fire belts around their farms in the dry season to prevent the spread of fire caused by hunters from burning their farms. Majority (80.5%) of the households indicated they need government intervention to help stop straw field burning. The type of government support varied with 46.9% indicating government needs to enact laws to prohibit straw field burning. However, others stated government needs to empower the Ministry of Food and Agriculture (MoFA), fire service unit, Chiefs, traditional authorities to pass laws at the district levels and punish culprits. Government's intervention can also be through education and creating awareness through training of farmers by Agriculture extension Agents (AEAs) in utilizing straw. Education helps individuals to be aware of problems associated with the

Table 8
Regression Analysis of Major legumes and cereals cultivated.

Model		Standardized Coefficients	*p* value
		Beta	
1	(Constant)		.805
	Level of Education	.089	.089
	Primary Occupation of respondent	.115	.027
	Farm size harvested in Acres for major crop	−1.109	.038
	Age in Years	.027	.693
	Years of farming	.032	.634
	Major crop farm size in Acres	.771	.155
	Major cereal farm size in Acres	.236	.052
	Major legume farm size in Acres	.232	.045
	Distance in Km	-.010	.851

At 5% significance level.

environment and their health (Kumar and Kumar, 2016). It also, influences their decision to utilize crop straw. These trainings enlighten farmers to adopt new and improved methods of straw utilization (Supaporn et al., 2013). Rosmiza et al. (2017) emphasized the need for government and agricultural agencies to provide technical trainings and necessary machinery and logistics for farmers to re-use straw resources efficiently and stop burning. Agricultural extension services helps to build the capacity of farmers and this has a positive influence on straw utilization. Effective agricultural extension service delivery increases farmers rate of straw utilization (Jaleta et al., 2013). There is the probability that farmers' who have access to agricultural extension services practice straw utilization in a sustainable manner (Raza et al., 2019).

Both government and farmers play an important role towards the utilization of straw resources. Farmer households need to invest in straw utilization, however, without the intervention of government, it will be difficult for this to be sustainable (Zhang and Wu, 2018). Government support should also focus on eco-friendly ways to manage straw which requires less funding (Qu et al., 2012). There is the need for a combination of both farmer and technical knowledge (Ingram et al., 2018) for effective utilization of straw resources. In addition, Ghana needs a national policy on crop straw burning to reduce the rampant state of burning. Government supporting farmers through education, awareness creation, trainings coupled with policies will empower farm households to undertake sustainable environmentally friendly practices (Parker et al., 2010) which will promote cleaner production.

4. Conclusion and recommendation

The total crop straw yield produced in Yendi, Saboba and Tatale-Sunguli for major cereals and legumes was 3.05 kton. Cereal straw yield had the highest percentage of 56.4% while legume straw was 43.6%. About 1.23kton (40.3%) of crop straws were utilized. The major utilization methods of crop straw in the districts are returning to the field (as mulch or incorporated into the soil), cooking fuel, fodder for livestock, sale and other uses (fencing, weaving, constructing huts and making soap). About 1.82kton (59.7%) of straw were openly burnt on the field. Either farmers, hunters or both normally practiced field burning in the dry season. The major reasons farmers burn straw are to save time during land preparation, ease ploughing and post planting operations. It also increases soil fertility, however, farmers indicated they burn straw because of inadequate knowledge on alternative methods of straw utilization which is closely related to inadequate agricultural extension trainings and lack of government support to ban field burning of straw. Field burning in Northern region has negative effects on human health, land, crop productivity, household livelihood and the environment. A linear regression analysis showed farming and farm size (major crop harvested and legumes) are the key influencing factors that affect straw burning practice. Increase in farming and farm size has a higher probability that field burning of straw will be practiced. There is the need for a comprehensive role on the parts of farmers, hunters and government to curtail field burning of straw which will help ensure the effective utilization of straw resources. We suggest that at the community levels chiefs or traditional leaders need to set voluntary monitoring teams to stop the activities of straw field burning. In addition, farmers need to form cooperatives or intensify already existing ones and prioritize straw utilization methods. Base on the inefficient utilization of straw resources and constant field burning, we suggest the following to government:

