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# Green house gas fluxes from rainfed sorghum (*Sorghum bicolour*) and pigeonpea (*Cajanus cajan*) – Interactive effects of rainfall and temperature

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## ABSTRACT

Carbon dioxide ($CO_2$), methane ($CH_4$) and nitrous oxide ($N_2O$) are important biogenic green house gases (GHGSs) from agricultural sector contributing to global warming. Temperature and rainfall play an important role in GHGS fluxes and information on their role in rainfed crops and systems is very scanty. Field studies were conducted at Hyderabad, India during 2012 rainy season to quantify GHGSs fluxes from two important food crops grown widely in rainfed regions viz. sorghum and pigeonpea. Quantum of fluxes ranged from 26 - 85 mg $CO_2$ - C $m^{-2}$ $h^{-1}$ in case of $CO_2$ and 18 – 68 µg $N_2O$-N $m^{-2}$ $h^{-1}$ in case of $N_2O$ at different stages of crop growth. Cumulative seasonal fluxes are 1.18 and 1.24 Mg $CO_2$-C $ha^{-1}$ and 0.78 and 0.94 kg $N_2O$-N $ha^{-1}$, in sorghum and pigeonpea, respectively. Ambient temperature and rainfall significantly influenced $CO_2$ fluxes. $CO_2$ fluxes increased with increase in temperature from 25.9 °C to 31 °C and fluxes were highest at 28.4 °C in pigeonpea and at 27.7 °C in sorghum. Quantum of $CO_2$ fluxes were highest at grain filling stage in sorghum and grand growth period in pigeonpea. $N_2O$ fluxes increased with increase in temperature and moisture availability. These results provide evidence that rainfed crops in semi-arid regions contribute significant $CO_2$ and $N_2O$ fluxes which are influenced by temperature and rainfall, thus warrant further studies.

**Keywords*:*** Green house gas emissions, Indian rainfed agriculture, pigeonpea, sorghum, temperature

Agriculture sector is an important source of GHGSs emissions and AFLOU (Agriculture, Forestry and Other Land Use) sector contributed 24% of total emissions worldwide during 2010 (IPCC 2013). In India, 18% of the total emissions were from agriculture sector (INCAA 2010) which was also the largest source of $CH_4$ and $N_2O$ emissions and has contributed up to 73% of methane and 75% of nitrous oxide emissions at the country level in India during 2000 (NATCOM 2012). Current reporting of agricultural GHGSs emissions to the United Nations Framework Convention on Climate Change (UNFCCC) by developing countries are largely based on Tier-I methods and there is a need to move to higher tiers which require data on crop specific emissions and emission coefficients and complete set of activity data for tracking key management practices in various agricultural production systems (Ogle *et al.* 2014). Besides, quantification of GHGSs from agriculture is fundamental for identifying mitigation solutions that are consistent with goals of achieving greater resilience in production systems, food security, guiding national planning for low carbon development, informing consumers' choices with regard to reducing their footprints and supporting farmers in adopting less carbon intensive farming practices (Olander *et al.* 2013).

Rainfed agriculture in India is practiced over 58 per cent of cultivated areas and contributes 40 per cent of country's food production. Sorghum and pigeonpea are important rainfed crops grown under semi-arid conditions, spread over an area of 6.25 and 4.01 m ha produced 5.98 and 2.65 mt respectively during 2011- 12 (Raju *et al.* 2010). Sorghum is an important food crop for a large chunk of population of central India, where as pigeonpea is an important food legume of the entire country which is an essential ingredient of vegetarian meal. In order to meet ever increasing demand of food for growing population, there is a need to enhance productivity of these two important rainfed crops. In recent years there has been significant improvement in productivity of sorghum mostly through cropping intensification by greater use of resources which may also contribute to the release of GHGSs.

Practically no information is available on GHGSs emissions from rainfed crops, cropping and land use systems of India. Knowledge on this may help to identify appropriate systems which are profitable and environment friendly. Quantification of GHGSs emissions from these systems assists in the development/ modification of management practices which can stabilize or possibly enhance yields at the same level of input use and emissions. Magnitude of gas emissions varies spatially and affected by factors like seasonal climatic conditions, air and soil temperatures and sampling frequency and cropping systems (Drury *et al.* 2004). For a comprehensive understanding of all these, a study was carried out to quantify green house gas emissions from these two important rainfed crops representing semi arid conditions.

