Environmental Footprint of Maize-based Cropping Systems under Different Crop Establishment Methods in North-west India

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Introduction

Food security is going to be one of the major problems in Indo-Gangetic Plains (IGP) of South Asia, where about 40 percent of the population are already living in extreme poverty (Balasubramanian et al., 2013). Projections indicate that production of rice, wheat and maize will have to increase by about 1.1 percent, 1.7 percent and 2.9 percent per annum, respectively, over the next four decades, to ensure food security in South Asia (Gathala et al., 2013). Maize is the most versatile crop with wider adaptability in varied agro-ecologies and it has the highest- genetic yield potential among the food grain crops. As the demand for maize is growing globally due to its multiple uses for food, feed and industrial sectors, more will need to be produced from the same or fewer resources. In the post-Green Revolution era, there has been an impressive increase in the productivity of major food crops. However, these gains in productivity were possible only with the use of more and more production inputs that led to many environmental consequences including greenhouse gas (GHG) emissions. Agriculture is a major emitter of GHGs accounting for 14 percent of total anthropogenic emission (Schaffnit-chatterjee et al., 2011). Emission of GHGs occurs due to use of energy and inputs for production and also while performing different agricultural activities. Unnecessary tillage for land preparation and planting, indiscriminate irrigation and fertilizer application are the main sources of GHG emission from agricultural production systems. At the same time, agriculture is part of the solution in mitigating climate change: by both reducing GHG emission into the atmosphere and sequestering atmospheric carbon into plant biomass and soil. Therefore, agricultural production system can be either a net source- or sink- of GHGs depending on the management practices.

By adopting better agronomic and land management practices, there is a large potential to mitigate GHG emission from agriculture. For instance, (IPCC, 2007) reports that there is potential to sequester 400-800 million tons C yr^{-1} globally in agricultural soils. IPCC (2007) also documented that sustainable land management practices are appropriate methods for reducing GHG emissions from agriculture irrespective of the agro-climatic variation. Therefore, enhancing food security while contributing to climate change mitigation and preserving the natural resource base and vital ecosystem services, requires the agricultural production systems that are more productive, use inputs more efficiently, have less-variability and greater-stability in their outputs, and are more resilient to risks, shocks and long-term climate variability. More productive, emission-efficient and more resilient agriculture entails a major shift in the way the land, water, soil nutrients and genetic resources are managed to ensure that these resources are used more efficiently. Achieving this will require a holistic-systems-approach, incorporating the principles of conservation agriculture and judicious crop rotation (Balasubramanian et al., 2013). Conservation agriculture is commonly defined around a set of three principles: minimum tillage, soil surface cover, and diversified crop rotations. Conservation agriculture often results in more stable and economically favorable yield conserves soil moisture thereby adapting to water stress condition and improves soil quality. Although CA was initially promoted as agricultural practices that conserve production resources and increase agriculture sustainability, it is gradually being accepted as production system with a potential to mitigate greenhouse gas emissions as well.

Under the CGIAR research program on climate change agriculture and food security (CCAFS), CIMMYT is extensively involved in quantification of GHG mitigation potential of various production systems in South Asia using a static-chamber method. These include wheat- and maize-based cropping systems under various crop establishments, cropping sequence, residue management and nutrient management strategies in different agro-ecological conditions in IGP. The main objective of this plot-level measurement is to generate science-based evidence of mitigation potential in these production systems. The data generated from plot-level measurement will be used to calibrate and validate suits of process-based and empirical models which can then be used to quantify GHG emission at the landscape-level so as to identify the landscape-level implication of such practices. The strategy aims to influence policy through empirical evidence on landscape-level implications and analyses so that key agencies promote greenhouse gas mitigation practices with other co-benefits. This paper presents the result from one of such measurements in maize-based cropping systems.

In view of declining labor and water availability in IGP, maize-based production system could be a potential alternative to the rice-wheat system, a dominant crop rotation in the region. On-going efforts with alternative crop establishment methods and cropping systems have proved successful to boost productivity and enhance profitability. However, there is a lack of empirical science on the environmental footprint of maize-based cropping systems under various crop-establishment methods, particularly in South Asia. A long-term study, initiated in 2008, at the Directorate of Maize Research (DMR), New Delhi, evaluated the effect of maize-based cropping systems under conventional- and alternate-crop establishment techniques to measure system-productivity, economic-profitability, soil-quality and environmental-footprint. This paper presents the GHG emission and total global warming potential of Maize-Wheat-Mungbean (MWM) and Maize-Maize–*Sesbania* (MMS) cropping systems under three 'tillage and crop establishment' methods i.e. conventional tillage (CT), bed planting (BP) and no-tillage (NT).

