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*Full Length Research Paper*

# Mitigating droughts effects on tropical agriculture systems: The role of improved soil management practices in regulating soil moisture, temperature and carbon losses

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**Climate change is unequivocal and its threat on rain fed agriculture in the tropics is a fact. Changes in temperature, sparse and irregular rainfall, runoff patterns entail droughts extremes, excess evapotranspiration and loss of soil moisture. These items drive soil degradation, crop production, distribution, and supply of food, and subsequently food riot and social stability. Therefore, it urges to develop and improve cost effective agricultural water management and soil conservation in order to increase its resilience and adaptation to climate change. This study focused on the pre-wetted straw amendments effects on soil temperature (ST, °C), moisture content (SMC, %), soil organic carbon density (SOCD, t/ha) and core relationships SOCD versus ST and SMC under short-term field experiment in Nigeria. Results indicated significant difference of treatments on each parameter evaluated ($p<0.001$). Three best treatments were identified. Their responses (TR, %) to each variable were soil temperature (ST, °C) reduction was up to 20 %, soil moisture content (SMC, %) increase about 41%. Similarly, SOCD (t/ha) had increased to 40.3%. Moreover, the study revealed strong evidence of SOCD linear decrease with ST increase ($r = -0.8$), but polynomial increase with SMC increase ($r = 0.9$). It was then concluded that this approach is vital for agricultural water management and soil conservation indispensable to adapt to droughts extremes on tropical rain fed agro-ecosystems in sub Saharan Africa (SSA), while increasing resilience to food insecurity and adaptation to climate change.**

**Key words:** Climate change, droughts, food security, mitigation, adaptation, soil conservation, sub Saharan Africa (SSA).

## INTRODUCTION

Agriculture and climate change are inextricably linked (Adejuwon, 2006; Ngaira, 2007; FAO, 2010; IPCC, 2013; Recha et al., 2014; koglo et al., 2015). As victim and driver of climate change, it also plays an imminent role in mitigating and adapting to the change (Christensen et al., 2007; Brown and Hansen, 2008; FAO, 2010; Recha et al., 2014). Climate change is unequivocal and its threat on rain fed agriculture in the tropics is a fact. Changes in temperature, sparse and irregular rainfall, runoff patterns entail droughts extremes, excess evapotranspiration and loss of soil moisture. These items drive soil degradation, crop production, distribution, and supply of food, and subsequently food riot and social stability in sub-Saharan Africa (SSA) (FAO, 2010). SSA agriculture is mainly rainfed, employed up to 70% of active population; and in the meantime contributing up to 70% of the GDP with a projecting decline of about 2 to 7% by 2100 due to climate change (FAO, 2010; Porter et al., 2014; Lobell et al., 2008; Roudier et al., 2011; Dinar et al., 2008; TerrAfrica, 2009) owing to its fragility (soil, water scarcity, inadequate crop management systems) and weak responses to climate change stimuli (Hatibu et al., 2000; Duveskog, 2001; Cooper et al., 2006; de Wit and Stankiewicz, 2006; Ngaira, 2007; GWP, 2010; IPCC, 2013; AGRA, 2014).

Therefore, emphasis on sustainable and cost effective agricultural land management practices in the context of soil fertility enhancement, soil conservation and water management, and carbon sequestration, are of utmost relevance to withstand climate effects and enhance vulnerable smallholder’s farmers adaptive capacities via improvement of their socio economic livelihoods activities (Vlek et al., 2004; Mati, 2007; Blank et al., 2007; Barron et al., 2008; Twomlow et al., 2008; Varughese, 2011; Wang et al., 2013; Lenton and Muller, 2009; Liu et al., 2011; Wang et al., 2014; koglo et al., 2016). These reasons underscore the initiation of this field experiment in Nigeria, especially in Niger State, where the gap in these knowledge’s are at juvenile stage and not yet implemented and propagated in rural farming areas (Fasona and Omojola, 2005; Obioha, 2008; Akinro et al., 2008; Ojeniyi et al., 2009; Nigeria Environmental Study/Action Tool: NEST, 2011). Objectives of this study were (i) to evaluate soil temperature (ST) variation under each pre-wetted technique, (ii) to compute soil moisture content (SMC) stored under each pre-wetted integrated technique, (iii) to determine the significant variation of soil organic carbon density (SOCD), (iv) to determine the implications of ST and SMC on SOCD variation, and (v) identify the best pre-wetted techniques that have significant impacts on soil temperature increase, SMC enhancement and SOCD storage.

## MATERIALS AND METHODS

### Experiment site and design

This study was conducted at Edozhigi, Niger State, Nigeria. It lies between Longitude 5°46$^1$ to 6° 03$^1$E and Latitude 8°25$^1$ to 9° 13$^1$N at 12 km northwards Bida town. Estimated population is about 150,640 habitants and more than 70% of the villagers are totally involved in rainfed agriculture as main revenue source (Nigeria Environmental Study/Action Tool: NEST, 2011). Edozhigi serves as a market centre for mainly rice followed by sorghum, yams, millet, groundnuts and cotton. It experiences two spells of season, namely, rainy and dry season, respectively from April to October and November to March. Annual average of rainfall is up to 1,600 mm with an average maximum temperature up to about 32°C (Analysed Climate data from 1994 to 2014; collected from Nigerian Meteorological Agency). In terms of soil type, ferruginous tropical soils are predominant. Most of the soils in the area are poorly drained. Land use pressure and inadequate soil practices on the fragile soils exposed most of them to erosion and an exacerbate depletion of soil nutrients (Gwary, 2008). The experimental design was a Randomized Complete Block Design, and ten integrated formulations (treatments) were used with four replications. Each replication was made of ten plots giving a total number of forty plots. Each plot measured 2 m × 2 m. Experiment design occupied 406 $m^2$ as total surface, but 160 $m^2$ as useful surface excluding borders, space between plots and alley between blocks. Space within plots and between replications was respectively 1 m and 2 m. Integrated formulations (Treatments; Table 1) were disposed randomly in each block and each treatment was replicated once within each block including the witness.

### Pre-wetted technic implementation and trial management

For the integrated land management approach (Pre-wetted technique), incorporation of straw and urea on each corresponding plot was not direct. The straw of each treatment was wetted first with equal and minimum volume of water (1.5 L) and then covered with small empty tilts of 50 kg during seven days at ambient temperature conditions. After seven days, insignificant quantity of urea was broadcasted based on the rate of each treatment (Table 1) and each treatment was covered again with the same tilts for the same period of seven days before plotting (DBP). On the fifteen day of plotting (DOP: 15-03-2015), each pre-wetted treatment was now incorporated on each plot using hoes. In addition, hoes were used to mix-up soil surface with the incorporated application on each plot for each replication without soil disturbance. Thereafter, an additional quantity of water (1.5 L/plot) was added after each fifteen days after plotting (DAP). Trial was monitored, managed and different data were collected over a period of three months from 15th March to 15th June 2015. Data were collected based on documentation and experimentation requirements. Data were analysed using GenStat2010, Excel2013 and Matlab 11.0. Treatments means were discriminated through Duncan’s Multiple Range Test at 95% confidence level.

### Data collection procedure

#### *Soil temperature (ST, °C)*

A composite diurnal soil temperature was collected from each plot at 0 to 5 and 5 to 15 cm depth on fifteen days interval by using digital thermocouple probe. The spike stem of the thermometer was pressed into the soil at different depths of measurement during

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**Table 1.** List of the integrated formulations (Treatments).

| S/N | Treatment (xt/haS+ykg/haF) | Treatment code |
|---|---|---|
| 1 | 0S+0F | C |
| 2 | 3S+50F | T1 |
| 3 | 4S+50F | T2 |
| 4 | 2S+75F | T3 |
| 5 | 4S+75F | T4 |
| 6 | 4S+25F | T5 |
| 7 | 2S+25F | T6 |
| 8 | 2S+50F | T7 |
| 9 | 3S+75F | T8 |
| 10 | 3S+25F | T9 |

S: Rice straw; F: Fertilizer (Urea), C: Control, XS+YF (X=quantity of straw in t/ha; Y=quantity of urea in kg/ha).

each diurnal temperature data collection. The average soil temperature was computed at the end of three months in order to see the mean monthly temperature under each treatment and its implications on soil organic carbon stored after three months.

***Soil moisture content (SMC, %)***

Soil samples were collected from each plot after three months at different depths from 0 to 5 and 5 to 15 cm using soil sampler. Samples were weighted and oven-dried for 48 h at 105°C and were weighted again. Soil water after the three months was computed using gravimetric method based on the following formula:

$$\theta(\%) = \frac{M_w - M_d}{M_d - M_c} \times 100$$

where ϴ (%), $M_w$, $M_d$, and $M_c$ are respectively soil water content (%), mass of wet soil sample (g), mass of dry soil sample with the container (g) and weight of the container (g). The average soil moisture was computed at the end of three months in order to assess the ability of each treatment to conserve soil moisture and its impacts on soil organic carbon storage after three months.

***Soil organic carbon density (SOCD, t/ha)***

Wet chemical oxidation method (Walkley and Black, 1934; Konen et al., 2002; Schumacher, 2002) was adopted to determine SOC concentration (%) which was used to compute the density (dose). Composite soils of each treatment were sampled for determining SOC concentration after three months. For bulk density determination, soil samples were collected from all plots from 0 to 5 and 5 to 15 cm depths. Samples were collected by using a core sampler of 5. 5 cm diameter and 4 cm long cores from 0 to 5 cm and 6 cm long cores from 5 to 15 cm. The dry bulk density was computed for each plot by using the oven dried method. The dry weight of soil was obtained by oven drying it at 105°C for 48 h until the constant weight obtained. The dry bulk density was computed using the following equation (Lal, 2009):

$$BD\left(\frac{g}{cm^3}\right) = \frac{M_s}{V_t}$$

where BD stands for dry bulk density; $M_s$ for mass of oven dried soil at 105°C and $V_t$ the volume of each core (total volume of soil of each core). Thereafter, knowing the dry bulk density, the density (dose) of soil organic carbon under each treatment was determined using the following formula (Lal, 2009; Chan et al., 2010).

$$SOCD\left(\frac{t}{ha}\right) = C_{SOC} \times BD \times H$$

where $C_{SOC}$, BD and H are respectively the concentration of soil organic carbon (%), dry bulk density (g/cm$^3$) and soil thickness (cm).

***Determination of the interplay between ST (°C), SMC (%) and SOCD (t/ha)***

Mean soil moisture, SOC dose and soil temperature values were used to determine the existing relationship. Correlation and regression method were used to appreciate how SOC dose varies with soil temperature and moisture under the pre-wetted conditions.

