Short title: Using wastes to reduce jasmine plantation greenhouse-gas emissions

EFFECTS OF STRAW COMBINED WITH INDUSTRIAL AND AGRICULTURAL WASTES ON GREENHOUSE-GAS EMISSIONS IN A SUBTROPICAL JASMINE PLANTATION

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SUMMARY

The effects of straw alone or combined with industrial and agricultural wastes as fertilizers on GHG emissions in cropland areas are still poorly known. Here, we studied the effects of 3.5 Mg ha^{-1} straw and 3.5 Mg ha^{-1} straw combined with 8 Mg ha^{-1} of diverse wastes on GHG emission in a subtropical *J. sambac* plantation in southeastern China. There were five treatments in a completely randomized block design: control; straw only; straw + biochar; straw + steel slag; and straw + gypsum slag. Emissions of CO_2 were generally higher in the treatments with waste than in the control or straw-only treatments, whereas the contrary pattern was observed in CH_4 and N_2O emission rates. Moreover, the total global-warming potentials (GWPs) were no significantly higher in most of the amended treatments as compared to the control and straw-only treatments. In relation to the treatment with only straw, GWPs was 9.4% lower when steel slag was used. This finding could be a consequence of Fe amount added by steel slag, which would limit and inhibit the emissions of GHGs and their transport from soil to atmosphere. Our results showed that the application of slags did not increase the emission of GHGs and the combination of straw with steel slag or biochar could be more effective than straw alone for controlling GHGs emission and improve soil C and nutrient provision.

Keywords: CH_4 flux; CO_2 flux; N_2O flux; climate change; straw; biochar; steel slag; gypsum slag; jasmine plantation

INTRODUCTION

Global warming is caused by emission of large amounts of greenhouse gases (GHGs) to the atmosphere from the combustion of fossil fuels, land-use changes and other human activities (IPCC, 2013). Global GHG emissions from agricultural activities are about 5.1-6.1 Pg CO_2-eq y^{-1} (Smith *et al*., 2007), which can contribute to approximately 20% of the current emissions (Hütsch, 2001). The emissions of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) from agricultural lands are especially relevant (Myhre *et al*., 2013). Minimizing the emission of GHGs is an important task for mitigating their adverse impacts on climate change. Many methods have been developed to reduce and/or control the emission of GHGs, through water, fertilizers and tillage management (Peyron *et al*., 2016; Gupta *et al*., 2016; Malhi *et al*., 2016).

Recycling industrial and agricultural waste is becoming an effective way to solve environmental and resource availability issues, with the application of industrial and agricultural waste on agricultural lands gradually increasing (Wang *et al*., 2015a,b). The effects of waste application on soil nutrients and properties (Prendergast Miller *et al*., 2014), plant growth (Wang *et al*., 2015a, b) and GHG emission (Zhang *et al*., 2012) have been evaluated. Waste materials such as biochar (Zhang *et al*., 2010) and steel slag (Wang *et al*., 2012a) have been widely studied for increasing crop yields and mitigating GHG emissions. However, the effect of mixed waste application on the emission of GHGs is more complex and has been rarely and inconclusively studied. Industrial and agricultural wastes contain high concentrations of electron acceptors such as the active and free-oxide forms of iron (Fe), sulfur, nitrogen (N) and phosphorus (P).

Recently, biochar application has been found to significantly increase soil CO_2 fluxes by 22%, while decreasing N_2O fluxes by 31% without any effect in CH_4 fluxes (He *et al*., 2017). Such effects were dependent on latitude, soil type and soil use (Fan et al., 2017; He *et al*., 2017; Wang *et al*., 2017a). The use of steel and gypsum slag application to reduce GHGs emissions has been less studied, despite some positive effects (reduction in GHGs emissions) in rice fields (Susilawati *et al*., 2015; Wang *et al.,* 2017b). Few studies have provided an overall evaluation of the total global-warming potential (GWP) of CO_2, CH_4 and N_2O, the three main GHGs (Wang *et al*., 2015a,b). The combined application of biochar and steel slag has been associated with decreases in GHG emissions by rice crops (Wang *et al*., 2016; 2017).