- Invest in Irrigation and mechanized farming: Government investment in irrigation system and mechanized farm implements particularly in the study area will help to promote crop productivity and ensure farming all year round. Provision of farm machinery eases farming operations and increases productivity. Increase in crop productivity will positively influence straw yield.
- Intensify trainings and Campaigns on effective crop straw utilization: Government must equip the Ministry of food and Agriculture (MoFA) to train farmers on various straw utilization methods. These trainings must be instituted throughout the farming seasons. Liaising with Non-Governmental Organizations (NGOs) to train farmers will also help to inform them about the benefits of straw utilization and thus reduce burning.
- Promote research and development of crop straw: The Government needs to support scientists to research and develop straw utilization across the country. Promoting and financing research and development of utilizing straw will help ensure effective management of straw. Efficient utilization of straw will help promote economic development of the country.
- Prohibit field burning of straw: Government needs to employ administrative measures such as policies, which are consistent across all regions in Ghana to prohibit and punish culprits against field burning of straw. The policies must be supported with constant monitoring to make the approach more effective. Prohibiting field burning of straw will help to promote the effective utilization of straw in a sustainable manner.

These measures will ensure abundance and efficient utilization of straw resources within the study area and in the Northern region in general. The prevention of field burning of straw will promote cleaner production and sustainable development. The limitations in this research are that, respondents were only farmers but we could include non-farmers since hunters unconsciously practiced straw burning as well. Further research will require the involvement of government institutions particularly Ministry of Food and Agriculture and other agricultural related institutes and stakeholders to ascertain their engagement in straw research and field burning. We focused on major cereals and legumes straw but other sources of crop straw can be explored since there are diverse straw resources in Ghana. In addition, future research should quantify the proportions of straw re-used for the various utilization methods coupled with the cost benefit analysis of straw utilization and burning to help give a better idea on the need to efficiently utilize crop straw. Future research must be extended to remaining regions of Ghana to cover the whole country.

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.

CRediT authorship contribution statement

Patience Afi Seglah: Conceptualization, Data curation, Investigation, Methodology, Writing - original draft. **Yajing Wang:** Supervision, Validation, Resources. **Hongyan Wang:** Validation, Formal analysis. **Yuyun Bi:** Conceptualization, Supervision, Funding acquisition. **Ke Zhou:** Formal analysis. **Ying Wang:** Investigation. **Huan Wang:** Project administration. **Xinxin Feng:** Writing - review & editing.

Acknowledgments

Financial support for this research was provided by the National Science Foundation of China (41771569). We thank the various farmer households and contact persons in Yendi municipality, Saboba and Tatale- Sanguli districts who willingly availed themselves for this study.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2020.121191.

References

Abdulai, Y., Al-hassan, S., 2016. Effects of contract farming on small-holder soybean farmers' income in the Eastern Corridor of the northern region, Ghana. http://www.udsspace.uds.edu.gh/handle/123456789/1039. (Accessed 4 June 2019).

Abukari, A., 2014. Effect of rice husk biochar on maize productivity in the guinea savannah zone of Ghana. Doctoral dissertation. http://dspace.knust.edu.gh/handle/123456789/6595. (Accessed 1 January 2019).

Adjapong, A.O., Ansah, K.D., Angfaarabung, F., Sintim, H.O., 2015. Maize residue as a viable substrate for farm scale cultivation of oyster mushroom (Pleurotus ostreatus). Adv. Agric. 2015, 1–6. https://doi.org/10.1155/2015/213251.

Ahmed, T., Ahmad, B., 2013. Why Do Farmers Burn Rice Residue? Examining Farmers' Choices in Punjab, Pakistan. SANDEE, Kathmandu, Nepal.

Ahmed, T., Ahmad, B., Ahmad, W., 2015. Why do farmers burn rice residue? Examining farmers' choices in Punjab, Pakistan. Land Use Pol. 47, 448–458. https://doi.org/10.1016/j.landusepol.2015.05.004.

Alkhtib, A., Wamatu, J., Kassie, G.T., Rischkowsky, B., 2017. Analysis of crop residue use in small holder mixed farms in Ethiopia. Renew. Agric. Food Syst. 32, 454–462. https://doi.org/10.1017/S1742170516000399.