***Identification of best treatments***

Identification of best treatments was based on the mean value of SOC dose, soil temperature and soil moisture computed. Treatments were ranked based on the amount of soil organic carbon density to determine best treatments in terms of significant SOC storage, low soil temperature with significant moisture content. Treatments responses (TR, %) on soil temperature, moisture, soil organic carbon dose, SOC dose per month and greenhouse gas emissions, were determined with the following mathematical expression.

$$TR_{vi} = \frac{V_{vi}}{\sum_{n=10}^{n} T} \times 100$$

With $TR_{vi}$ standing for treatment response to variable i (%), $V_{vi}$ for variable value of treatment I (%, °C, kg/ha or t/ha)

**Table 2.** Effect of straw mulch and urea formulation on soil temperature variation at various depth.

| Treatment | | | Depth (cm) | |
|---|---|---|---|---|
| | | | 0 - 5 cm | 5 - 15 cm |
| | | | Temperature mean significant value (°C) | |
| Straw + Urea | T2 | 4S+50F | 3.075[a] | 3.33[a] |
| | T4 | 4S+75F | 2.725[a] | 2.85[a] |
| | T5 | 4S+25F | 2.475[a] | 2.68[a] |
| | T1 | 3S+50F | 4.3[b] | 4.58[b] |
| | T3 | 2S+75F | 4.85[b] | 5[b] |
| | T6 | 2S+25F | 4.975[b] | 5.1[b] |
| | T7 | 2S+50F | 5.05[b] | 5.13[b] |
| | T8 | 3S+75F | 4.275[b] | 4.43[b] |
| | T9 | 3S+25F | 4.3[b] | 4.6[b] |
| | C | 0S+0F | 6.225[c] | 6.58[c] |
| | C.V. (%) | | 9.0 | 6.1 |
| | lsd | | 0.60 | 0.71 |
| | Mean ($^0$C) | | 4.2 (± 0.4) | 4.4 (±0.4) |

S: Rice straw (t/ha); F: urea (kg/ha); CV: coefficient of variation; lsd: least significant difference. Numbers with same letter are not significantly different at 5% level of probability using Duncan Multiple Range Test (DMRT at 5%).

and $\sum_{n=10}^{n} T$ for total value of treatment for the variable i (%, °C, kg/ha or t/ha).

## RESULTS AND DISCUSSION

### Soil temperature (ST, °C)

Results (Table 2) indicate high significant difference (P<0.001) of soil temperature variation from 0 to 5 cm and 5 – 15 cm under each treatment and the control. T2, T4 and T5 have the same level of influence on soil temperature reduction at various depth. Alike, T1, T3, T6, T7, T8 and T9 effects on soil temperature is not significantly different.

It is likely that, T2, T4 and T5 have ability to reduce incoming solar radiation; therefore, deplete soil temperature under high ambient temperature is significantly different when compared with T1, T3, T6, T7, T8 and T9. However, both of them proffered better response of temperature reduction compared to the control due to the addition of mulch. Conclusions drawn from the analysis lead to the fact that, the level of significance observed under each treatment was a function of the rate of straw incorporated, and likely due to the amount of urea applied. Indeed, crop residues applied as mulch have a huge capacity to reduce and intercept the flux of incoming solar energy into the soil, and as a result, maximum soil temperature is less under mulched lands than uncovered agricultural lands (Horton et al., 1996; Pervaiz et al., 2009; Chan et al., 2010; Varughese, 2011, Liu et al., 2011). Accordingly, pre-wetted technique gives valuable effects on soil temperature depletion when compared to previous studies undertaken over long-term by direct combined application of straw and urea (Campel et al., 2001; kar and Kumar, 2007; Zhang et al., 2009; Chan et al., 2010; Liu et al., 2011; Wang et al., 2015).

### Soil moisture content (SMC, %)

Table 3 was used to test the significance difference of each treatment on soil moisture storage at various depth. Results of the integrated formulation give high significant difference (P<0.001) in terms of treatments contribution to soil moisture storage. The level of response to soil moisture content (SMC) varies from one treatment to another at different depth. Meanwhile, the least significant error reveals no significance of soil depth on SMC.

Treatment T4 has given the highest moisture content both at 5 and 15 cm for 15.0 and 14.5%, respectively compared to treatment T2. Similarly, T2 effect on soil moisture storage is higher when compared with T5 which also gives higher soil moisture content than T6. Moreover, T9, T3 and T7 have given the same moisture content level but significantly different from T1 and T8 with same level of significance. These results are indicating simply that, the probability to enhance agriculture lands water content will be significant if pre-wetted techniques are implemented on the land. Long-term experiments using direct urea and straw applications also give the same results (kar and Kumar, 2007; Mulumba and Lal, 2008; Mousavi et al., 2012) and consistent with Gupta and Acharya (1993), Varughese

**Table 3.** Effect of treatments on soil moisture content (%) at various depth.

| Treatment | | | Depth (cm) | |
|---|---|---|---|---|
| | | | 0 - 5 cm | 5 - 15 cm |
| | | | Soil moisture content mean significant value (%) | |
| Straw + Urea | T4 | 4S+75F | 15.0[a] | 14.5[a] |
| | T2 | 4S+50F | 13.7[b] | 13.1[b] |
| | T5 | 4S+25F | 13.1[c] | 12.6[c] |
| | T6 | 2S+25F | 10.8[d] | 10.1[d] |
| | T9 | 3S+25F | 9.9[e] | 9.3[e] |
| | T3 | 2S+75F | 9.6[e] | 8.8[e] |
| | T7 | 2S+50F | 9.5[e] | 9.1[e] |
| | T1 | 3S+50F | 9.3[f] | 9.1[e] |
| | T8 | 3S+75F | 8.1[f] | 7.7[f] |
| | C | 0S+0F | 3.8[g] | 3.4[g] |
| | C.V. (%) | | 5.7 | 6.4 |
| | lsd | | 3.4 | 3.5 |
| | Mean (%) | | 10.3 (±1) | 9.8 (±1) |

S: Rice straw (t/ha); F: urea (kg/ha); CV: coefficient of variation; lsd: least significant difference. Number with same letter are not significantly different at 5% level of probability using Duncan Multiple Range Test (DMRT at 5%).

**Table 4.** Effect of treatments on soil organic carbon density (t/ha) from 0 - 15 cm.

| Treatment | | | Depth (cm) | |
|---|---|---|---|---|
| | | | 0 - 5 cm | 5 - 15 cm |
| | | | Soil organic carbon density (t/ha) mean significant value | |
| Straw + Urea | T4 | 4S+75F | 18.4[a] | 38.4[a] |
| | T2 | 4S+50F | 14.6[b] | 30.9[b] |
| | T5 | 4S+25F | 11.7[c] | 23.9[c] |
| | T1 | 3S+50F | 9.5[d] | 20.1[d] |
| | T3 | 2S+75F | 11.1[d] | 22.6[d] |
| | T6 | 2S+25F | 10.0[d] | 20.1[d] |
| | T7 | 2S+50F | 8.5[d] | 17.6[d] |
| | T8 | 3S+75F | 10.1[d] | 20.7[d] |
| | T9 | 3S+25F | 10.4[d] | 21.6[d] |
| | C | 0S+0F | 7.7[e] | 14.6[e] |
| C.V. (%) | | | 14.7 | 14.8 |
| lsd | | | 3.3 | 7.1 |
| Mean (t/ha) | | | 11.2 (±0.9) | 23.1 (± 2.2) |

S: Rice straw (t/ha); F: urea (kg/ha); CV: coefficient of variation; lsd: least significant difference. Numbers with same letter are not significantly different at 5% level of probability using Duncan Multiple Range Test (DMRT at 5%).

(2011), Liu et al. (2011), Wang et al. (2014), and Wang et al. (2015) with our findings.

## Soil organic carbon density (SOCD, t/ha)

Pre-wetted technique proffered valuable carbon and enhances its density (P<0.001; Table 4). This significant difference can be explained based on the fact that, soil depth and bulk density were taken into account during SOCD computation. Therefore, the higher the depth, the higher its carbon density (t/ha) compared to soil organic carbon concentration (%) which decreases with depth. This assertion is in accordance with those reported by Bationo et al. (2006); Chan et al. (2010); koglo et al. (2016)

In fact, pre-wetted technique enhances the micro-organism compounds and humification processes of the