At the best of our knowledge no information is available on the effects of industrial and agricultural wastes on GHG emissions from subtropical *Jasmine sambac* plantations. *J. sambac* tea is unique and more than half of the *J. sambac* tea in China is produced in Fuzhou Province (Yang *et al*., 2008). Developing effective strategies to enhance the yield of *J. sambac* flowers without increasing GHG emissions is considered as an important policy for minimizing future adverse conditions induced by climate change. On the other hand, use of waste materials for the management of *J. sambac* plantations and GHG emission would be an alternative way to recycle waste without environmental risks.

Here, we evaluated the effects of various waste materials (straw, and straw

combined with steel slag, biochar or gypsum slag) as fertilizers on the GHG emissions under field conditions, taking into account soil traits and the relationships between CO_2, CH_4 and N_2O emissions and soil traits.

MATERIALS AND METHODS

Study site and experimental design

A field experiment was conducted in a *Jasminum sambac* (L.) field in Fujian Province, China (*Suppl. material* ~~Suppl. Material~~ Figure S1~~Figure S1~~, 25°59'10"N, 119°20'7"E, ~~XXX~~ 220 m a.s.l), during *J. sambac* growing season from April to October 2015. This region has a subtropical monsoonal climate, with a mean air temperature of about 25 °C during the study period and a mean annual precipitation of approximately 1400 mm. About 80% of the total rainfall was concentrated in the rainy season between May and October (Figure S1). The soil contained 25%, 59% and 16% sand, silt and clay, respectively. Bulk density was 1.2 g cm^{-3}, pH 4.4, salinity of 0.15 mS cm^{-1} and concentrations of total carbon, total N, total P and total potassium were 11.7, 1.1, 0.5 and 13.3 g kg^{-1}, respectively. The study site has been cultivated with *J. sambac* since 2008.

J. sambac was cultivated using a ridge and ditch system, with a ridge height of 20 cm, ridge width of 100 cm and ditch width of 30 cm. Double-valve J. sambac branches (10 cm long) were transplanted by hand at a distance among them of 3 cm. along the ridges and 20 cm from the nearest plant in the side ridges in April 2008~~*Double-valve J. sambac branches (10 cm long) were transplanted by hand in the ridges at a spacing of 3×20 cm in April 2008*~~ . The *J. sambac* was cut at the end of March or early April each year when the air temperature was about 20 °C. About 3.5 Mg ha^{-1} of branches and leaves were returned to the field, which was ridged but not plowed each year. *J. sambac* branches and leaves began to grow from early April to early May. *Growth period last from early May to the end of May*~~Growth period last - from early May to the end of May~~. Flowering occurred from early June to late September, when the final growth period began. A complete fertilizer ($N:P_2O_5:K_2O$, 16:16:16) *was applied in two applications: the first application was 130 kg ha^{-1} one day after J. sambac was pruned*~~was applied in two splits: the first application was 130kg ha^{-1} one day after *J. sambac* was pruned~~; and the second one was 100 kg ha^{-1} one day after the first *J. sambac* flowers were collected~~and the second one was 100 kg ha^{-1} one day after the first *J. sambac* flowers were collected~~.

Triplicate plots (20 m^2 each) were established for five treatments in a completely randomized block design: 1) no straw or waste (control); 2) straw only (straw); 3) straw combined with steel slag (straw+steel slag); 4) straw combined with biochar (straw+biochar); and 5) straw combined with gypsum slag (straw+gypsum slag). Straw was added at 3.5 Mg ha^{-1}, and the biochar and steel and gypsum slags were added at 8 Mg ha^{-1} as granules (2 mm in diameter). The steel slag was collected from the Jinxing Iron & Steel Co., Ltd in Fujian (China). The biochar was collected from the Qinfeng Straw Technology Co., Ltd in Jiangsu Province. The gypsum slag was collected from building waste (from the indoor decoration of buildings). The industrial and agricultural wastes used in this study were rich in Si, Ca and K, which are essential nutrients for plant growth (Prendergast - Miller et al., 2014) (Table 1). All treatments received the

same water management~~The industrial and agricultural wastes used in this study were rich in Si, Ca and K, which are essential nutrients for plant growth (Prendergast - Miller et al., 2014) (Table 1). All treatments received the same water management~~.

Measurement of CO_2, CH_4 and N_2O emissions

The experimental period was from April 2015 to March 2016. Static closed chambers were used to measure CO_2, CH_4 and N_2O emissions, as described by Wang et al. (2015a). The chambers were made of rigid PVC and consisted of two parts, an upper transparent compartment (100 cm height, 30 cm width, 30 cm length) placed on a permanently installed bottom collar (10 cm height, 30 cm width, 30 cm length). Each chamber had two battery-operated fans to mix the air inside the chamber headspace, an internal thermometer to monitor temperature changes during gas sampling and a gas-sampling port with a neoprene rubber septum at the top of the chamber for collecting gas samples. Three replicate chambers in each treatment were used. A wooden boardwalk was built for accessing the plots to minimize disturbance of the soil during gas sampling. The chambers had a vent to avoid pressure buildup.