## MATERIALS AND METHODS

This study was conducted during 2012 rainy season at Hayathnagar Research Farm of Central Research Institute for Dryland Agriculture (CRIDA), Hyderabad. The soil of experimental field is Alfisol in nature with pH 5.3 and EC 0.085 dS $m^{-1}$. The soils were low in available nitrogen (145 kg $ha^{-1}$), medium in available phosphorus (12.5 kg $ha^{-1}$) and available potassium (179.2 kg $ha^{-1}$). The initial organic carbon content of the soils was 3.7 g $kg^{-1}$. Sorghum and pigeonpea were sown during the first fortnight of June, 2012 and harvested during 3rd week of October and December, respectively. Sorghum has received 40:40:0 kg $ha^{-1}$ where as pigeonpea has received 20:50:20 kg $ha^{-1}$ of N, P and K fertilizers, respectively. Nitrogen and phosphorus are applied in the form of diammonium phosphate and potassium in the form of muriate of potash. In sorghum, nearly half of nitrogen, entire phosphorus and potassium were applied basally at sowing and remaining nitrogen was top dressed at 45 days after sowing (DAS). In case of pigeonpea entire nitrogen, phosphorus and potassium were applied basally. Total rainfall received during crop season was 661.7 mm over 30 days (Fig.1). Mean maximum temperature during crop growing period was 41.4 °C where as mean minimum temperature was 19.9 °C. GHGs fluxes were quantified for entire crop growing season at 15 days interval. However, more observations were taken during periods of high soil moisture and post nitrogen fertilization. Sampling was done at 15 minutes interval of one hour during morning hours (10.00-12.00 am) to reduce variability in GHGs flux due to diurnal changes in temperature. Chambers were placed between crop rows and crops were not placed in the chamber and fluxes were collected using closed chamber technique as suggested by Hutchinson and Mosier (1981). Chambers are rectangular in shape with 53 x 33 x 37 cm size made of 6 mm thick acrylic sheets with aluminium frames and mounted on an iron stand. Iron stands were inserted between crop rows one week after sowing to a depth of 10 cm. Chambers were mounted on frames prior to taking observations every time. To ensure that there was no gas exchange between chamber and atmosphere during sampling, chambers were made airtight by sealing all spaces between the frame and chamber with water before sampling. Gas samples of approximately 20 ml were collected at 15 minutes interval for one hour. Samples were collected into 20 ml polypropylene syringes, equipped with three way stopper by hypodermic needle (24 gauge) through rubber septum located on chamber's top. Thermometer was inserted into the chamber through another septum to record the temperature inside the chamber during sampling period. A small DC operated fan (runs with the help of 9 volt battery) is used to homogenise the sample inside the chamber before sampling.

Air temperature and precipitation data were obtained from weather station at the farm. Gases collected were analysed immediately with the help of a gas Chromatograph (Model 450-GC, Varian Inc., Walnut Creek, CA) fitted with thermal conductivity detector, flame ionization detector and electron capture detector, respectively. Fluxes of $CO_2$ and $N_2O$ were calculated using the following equation (Pathak *et al.* 2013)

$$CO_2\text{-C flux (mg m}^{-2}\text{ h}^{-1}) = \frac{\Delta X \times EBV_{(STP)} \times 12 \times 10^3 \times 60}{10^6 \times 22400 \times T \times A}$$

$$N_2O\text{-N flux (}\mu\text{g m}^{-2}\text{ h}^{-1}) = \frac{\Delta X \times EBV_{(STP)} \times 28 \times 10^3 \times 60}{10^6 \times 22400 \times T \times A}$$

Where,

"X = difference in flux value between 60 min and 0 min (in ppm for $CO_2$ & ppb for $N_2O$), $EBV_{(STP)}$ = effective box volume at standard temperature and pressure, T = flux time (min), A = base area of chamber ($m^2$). Quantum of emissions over different stages of crop growth were averaged and the total emissions for crop growth period was arrived at by multiplying with crop duration. The relationships between

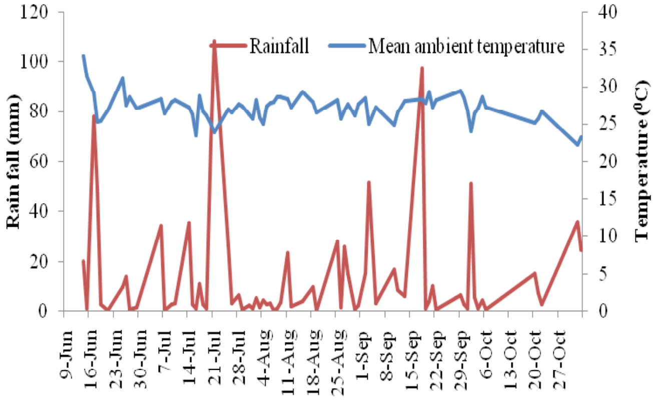

**Fig. 1:** Temperature and rainfall during rainy season of 2012

$CO_2$ and $N_2O$ emissions, maximum temperature and rainfall were examined using different regression equations derived with SPSS V 15.