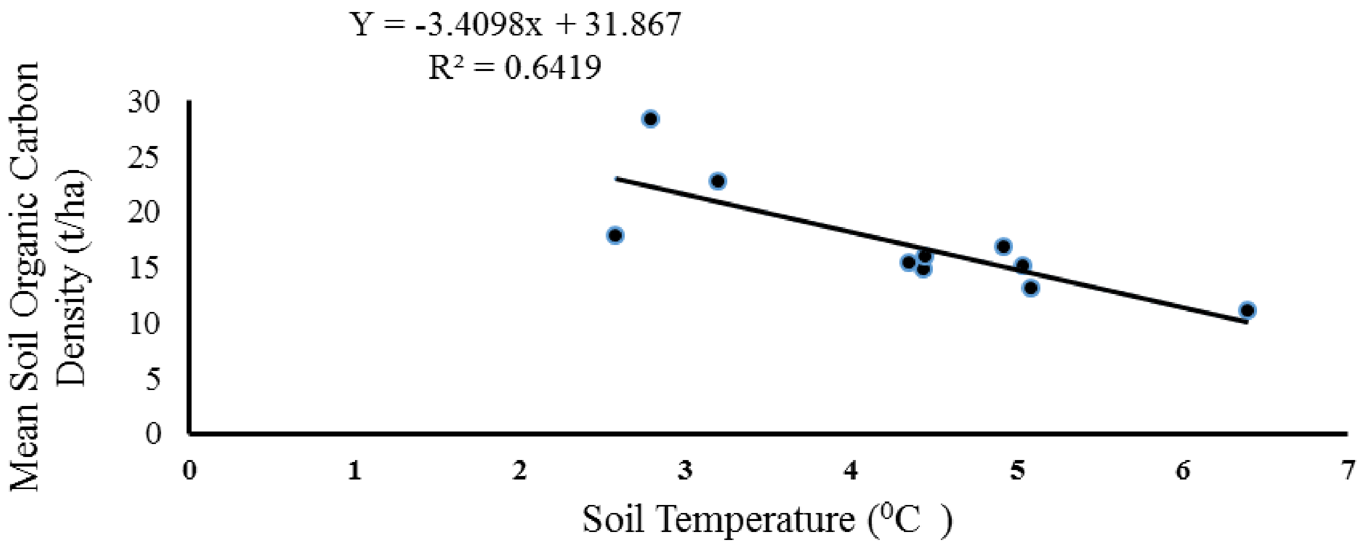


**Figure 1.** Mean variation of soil organic carbon density (t/ha) versus treatments soil temperature (°C).

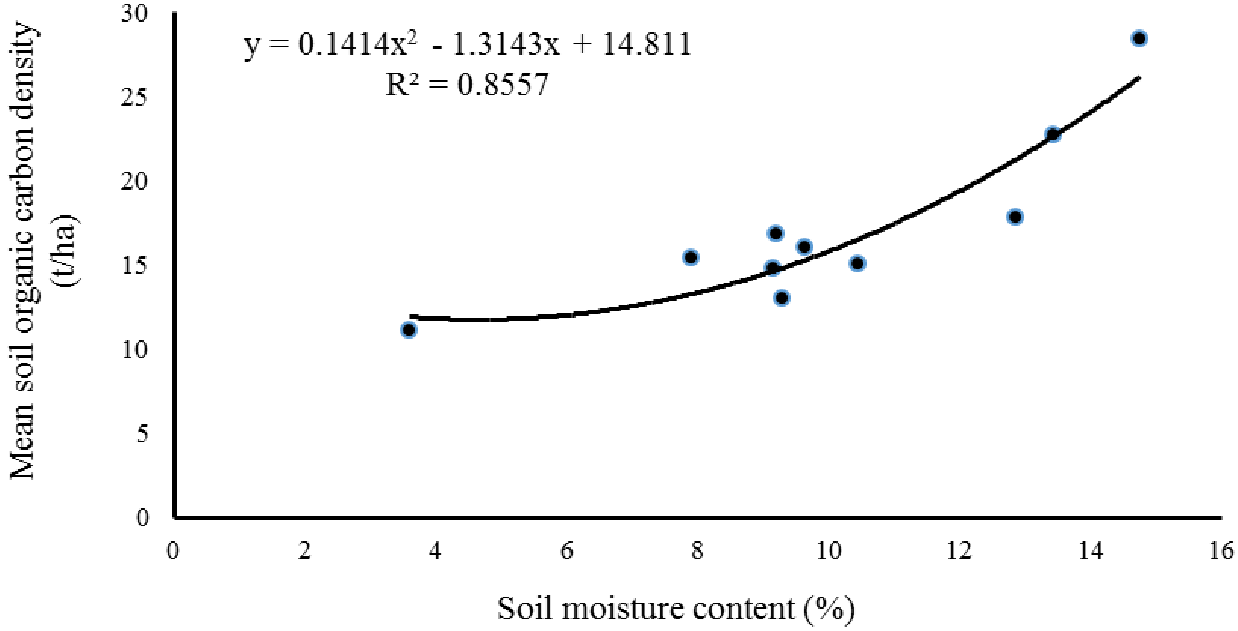


**Figure 2.** Mean polynomial variation of soil organic carbon density (t/ha) versus treatments soil moisture content.

soil, and therefore, generates more carbon than the direct application does. In addition, our findings confirm strongly previous studies conducted over long-term (Jacinthe et al., 2002; Green et al., 2005; Ma et al., 2009; Lopez-Frando and Pardo, 2009; Gruber et al., 2011; koglo et al., 2016) and Sheng-wei Nie et al. (2012) have also underlined similar results under semi-arid and temperate environment using the existing method.

## Interplay between ST, SMC and SOCD

### *ST and SOCD*

Figure 1 gives strong negative correlation (r=-0.8) between organic carbon input and soil temperature increase. Coefficient of determination $R^2$, indicates that soil organic carbon releases due to soil temperature

**Table 5.** Summary Table of Treatments versus Measured Variables.

| Treatment | Measured variables | | | |
|---|---|---|---|---|
| | Code | ST (°C) | SMC (%) | SOCD (t/ha) |
| T4 | 4S+75F | 2.8 | 14.8 | 28.4 |
| T2 | 4S+50F | 3.2 | 13.4 | 22.8 |
| T5 | 4S+25F | 2.6 | 12.9 | 17.8 |
| T3 | 2S+75F | 4.9 | 9.2 | 16.8 |
| T9 | 3S+25F | 4.6 | 9.6 | 16 |
| T8 | 3S+75F | 4.4 | 7.9 | 15.4 |
| T6 | 2S+25F | 5 | 10.4 | 15 |
| T1 | 3S+50F | 4.4 | 9.2 | 14.8 |
| T7 | 2S+50F | 5.1 | 9.3 | 13 |
| C | 0S+0F | 6.4 | 3.6 | 11.1 |

ST: Soil temperature; SMC: soil moisture content; SOCD: soil organic carbon density.

**Table 6.** Pre-wetted practices identified for croplands sustainable management.

| Treatment | Measured variables | | | |
|---|---|---|---|---|
| | Code | ST (°C) | SMC (%) | SOCD (t/ha) |
| T4 | 4S+75F | 2.8 | 14.8 | 28.4 |
| T2 | 4S+50F | 3.2 | 13.4 | 22.8 |
| T5 | 4S+25F | 2.6 | 12.9 | 17.8 |
| Treatment's response (TR, %) | | 20 | 41 | 40.3 |

ST: Soil temperature; SMC: soil moisture content; SOCD: soil organic carbon density.

increase accounts for 64%, whereas other factors account 36%. Simply put, it is likely that, when soil temperature increases, the amount of organic carbon also decreases therefore, high emission of carbon can occur.

Therefore, pre-wetted results confirm the existing knowledge (Kirschbaum, 1994; Jarecki et al., 2006; Potter et al., 2007; Wang et al., 2010). This shows a tradeoff between the amount of pre-wetted amendment incorporated and the amount of radiation intercepted subsequently the level of moisture stored. Pre-wetted is therefore efficient and fast recovery soil carbon than the direct application.

### *SMC and SOCD*

Results (Figure 2) reveal a strong positive (r = 0.9) effects of soil moisture increase on soil carbon input. Simply put, the higher the soil moisture storage, the higher the ability of humification and microorganisms population, therefore, an increase of carbon sink.

Moreover, the risk of error and the level of uncertainties for this relationship are very low when referred to the coefficient of determination ($R^2$) which accounts for 85% of confidence level. Meaning that, the risk of increasing carbon emission through agricultural practices that can enhance soil moisture content is 15% compared to the benefit to enhance carbon sequestration which accounts for 85%. Results are aligned with those reported by Rawls et al. (2003), Jarecki et al. (2006) and Wang et al. (2010) on the fact that, carbon dioxide fluxes are negatively correlated with soil moisture content also demonstrated that soil carbon content is also function of soil moisture content.

### *Identification of best treatments*

In summary (Table 5), pre-wetted amendments have performed very well for a short-term response to soil temperature, moisture content and soil organic carbon density. T2, T4 and T5 (Table 6) are more efficient vis a vis to farmers practice (control).

## Conclusion

Findings from this study proffered more understanding and significant relevance of short-term experiment using pre-wetted technique. It is obvious that, compared to the existing long-term experiment method, there is significant difference in terms of soil temperature reduction over short- term. In the main, pre-wetted technique has a great potential to the attainment of sustainable agricultural land management in tropical areas with erratic rainfall events with high sensitivity to climate change.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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# Assessment of anthropogenic influence on the level of selected heavy metals (Cu, Zn, Cd and Pb) in soil

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**The study aimed at assessing potential influence of anthropogenic activities on the level of selected toxic heavy metals in soil in Tsumeb Township, Namibia. This was with a view of evaluating possible implications on human health and across the food chain. Soil samples were randomly collected from stratified areas and taken to the laboratory for pre-treatment and analysis. Soil metallic contents were extracted using acid digestion technique and were quantified using ICP-OES. Experimental protocol was validated using the standard metal addition techniques and was found to be applicable with quantitative metallic recoveries (n= 3) in the range of 85-90%. The overall mean concentration of analysed metals in soil samples ranged from 39.0 - 2532.8 mg/kg (Cu); 59.5- 1994.8 mg/kg (Zn); 1.7-21.3 mg/kg (Cd) and 1.2-141 mg/kg (Pb) across SCP1-SCP4. The analysed metals increased variedly at the SCPs in the order Cu: SCP1>SCP2>SCP4>SCP3; Zn: SCP1>SCP2>SCP4> SCP3; Cd: SCP1>SCP2>SCP3>SCP4; Pb: SCP1>SCP2>SCP3>SCP4. Hence, highest or most profound anthropogenic influence was observed at SCP1 for all metals while the lowest was as SCP4. Strong metallic correlation (r > 0.99) was obtained between all analysed metals and some significant above threshold metallic levels in soil were obtained for Cu and Zn but most worrisome was the high level of Cd obtained in soil. Possible uptake of these metals by plants and transfer across the food chain is highly probable.**

**Key words:** Heavy metals, soil, human health, anthropogenic, ICP-OES, Namibia.

## INTRODUCTION

The prevalence of toxic heavy metals such as Cd, As, Pb, Zn, Cu and others in the ecosystems at elevated levels continues to be of great concern in view of the health implications. The earth crust is known to contain natural level of heavy metals (Singh et al., 2011). However, as a result of rapid development and industrialization, anthropogenic activities have introduced substantial amount of these metals into the environment at an unprecedented rate (Armah et al., 2014). These activities include mining operations, metal foundries, vehicular use, petrochemicals and agricultural such use application of inorganic fertilizers, sewage sludge, pesticides and others. Heavy metals that are mostly found as a result of soil contamination by these activities include copper (Cu), zinc (Zn), lead (Pb), cadmium (Cd), manganese (Mn) chromium (Cr) mercury (Hg), arsenic

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(As) and some others (Tahar and Keltoum, 2011; Yan et al., 2012; Aslam et al., 2013).Some of these metals such as Cadmium (Cd) and Arsenic (As) have no physiological benefits; hence their transfer across the food chain and resultant health implication forms the basis of concern. The concerns are justified since Cd is a known endocrine disruptor in human (Kartenkamp, 2011) while lead (Pb) has been implicated in the disruption of gene expression (Gillis et al., 2012). Hence, the interest in monitoring the level and distribution of these metals in the ecosystems including the soil is of utmost importance.

Soil has been described as sink for heavy metals that are released into the environment due to anthropogenic activities (Cheng et al., 2013). The concern about the prevalence of these toxic metals in the environment is exacerbated by their potential for inter-ecosystem mobility. Enrichment of the aquatic bodies by heavy metals as a result of surface soil erosional process has been reported (Wantzen and Mol, 2013; Issaka and Ashraf, 2017). Soil contamination by heavy metals will continue to be of great concern as a result of the health implications on human and wildlife. The implications are reflected through the uptake of these metals by plants, the consumption of metal laden plants by ruminants and the eventual consumption of ruminant by human. Consumption of contaminated water as well as inhalation dust particles are other routes of exposure. Hence, continual monitoring and assessment of these toxic metals in soil is of great importance in view of the fact that soil continues to be viewed as a repository of heavy metals (Cai et al., 2012).

