Yield and soil nitrous oxide emissions of *Vigna radiata* under contrasting fertilizer management practices in Maharashtra, India

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29 Sep. 2017

Rationale

The *Soil Protection and Rehabilitation for Food Security* global program, commissioned by the German Federal Ministry for Economic Cooperation and Development (BMZ) and implemented by GIZ and partners in Benin, Burkina Faso, Ethiopia, India and Kenya, addresses the issue of soil degradation and loss of productivity and its impact on smallholder livelihoods. The primary goal – as the program title implies – is to support and promote the immediate function that protected, fertile soils play in terms of providing and sustaining food security. In addition improved agricultural management practices may have a role to play in terms of climate change mitigation. Besides increased *productivity* and climate change *resilience*, *mitigation* is the third pillar of climate smart agriculture (CSA). To assess the climate smartness of selected GIZ-supported soil protection and rehabilitation measures in the five countries, GIZ engaged CIAT scientists in the project *Climate-smart soil protection and rehabilitation in Benin, Burkina Faso, Ethiopia, India and Kenya*, which builds on CIAT's expertise in both soil science and CSA.

As part of the *Soil Protection and Rehabilitation for Food Security* project, various improved soil and agronomic management practices where tested in the State of Maharashtra in India by experts of the *Watershed Organization Trust, WOTR*. A sub-set of these practices were assessed in detail in terms of their climate smartness and results summarized in a CIAT report (Birnholz et al. 2017a). The climate smartness assessment included a quantification of greenhouse gas (GHG) emissions using IPCC Tier-1 and Tier-2 empirical equations applying the *Kalkulator*; a Microsoft Excel based spreadsheet tool (Birnholz et al. 2017b). In addition, exemplarily, emissions of nitrous oxide (N_2O) – a very potent GHG – from soils were measured *in-situ* in an on-farm agronomic field trial. Here, green gram (*Vigna radiata*; also known as mung bean) was exposed to contrasting fertilizer management practices. This brief report summarizes major findings, focusing on the agronomic performance (yield) and N_2O emissions.

Material and Methods

Study area

The study area is located in Parner block of Ahmednagar district, Maharashtra. The experimental project site is located near Bhalwani village (19.113157 °N and 74.550047 °E). The villages in Parner block are characterized by hot summers and a generally dry climate except during the south-west monsoon season. The study area falls in the semi-arid region of Ahmednagar district. The southwest monsoon is the major source of annual precipitation which generally starts the 2nd-3rd week of June and last until October – the *kharif* season. The region also receives some (return monsoon) rainfall from mid-October to November during the *rabi* season. The annual rainfall ranges between 500 and 600 mm.

Most of the soils in the study region are shallow to medium with some patches of deep black soil. Farmers in the region are reporting problems associated with soil erosion, salinity and alkalinity which result in low agricultural yields in the region. Green gram and pearl millet are the major crops grown in the kharif season while onion, wheat and sorghum are the major crops of the rabi season. Use of chemical fertilizers is common in the region, and increasingly pesticides are also applied.

Considering all these issues, with the support of German Federal Ministry for Economic Cooperation and Development (BMZ) under the "One World, No Hunger" initiative Watershed Organization Trust (WOTR) is undertaking the program on 'Soil protection and rehabilitation for food security' in selected villages of Maharashtra. The current study was undertaken to assess the various ongoing agricultural practices and their impacts on agricultural productivity and climate change.

Agronomic management

The experimental plots fall into the 'hot semi-arid eco region with shallow and medium (dominant) black soils'. A detailed analysis of the soil from the experimental plots showed that the soil texture is clay (67 % clay, 16 % sand and 17 % silt), with a bulk density of about 1.26 g/cm^3 and a particle density of 2.72 g/cm^3. Detailed information on soil properties from the experimental plots are given below (Table 1).

Table 1: Chemical properties of the top soil (0–15 cm depth) of the study site

pH (-)	**EC (dS/m)**	**OC (g/100 g)**	**Available N (kg/ha)**	**Available P_2O_5 (kg/ha)**	**Available K_2O (kg/ha)**
8.53	0.28	0.87	243	10	321

Nitrogen was measured by alkaline permanganate method, P_2O_5 by Olsen's method and K_2O by ammonium acetate extraction.