Materials and Methods

Experimental site

The study was conducted at the Research Farm of Directorate of maize research (DMR) in New Delhi, situated at $28^{0}4'$ N latitude, $77^{0}12'$E longitude and 228.6 meters above mean-sea- level. The soil at the study site is sandy loam in texture. The study was started in 2008 and is currently in its seventh year. GHG measurement on this trial was started from August, 2012 and continued until June, 2013.

Treatments and study design

Performance of four maize-based cropping systems i.e. maize-wheat-mungbean (MWM), maize-chickpea-*Sesbania* (MCS), maize-maize–*Sesbania* (MMS) and maize-mustard-mungbean (MMM) were tested in three-tillage and crop establishment methods i.e. conventional tillage (CT), zero tillage (ZT) and permanent bed planting (PB). The treatments were laid-out in split-plot design considering tillage and crop establishment methods as the main plot factor and cropping systems as sub-plot factors, each sub-plot factor having three pseudo-replications. The size of replicated sub-plot was 10.72 m^2. For this paper we considered only two cropping systems (sub-plots) i.e. maize-wheat-mungbean (MWM) and maize-maize–*Sesbania* (MMS) under all three tillage and crop establishment methods covering a complete cropping system r (2012 to 2013).

Crop establishment and management

Irrespective of tillage and cropping system, maize was seeded in a row spacing of 67 cm. Plant-to-plant spacing was maintained at 25 and 20 cm in summer and winter crop, respectively. Summer maize was seeded in July whereas winter maize was seeded during the last week of October. The wheat crop (cv. HD 2967) was sown in November at a row spacing of 22.5 cm in the plots under CT and ZT while two rows of wheat were planted on the top of the raised beds by a spacing of 18.5 cm seed rate (100 kg ha^{-1}) for wheat. The mungbean (cv. Pusa Vishal) was sown with a row spacing of 30 cm in ZT and CT while two rows were seeded on the top of bed in PB. Seeding was done during the first two-weeks of April using a seed rate of 25 kg ha^{-1}. The maize, wheat and mungbean were sown with a multi-crop bed planter in PB, a zero-till multi-crop planter in ZT and a multi-crop planter in CT. The *Sesbania* was broadcasted (seed rate 35 kg ha^{-1}) in the field during the second two weeks of April.

In PB and ZT plots, weeds prior to seeding were killed using pre-plant application of glyphosate at the rate of 0.5 kg ha^{-1} two days before the sowing of the crops. After one or two days of sowing, maize plots were sprayed with pre-emergence herbicide Atrazine at the rate of 1.0 kg ha^{-1} to control weeds during both seasons. One-hand weeding was also done at 30 to 40 days after sowing to manage the weeds in CT maize. In the case of wheat, isoproturon (75 WP at 1 kg a.i. ha^{-1}) and 2,4-D sodium salt (80 WP at 0.5 kg a.i . ha^{-1}) was applied 35 days after sowing to control grassy- as well as broad-leaf weeds. In addition, one-hand weeding was also conducted 40 days after sowing in CT plots, whereas no weeding was required in ZT and PB expected uprooting of big weed plants. In mungbean, pendimethalin was sprayed at the rate of 1.0 kg ha^{-1} within 2–3 days after sowing.

Independent of the treatment, summer and winter maize were fertilized at the rate of 150:80:40 and 180:80:60 $N:P_2O_5:K_2O$ kg ha^{-1}, respectively, whereas the wheat crop was fertilized at the rate of 120:60:40 $N:P_2O_5:K_2O$ kg ha^{-1}. Mungbean was fertilized at the rate of 30 and 40 kg N and P_2O_5, respectively. In both maize and wheat crops, the total amount of P_2O_5 and K_2O and 33 percent of N was applied at the time of seeding as basal dose. The remaining N was applied as two equal splits: at knee- high and tasseling- stage in maize and immediately after the first- and third-irrigation in wheat. No fertilizer was applied to the *Sesbania* crop.

Crops were irrigated based on the crop water requirement and gap in rainfall during both the seasons. Accordingly, summer maize received three-irrigations, whereas both winter maize and wheat received five-irrigations during the season. Mungbean received two-irrigations and *Sesbania* required no irrigation.