The anthropogenic generated or forms of these heavy metals in soil tend to be more mobile and readily bioavailable when compared to the pedogenic or lithogenic forms (Kaasalainen and Yli-Halla, 2003). As a result of this bioavailability, the metals can be taken up by plants with further distribution and accumulation across the food chain. The migration or transfer of heavy metals from soil to other organisms such as lower animals (Lavelle et al., 2004; Ting-li et al., 2014) and plants (Lato et al., 2012; Aktaruzzaman et al., 2013) have been reported. Soil metallic burden will eventually affect the sustenance and livelihood of lower organisms such as earthworm, insects and others.

Therefore, these lower organisms are frequently used as indicator organisms of soil heavy metals burden due to their close contact and dependence on this ecosystem. Several organisms such as earthworms, insects and plants that are in close contact with soil have been used as environmental indicators of the level of heavy trace metals level (Awofolu, 2005; Karadjova and Markova, 2009; Aleagha and Ebadi, 2011; Steindor et al., 2016). Related studies also reveal inter-ecosystem migration of trace metals from terrestrial (soil) to aquatic (Pelfrene et al., 2009; Lynch et al., 2014) and the atmospheric (Perin et al., 2012) ecosystems.

In view of the environmental and human health implications of the prevalence and mobility of these toxic heavy metals, this study aimed at assessing the influence of anthropogenic activities on the level of selected trace metals (Cu, Zn, Cd and Pb) in soil from a local municipal area of Namibia. Several commercial and industrial activities that could potential influence the metallic level and distribution are located in the area.

## MATERIALS AND METHODS

### Study area

The study was conducted in the local municipal area of Tsumeb in the Northern part of Namibia. The geographic description of the area is: altitude of 1, 266 m, latitude -19, 2333 (1913'59.880''S) and longitude 17, 7167 (1743'0.120''E). The study area was stratified into four stratum and samples collected randomly from each stratum named as sample collection points (SCPs). Hence the location of SCP 1:S19° 13' 58.8"; E017° 42' 35.7"; SCP 2: S 19° 14' 41.7"; E 017°43' 12.0"; SCP 3: S19° 15' 21.6"; E 017° 42' 08.5" and SCP 4: S19° 15' 38.5"; E 017° 42' 43.2".

### Samples and sampling process

Soil samples to the depth of about 100 mm were collected randomly from each sample collection site (SCS) with the aid of clean stainless steel soil trowel. The trowel was washed and rinsed properly with water after each sampling.

Soil samples were collected from the four different sites represented as SCP1, SCP2, SCP3 and SCP4 between the periods of June to November 2015 using stratified random sampling within each stratum. Six different sampling periods (SPs) was undertaken between July and Nov 2015 with a view of assessing possible trend and variation in trace metal level across sampling periods and within sample collection sites. Control samples were collected from an area in Windhoek which is about 350 km distance away from the sampling site. This are is characterised by very low anthropogenic activities. These were placed in transparent plastic zipper bags, labelled and taken to the laboratory for further treatment and analysis.

### Sample treatment and analysis

Soil samples were oven dried at 30°C for 12 h and then grinded gently in an acid washed mortar and pestle and then passed through a sieved with 0.63 um pore size. All metal determinations were based on the final fine powdery samples. The metallic content of soil samples were extracted using acid digestion technique as previously described by Awofolu (2005). Briefly, about 5 g of soil samples was placed in 100 mL beaker and 3 mL of 30% $H_2O_2$ was added. This was left to stand for about 1 h until the vigorous reaction ceased. 75 mL of 0.5 M solution of HCl was then added and the content heated gently at low heat on the hot plate for about two hours. The digest was allowed to cool and then filtered into 50 mL standard flask. Triplicate digestion of each sample together with blank was also carried out. Quality assurance of the analytical process was by standard metal addition and quantification in all cases was by Inductively-Coupled Plasma Optical Emission Spectroscopy (ICP-OES).

### Statistical analysis

Possible relationship between analysed trace metals was

**Table 1.** Mean concentration of trace metals (mg/kg) in soil samples at SCP 1 across the six sampling periods in July 2015.

| Sampling period (SPs) | Trace metals | | | |
|---|---|---|---|---|
| | Cu | Zn | Cd | Pb |
| SP 1 | 1999.5 | 1724 | 16.0 | 97.8 |
| SP 2 | 3755 | 3135 | 31.7 | 188.9 |
| SP 3 | 2695.5 | 2230 | 14.3 | 173.4 |
| SP 4 | 1852 | 1312 | 18.5 | 146.1 |
| SP 5 | 1785 | 1323 | 17.5 | 121.9 |
| SP 6 | 3110 | 2397 | 29.8 | 117.6 |

CSP = Sample collection point; SP = Sampling period.

**Table 2.** Mean concentration of trace metals (mg/kg) in soil samples at SCP 2 across the six sampling periods in August 2015.

| Sampling period (SPs) | Trace metals | | | |
|---|---|---|---|---|
| | Cu | Zn | Cd | Pb |
| SP 1 | 115.8 | 131.8 | 6.1 | 84.5 |
| SP 2 | 123.6 | 103.5 | 4.3 | 61 |
| SP 3 | 116.5 | 66.5 | 3.3 | 47.9 |
| SP 4 | 86.7 | 58.0 | 2.2 | 36.5 |
| SP 5 | 180.9 | 117.7 | 5.8 | 91.6 |
| SP 6 | 185.4 | 120.7 | 3.4 | 50.5 |

CSP = Sample collection point; SP = Sampling period.

determined from the mean metal concentration across the six sampling periods for the four sample collection point (SCP1-4) using the Pearson Correlation Coefficient. The heavy metal contamination factor (CF) was calculated from the ratio of the mean concentration of each metal to that obtained from the control site (CS) in order to assess the extent of contamination at the sample collection site.

$$CF = X/CS$$

Where X = mean metal concentration; CS mean metal concentration at control site. CF value of < 1 is regarded as low; between 1 and 3 = moderate; from 3 to 6 = appreciable contamination while > 6 = high contamination.

The pollution load index (PLI) provides an estimate of metal contamination status and was determined as previously described by Tomlinson et al. (1980) and Likuku et al. (2013) and expressed as:

$$PLI = (CF_1 \times CF_2 \times CF_3 \ldots . CF_n)^{1/n}$$

PLI values that is < 1 signify pristine (no pollution) condition; when PLI = 1, it shows minimal or baseline level of pollution while PLI > 1 indicates gross contamination or deterioration in soil quality (Tomlinson et al., 1980). The Analysis of variance (ANOVA) at P < 0.05 was also carried out in order to evaluate whether variation in data between the heavy metals and sampling sites is significant or not significant.

## RESULTS

Elevated levels of toxic trace metals in soil can be attributed to anthropogenic activities. Hence, assessment of the level of analysed metals in soil from the study area where potential impactors are located. This was with a view of examining possible anthropogenic influence on metal soil enrichment and potential implication across the food chain. The quality assurance of an experimental process is important in order to check the applicability of the method for sample analysis. Hence result of this process, represented by percentage metal recoveries were in order of 90.4% (Cu); 90.1% (Zn); 85.5% (Cd) and 89.6% (Pb).

### Level of trace metals in analysed soil samples

Results of the analysed heavy metals in soil samples across the sample collection points (SCPs) are presented in Tables 1 to 4. The overall mean concentration is as presented in Table 5 while the variation trend of analysed heavy metals across these points is as shown in Figure 1. The mean concentration of trace metals at SCP 1 and across the sampling period ranged from 1785 mg/kg (SP5) – 3755 mg/kg (SP2); 1312 mg/kg (SP4) – 1335 (SP2); 14.5 mg/kg (SP3) – 31.7 mg/kg (SP2) and 97.8 mg/kg (SP1) – 188.9 mg/kg (SP2) for Cu, Zn, Cd and Pb respectively as presented in Table 1.

The mean level of analysed metals at SCP2 (Table 2) varied from 86.7 mg/kg (SP4) – 185.4 mg/kg (SP6) for

**Table 3.** Mean concentration of trace metals (mg/kg) in soil samples at SCP 3 across the six sampling periods in September 2015.

| Sampling period (SPs) | Trace metals | | | |
|---|---|---|---|---|
| | Cu | Zn | Cd | Pb |
| SP 1 | 64.7 | 120 | 2.2 | 30.1 |
| SP 2 | 28.5 | 58.6 | 1.7 | 23.5 |
| SP 3 | 59.9 | 63.0 | 2.3 | 48.0 |
| SP 4 | 17.7 | 23.7 | 1.3 | 4.4 |
| SP 5 | 23.8 | 29.3 | 1.1 | 11.3 |
| SP 6 | 39.1 | 62.4 | 2.5 | 12.7 |

CSP = Sample collection point; SP = Sampling period.

**Table 4.** Mean concentration of trace metals (mg/kg) in soil samples at SCP 4 across the six sampling periods in October 2015.

| Sampling period (SPs) | Trace metals | | | |
|---|---|---|---|---|
| | Cu | Zn | Cd | Pb |
| SP 1 | 29.1 | 57.2 | 1.0 | 9.3 |
| SP 2 | 90.3 | 167.2 | 2.2 | 36.0 |
| SP 3 | 48.5 | 59.2 | 1.8 | 17.8 |
| SP 4 | 25.7 | 32.8 | 1.7 | 11.4 |
| SP 5 | 68.2 | 64.5 | 1.9 | 18.3 |
| SP 6 | 57.7 | 72.9 | 1.6 | 10.7 |

CSP = Sample collection point; SP = Sampling period.

**Table 5.** Overall mean concentrations (mg/kg) of HMs across SCPs and threshold values in soil.

| | Sample collection point (SCPs) | Trace metals | | | |
|---|---|---|---|---|---|
| | | Cu | Zn | Cd | Pb |
| Sample collection point (SCPs) | SCP1 | 2532.8 | 1994.8 | 21.3 | 141 |
| | SCP2 | 134.8 | 99.7 | 4.2 | 62 |
| | SCP3 | 39 | 59.5 | 1.85 | 21.7 |
| | SCP4 | 53.3 | 75.6 | 1.7 | 17.3 |
| | CS | 162.2 | 91.4 | 5.6 | 1.2 |
| *Threshold values | **Location** | | | | |
| | EU | 13-140 | 300 | 3.0 | 300 |
| | UK | 63 | 100-200 | 1.4 | 70 |
| | Dutch | 36 | 50 | 0.8 | 85 |

CSP = Sample collection point; CS = Control Site; *Values in unpolluted soil (Denneman and Robberse, 1990).