Ansah, T., Issaka, A.C., 2018. Ruminant livestock feed resources in the Kumbungu district of Ghana. J. Anim. Sci. 9, 100–107.

Ansong Omari, R., Bellingrath-Kimura, S., Sarkodee Addo, E., Oikawa, Y., Fujii, Y., 2018. Exploring farmers' indigenous knowledge of soil quality and fertility management practices in selected farming communities of the Guinea savannah agro-ecological zone of Ghana. Sustainability 10, 1034. https://doi.org/10.3390/su10041034.

Arai, H., Hosen, Y., Pham Hong, V.N., Thi, N.T., Huu, C.N., Inubushi, K., 2015. Greenhouse gas emissions from rice straw burning and straw-mushroom cultivation in a triple rice cropping system in the Mekong Delta. Soil Sci. Plant Nutr. 61, 719–735. https://doi.org/10.1080/00380768.2015.1041862.

Arranz-Piera, P., Bellot, O., Gavaldà, O., Kemausuor, F., Velo, E., 2016. Trigeneration based on biomass-specific field case: agricultural residues from smallholder farms in Ghana. Energy Procedia. 93, 146–153. https://doi.org/10.1016/j.egypro.2016.07.163.

Aruya, E.I., Yusuf, R.O., Yusuf, Y.O., 2016. An assessment of crop residue characteristics and factors militating against efficient management in the Ikara local government area of Kaduna state, Nigeria. WIT Trans. Ecol. Environ. 202, 333–344.

Ayamga, E.A., Kemausuor, F., Addo, A., 2015. Technical analysis of crop residue biomass energy in an agricultural region of Ghana. Resour. Conserv. Recycl. 96, 51–60. https://doi.org/10.1016/j.resconrec.2015.01.007.

Ayantunde, A.A., Boubacar, H.A., Adamou, K., Moumini, O., Umutoni, C., 2019. Evaluation of Feed Resources in the Mixed Crop-Livestock Systems of the Sahelian Zone in Burkina Faso and Niger.

Azhar, R., Zeeshan, M., Fatima, K., 2019. Crop residue open field burning in Pakistan; multi-year high spatial resolution emission inventory for 2000–2014. Atmos. Environ. 208, 20–33. https://doi.org/10.1016/j.atmosenv.2019.03.031.

Badarinath, K.V.S., Chand, T.K., Prasad, V.K., 2006. Agriculture crop residue burning in the Indo-Gangetic Plains—a study using IRS-P6 AWiFS satellite data. Curr. Sci. 91, 1085–1089.

Bakker, R.R.C., Elbersen, H.W., Poppens, R.P., Lesschen, J.P., 2013. Rice Straw and Wheat Straw-Potential Feedstocks for the Biobased Economy. NL Energy and Climate Change, The Netherlands.

Berazneva, J., 2013. Economic value of crop residues in African smallholder agriculture. In: Paper Presented at the Annual Meeting of the Agricultural and Applied Economics Association, Washington, DC. August 4–6, 2013.

Batra, M.C., 2017. Stubble burning in North-west India and its impact on health. J. Chem. En. Sci. 4, 13–18. https://doi.org/10.15415/jce.2017.41002.

Bi, Y., Gao, C., Wang, Y., Li, B., 2009. Estimation of straw resources in China. Trans. CSAE. 25, 211–217. In Chinese.

Cao, G., Zhang, X., Wang, Y., Zheng, F., 2008. Estimation of emissions from field burning of crop straw in China. Chin. Sci. Bull. 53, 784–790. https://doi.org/10.1007/s11434-008-0145-4.

Cardoen, D., Joshi, P., Diels, L., Sarma, P.M., Pant, D., 2015. Agriculture biomass in India: Part 2. Post-harvest losses, cost and environmental impacts. Resour. Conserv. Recycl. 101, 143–153. https://doi.org/10.1016/j.resconrec.2015.06.002.

Cassou, E., 2018. Field Burning. Agricultural Pollution. World Bank, Washington, DC. https://openknowledge.worldbank.org/handle/10986/29504. (Accessed 15 June 2019).

Chen, J., Gong, Y., Wang, S., Guan, B., Balkovic, J., Kraxner, F., 2019. To burn or retain crop residues on croplands? An integrated analysis of crop residue management in China. Sci. Total Environ. 662, 141–150. https://doi.org/10.1016/j.scitotenv.2019.01.150.