Gas flux was measured for all chambers twice weekly during the growing season and four times a week during the other seasons. The temperature in chamber was not significantly changed during sampling process (30 min). Gas samples were collected from the chamber headspace using a 100-mL plastic syringe with a three-way stopcock 0, 15 and 30 min after chamber deployment. The samples were immediately transferred to 100-mL air-evacuated aluminum-foil bags (Delin Gas Packaging Co., Ltd., Dalian, China) sealed with butyl rubber septa and transported immediately to the laboratory for evaluation of CO_2, CH_4 and N_2O concentrations.

CO_2, CH_4 and N_2O concentrations were determined by gas chromatography (Shimadzu GC-2010 and Shimadzu GC-2014, Kyoto, Japan) using a stainless steel Porapak Q column (2 m length, 4 mm OD, 80/100 mesh). A methane-conversion furnace, flame ionization detector (FID) and electron-capture detector (ECD) were used for determining CO_2, CH_4 and N_2O concentrations, respectively. The operating temperatures of the column, injector and detector for quantifying CO_2, CH_4 and N_2O were adjusted to 45, 100 and 280°C; to 70, 200 and 200°C and to 70, 200, and 320°C, respectively. Helium (99.999% purity) was used as a carrier gas (30 mL min^{-1}), and a make-up gas (95% argon and 5% CH_4) was used for the ECD. The gas chromatograph was calibrated before and after each set of measurements using 503, 1030 and 2980 μL CO_2 L^{-1} in He; 1.01, 7.99 and 50.5 μL CH_4 L^{-1} in He and 0.2, 0.6 and 1.0 μL N_2O L^{-1} in He (CRM/RM Information Center of China) as standards. CO_2, CH_4 and N_2O fluxes were then calculated as the rate of change in the mass of CO_2, CH_4 and N_2O per unit of surface area and per unit of time. Three injections were used for each analysis. One sample was injected to the GC for each analysis. The detection limits of the instrument for CO_2, CH_4 and N_2O were 1, 0.1 and 0.05 ppm, respectively.

Global warming potential (GWP)

GWP is typically estimated using CO_2 as the reference gas, and changes in emission of CH_4 or N_2O are converted to "CO_2-equivalents" (Hou *et al.*, 2012). The GWP of the

combined emission of CH_4 and N_2O was calculated as (Ahmad *et al*., 2009): GWP = (cumulative CO_2 emission × 1) + (cumulative CH_4 emission × 34) + (cumulative N_2O emission × 298)

Measurement of soil properties

Three replicates of soil samples were collected from each treatment. The samples were transported to the laboratory and stored at 4°C until analysis. The temperature, pH, salinity and water content of the top 15 cm of soil were measured *in situ* at each plot on each sampling day. Soil pH was measured with a pH/temperature meter (IQ Scientific Instruments, Carlsbad, USA), while salinity was measured using a 2265FS EC meter (Spectrum Technologies Inc., Paxinos, USA) and water content measured using a TDR 300 meter (Spectrum Field Scout Inc., Aurora, USA). Soil samples were collected from the 0-15 cm layer from each plot for quantifying ferric, ferrous and total Fe concentrations. Total Fe concentration was determined by digesting fresh soil samples with 1 M HCl. Ferrous ions were extracted using 1,10-phenanthroline and measured spectrometrically (Lu, 1999). Ferric concentration was calculated by subtracting the ferrous concentration from the total Fe concentration. After 60 DAT total soil C, N and P were analyzed. Total soil C and N were determined by Elementar Vario MAX CN Analyzer (Elementar Scientific Instruments, Hanau, Germany). Total soil P concentration was quantified by perchloric-acid digestion followed by ammonium-molybdate colorimetry, using a UV-2450 spectrophotometer (Shimadzu Scientific Instruments, Kyoto, Japan).