Cu; 58 mg/kg (SP4) – 131.8 mg/kg (SP1) for Zn; 2.2 mg/kg (SP4) – 6.1 mg/kg (SP1) for Cd and 36.5 mg/kg (SP4) – 91.6 mg/kg (SP5) for Pb at the SCP2. Table 3 shows the mean concentration of heavy metals at SCP3 which ranged from 17.7 mg/kg (SP4) – 64.7 mg/kg (SP1) for Cu; 23.7 mg/kg (SP4) – 120 mg/kg (SP1) for Zn; 1.1 mg/kg (SP5) – 2.5 mg/kg (SP6) for Cd and 4.4 mg/kg (SP4) – 48.0 mg/kg (SP2) for Pb. In Table 4, the mean level of heavy metals at SCP4 ranged from 25.7 mg/kg (SP4) – 90.3 mg/kg (SP2) for Cu; 32.8 mg/kg (SP4) – 167.2 mg/kg (SP2) for Zn; 1.0 mg/kg (SP1) – 2.2 mg/kg (SP2) and 9.3 mg/kg (SP4) – 36.0 mg/kg (SP2) for Pb. The overall mean concentration of analysed heavy metals in soil samples are as presented in Table 5. This ranged from 39.0 mg/kg (SCP3) – 2532.8 mg/kg (SCP1) for Cu; 59.5 mg/kg (SCP3) – 1994.8 mg/kg (SCP1) for

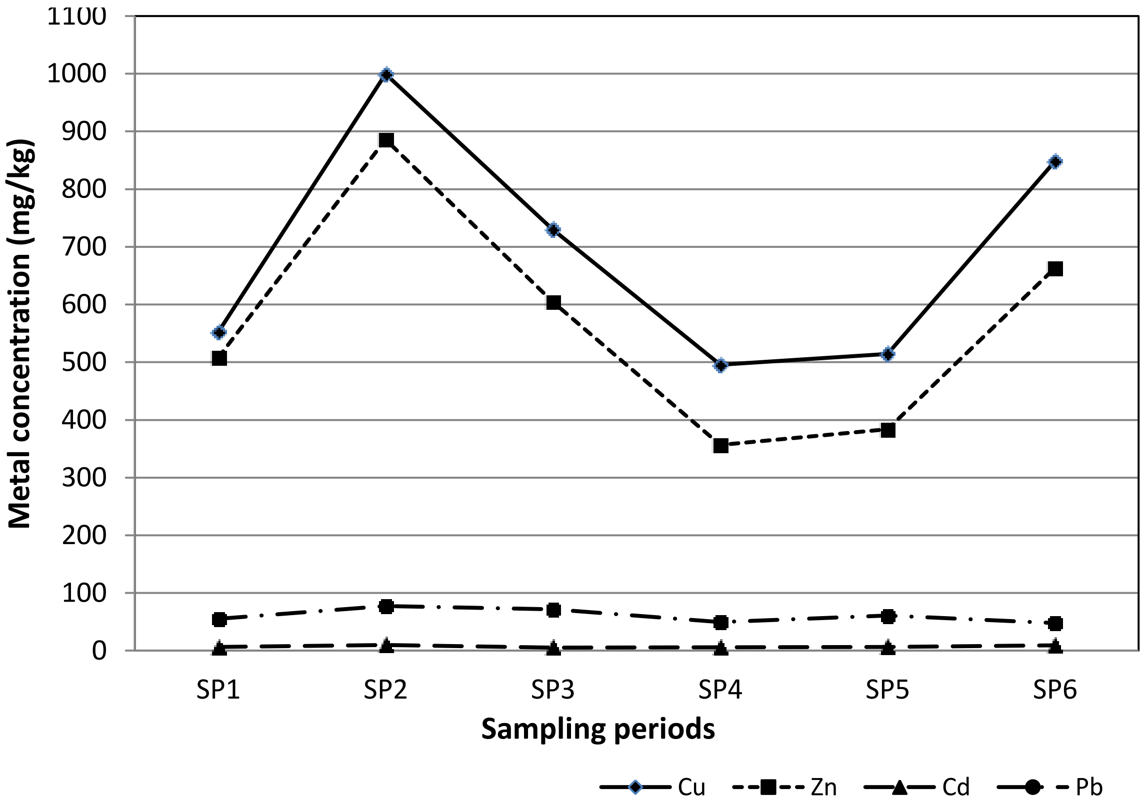


**Figure 1.** Variation in the mean concentrations of trace metals across sampling periods.

**Table 6.** Mean concentration (mg/kg) of heavy metals across sampling periods.

| Sampling period (SPs) | Trace metals | | | |
|---|---|---|---|---|
| | **Cu** | **Zn** | **Cd** | **Pb** |
| SP1 | 552.3 | 508.3 | 6.3 | 55.4 |
| SP2 | 999.4 | 886.1 | 10 | 77.4 |
| SP3 | 730.1 | 604.7 | 5.4 | 71.8 |
| SP4 | 495.5 | 356.6 | 5.9 | 49.6 |
| SP5 | 514.5 | 383.6 | 6.6 | 60.8 |
| SP6 | 848.1 | 663.1 | 9.3 | 47.9 |
| X (Mean) | 689.9 | 567.1 | 7.3 | 60.5 |
| CS | 162.2 | 91.4 | 5.6 | 1.2 |
| CF | 4.3 | 6.2 | 1.29 | 50.4 |
| PLI | 6.5 | | | |

CS= Control site; CF = Contamination Factor; PLI = Pollution Load Index. SP = Sampling period.

Zn; 1.70 mg/kg (SCP4) – 21.3 mg/kg (SCP1) for Cd and 17.3 mg/kg (SCP4) – 141 mg/kg (SCP1) for Pb. The mean concentration of heavy metals in soil samples from the control site (CS) varied from 162.2 mg/kg (Cu); 91.4 mg/kg (Zn); 5.6 mg/kg (Cd) and 1.2 mg/kg (Pb).

Results of the metal contamination factor (CF) and Pollution Load Index (PLI) are presented in Tables 6 and 7, respectively. Contamination factors (CFs) of analysed heavy metals in soil samples were 4.3, 6.2, 1.3 and 50.4 for Cu, Zn, Cd and Pb respectively while the PLI was 6.5.

## DISCUSSION

From the quality assurance of the applied method, good recoveries (> 85 %) of the added metals standards were obtained. This indicated the applicability of the method in the analyses of selected metals in soil samples. Similar applicable range has been reported (Shirin et al., 2015).

## Level of heavy metals in the analysed soil samples

Elevated level of heavy metals above the natural constituents in soil has been attributed to anthropogenic activities (Tchounwou et al., 2012). It was against the backdrop that the assessment was conducted in the study area where potential impactors are located. In this study, the selected metals were detected in all analysed soil samples from sample collection points (SCPs) across the periods of sampling. The overall mean concentration of Cu (39.0 mg/kg – 2532.8 mg/kg) obtained in soil samples from this study were higher than 36 mg/kg limit recommended by the Dutch Ministry of Environment (MHSPE, 2000). With the UK limit of 63 mg/kg of Cu in soil, only samples from SCP1 and SCP 2 exceeded the limit. However, using the EU threshold limit of 13-140 mg/kg of Cu in soil, only soil sample at SCP 1 was above the prescribed limit (Denneman and Robberse, 1990).

The highest level of Cu was obtained at SCP1 (2532.8 mg/kg) and during SP2 (3755 mg/kg) as shown in Table 5 and Table 1 respectively. The high level obtained at this SCP might be due to the nature of anthropogenic activity within this section of the study area when compared to other sampled sections. Notable activities in this area include mining, metal foundries, petrochemicals operations among others which might be responsible for the high level of contamination. The least value of 39.0 mg/kg of Cu was obtained at SCP3.

Incremental trend of Cu across the sample the SCPs were in the order of SCP1> SCP2 >SCP4 > SCP3. The mean value of 162.2 mg/kg of Cu obtained from the control site (CS) was higher than those obtained at SCP2, SCP3 and SCP4. In environmental studies, assumptions are that the level of pollution at control sites would be lower than those at the study areas or sites since control sites are generally assumed to be relatively “pristine” with much lower anthropogenic influence. This is however, not always the case. Studies where CS values were higher than those from the study areas have been reported (Ali et al., 2014).

Although, Cu is regarded as essential element due to its’ physiological roles in living organisms, high level has been reported to be toxic and dangerous to human health (Osredkar and Sustar, 2011). Copper has been implicated in the genetic disorder of hepatic copper metabolism commonly referred to as Wilson disease (Seth et al., 2004). The general implication of this considerable contamination is the potential accumulation and transfer of this metal across the food chain. Consumption of milk and meat products from ruminants that feed on road side grasses may lead to such transfer across the food chain with health implication.

Zinc (Zn) is another metal that is regarded as “essential” due to some of the role it plays as food supplement especially in sporting activities (Yang et al., 2003). High level of this metal has however, been reported to be toxic (Plum et al., 2010). The overall mean concentration of zinc metal (Zn) across the SCPs varying from (59.5 mg/kg – 1994.8 mg/kg). From this range, all mean concentrations obtained were higher than the Dutch Threshold Limit of 50 mg/kg of Zn in unpolluted soil (MHSPE, 2000). However, with the UK and EU limits of 200 and 300 mg/kg respectively, only the concentration at SCP1 as shown in Table 5 was higher than these limits. However, concentration of 91.4 mg/kg of Zn recorded at the control site (CS) was higher than those obtained at SCP 3 and SCP4.

The highest recorded value of 3135 mg/kg of Zn was obtained during SP2 with overall mean also at SCP1 as presented in Tables 5 and 1 respectively. Generally, the incremental trend of Zn in soil samples across the SCPs were SCP1>SCP2>SCP4>SCP3. This trend also revealed SCP1 as the most contaminated point within the study area. Metal ore processing activity is located within this section of the study area. Lowest overall mean value of 59.5 mg/kg was recorded at SCP3 and the lowest individual recorded concentration of 23.7 mg/kg was recorded during SP4 (Table 3). This was not surprising since anthropogenic activities within the section of the study area can be regarded as minimal with majorly residential outlook and some road side auto-repair local activities.

Cadmium (Cd) is a heavy metal that is of significant interest to environmental scientists, toxicologists and the healthcare service providers due to its’ non-essentiality and high toxicity even in small amount. The metal has been implicated in carcinogenic and endocrine disrupting activities including in humans (Pollack et al., 2011; Ali et al., 2012). Hence, monitoring of the level and anthropogenic contributions to the environment especially in soil is of utmost importance. The overall mean concentration of Cadmium (Cd) obtained in this study across the SCPs ranged from (1.7 mg/kg – 21.3 mg/kg).

All the mean concentrations of Cd were higher than the Threshold limit of 1.4 mg/kg prescribed by UK as well the 0.8 mg/kg by the Dutch’s guideline (MHSPE, 2000). Only the overall mean values obtained from SCP3 and SCP4 were below the recommended threshold limit of 3 mg/kg of Cd in unpolluted soil by the EU while all values were below that of the control site (CS) with the exception of 21.4 mg/kg as the highest overall mean value of Cd obtained at SCP1. The lowest individual concentration of Cd obtained was 1.0 mg/kg during SP1 (Table 4). Hence, the incremental trend of Cd across the SCPs was from SCP1>SCP2>SCP3>SCP4.