Domínguez-Escribà, L., Porcar, M., 2010. Rice straw management: the big waste. Biofuel. Bioprod. Biorefin. 4, 154–159.

Faostat, 2018. Food and agriculture organization of the united nations statistical database. http://www.fao.org/faostat/en/#data. (Accessed 4 May 2019).

Fang, Y., Xu, K., Guo, X., Hong, Y., 2020. Identifying determinants of straw open field burning in northeast China: toward greening agriculture base in newly industrializing countries. J. Rural Stud. https://doi.org/10.1016/j.jrurstud.2019.12.013.

Gadde, B., Bonnet, S., Menke, C., Garivait, S., 2009. Air pollutant emissions from rice straw open field burning in India, Thailand and the Philippines. Environ. Pollut. 157, 1554–1558. https://doi.org/10.1016/j.envpol.2009.01.004.

Ghaffar, S.H., Fan, M., McVicar, B., 2015. Bioengineering for utilisation and bioconversion of straw biomass into bio-products. Ind. Crop. Prod. 77, 262–274. https://doi.org/10.1016/j.indcrop.2015.08.060.

Government of Ghana, 2013. Ghana districts. A resource base for all local assemblies in Ghana. Northern region, Yendi municipal, Saboba and tatale/sanguli district. www.ghanadistricts.gov.gh. (Accessed 19 August 2019).

Guan, Y., Chen, G., Cheng, Z., Yan, B., 2017. Air pollutant emissions from straw open burning: a case study in Tianjin. Atmos. Environ. 171, 155–164. https://doi.org/10.1016/j.atmosenv.2017.10.020.

Gupta, S., Agarwal, R., Mittal, S.K., 2016. Respiratory health concerns in children at some strategic locations from high PM levels during crop residue burning episodes. Atmos. Environ. 137, 127–134. https://doi.org/10.1016/j.atmosenv.2016.04.030.

Haider, M.Z., 2013. Determinants of rice residue burning in the field. J. Environ. Manag. 128, 15–21. https://doi.org/10.1016/j.jenvman.2013.04.046.

Haile, E., Gicheha, M., Njonge, F.K., Asgedom, G., 2016. Determining nutritive value of cereal crop residues and lentil (lens esculanta) straw for ruminants. Open J. Anim. Sci. 7, 19–29. https://doi.org/10.4236/ojas.2017.71003.

He, J., Zhuang, T., 2013. The utilization of straw resources in China. Biotechnol. Ind. J. 8, 18–21.

Hesammi, E., Talebi, A.B., Hesammi, A., 2014. A review on the burning of crop residue on the soil properties. WALIA J 30, 192–194.

Huang, X., Cheng, L., Chien, H., Jiang, H., Yang, X., Yin, C., 2019. Sustainability of returning wheat straw to field in Hebei, Shandong and Jiangsu provinces: a contingent valuation method. J. Clean. Prod. 213, 1290–1298. https://doi.org/10.1016/j.jclepro.2018.12.242.

Illo, A.I., Kamba, A.A., Umar, S., Abubakar, A., 2018. Analysis of crop residues availability for animal feed in Kebbi State, Nigeria. Int. J. Agri. Ext. 6, 89–97.

Ingram, J., Dwyer, J., Gaskell, P., Mills, J., de Wolf, P., 2018. Reconceptualising translation in agricultural innovation: a co-translation approach to bring research knowledge and practice closer together. Land Use Pol. 70, 38–51.