Statistical analysis

Differences in soil properties and CO_2, CH_4 and N_2O emissions among the treatments were tested for statistical significance by repeated-measures analyses of variance. The relationships between mean GHG emissions and soil properties were evaluated by Pearson correlation analysis. These statistical analyses were performed using SPSS Statistics 18.0 (SPSS Inc., Chicago, USA). The effects of treatments on total soil C, N and P concentrations were analyzed by one-way ANOVA, with Tukey post hoc test using Statistica 8.0 (StatSoft, Inc. Tule, Oklahoma, USA).

RESULTS

CO_2, CH_4 and N_2O emissions and plant growth

CO_2 emission varied significantly among sampling dates but not among treatments (Tables S1, S2). In general, CO_2 flux remained low (<1040 mg m^{-2} h^{-1}) during the first 16 days after treatment (DAT) and then increased to a seasonal peak (>1610 mg m^{-2} h^{-1}) between 16 and 91 DAT (Figure ~~2A~~1A). *J. sambac* was nearly mature by 106 DAT, with a corresponding decrease in CO_2 emission.

~~CH_4 emission did not vary among sampling dates and treatments~~ N_2O emission varied significantly among sampling dates but not among treatments (Tables S1, S2). Maximum fluxes were earliest in the straw+gypsum treatment at 16 DAT (2.11 mg m^{-2} h^{-1}). The N_2O flux peaked at 46 DAT in the control (2.56 mg m^{-2} h^{-1}), straw (2.01 mg

m^{-2} h^{-1}), straw+biochar (1.78 mg m^{-2} h^{-1}) and straw+steel slag (1.57 mg m^{-2} h^{-1}) treatments (Figure ~~2C~~1C). N_2O emissions from the *J. sambac* plantation presented a decreasing trend until 316 DAT.

The flowering period lasts from 91 DAT to the sampling date. During this period plants had reached their maximum height and did not grow more (Figure ~~2D~~1D). *The little changes in plant height from 91 DAT to the harvest (286 DAT) observed in* Figure ~~2D 2~~1D *were not significant*.

Cumulative emissions

The cumulative CO_2 emissions during the study period were higher for straw + gypsum slag than the control. Cumulative CO_2 emission were not statistically different in steel slag, the straw+biochar and straw+gypsum slag treatments than in the straw treatment (Figure ~~3A~~2A). The cumulative CH_4 emissions were not statistically different in straw, steel slag, the straw+biochar and straw+gypsum slag treatments than in the control (Figure ~~3B~~2B), Cumulative N_2O emissions were not statistically different in straw, steel slag, the straw+biochar and straw+gypsum slag treatments than in the control (Figure 2C) (Tables S1 and S2).

Soil properties

Soil pH, temperature, water content and ferrous, ferric and total Fe concentrations varied among the treatments (Figure ~~4~~3, Tables S3, S4). Soil pH was higher in the straw+biochar, straw+steel slag and straw+gypsum slag treatments than in the control and straw treatments (P<0.05). Soil salinity did not differ significantly among the different experimental treatments but all the treatments were significantly higher than in the control (P<0.05), and straw+biochar and straw gypsum slag treatments had more effect on the soil salinity than that of straw treatment (P<0.05). Soil-water content was also higher in the straw+biochar and straw+gypsum slag treatments than the in control and was higher in the straw+biochar treatment than in the straw treatment (P<0.05). Soil Fe^{2+} concentration was significantly higher in all amended treatments than the control (P<0.05), while Fe^{3+} concentration was significantly lower in the straw treatment than in the control, straw+biochar, straw+steel slag and straw+gypsum slag treatments (P<0.05). Total Fe concentration was significantly higher in the straw+steel slag treatment than in the control (P<0.05).

Relationships between CO_2, CH_4 and N_2O emissions and soil properties

Seasonal CO_2 and N_2O emissions were correlated positively (P<0.01) with soil temperature (Table S5) and negatively with soil Fe^{3+} and total Fe concentrations (P<0.01) in all treatments. Soil salinity and water content were also positively correlated with CO_2 emission in all treatments (P<0.01). Seasonal CH_4 emission was negatively correlated with soil Fe^{2+} concentration (P<0.05) in the straw and straw+steel slag treatments. Salinity and water content were also positively correlated and soil pH was negatively correlated with N_2O emission (P<0.05) in all treatments.

Global warming potential (GWP)

GWP was significantly higher for CO_2 than for CH_4 and N_2O emissions. However, total GWP was similar in among treatments (Table 2).