Lead (Pb) is another toxic heavy metal with no physiological importance in human. It has been implicated in a number of health problems in human including brain damage and neurological disorder in children (Monnot et al., 2015). The overall mean concentration of Pb across the SCPs varying from (17.3

mg/kg – 141.0 mg/kg). From this range, all overall mean concentrations were below the UK and Dutch threshold limits of 70 mg/kg and 85 mg/kg respectively of Pb in unpolluted soil with the exception of the highest value of 141 mg/kg of this metal obtained at SCP1. In addition, all individual mean concentration of Pb obtained during SP1-SP6 at SCP1 were higher than these limits. However, both the overall mean values across SCPs and the individual mean concentration of Pb across SPs were below the 300 mg/kg threshold values recommended by the EU (Table 1) as well as the 1.2 mg/kg of Pb obtained at the control site. In a similar manner with Cd, the incremental pattern of Pb across the SCPs were in the order of SCP1>SCP2>SCP3>SCP4.

**Contamination Factor (CF), Pollution Load Index (PLI), Inter-elemental Correlation (r), ANOVA ($p < 0.05$) and metal variation pattern**

The extent of contamination of the soil was deduced from the contamination factor (CF) as described earlier. The CF for Cu was in the category of "appreciable", that is, considerable contamination with a value of 4.3. Zinc recorded a CF of 6.2 which was within the "highly contaminated" category. Anthropogenic input is most likely to be the contributing factor to this high level of contamination in soil. Some studies have reported similar level of anthropogenic contributions on the level of toxic metals in soil (Rahman et al., 2012; Jiao et al., 2015). Potential uptake of these heavy metals by plants and subsequent accumulation across the food chain cannot be ruled out. Contamination factor of 1.3 was recorded for Cd which indicated moderate level of pollution. By this, anthropogenic contribution could be regarded as minimal. Nonetheless, possible impact across environmental strata is possible in view of the non-essentiality of this metal to living organisms. Potential contributing sources of Cd include atmospheric deposition from mining activities, wastes from Cd-based batteries and runoff from agricultural soils where phosphate fertilizers are used. Cadmium is a common impurity in phosphate fertilizers (Benson et al., 2014).

Contamination Factor (CF) value of 50.4 was obtained for Pb which indicated gross/high contamination of the metal in soil samples. Anthropogenic influence could be responsible for the high CF of this metal in soil. High level of Cd in the environment particularly in soil is quite worrisome. Apart from possible uptake of the metal by plants and consumption of these plants by ruminants, the lower organisms that inhabit the soil such as earthworms and insects could be affected with possible loss of biodiversity. Possible sources of Pb in the environment include atmospheric particulate deposition, lead-based wastes such as painted materials, used dry-cell batteries and mine tailings. The inter-elemental correlation analysis as presented in Table 7 revealed that correlation, $r > 0.9$ was obtained for all analysed metals. For Cu/Zn ($r = 0.999$); Cu/Cd ($r = 0.996$) and Cu/Pb ($r = 0.95$). For Zn/Cd ($r = 0.994$); Zn/Pb ($r = 0.94$) and Cd/Pb ($r = 0.97$). These strong correlations reflected an association between the analysed metals and the sampled sites. In addition, the analysis of variance revealed no significant difference between the analysed metals and the SCPs with $p > 0.05$. Furthermore, the post-hoc analysis revealed that the factor level SP1 is significantly different from all the other levels, but SP2, SP3 and SP4 are not significantly different from each other.

A distinctive variation pattern for the analysed metals can be observed with respect to the sampling periods as shown in Figure 1. An increase in metallic level was observed from SP1 – SP2 which then decreased across SP3 and SP4. There was a marginal increase in metallic level from SP4 to SP5 which was followed by a sharp increase during SP6. The increases during SP2 and SP6 might be due to corresponding increase in anthropogenic activities during these periods. However, the influence of climatic factors such as rainfall on the metallic pattern may not be ruled out. The influence of erosion on metallic mobility and variation in some studies has been reported (Wijngaard et al., 2017).

Pollution Load Index (PLI) value of 6.5 was obtained in this study (Table 6). This value is > 1, which according to the index scale represents a highly polluted condition. The high level of analysed metals obtained across the SPs at SCP1 when compared to others would most likely have significant influence on the high PLI value obtained in this study. This might be due to the nature of anthropogenic activities taking place in this area which include mining, metal foundry involving use of Pb solder and automobile garages. The high level of heavy metals obtained in this section of the study area could be remedied through the use of hyper-accumulating plants. However, the long-term remedial action is to identify the source of these metals and prevent them from entering the ecosystems.

The high PLI and various levels of soil contamination at the SCPs as revealed by the CF values will have negative impact on living organisms including human being. Soil as a form of physical environment can act as a reservoir through which metallic contaminants can find their way into the atmosphere and aquatic ecosystems. Human health has been reported to be compromised through environmental physical exposures such as air pollution (Ghorani-Azam et al., 2016). Hence, people living within the study area may be exposed to these metals through atmospheric particulate matter (PM) distribution. Exposure and continual inhalation of metal-bound PMs especially those with particle sizes of < $PM_{2.5}$ fractions could result in serious health problem. Exposure to PMs has been found to result in cardiovascular and respiratory mortality and morbidity (Laumbach and Kipen, 2012; Huang and Mao, 2012). Children are noted for ingesting small amount of dust especially during recreational activities. Lead (Pb) laden soil has been

**Table 7.** Inter-elemental correlation of analysed metals in soil.

| Correlation | Cu | Zn | Cd | Pb |
|---|---|---|---|---|
| Cu | 1 | | | |
| Zn | 0.999832 | 1 | | |
| Cd | 0.996107 | 0.994326 | 1 | |
| Pb | 0.947569 | 0.94156 | 0.972046 | 1 |

known to affect cognitive development in children (Bellinger, 2008). Lead is probably carcinogenic to human and its' compound can damage human organs in the event of prolong exposure (Towle et al., 2017).

Children are noted for ingesting small amount of dust especially during recreational activities. Lead (Pb) laden soil has been known to affect cognitive development in children (Bellinger, 2008). Lead is probably carcinogenic to human and its' compound can damage human organs in the event of prolong exposure (Towle et al., 2017).

The removal of top soil into aquatic bodies through erosional processes may increase the metallic burden of the aquatic ecosystem. Consumption of contaminated water resources and aquatic organisms such as fishes from such contaminated water bodies may result is serious health problems. Hence, it is important for the level of these toxic metals to be monitored and for countries to pass stringent legislation for the control, management, use and disposal of wastes containing these toxic metals.

## Conclusion

The outcome of the study showed the influence of anthropogenic activities on the level of heavy metals in soil samples. This influence was revealed by the high level of analysed metals when compared to international threshold limits of the analysed metals in soil. This was further corroborated through statistical pollution indicators such as CF and PLI which indicated the high level of pollution based on the data obtained. Of particular concern was the high level of metallic contamination recorded at SCP1 when compared to other sites. This section of the study area is noted for higher concentration of anthropogenic activities which was reflected in the level of heavy metals in soil obtained. As a consequence, metallic mobility across the ecosystems may occur as a result of the high level of contamination of the soil. The study generally revealed the influence of anthropogenic activities on the level of analysed heavy metals in soil samples. This could have serious implications on human health based on potential metal transfer across the food chain.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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# Soil respiration from paddy field in relation to incorporated cover crop biomass composition

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**Winter cover crops are cultivated during cold fallow season in temperate countries for green manure and animal feed. Literature on incorporated biomass composition in relation to soil respiration like $CH_4$-C and $CO_2$-C is not available. Therefore, soil respiration as affected by variable biomass composition was determined from paddy soil. Soil respiration rate (1280-1341 kg ha$^{-1}$) was significant when 197 and 204 day-old plants were incorporated. The $CH_4$–C and $CO_2$-C respiration rates were significantly correlated with cellulose, lignin, protein, and ash. However, $CH_4$-C respiration was negatively related with $CO_2$-C respiration. These implies that biomass composition is influenced by age of cover crops that ultimately dictates paddy soil respiration rates.**

**Key words:** Rice field, biomass composition, age of biomass, $CH_4$-C, $CO_2$-C.

## INTRODUCTION

Plant biomass decomposition is an important source of greenhouse gas (GHG) emission (Sinsabaugh et al., 2002). The decomposition rates depends on soluble and insoluble fractions of plants of which cellulose, hemi-cellulose and lignin form a complex chemical network that influences biological decomposition (Bertrand et al., 2006; Šnajdr et al., 2011). However, lignin is the recalcitrant component of green manured crops (Melillo et al., 1982; Berg and McClaugherty, 2008) to extracellular enzymes (Sinsabaugh et al., 2002; Allison and Vitousek, 2004; Šnajdr et al., 2011). Although biomass quality determines nutrient cycling, grain quality and production of crops (Bala et al., 2008; Mirza et al., 2010), its decomposition by enzyme activity may not always be reflected in soil environments.

Cultivation of seasonal mono-rice and winter cover crops are the farming feature in temperate regions. Usually non-leguminous (Barley) and leguminous (Hairy vetch) cover crops are used as green manure in South Korea (Kim et al., 2007; Zhang et al., 2007; Haque et al., 2015a) for supplementing rice crop’s nutrient requirements and improving soil organic matter content (Elfstrand et al., 2007; Pramanik et al., 2013a; Haque et al., 2015a, b). However, paddy field is a major source of methane ($CH_4$), carbon dioxide ($CO_2$) and nitrous oxide ($N_2O$) emissions (Sass et al., 1999; Haque et al., 2015a). In paddy soil, the organic amendment favors microbial activities, which results in increasing GHG emission from soil (Pramanik et al., 2012; Kim et al., 2013). Therefore, it is important to evaluate the efficacy of agricultural

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practices for the mitigation of GHG emissions to avoid climate change.

Generally, barley and hairy vetch is cultivated for about 7 months before incorporation into soil. Since cellulose, lignin and hemi-cellulose contents depend on plant age, use of younger plants as green manure could contains less complexed organic molecules rendering faster decomposition. Moreover, substrates produced there on might encourage microbial activities for GHG production. Older plants generally decompose slowly and might have influence on soil respiration, but no literature is available in this regard, especially with paddy soil. The present study was, therefore, undertaken to evaluate paddy soil respiration as influenced by age and compositions of incorporated barley and hairy vetch biomass.

## MATERIALS AND METHODS

### Experimental site, cover crop harvesting, and rice cultivation

Experiment was conducted at the agricultural farm of Gyeongsang National University (36°50´N and 128°26´E), Jinju, South Korea. The selected soil was silt loam in texture and classified as typic Haplaquents with somewhat impeded drainage. The soil was characterized by pH (1:5 with $H_2O$), 6.2; organic carbon, 11.9 g $kg^{-1}$; available P, 35 mg $kg^{-1}$ and bulk density, 1.39 g $cm^{-3}$. The recommended seeding rate of barley and hairy vetch as winter cover crop was 120 and 90 kg $ha^{-1}$ for Korean paddy soils (Jeon et al., 2011; Haque et al., 2013). Mixture of barley and hairy vetch seeds were spread in the field on 1st November, 2011. Green manuring crops were harvested on 10, 16, 23 and 30 May, 2012 for incorporation into paddy soil at 3 Mg $ha^{-1}$ before rice transplanting. Ages of biomass before incorporation were, 183, 190, 197, and 204 days. After incorporation, soil was flooded immediately and $CH_4$ and $CO_2$ gases were measured.