## RESULTS AND DISCUSSION

### *Carbon dioxide fluxes*

$CO_2$ fluxes were quantified from germination to harvest during the cropping season and these ranged from 29.5 – 85.4 and 25.8 – 75.6, mg $CO_2$ - C $m^2 h^{-1}$ from pigeonpea and sorghum, respectively. Relatively higher fluxes were recorded in pigeonpea in comparison to sorghum (Table 1). $CO_2$ fluxes increased with age of the crop and maximum fluxes were recorded at grain filling stage for sorghum (75 days after sowing) and at vegetative stage (70-075 days after sowing) in case of pigeonpea and gradually declined thereafter (Fig. 2). During this period significant quantity of rainfall was received. During high rainfall events (on 15 September 2012 with a rainfall of 102.7 mm), considerable quantity of $CO_2$ got released into the atmosphere, which was several orders of magnitude greater than rain free days. High rainfall events trigger microbial respiration, and the percolating rainwater physically displace soil, air rich in $CO_2$ and squeeze out $CO_2$ into atmosphere (Borken *et al.* 2003). Crop growth was vigorous during the active vegetative growth and root respiration also contributed towards higher $CO_2$ fluxes during this stage. Root respiration is a contributor to soil $CO_2$ fluxes and this contribution can be from 10 to 90%, depending on vegetation type and time during the growing season. In annual crops it is suggested that the root contribution to soil respiration is higher during the growing season but low in dormant periods (Hansen et al. 2000). In some cereals about 40% of photosynthetically fixed carbon can be translocated belowground before flowering and about 16% of this is lost as respiration and exudates. However, after flowering this decreases due to the increasing sink demand by developing seeds. Higher fluxes from pigeonpea compared to sorghum could be due to the leguminous nature of the pigeonpea, resulting in higher supply of nitrogen to microbes thereby increasing their activity leads to more emissions.

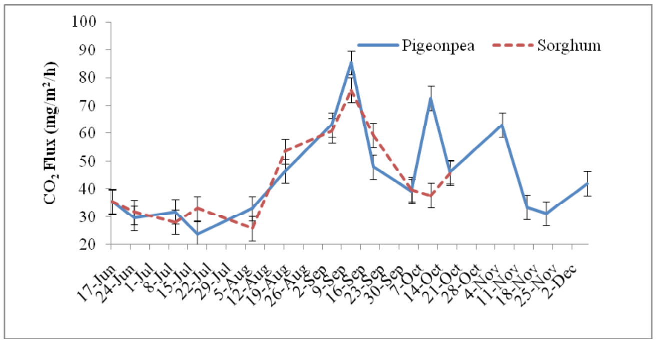

**Fig. 2:** $CO_2$ fluxes from pigeonpea and sorghum during cropping period

### *Seasonal emissions of $CO_2$*

$CO_2$ fluxes were summed up for entire crop duration and total $CO_2$ fluxes in pigeonpea were 1.24 t $ha^{-1}$ while fluxes in sorghum were 1.18 t $ha^{-1}$ (Table 1). Seasonal $CO_2$ fluxes reported earlier from cereal crops such as maize, wheat, barley varied from 4.2 to 5.2 Mg $ha^{-1}year^{-1}$ in temperate regions (Johnson and Barbour 2010), 3.0 to 4.37 Mg $ha^{-1}year^{-1}$ in subtropical regions of the USA (Vyn *et al.* 2013) and 2.8 to 6.6 Mg $ha^{-1}$ $year^{-1}$ in tropical regions (Bajgai *et al.* 2011) where the soil organic carbon levels ranged from 5.6 g $kg^{-1}$ in temperate regions to 7.7 g $kg^{-1}$ in subtropical regions and under relatively higher moisture conditions. The quantum of fluxes recorded in our study is relatively less which could be due to low rainfall and low soil organic carbon status (3.7 g $kg^{-1}$). The quantum of fluxes observed in the present study are nearer to Shi *et al.* (2006) who found 1.58 t $ha^{-1}$ of $CO_2$ flux from wheat under temperate environment of China, which has medium organic carbon content and with adequate surface moisture.