Total soil C, N and P concentrations

Soil total C, N and P concentrations after 60 days (growing period) of treatments application were higher in treatment plots than in control plots (Figure ~~5~~4). Total soil C and N concentrations followed the order of straw+biochar > straw+steel slag = straw+gypsum slag > straw > control (Figure ~~4A3~~4A,B). Total soil P concentration values followed the order straw = straw+steel slag > straw+biochar = straw+gypsum slag > control (Figure ~~5C~~4C).

DISCUSSION

Effects of the treatments on soil properties

Soil pH was higher in the straw+biochar, straw+steel slag and straw+gypsum slag treatments than the control and straw treatments, likely due to the high alkaline contents of the amendment material. Many cations are released due to the increase of pH (Wang *et al*., 2015a). Soil salinity was significantly higher in the amended treatments than the control (P<0.05). The straw, biochar, steel and gypsum amendment materials used in this study contained some elements such as K and Ca that can easily been released into the soil solution increasing the salinity (Wang *et al*., 2015a). Soil-water content was also higher in the straw+biochar treatment than in the control and straw treatments. Biochar can absorb water, because it has high total porosity, and can thus increase soil-water content (Asai *et al*., 2009).

Soil Fe^{2+} concentration was significantly higher in all amended treatments than the control. The wastes are rich in minerals containing Fe^{3+} and straw decomposition would add more carbon substrates, such as short-chain fatty acids that can act as electron donors, favoring altogether the conditions for Fe^{3+} reduction to Fe^{2+} (Li *et al*., 2011). At this regard it is important to highlight the important inputs of iron that the treatments suppose (207, 16 and 17 kg ha^{-1}, for steel slag, biochar and gypsum slag, respectively). Higher soil concentrations of organic matter and CO_2 production and Fe^{2+} under treatments should also favor methane production (da Silva *et al*., 2010), mostly in the soil water contents between 40 and 60% observed in the studied period. At these levels of soil moisture, several soil meso- and micro-pores should be flooded favoring anaerobic conditions and methane production (Wagner, 2017).In our study, the Fe^{3+} concentration was lower in the straw treatment than the control, supporting the premise that straw or straw combined with waste could increase the reduction of Fe^{3+} to Fe^{2+} and increase the Fe^{2+} concentration.

All treatments increased total soil C, N and P concentrations respect to control after a year of application, which suppose a general increase of soil nutritional capacity, especially in the soils receiving the application of straw + biochar that presented the highest total soil C and N concentrations. The increases of soil N concentrations would

be especially important considering that those wetlands have been proved to be N-limited (Wang *et al.*, 2015a).

Effects of the treatments on CO_2, CH_4 and N_2O emissions

CO_2 emission changed significantly during the *J. sambac* growing season, and seasonal CO_2 emission was positively correlated with soil temperature in all treatments. CO_2 emission was negatively correlated with soil Fe^{3+} and total Fe concentrations. Iron plaques form around *J. sambac* roots at high Fe concentrations, which would limit the transport of CO_2 from the soil to the atmosphere by the internal system of interconnected gas lacunae of the plants. Soil-water content was also positively correlated with CO_2 emission. When soil is not water saturated, soil respiration can increase during wetter periods, so soil CO_2 emissions are then positively related to soil water content (McElligott *et al.*, 2017).

Straw application can increase CO_2 emissions by several mechanisms. First, the decomposition of straw directly releases CO_2 (Curtin *et al.*, 1998). Second, the decomposition of straw adds carbon substrates to the soil, which will increase the amount and activity of soil microbes and then increasing emission of CO_2 (Curtin *et al.*, 1998). Despite not statistically significantly, mean CH_4 emissions were generally higher in the straw, straw+biochar and straw+gypsum slag treatments than the control, most likely due to the input of carbon substrates from the straw. The decomposition of straw would increase the carbon concentration of the soil and promote the emission of CH_4 (Wang *et al.*, 2015b). Contrarily mean CH_4 emissions tend to be lower in the straw+steel slag treatment than the control. The steel slag is rich in Fe^{3+} and would increase the concentration of soil Fe^{3+}, which is an alternative electron acceptor that can use C substrates before methanogens (Jiang *et al.*, 2013) and thereby decrease the amount of CH_4 production and emission (Gauci *et al.*, 2008) by competing with methanogens for C substrates (Jiang *et al.*, 2013).