Iye, E.L., Bilsborrow, P.E., 2013. Assessment of the availability of agricultural residues on a zonal basis for medium-to large-scale bioenergy production in Nigeria. Biomass Bioenergy 48, 66–74. https://doi.org/10.1016/j.biombioe.2012.11.015.
Jaleta, M., Kassie, M., Shiferaw, B., 2013. Tradeoffs in crop residue utilization in mixed crop–livestock systems and implications for conservation agriculture. Agric. Syst. 121, 96–105. https://doi.org/10.1016/j.agsy.2013.05.006.
Jaleta, M., Kassie, M., Erenstein, O., 2015. Determinants of maize stover utilization as feed, fuel and soil amendment in mixed crop-livestock systems, Ethiopia. Agric. Syst. 134, 17–23. https://doi.org/10.1016/j.agsy.2014.08.010.
Jenkins, B.M., Turn, S.Q., Williams, R.B., 1992. Atmospheric emissions from agricultural burning in California: determination of burn fractions, distribution factors, and crop-specific contributions. Agric. Ecosyst. Environ. 38, 313–330. https://doi.org/10.1016/0167-8809(92)90153-3.
Jin, Q., Ma, X., Wang, G., Yang, X., Guo, F., 2018. Dynamics of major air pollutants from crop residue burning in mainland China, 2000–2014. J. Environ. Sci. 70, 190–205. https://doi.org/10.1016/j.jes.2017.11.024.
Junpen, A., Pansuk, J., Kamnoet, O., Cheewaphongphan, P., Garivait, S., 2018. Emission of air pollutants from rice residue open burning in Thailand. Atmosphere 9, 449. https://doi.org/10.3390/atmos9110449.
Karlen, D.L., Huggins, D.R., 2014. Crop residues. In: Karlen, D.L. (Ed.), Cellulosic Energy Cropping Systems. John Wiley and Sons, Ltd., Hoboken, New Jersey, pp. 131–147. https://doi.org/10.1002/9781118676332.ch8.
Kemausuor, F., Kamp, A., Thomsen, S.T., Bensah, E.C., Østergård, H., 2014. Assessment of biomass residue availability and bioenergy yields in Ghana. Resour. Conserv. Recycl. 86, 28–37. https://doi.org/10.1016/j.resconrec.2014.01.007.
Kombiok, J.M., Buah, S.S.J., Sogbedji, J.M., 2012. Enhancing soil fertility for cereal crop production through biological practices and the integration of organic and In-organic fertilizers in northern Savanna zone of Ghana. In: Issaka, R.N. (Ed.), Soil Fertility. Intech, Croatia, pp. 3–32.
Konlan, S.P., Ayantunde, A.A., Weseh, A., Dei, H.K., Avornyo, F.K., 2015. Opportunities and Challenges of Emerging Livestock Feed Markets in Northern Ghana.
Kumar, P., Kumar, S., Joshi, L., 2015. Socioeconomic and Environmental Implications of Agricultural Residue Burning: A Case Study of Punjab, India. Springer, New Delhi, pp. 69–89.
Kumar, S., Kumar, P., 2016. Economic impact of air pollution from agricultural residue burning on human health. In: Climate Change Challenge (3C) and Social-Economic-Ecological Interface-Building. Springer, pp. 297–313. https://doi.org/10.1007/978-3-319-31014-5_17.
Lal, R., 2005. World crop residues production and implications of its use as a biofuel. Environ. Int. 31, 575–584. https://doi.org/10.1016/j.envint.2004.09.005.
Lohan, S.K., Jat, H.S., Yadav, A.K., Sidhu, H.S., Jat, M.L., Choudhary, M., Peter, J.K., Sharma, P.C., 2018. Burning issues of paddy residue management in north-west states of India. Renew. Sustain. Energy Rev. 81, 693–706. https://doi.org/10.1016/j.rser.2017.08.057.
Long, X., Tie, X., Cao, J., Huang, R., Feng, T., Li, N., Zhao, S., Tian, J., Li, G., Zhang, Q., 2016. Impact of crop field burning and mountains on heavy haze in the North China Plain: a case study. Atmos. Chem. Phys. 16, 9675–9691. https://doi.org/10.5194/acp-16-9675-2016.
Liu, B., Wu, Q., Wang, F., Zhang, B., 2019. Is straw return-to-field always beneficial? Evidence from an integrated cost-benefit analysis. Energy 171, 393–402. https://doi.org/10.1016/j.energy.2019.01.031.
McCarty, J.L., Justice, C.O., Korontzi, S., 2007. Agricultural burning in the Southeastern United States detected by MODIS. Remote Sens. Environ. 108, 151–162. https://doi.org/10.1016/j.rse.2006.03.020.
MoFA, 2007. Food and Agriculture Sector Development Policy (FASDEP II). Ministry of Food and Agriculture (MoFA), Ghana.