GHG quantification

Gas samples were collected using two-part static chambers. The base of the chamber (43 cm i.d.) was permanently placed in the plots and removed only during field operations i.e. tillage, seeding or harvesting. The upper part of the chamber was placed over the base of the chamber at the time of sampling. Each chamber unit was painted white from the outside to serve the purpose of thermal insulation and reflective covering to minimize internal heating by solar radiation. Each chamber had a digital thermometer installed on the top for recording the chamber temperature during GHG sampling. The chamber was equipped with a battery-powered fan to facilitate mixing of the chamber headspace. All the vents and openings were sealed with adhesive to make the assembly airtight.

Sampling of air from the chamber headspace for GHG analysis was started in 9th August, 2012, after sowing summer crop. Thereafter, gas samples were collected once-a-week. Besides this regular interval, gas samples were collected for seven-consecutive days after each event that is supposed to induce emission such as fertilizer application, rainfall or tillage operation. Gas samples were collected through a septum using a 50 ml polypropylene disposable syringe with a three-way leur lock. From this syringe, 50 ml gas was injected into the pre-evacuated and labelled 30 ml vial. Injecting 50 ml gas in 30 ml vial ensures negative pressure inside the vial thus avoids contamination of air sample in the vial from ambient air. At each sampling, gas samples were collected at 0, 10, 20 and 30 minute intervals from each gas chamber. Sampling was performed during time of the day when soil surface temperature is believed to be equal to the daily average i.e. between 10:00 and 13:00. Collected samples were analyzed for GHG (N_2O and CO_2) using a Gas Chromatograph (GC) (Figure 1) equipped with Flame Ionization Detector (FID) and Electron Capture Detector (ECD). To address the issue of GC drift, GC was calibrated periodically using standards of nitrous oxide and carbon dioxide of known concentration from Linde Engineering India Pvt. Ltd.

Figure 1. Sample feeding in GC for the GHG analysis at DMR laboratory, New Delhi

Data analysis and interpretation

Gas concentration in parts per million (ppm) at each sampling (0, 10, 20 and 30 minutes after chamber deployment) were converted into mole-of-gas by using an ideal gas law-taking chamber-temperature into account. The mole unit of gas was then converted into weight of gas considering the molecular weight of that particular gas. Linear regression was performed with consideration given to sampling time as an independent variable and gas concentration as a dependent variable to calculate the rate-of-gas-emission per unit of time, to determine the flux per unit area per day. The fluxes in-between two-sampling dates were estimated by linear interpolation. The gas fluxes of all days in a crop season were summed to calculate cumulative emission during the whole crop season. The study did not detect quantifiable CH_4 emission from maize production fields and therefore only CO_2 and N_2O were used to calculate global warming potential (GWP) from soil flux. GWP was calculated using following equation:

GWP from soil flux = CO_2 emission + N_2O emission*310

Cumulative emission data was subjected to analysis of variance (ANOVA) for split-plot design using the CoStat Software (CoHort, 2012).

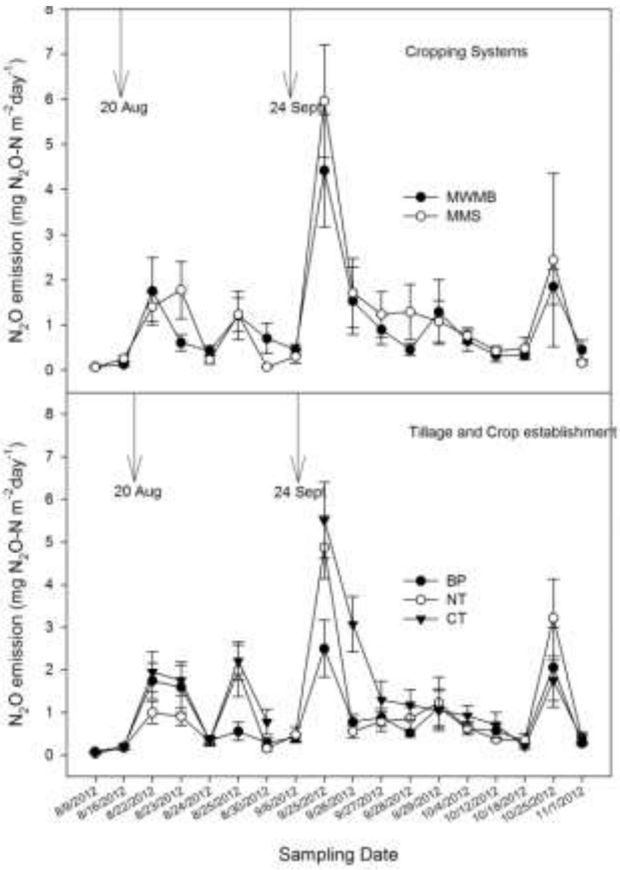

Figure. 2. Seasonal trend of N2O emission under two cropping systems (above) and three tillage/crop establishment methods (bottom) during 2012 summer maize season. Emission values in the cropping systems are averaged over three tillage/crop establishment methods and three replication (n=9) and values in tillage/crop establishment are averaged over two cropping systems and three replication (n=6). The vertical bars show the standard error of the mean.