### *Effect of temperature and precipitation on $CO_2$ emissions*

Soil $CO_2$ fluxes correlated significantly with temperature during cropping season (Table 2). $CO_2$ fluxes from pigeonpea and sorghum increased with increase in temperature from 25.9 °C to 31 °C and fluxes were highest at 28.4 °C in case of pigeonpea and 27.7 °C in sorghum. Significant correlation between $CO_2$ flux and temperature was observed in both the crops. Temperature is the primary factor governing $CO_2$ emissions when soil moisture is not

**Table 1**: GHGs fluxes from pigeonpea and sorghum during cropping period

| Crop /System | $CO_2$ (mg $m^{-2}hr^{-1}$) | | $N_2O$ ( µg $m^{-2}hr^{-1}$) | | Seasonal fluxes | |
|---|---|---|---|---|---|---|
| | Range | Mean | Range | Mean | $CO_2$ (t $ha^{-1}$) | $N_2O$ (kg $ha^{-1}$) |
| Pigeonpea | 29.5-85.37 | 43.53±18.68 | 22.5-67.5 | 32.79±21.60 | 1.24 | 0.94 |
| Sorghum | 25.8-75.6 | 40.82±9.95 | 17.9-44.9 | 27.21±7.85 | 1.18 | 0.78 |

**Table 2**: Best-fit regression equations for $CO_2$ flux on the interactive effect of temperature and rainfall on $CO_2$ flux in pigeonpea and sorghum

| Variable(s) | Pigeonpea | | | Sorghum | | |
|---|---|---|---|---|---|---|
| | Equation | r | t | Equation | r | t |
| Temperature | $Y=6.304x+0.407$ | 0.30 | 1.35 | $Y=3.408x+4.763$ | 0.02 | -0.05 |
| Rainfall | $Y=0.344x+0.146$ | 0.57 | 2.95 | $Y=0.114x+0.136$ | 0.53 | 1.99 |
| Temperature and rainfall | $Y=0.005x^2+0.838x+1.692$ | 0.60 | 0.19 | $Y=0.192x^2+1.033x+10.61$ | 0.01 | 0.002 |

**Table 3**: Best-fit regression equations for $N_2O$ flux on the interactive effect of temperature and rainfall on $N_2O$ flux in pigeonpea and sorghum

| Variable(s) | Pigeonpea | | | Sorghum | | |
|---|---|---|---|---|---|---|
| | Equation | r | t | Equation | r | t |
| Temperature | $Y=0.438x+14.94$ | 0.07 | 0.29 | $Y=1.028x-5.407$ | 0.03 | 0.01 |
| Rainfall | $Y=-0.11x+34.10$ | 0.20 | 0.88 | $Y=0.397x+16.84$ | 0.04 | -0.13 |
| Temperature and rainfall | $Y=0.053x^2+0.438x+14.94$ | 0.38 | 0.97 | $Y=-0.066x^2+1.618x+30.02$ | 0.05 | 0.07 |

limiting as $CO_2$ release by aerobic respiration is primarily temperature dependent (Omonode *et al.* 2007).

Wiant and Harry (1967) observed no $CO_2$ evolution at 10 °C followed by a logarithmic increase in $CO_2$ evolution between 20 and 40 °C and has declined rapidly at 50 °C and above. At higher temperatures, partial inhibition of microbial respiration occurs, which is attributed to inactivation of biological oxidation systems. Lowest $CO_2$ fluxes at low temperatures could be due to minimal soil microbial activity, and hence reduced soil respiration (Al Kaisi and Yin 2005). $CO_2$ fluxes from crop rows during growing season derived mainly from root and shoot respiration when plants were retained under the gas sampling chambers, while emissions from bare soil between inter rows reflected both soil and root respiration during the growing season. In the present study, $CO_2$ fluxes were measured from soil surface between two crop rows, hence seasonal $CO_2$ emissions reported can be attributed mostly towards residue decomposition and to a lesser degree towards root respiration.

In our study, a significant positive correlation was observed between rainfall and $CO_2$ flux in both the crops. Soil moisture affects soil respiration and hence $CO_2$ evolution. When the soil is wet the activity of the microbes, which were in a latent state in dry soil, increases accompanied by release of air trapped in the soil pores contributing to an increase in $CO_2$ fluxes. Apart from the direct effects of temperature and moisture, interaction of these two assumes great significance in view of global warming. In pigeonpea, highest flux of $CO_2$ was observed at 29 °C, coinciding with a significant amount of rainfall and showed a positive, linear relation with rainfall received. Soil $CO_2$ flux was lower with lower rainfall at the same temperature.