Mean N_2O emissions tended to be lower in the straw+biochar and straw+steel slag treatments than the straw treatment. Biochar can decrease N_2O emission (Wang *et al.*, 2011) and is rich in alkaline material, so it can increase soil pH, stimulate N_2O reductase activity and thereby induce the reduction of N_2O to N_2 (Yanai *et al.*, 2007). Biochar may also improve soil aeration and impede the function and diversity of denitrifying bacteria, thereby decreasing N_2O emission (Cavigelli and Robertson, 2001). Steel slag is also rich in Fe^{3+}, and an increase in soil Fe^{3+} concentration could suppress microbial activity, including N_2O production (Noubactep, 2011).

CONCLUSIONS

The total GWPs for all emissions were not different in the amended treatments than the control.

All treatments increased total soil C, N and P concentrations after one-year of their application. The high increase of total soil N concentration under straw + biochar was especially important due to the limiting role of N in these wetlands. Moreover, biochar and steel slag are rich in nutrients, such as Si, Ca and magnesium, which can all improve soil fertility

The alkalinity of the biochar and the steel and gypsum slags also improved the soil quality in this J. *sambac* producing area with high levels of acid deposition. The soil-water content also increased. Our results also suggested that the application of straw combined with biochar, steel slag or gypsum slag effectively reduced the adverse impacts of *J. sambac* agriculture on plant growth and soil properties, even increasing the soil N and P stocks without increasing significantly the GWPs.

Another positive aspect is that the wastes used as fertilizer materials in this study are in abundant supply for application to agriculture. They also have a low cost and contribute to the recycling of wastes.

Summarizing, our results thus provide strong evidence for several benefits from the application of these fertilizers: recycling of several waste materials and improved *J. sambac* production without affecting GHG emissions. Thus, the application of straw combined with steel slag, and especially with biochar is a potentially positive and sustainable agricultural practice that moreover is largely available and have a low economical cost."

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Tables

Table 1. Chemical properties of different waste amendments in this study.

Treatments	Chemical properties										
	Fe_2O_3 (%)	Fe (%)	SO_3 (%)	S (%)	SiO_2 (%)	C (%)	N (%)	P (%)	K (%)	Mg (%)	Ca (%)
Steel slag	4.8	-	-	-	40.7	0.79	0.01	0.01	0.5	0.36	24.9
Biochar	-	0.2	-	0.6	-	56.6	1.4	1.0	1.8	1.0	0.5
Gypsum slag	0.4	-	54.4	-	0.7	0.7	0.01	0.01	0.1	0.3	30.6

Table 2. Effect of the amended treatments on the global-warming potential.

Treatment	Global warming potential (kg CO_2-eq ha^{-1})			Global-warming potential (kg CO_2-eq ha^{-1})
	CO_2	CH_4	N_2O	
Control	52572.44±1226.13a	2.65±2.89a	41.34±13.66a	52616.43±1321.25a
Straw	66162.44±11791.43a	4.11±4.40a	31.56±4.90a	66198.12±11790.94a
Straw+biochar	66714.37±8762.01a	25.14±22.09a	28.99±2.45a	66768.50±8753.62a
Straw+steel slag	59953.90±7961.67a	1.71±2.66a	20.41±7.89a	59976.01±7971.45a
Straw+gypsum slag	71004.78±5828.47a	15.20±10.37a	32.21±7.10a	71052.19±5822.38a

Different letters within a column indicate significant differences between the amended and control treatments (P<0.05) obtained by Bonferroni's post hoc test.

Figure legends

Figure 1. CO_2 (A), CH_4 (B), N_2O (C) emissions and Plant height (D) in the control and treatment. Error bars indicate one standard error of the mean of triplicate measurements. Different letters indicate significant differences (P<0.05) between treatments.

Figure 2. Cumulative emissions of CO_2 (A), CH_4 (B) and N_2O (C) in the amended and control treatments during the study period. Error bars indicate one standard error of the mean of triplicate measurements. Different letters indicate significant differences (P<0.05) between treatments.

Figure 3. Soil pH (A), temperature (B), salinity (C), water content (D), Fe^{2+} concentration (E), Fe^{3+} concentration (F) and total Fe concentration (G) in the control and treatment. Error bars indicate one standard error of the mean of triplicate measurements. Different letters indicate significant differences (P<0.05) between treatments.

Figure 4. Total soil C (A), N (B) and P (C) concentrations observed in each treatment plots after one-year of treatments application. Error bars indicate one standard error of the mean of triplicate measurements. Different letters indicate significant differences (P<0.05).