Results and Discussion

The seasonal trend of N_2O emission was similar in two-cropping systems and in three-tillage and crop-establishment methods. Irrespective of tillage- and crop- establishment as well as cropping system, fertilizer application clearly induced N_2O emissions particularly when the fertilizer application coincided with sufficient moisture in the field (Figure 2). The same trend was observed during the 2012 to 2013 *Rabi* season i.e. no apparent difference between the cropping systems as well as among tillage and crop/establishment methods but a clear N_2O peak after each fertilization event.

Irrespective of cropping systems, cumulative CO_2 emissions in the summer maize season were significantly higher in CT and BP than NT. Cumulative CO_2 emissions during the summer maize growing season was about 2.75 Mg CO_2-C ha^{-1} under CT and BP while it was 2.41 Mg CO_2-C ha^{-1} under NT (Figure 3). Similarly, cumulative N_2O emission during the same season was 0.84, 0.55 and 0.50 kg N_2O-N ha^{-1} under CT, NT and BP, respectively. Cumulative CO_2 and N_2O emission was not significantly different among the tillage systems and between cropping systems (during the winter and spring crop seasons). As in summer season, cumulative CO_2 emissions during winter and spring crop seasons were also higher in CT and BP (about 11.5 Mg CO_2-C per ha) than in NT (8.5 Mg CO_2-C per ha). Similarly, both CO_2 and N_2O emissions were not significantly different among cropping systems and crop establishment methods at the system level, except the effect of tillage/crop establishment to the total cumulative N_2O emission (Table 1). Our results show that the N_2O emission during the crop cycle, ranges from 0.5 percent to 1.2 percent of applied nitrogen fertilizer. The system level global warming potential based on soil flux (without considering photosynthetic uptake) in our study, ranged from 33 to 69 Mg CO_2-eq ha^{-1}with no significant difference among tillage/crop establishment methods and between the two-cropping systems.

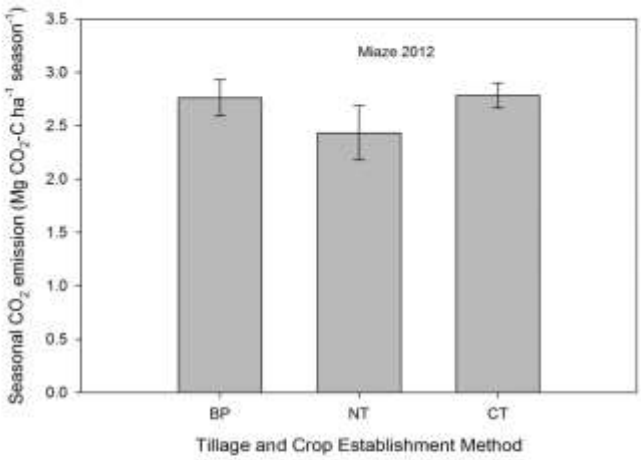

Figure 3. Cumulative CO2-C emission during 2012 summer maize season as affected by different tillage and crop establishment practices. The vertical bar is the standard error of the mean.

Table 1. System level cumulative emission of CO_2, N_2O and total global warming potential under different tillage/crop establishment methods and cropping systems. CT=conventional tillage, BP=bed planting, NT=No tillage, MWMB =maize-wheat-mungbean, MMS=maize-maize-*sesbania*

Tillage and Crop Establishment method	Cropping Systems		Tillage/crop establishment mean
	MWMB	MMS	
	System level cumulative CO_2 emission (Mg CO_2-C ha^{-1})		
CT	15.10	12.66	13.88
BP	16.40	10.68	13.54
NT	10.81	11.07	10.94
Cropping System mean	**14.10**	**11.47**	
	System level cumulative N_2O emission (kg N_2O-N ha^{-1})		
CT	1.44	1.32	1.38a
BP	0.78	1.18	0.98b
NT	1.06	1.09	1.08b
Cropping System mean	**1.09**	**1.20**	
	System level global warming potential (Mg CO_2-eq ha^{-1})		
CT	56.06	47.07	51.56
BP	60.51	39.75	50.13
NT	40.17	41.11	40.64
Cropping System mean	**52.25**	**42.64**	

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