MoFA, 2015. Agriculture in Ghana-Facts and Figures. Statistics, Research and Information Directorate (SRID). Ministry of Food and Agriculture (MoFA), Ghana.
MoFA, 2017. Agriculture in Ghana-Facts and Figures. Statistics, Research and Information Directorate (SRID). Ministry of Food and Agriculture (MoFA), Ghana.
Mohammadi, A., Cowie, A., Mai, T.L.A., de la Rosa, R.A., Brandão, M., Kristiansen, P., Joseph, S., 2016. Quantifying the greenhouse gas reduction benefits of utilising straw biochar and enriched biochar. Energy Procedia. 97, 254–261. https://doi.org/10.1016/j.egypro.2016.10.069.
Ofosu, F.G., Hopke, P.K., Aboh, I.J., Bamford, S.A., 2013. Biomass burning contribution to ambient air particulate levels at Navrongo in the Savannah zone of Ghana. J. Air Waste Manage. 63, 1036–1045. https://doi.org/10.1080/10962247.2013.783888.
Parker, B.Q., Osei, B.A., Armah, F.A., Yawson, D.O., 2010. Impact of biomass burning on soil organic carbon and the release of carbon dioxide into the atmosphere in the coastal savanna ecosystem of Ghana. J. Renew. Sustain. Energy 2. https://doi.org/10.1063/1.3449299, 033106.
Präger, F., Paczkowski, S., Sailer, G., Derkyi, N.S.A., Pelz, S., 2019. Biomass sources for a sustainable energy supply in Ghana–A case study for Sunyani. Renew. Sustain. Energy Rev. 107, 413–424. https://doi.org/10.1016/j.rser.2019.03.016.
Prew, R.D., Ashby, J.E., Bacon, E.T.G., Christian, D.G., Gutteridge, R.J., Jenkyn, J.F., Powell, W., Todd, A.D., 1995. Effects of incorporating or burning straw and of different cultivation systems on winter wheat grown on two soil types, 1985–91. J. Agric. Sci. 124, 173–194. https://doi.org/10.1017/S0021859600072853.
Qu, C., Li, B., Wu, H., Giesy, J.P., 2012. Controlling air pollution from straw burning in China calls for efficient recycling. Environ. Sci. Technol. 46, 7934–7936. https://doi.org/10.1021/es302666s.
Quartey, E.T., Chýlková, J., 2012. Challenges and opportunities in managing agricultural waste in Ghana. http://www.wseas.us/e-library/conferences/2012/Zlin/ENAGROBIO/ENAGROBIO-36.pdf. (Accessed 12 July 2019).
Ravindra, K., Kaur-Sidhu, M., Mor, S., John, S., 2019. Trend in household energy consumption pattern in India: a case study on the influence of socio-cultural factors for the choice of clean fuel use. J. Clean. Prod. 213, 1024–1034. https://doi.org/10.1016/j.jclepro.2018.12.092.
Raza, M.H., Abid, M., Yan, T., Naqvi, S.A.A., Akhtar, S., Faisal, M., 2019. Understanding farmers' intentions to adopt sustainable crop residue management practices: a structural equation modeling approach. J. Clean. Prod. 227, 613–623. https://doi.org/10.1016/j.jclepro.2019.04.244.
Ren, J., Yu, P., Xu, X., 2019. Straw utilization in China—status and recommendations. Sustainability 11, 1762. https://doi.org/10.3390/su11061762.
Romasanta, R.R., Sander, B.O., Gaihre, Y.K., Alberto, M.C., Gummert, M., Quilty, J., Castalone, A.G., Balingbing, C., Sandro, J., Correa Jr., T., Wassmann, R., 2017. How does burning of rice straw affect CH4 and N2O emissions? A comparative experiment of different on-field straw management practices. Agric. Ecosyst. Environ. 239, 143–153. https://doi.org/10.1016/j.agee.2016.12.042.
Rosmiza, M.Z., Davies, W.P., Aznie, R.C., Mazdi, M., Jabil, M.J., Toren, W.W., Rosmawati, C.C., 2014. Farmers' participation in rice straw-utilisation in the MADA region of Kedah, Malaysia. Mediterr. J. Soc. Sci. 5, 229.
Rosmiza, M.Z., Davies, W.P., Cr, R.A., Mazdi, M., Jabil, M.J., 2017. Farmers' knowledge on potential uses of rice straw: an assessment in MADA and Sekinchan, Malaysia. Geografia Malays. J. Soc. Space. 10, 30–43.
Saggu, G.S., Mittal, S.K., Agarwal, R., Beig, G., 2018. Epidemiological study on respiratory health of school children of rural sites of Malwa region (India) during post-harvest stubble burning events. MAPAN 33, 281–295. https://doi.org/10.1007/s12647-018-0259-3.