In total, 5 main treatments and 2 sub-treatments with 3 replications (30 plots in total) were installed to assess the impact of different agricultural practices on agronomic performance and GHG emissions.

Main Treatments were – see Table 2 for exact amounts of nutrients applied:

1) Farmer's Practice – The plots under this treatment were managed as per the current farmer's practice in the region, with the same fertilizer source and crop protection treatments as being applied by local farmers, if any (generally farmers go with chemical measures if the infestation is very high for low/limited infestation no prevention/curative actions are followed).
2) Chemical Fertilizer – The plots under this treatment received 100 % of the recommended dose of chemical fertilizer.
3) Integrated Nutrient Management (INM) – the plots under this treatment received 50 % of the recommended amount of chemical fertilizer and remaining 50% were added in the form of vermi-compost.
4) Organic – The plots under this treatment received 100 % of the recommended rate of fertilizer in the form of vermi-compost.
5) Controlled Treatment – No fertilizer was added to the plots under this treatment.

Sub Treatments were:

A) Seeds without treatment – Good quality seeds were used together with standard sowing practices.

B) <u>Seeds with treatment</u> – Seeds were treated with bio-fertilizers (*Rhizobium* and *Phosphate Solubilizing Bacteria,* PSB) prior to sowing.

Table 2: Amount of nitrogen and phosphate applied to the various main treatments

Treatment\Fertilizer		20:20:0	DAP	Urea	Vermi-compost	SUM
				Elemental N (kg/ha)		
T1	Farmer Practice	25	0	0	0	**25**
T2	Chem. Fertilizer	0	15.8	9.4	0	**25**
T3	INM – 50 % Chem., 50 % Organic	0	7.9	4.7	12.5	**25**
T4	Organic Fertilizer	0	0	0	25	**25**
T5	No Fertilizer	0	0	0	0	**0**
				Elemental P (kg/ha)		
T1	Farmer Practice	11.0	0	0	0	**11.0**
T2	Chem. Fertilizer	0	17.6	0	0	**18**
T3	INM – 50 % Chem., 50 % Organic	0	8.8	0	2.5	**11**
T4	Organic Fertilizer	0	0	0	5	**5**
T5	No Fertilizer	0	0	0	0	**0**

Plant protection measures were implemented as required during crop growth. Therefore, *Dashparni ark* (5 %) and *NSKE* was applied to the plots managed organically. The bio-pesticide *Dashparni Ark* is produced by mixing of ten types of locally available plant leaves: Neem, Lantana camera, pongamia, pinnata, thevatia, peruviana, jatropho or castor, tinospora cordifolia, custard apple, cow urine and cow dung, while *NSKE* is made up of powder of neem seed, cow dung, cow urine, jaggery and costic soda (http://agritech.tnau.ac.in/org_farm/orgfarm_ofk_pltprotection.html). The farmer practice plots and the chemical-only fertilizer plots were managed with recommended/permitted commercial chemical products to protect plants from pests or diseases. The control treatment had no such interventions.

N_2O measurements and flux calculations

A low cost static chamber method was used to measure the GHG fluxes from the agricultural field (Figure 1). The design of chambers and the sampling technique followed closely the guidelines published by the International Maize and Wheat Improvement Center, CIMMYT, and the Indian Council of Agricultural Research (Sapkota *et al.*, 2014). Gas samples for the determination of soil nitrous oxide (N_2O) emissions from all plots were taken 14 times during the season, namely 0, 1, 2, 3, 4, 5, 11, 18, 25, 32, 38, 46, 53 and 60 days after planting. Samples were taken 0, 15, 30 and 45 min after the top of the chamber was mounted using a syringe, and samples were then transferred into evacuated glass vials. To avoid diurnal variations, the sampling start time was fixed to 10:30 in the morning. In total, five skilled persons were involved in the data collection from the 30 experimental plots. Along with the GHG gas sample collection some environmental parameters, namely soil temperature, temperature of ambient air and temperature of the air inside the static chamber was manually recorded, along with weather data from an automatic weather station installed by WOTR within the vicinity of the site.