### *Nitrous oxide fluxes*

Magnitude of seasonal $N_2O$-N fluxes varied from 18–68 µg $N_2O$-N $m^{-2}h^{-1}$ (Table 1). Relatively higher $N_2O$-N fluxes were observed in pigeonpea (32 µg $N_2O$-N $m^{-2}$ $h^{-1}$) in comparison to sorghum (27 µg $N_2O$-N $m^{-2}h^{-1}$). In the present investigation, two peaks of $N_2O$ fluxes were observed in pigeonpea; the first was about 10 DAS and a second peak at 98 DAS coinciding with high rainfall. In sorghum, an initial peak was observed a few days after sowing and another at about 80 DAS which also coincided with high rainfall and decreased thereafter. In both crops, higher fluxes at germination and seedling growth could be due to the fertilizer applied at sowing. Soil moisture is a major driver of $N_2O$ emissions as it regulates oxygen availability to soil microbes and moist soils had their optimum $N_2O$ emissions under wetter conditions (Butterbach-Bahl *et al.* 2013). An increase in $N_2O$-N emissions after sowing may be due to nitrification of $NH_4^+$ triggered by substrate availability due to application of fertilizers and another peak of $N_2O$ fluxes during later part of season due to availability of moisture.

### *Seasonal fluxes of $N_2O$*

Of the two crops, quantum of fluxes for entire cropping season was found to be relatively high in pigeonpea (0.9 kg $N_2O$-N $ha^{-1}$). $N_2O$ fluxes in agricultural lands depend on fertilizer application during current year and nitrogen applied to the previous crop, biological nitrogen fixation by legumes and atmospheric nitrogen deposition (Kim *et al.* 2013). In addition to this, plant residues also provide a substrate for nitrification and denitrification, leading to $N_2O$ production. Relatively higher $N_2O$ fluxes from pigeonpea could be due to leguminous nature of the crop and also their ability to produce large quantities of residues which have relatively higher nitrogen content resulting in rapid decomposition of leguminous residues. Pigeonpea produces about 2 Mg of litter during one season which contains up to 26 kg nitrogen and some of which might have released by decomposition during cropping season itself. Though pigeonpea crop has received less nitrogen through fertilizers in comparison to sorghum, substantial quantum of nitrogen is added through litter. Rates of denitrification differ in different soils and higher denitrification rates in soils grown with legumes in comparison to cereal crops have been reported. Based on the summary of 180 experiments, it has been summarized that the fertilizer induced $N_2O$ emissions varied between 0 and 8% of applied nitrogen (Bowman, 1996). The extent of $N_2O$ emissions from Ammonium sulphate/phosphate fertilizers ranges from 0.06 to 7% of the applied fertilizer. The values observed in our study are within this range.

### *Effect of temperature and precipitation on $N_2O$ emissions*

$N_2O$ fluxes increased with increase in temperature in both the crops. $N_2O$ fluxes from pigeonpea and sorghum increased with increase in temperature and fluxes were highest at 27.6 °C in pigeonpea and 27.1 °C in sorghum. Significant correlation of $N_2O$ flux with temperature and precipitation was observed in both crops. The interaction of moisture and temperature was also found to be significant and highest quantum of fluxes were observed during second week of September after the receipt of a rainfall of 97 mm and at an ambient temperature of 29.8 °C. Like other biological processes, nitrification and denitrification rates increase with increasing temperature within certain range. Higher temperature favours higher ratio of $N_2O$ from nitrification provided sufficient moisture exists which might have got restricted due to limitation of moisture under rainfed conditions. As soil temperature increases, $N_2O$ fluxes also increases up to 37 °C and declines thereafter. Regression analyses for both crops indicated interaction of temperature and precipitation exerts a strong control on nitrous oxide fluxes.

## CONCLUSION

The quantum of fluxes from water constrained semi arid environments were up to 1.24 Mg which are relatively less in comparison to reported values from subtropical environments with high organic content and moisture regime. Seasonal fluxes from pigeonpea were higher in comparison to sorghum. Temperature and moisture availability played an important role in both the $CO_2$ and $N_2O$ fluxes. Quantum of $N_2O$ fluxes were up to 0.9 kg $N_2O$ /$ha^{-1}year^{-1}$, but when the background emissions were taken into consideration the quantum was less than 1% of the applied fertilizer. These results provide further evidence that crops grown under semi arid environments have significant $N_2O$ fluxes which calls for comprehensive understanding of interactions between temperature and moisture with the fluxes.

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