Sartori, M., Philippidis, G., Ferrari, E., Borrelli, P., Lugato, E., Panagos, P., Montanarella, L., 2019. A Synergy between the Biophysical and the Economic: the Global Market Impacts of Soil Erosion. FAO. https://citarea.cita-aragon.es/citarea/bitstream/10532/4859/1/2019_407.pdf. (Accessed 24 February 2020).
Seglah, P.A., Wang, Y., Wang, H., Bi, Y., 2019. Estimation and efficient utilization of straw resources in Ghana. Sustainability 11, 4172. https://doi.org/10.3390/su11154172.
Shi, T., Liu, Y., Zhang, L., Hao, L., Gao, Z., 2014. Burning in agricultural landscapes: an emerging natural and human issue in China. Landsc. Ecol. 29, 1785–1798. https://doi.org/10.1007/s10980-014-0060-9.
Silalertruksa, T., Gheewala, S.H., 2013. A comparative LCA of rice straw utilization for fuels and fertilizer in Thailand. Bioresour. Technol. 150, 412–419. https://doi.org/10.1016/j.biortech.2013.09.015.
Singh, A., Basak, P., 2019. Economic and environmental evaluation of rice straw processing technologies for energy generation: a case study of Punjab, India. J. Clean. Prod. 212, 343–352. https://doi.org/10.1016/j.jclepro.2018.12.033.
Singh, J., 2018. Paddy and wheat stubble blazing in Haryana and Punjab states of India: a menace for environmental health. Environ. Qual. Manag. 28, 47–53. https://doi.org/10.1002/tqem.21598.
Smith, J., Sones, K., Grace, D., MacMillan, S., Tarawali, S., Herrero, M., 2013. Beyond milk, meat, and eggs: role of livestock in food and nutrition security. Anim. Front. 3, 6–13. https://doi.org/10.2527/af.2013-0002.
Smith, J.U., Fischer, A., Hallett, P.D., Homans, H.Y., Smith, P., Abdul-Salam, Y., Emmerling, H.H., Phimister, E., 2015. Sustainable use of organic resources for bioenergy, food and water provision in rural Sub-Saharan Africa. Renew. Sustain. Energy Rev. 50, 903–917. https://doi.org/10.1016/j.rser.2015.04.071.
Supaporn, P., Kobayashi, T., Supawadee, C., 2013. Factors affecting farmers' decisions on utilization of rice straw compost in Northeastern Thailand. J. Agr. Rural. Dev. Trop. 114, 21–27.
Teshager, A.A., 2019. Paradoxical role of crop residue in the agriculture of Ethiopian highlands: a. GSJ 7, 808–814.
Tian, Q., Wang, L., Bao, Y., Li, S., 2011. A straw extraction and straw-burning fire detection mode using HJ-1B satellite measurements. Sci. Sin. Inf. 41, 117–127. https://doi.org/10.1360/zf2011-41-suppl-117.
Tomlinson, S.J., Carnell, E.J., Tang, Y.S., Sutton, M.A., Dragosits, U., 2017. Ammonia Emissions from UK Non-agricultural Sources in 2016: Contribution to the National Atmospheric Emission Inventory.
Townsend, T.J., Sparkes, D.L., Ramsden, S.J., Glithero, N.J., Wilson, P., 2018. Wheat straw availability for bioenergy in England. Energy Pol. 122, 349–357. https://doi.org/10.1016/j.enpol.2018.07.053.
Uddin, M.T., Fatema, K., 2016. Rice crop residue management and its impact on farmers livelihood-an empirical study. Progress. Agric. 27, 189–199. https://doi.org/10.3329/pa.v27i2.29330.
Vagg, A., 2015. Rice straw utilisation. Value adding and alternative uses for the Australian rice industry. A report for nuffield Australia farming scholars file:///C:/Users/Administrator/Downloads/1450736731AntonyVAGGFinalReport.pdf. (Accessed 2 November 2019).
Valbuena, D., Tui, S.H.K., Erenstein, O., Teufel, N., Duncan, A., Abdoulaye, T., Swain, B., Mekonnen, K., Germaine, I., Gérard, B., 2015. Identifying determinants, pressures and trade-offs of crop residue use in mixed smallholder farms in Sub-Saharan Africa and South Asia. Agric. Syst. 134, 107–118. https://doi.org/10.1016/j.agsy.2014.05.013.
Viana, M., López, J.M., Querol, X., Alastuey, A., García-Gacio, D., Blanco-Heras, G., López-Mahía, P., Piñeiro-Iglesias, M., Sanz, M.J., Sanz, F., Chi, X., 2008. Tracers and impact of open burning of rice straw residues on PM in Eastern Spain. Atmos. Environ. 42, 1941–1957. https://doi.org/10.1016/j.atmosenv.2007.11.012.
Wu, J., Kong, S., Wu, F., Cheng, Y., Zheng, S., Yan, Q., Zheng, H., Yang, G., Zheng, M., Liu, D., Zhao, D., 2018. Estimating the open biomass burning emissions in central and eastern China from 2003 to 2015 based on satellite observation.