Thirty-days-old 3 seedlings $hill^{-1}$ of Dongjin cultivar, Japonica type rice were transplanted (15 cm × 30 cm spacing) on 6th June 2012. Recommended dose of chemical fertilizer (N-P-K=110-20-48 kg $ha^{-1}$) was applied in each plot. The basal fertilizer dose (N-P-K= 55-20-33.7 kg $ha^{-1}$) was applied just before transplanting, while 22 kg N $ha^{-1}$ at active tillering stage (2 weeks after rice transplanting) and 33 kg N $ha^{-1}$ and 14.3 kg K $ha^{-1}$ were applied at 6 weeks after rice transplanting. Water level was maintained at 5 to 7 cm depth above the soil surface throughout the experiment. Rice was harvested on 15th October, 2012 and total grain and straw yield was recorded after air drying. Rice growth and yield characteristics were investigated at maturing stage.

### Characterization of cover crop

Cover crop biomass was recorded after oven drying at 70°C for 72 h. Total C and N was estimated by CHNS analyzer (Leco, USA). Cellulose content was determined using a colorimetric method with anthrone reagent at 620 nm (Updegraff, 1969) and lignin content was determined using the APPITA P11s-78 method (APPITA, 1978), ash was determined using a muffle furnace at 550°C for 4 h (Yoshida et al., 1976). Percentage of protein content was estimated as (Jones, 1941):

$$6.25*N\% \quad (1)$$

### $CH_4$ and $CO_2$ gas sampling and analysis

The transparent glass chambers having a surface area of 62 cm × 62 cm × 112 cm (Figure 1) were placed permanently in the flooded soil after rice transplanting for monitoring $CH_4$ emission rates. Eight rice plants were enclosed in a chamber. There were four holes at the bottom of the chamber to maintain water level at 5 to 7 cm depth above the soil surface. Independent with a closed chamber for estimating $CO_2$ emission rates, acrylic column chambers having a diameter of 20 cm and height 20 cm were placed into soil surface (Lou et al., 2004; Xiao et al., 2005; Iqbal et al., 2008; Haque et al., 2015a, b). All chambers were kept open in the field throughout the rice cultivation period except during gas sampling. The chamber was equipped with a circulating fan for gas mixing and a thermometer inside to monitor the temperature during the sampling time.

Air gas samples were collected by using 50 ml gas tight syringe at 0 and 30 min after chamber being closed. Gas samplings were carried out three times (8 am, 12 pm and 4 pm) in a day to get the average $CH_4$ and $CO_2$ emission rates. Collected gas samples were immediately transferred into 30 ml air evacuated glass vials sealed with a butyl rubber septum for analysis by gas chromatography (Shimadzu, GC-2010, Japan) with Porapak NQ column (Q 80-100 mesh). A flame ionization detector (FID), and thermal conductivity detector (TCD) were used for quantifying $CH_4$ and $CO_2$ concentrations, respectively. The temperatures of the column, injector and detector were adjusted at 100, 200, and 200°C for $CH_4$, 45, 75, and 270°C for $CO_2$, respectively. Helium and $H_2$ gases were used as the carrier and burning gases, respectively.

### Estimation of $CH_4$ and $CO_2$

Methane and $CO_2$ emission rates were calculated from the increase in $CH_4$ and $CO_2$ concentrations per unit surface area of the chamber for a specific time interval. A closed chamber equation was used to estimate $CH_4$, and $CO_2$ fluxes from each treatment (Haque et al., 2013, 2015a, b; Pramanik et al., 2013b).

$$F = \rho \times (V/A) \times (\Delta c/\Delta t) \times (273/T) \quad (2)$$

Where, F is the $CH_4$ and $CO_2$ emission (mg $m^{-2}$ $h^{-1}$), ρ is the gas density of $CH_4$ and $CO_2$ under a standardized state (mg $cm^{-3}$), V is the volume of the chamber ($m^3$), A is the surface area of the chamber ($m^2$), Δc/Δt is the rate of increase of $CH_4$ and $CO_2$ gas concentrations in the chamber (mg $m^{-3}$ $hr^{-1}$) and T (absolute temperature) is 273 + mean temperature in (°C) of the chamber. The seasonal $CH_4$ and $CO_2$ flux during entire rice cultivation period was computed by following formula (Singh et al., 1999):

$$\text{Seasonal } CH_4 \text{ and } CO_2 = \sum_i^n (R_i \times D_i) \quad (3)$$

Where, R*i* is the rate of $CH_4$ and $CO_2$ emission (g $m^{-2}$ $d^{-1}$) in the $i^{th}$ sampling interval, D*i* is the number of days in the $i^{th}$ sampling interval, and n is the number of sampling intervals.

### Soil sampling and analysis

Analysis of soil chemical properties were performed after rice harvest in 2012. Soil was collected at 0-15 cm depth from five different points in each plot, air-dried, and sieved (<2 mm). The chemical analysis included soil pH (1:5, with $H_2O$), available phosphate (RDA, 1988), DOC was extracted in the fresh soil using cold water (Lu et al., 2011), total carbohydrate (phenol-sulphuric acid method; Safari et al., 1992), and total C and N concentrations were measured by CHNS-932 analyzer (Leco, USA). A portion of the moist soil sample was dried at 105°C for 24 h to measure soil bulk density (BD, Blake and Hartge, 1986) according to the equation:

$$\text{Bulk density } (g/cm^3) = \text{Dry soil weight (g)/Soil volume } (cm^3) \quad (4)$$

**Table 1.** Biomass production and composition of mixed barley and hairy vetch cover crop.

| Parameter | Age (days) | | | | |
|---|---|---|---|---|---|
| | 183 | 190 | 197 | 204 | $LSD_{0.05}$ |
| Biomass (Mg ha$^{-1}$ dry wt.) | 6.84 | 11.90 | 13.48 | 12.00 | 0.37 |
| **Inorganic components** | | | | | |
| Total C (g kg$^{-1}$) | 41.25 | 41.76 | 42.20 | 42.28 | 0.26 |
| Total N (g kg$^{-1}$) | 1.89 | 2.45 | 2.45 | 2.47 | 0.79 |
| C/N ratio | 21.82 | 17.04 | 17.22 | 17.11 | 0.57 |
| **Organic components (%)** | | | | | |
| Cellulose | 22.93 | 24.71 | 26.13 | 29.08 | 0.31 |
| Hemi-cellulose | 12.49 | 12.30 | 12.09 | 12.33 | 0.17 |
| Lignin | 16.41 | 17.53 | 18.16 | 18.43 | 0.77 |
| Protein | 11.82 | 15.31 | 15.44 | 17.06 | 0.29 |
| ADF(Acid detergent fiber) | 47.01 | 51.89 | 52.59 | 55.88 | 0.36 |
| Ash | 7.6 | 7.6 | 8.3 | 8.4 | 0.29 |

Soil porosity was calculated using BD and particle density (PD, 2.65 Mg m$^{-3}$) according to the equation:

$$\text{Porosity (\%)} = (1 - BD/PD) \times 100 \quad (5)$$

### Statistical analysis

Statistical analyses were done using SAS software (SAS Institute 2003). A one-way ANOVA was carried out and Fisher's protected least significant difference (LSD) was calculated at the 0.05 probability level for making treatment mean comparisons.

## RESULTS

### Composition of cover crop biomass

Aboveground biomass significantly ($P \leq 0.05$) increased with growth duration upto 197 days before rice transplanting (Table 1). At 183 day, cover crop biomass productivity was low compared to 204 day-old plants. Carbon, N, cellulose, hemi-cellulose, lignin, protein, acid-detergent fiber (ADF), and ash contents of the cover crop increased with age of plants. Furthermore, the highest organic compounds were recorded with 204 day-old plants. The increase in physical and biochemical properties of plants between 197 day-old biomss and 204 day-old ones varied significantly (Table 1). However, most of the plant components studied were higher with 197 day-old biomass than 183, 190 day-old ones.

### Soil respiration

#### *$CH_4$-C respiration*

Methane-C respiration from biomass incorporated paddy soil increased upto 40 days after rice transplanting (DAT) and then decreased, although the rates were different depending on age (Figure 3) and quality of cover crop biomass. The lowest $CH_4$-C respiration rate was observed with 204 day-old biomass and the highest with 183 day-old ones. Cumulative $CH_4$-C respiration from 204 day-old biomass treated plots was 443 ± 4.23 kg ha$^{-1}$, which was 10, 9 and 5% lower than 183, 190 and 197 day-old biomass incorporated treatments, respectively.

#### *$CO_2$-C respiration*

The $CO_2$-C respiration increased gradually upto 60 DAT and decreased thereafter among treatments (Figure 3). Eventhough $CO_2$-C respiration did not differ significantly between 183 and 190 day-old biomass, it varied significantly with 204 day-old compared to 197 day-oldbiomass incorporated soil (Table 2). The $CO_2$-C respiration was low at the initial stage and at later growth stages of rice. Furthermore, $CO_2$-C respiration rate was low before transplanting than post transplanting.

### Soil respiration and biomass composition

Total soil respiration showed significant positive relationships with cover crop biomass components like cellulose, lignin, protein, and ash (Table 3). Nitrogen content had signicant and positive relationship with $CH_4$-C respiration but nonsignificant with $CO_2$-C respiration. Total soil respiration was influenced more by $CO_2$-C respiration than $CH_4$-C. Moreover, there was a negative correlation between $CO_2$-C and $CH_4$-C respiration rate.

### Changes in soil chemical properties

The DOC concentration was higher at about 30 DAT.

**Figure 1.** Static closed chamber for trapping methane in rice soil.

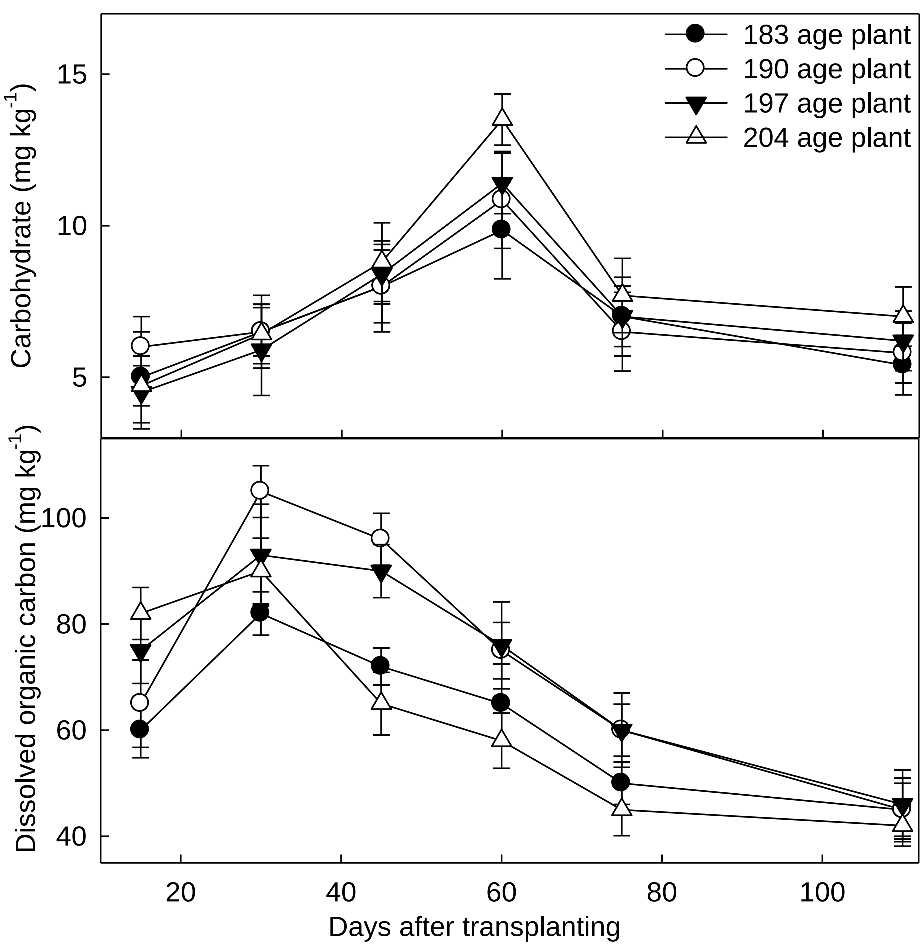


**Figure 2.** Determination of carbohydrate, and dissolve organic carbon during rice cultivation as affected by age (days) of incorporated biomass.

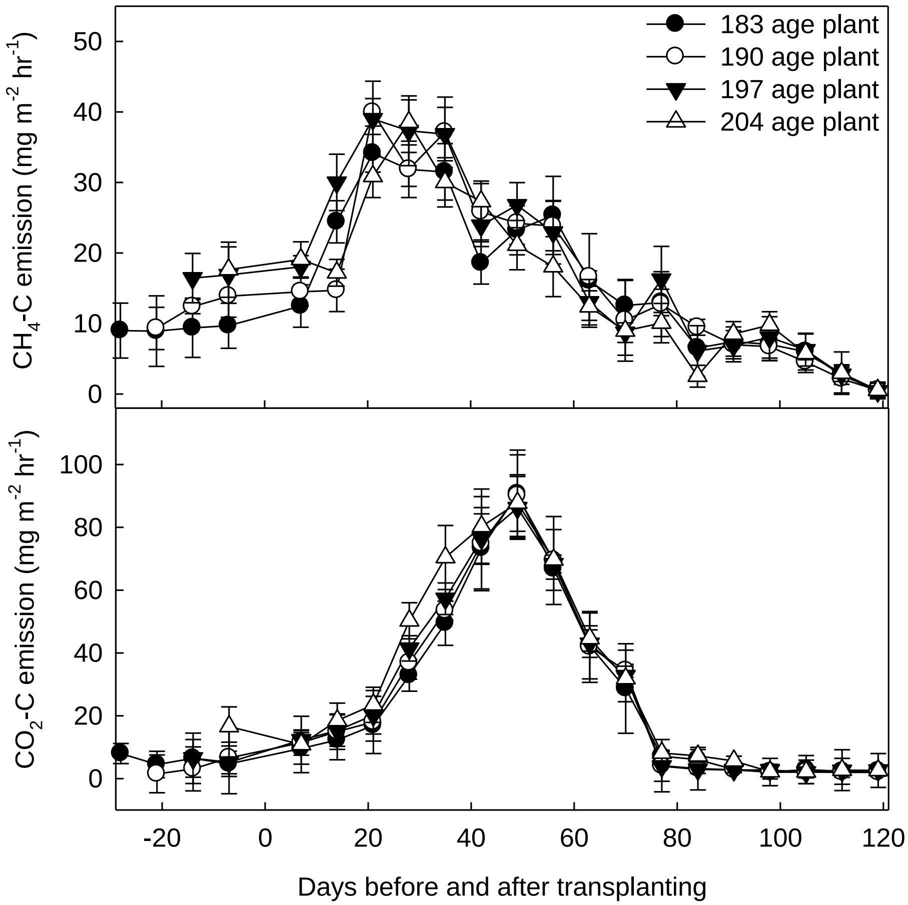


**Figure 3.** Emission fluxes of $CH_4$-C , and $CO_2$-C from soil as affected by age (days) of incorporated biomass.

**Table 2.** Soil respiration during rice cultivation as affected by age of incorporated barley and hairy vetch biomass.

| Parameter | Age (days) | | | | |
|---|---|---|---|---|---|
| | **183** | **190** | **197** | **204** | **LSD 0.05** |
| **Mean respiration rate** | | | | | |
| $CH_4$-C (mg $m^{-2}$ $day^{-1}$) | 407 | 401 | 388 | 369 | 6.99 |
| $CO_2$ -C (mg $m^{-2}$ $day^{-1}$) | 654 | 654 | 682 | 736 | 6.20 |
| $CH_4$-C+$CO_2$-C ( g $m^{-2}$ $day^{-1}$) | 1.06 | 1.05 | 1.07 | 1.11 | 0.23 |
| **Seasonal respiration (kg $ha^{-1}$)** | | | | | |
| $CH_4$-C | 488 | 482 | 467 | 443 | 4.64 |
| $CO_2$-C | 793 | 797 | 814 | 898 | 2.82 |
| $CH_4$-C+$CO_2$-C | 1281 | 1279 | 1280 | 1341 | 1.91 |

Carbohydrate concentrations also changed following similar patterns of $CO_2$ emission rates, but the highest concentration was observed around 60 DAT (Figures 2 and 3). The post harvest soil analysis showed higher total organic carbon, N, available P and porosity in 204 day-old biomass incorporated plot than others (Table 4).

## DISCUSSION

The production of methane from organic matter takes place when Eh value goes below -200 Mv. Most readily available organic carbon sources are utilized by the methanogens and thus methane is produced as a by-

**Table 3.** Relationship of soil respiration with cover crop biomass composition

| Compound | Nitrogen | Cellulose | Lignin | Protein | Ash | $CH_4$-C | $CO_2$-C |
|---|---|---|---|---|---|---|---|
| $CH_4$-C + $CO_2$-C | 0.347$^{ns}$ | 0.852*** | 0.573* | 0.625** | 0.625** | -0.881*** | 0.974*** |
| $CO_2$-C | 0.473$^{ns}$ | 0.935*** | 0.686** | 0.735** | 0.759** | -0.940*** | |
| $CH_4$-C | 0.612* | 0.961*** | 0.787** | 0.800** | 0.842*** | | |

$^{ns}$Not significant; and *, ** and *** Significant at $P \leq 0.05$, $P \leq 0.01$ and $P \leq 0.001$, respectively.

**Table 4.** Post harvest soil properties as affected by age of incorporated barley and hairy vetch biomass.

| Parameter | Age (days) | | | | |
|---|---|---|---|---|---|
| | 183 | 190 | 197 | 204 | $LSD_{0.05}$ |
| pH | 7.44 | 6.99 | 7.25 | 7.29 | 0.89 |
| Total organic matter (g kg$^{-1}$) | 20.90 | 21.53 | 21.02 | 21.72 | 0.18 |
| Total N (g kg$^{-1}$) | 1.70 | 1.72 | 1.70 | 1.76 | 0.34 |
| Available P (mg kg$^{-1}$) | 58 | 62 | 77 | 82 | 1.5 |
| Porosity (%) | 47.92 | 50.94 | 50.94 | 53.21 | 0.15 |

product as follows. This means composition of substrates (Le Mer and Roger, 2001) play an important role in methane production.

$$C_6H_{12}O_6 \rightarrow 3\ CO_2 + 3CH_4 + \text{energy}$$

Aged cover crop plants were responsible for higher seasonal soil respiration rates might be because of plant composition, especially higher contents of cellulose, lignin, protein, ADF and ash. There was higher inorganic and organic components with aged plants compared to immatured ones (Table 1), but total respiration was less with young plants than the aged ones due to lower amount of $CO_2$-C emission (Haque et al., 2015b). The rate of $CO_2$-C respiration was comparatively low at initial rice growth stage and then increased significantly with age of plants upto 60 DAT (Figure 3), which might have influenced total soil respiration. At this stage $CH_4$-C respiration was more because of increased methagen activity. Gunnarsson and Marstorp (2002) also found that low cellulose containing materials release more C than higher cellulose containing substrates. This C increased methanogen activity and produce higher amounts of $CH_4$-C at the initial rice growth stage. Moreover, higher cellulose and lignin contents slow down decomposition rates (Melillo et al., 1982; Tian et al., 1992; Gunnarsson and Marstorp, 2002) and thus $CH_4$-C respiration was less with 204 day-old incorporated biomass (Table 2). Although total DOC and carbohydrate play an important role in $CH_4$-C emission from flooded rice fields, no significant differences were observed in the present investigation (Figure 2). Organic and inorganic components of cover crop plants varied significantly depending on their age before incorporation (Table 1) and thus influenced physio-chemical properties of soil that ultimately resulted in increased $CH_4$-C and $CO_2$-C respiration (Table 2).

The incorporation of aged cover crop biomass decreases C source for methanogens (Vigil and Kissel, 1991) under anaerobic conditions and thus less $CH_4$-C respiration was recorded. Total soil respiration was significantly different between 204 and 197 day-old plants. Although there was no significant difference in soil respiration with 183, 190 and 197 day-old plants, biomass productivity and plant compositions were higher with 197 day-old ones. It means that cultivation of mixed barley and hairy vetch for 197 days before incorporation can be used to reduce soil respiration.

## Conclusion

Inorganic and organic compositions of cover crop plants increase with aging, which in turn might inecrease soil N and C contents following incorporation. Although total soil respiration was low with incorporated young plants having less lignin, cellulose, protein, and ash content, total biomass production was also low compared to aged cover crop. Since the viability of a technology depends of economy and easy handling, addition of 3 t ha$^{-1}$ biomass from young plants would require more production area that might not be acceptable to most of the farmers. Therefore, cultivation of cover crop for about 197 days can be a better option for enhancing biomass productivity and control of soil respiration from paddy soil.

## CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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