Atmos. Chem. Phys. 18, 11623–11646. https://doi.org/10.5194/acp-18-11623-2018.

Yageta, Y., Osbahr, H., Morimoto, Y., Clark, J., 2019. Comparing farmers' qualitative evaluation of soil fertility with quantitative soil fertility indicators in Kitui County, Kenya. Geoderma 344, 153–163. https://doi.org/10.1016/j.geoderma.2019.01.019.

Yahaya, A., Amoah, S.A., 2013. Bushfires in the nandom district of the upper west region of Ghana: perpetual threat to food crop production. J. Environ. Earth Sci. 3, 10–14.

Yang, X., Cheng, L., Yin, C., Lebailly, P., Azadi, H., 2018. Urban residents' willingness to pay for corn straw burning ban in Henan, China: application of payment card. J. Clean. Prod. 193, 471–478. https://doi.org/10.1016/j.jclepro.2018.05.066.

Yang, Y., Wang, X., Zhang, T., Li, D., 2014. Utilization of crop straw resources in Anhui province, eastern China. Bulg. J. Agric. Sci. 20, 1302–1310.

Yin, H., Zhao, W., Li, T., Cheng, X., Liu, Q., 2018. Balancing straw returning and chemical fertilizers in China: role of straw nutrient resources. Renew. Sustain. Energy Rev. 81, 2695–2702. https://doi.org/10.1016/j.rser.2017.06.076.

Yodkhum, S., Sampattagul, S., Gheewala, S.H., 2018. Energy and environmental impact analysis of rice cultivation and straw management in northern Thailand. Environ. Sci. Pollut. Res. 25, 17654–17664. https://doi.org/10.1007/s11356-018-1961-y.

Zhang, L., Liu, Y., Hao, L., 2016. Contributions of open crop straw burning emissions to PM2. 5 concentrations in China. Environ. Res. Lett. 11, 014014.

Zhang, L., Wu, B., 2018. Farmer innovation system and government intervention: an empirical study of straw utilisation technology development and diffusion in China. J. Clean. Prod. 188, 698–707. https://doi.org/10.1016/j.jclepro.2018.03.224.

Zhao, H., Sun, B., Lu, F., Zhang, G., Wang, X., Ouyang, Z., 2015. Straw incorporation strategy on cereal crop yield in China. Crop Sci. 55, 1773–1781. https://doi.org/10.2135/cropsci2014.09.0599.

Zhou, Y., Xing, X., Lang, J., Chen, D., Cheng, S., Lin, W., Xiao, W., Liu, C., 2017. A comprehensive biomass burning emission inventory with high spatial and temporal resolution in China. Atmos. Chem. Phys. 17, 2839–2864. https://doi.org/10.5194/acp-17-2839-2017.