Figure 1. GHG sample collection from agricultural plots at Bhalawani, Ahmednagar, Maharashtra

Samples were analysed for N_2O with a gas chromatograph at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) lab in Hyderabad. The N_2O flux is calculated from the linear increase of concentration inside the chamber over time applying the ideal gas law:

$$F = \frac{\Delta c * M * p * h}{R * T} \qquad \text{eq. 1}$$

where F is the gas flux(µg N/m^2/min), Δc (ppb/min) is the slope of the linear regression fitted to the increase in gas volumetric concentration measured over the 45 min, M is the molar weight of the gas (kg/kmol), p is the atmospheric air pressure (bar) measured with a barometer at day of sampling, h is the total chamber height (m), R is the ideal gas constant equal 0.08314 (m^3 bar/ kmol/K) and T is the air temperature (K) inside the chamber. As the chambers used in this study had a slight conical shape, the chamber height (1.02 m) had to be multiplied by a correction factor (0.91) to account for this none-cylindrical shape.

Statistical analysis

A two-way ANOVA (split-plot design) was carried out to detect whether fertilizer application and inoculation had a significant impact on yields.

To be able to calculate cumulative seasonal emissions, N_2O fluxes in-between days of measurements were estimated by linear interpolation.

We carried out a t-test of the slope of the linear regression, Δc, i.e. to test whether this was significantly significant from zero, and calculated the upper and lower 95 %-confidence of the slope.

We also tested whether fertilizer or inoculation had a significant impact on observed N_2O fluxes by two-way ANOVA using observation days as reps.

Results and Discussion

Yield

Green gram yields ranged between 0.72 and 1.20 t/ha (Figure 2). The ANOVA revealed that both, fertilizer application and inoculation, had a significant impact on yields (see also Appendix Table A 1). Not surprisingly, yields were lowest if no fertilizer was applied. But, farmer practice plots, even though fertilized, also achieved low yields; not any different from the unfertilized control. Highest yields were achieved when inorganic and organic fertilizer was applied together, or when only organic fertilizer was applied. These were also the only cases where inoculation with rhizobia and PSB significantly increased yields above treatments where inoculation was absent.

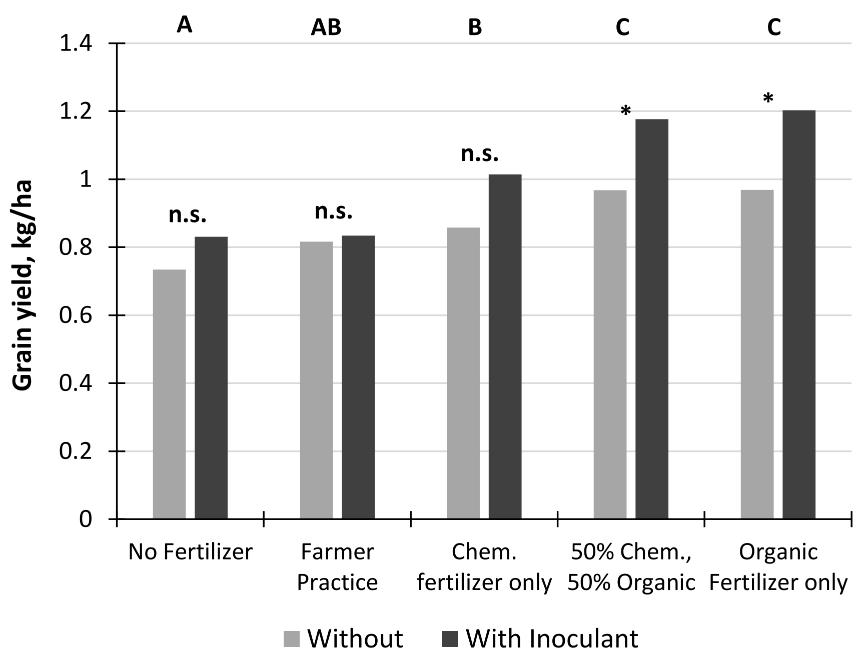

Figure 2: Yield of green gram in response to the application of various levels of inorganic and organic fertilizer and inoculation with rhizobia and phosphate solubilizing bacteria (PSB). Different letters (top of the graph) indicate significant differences between yields owing to fertilizer application, while asterisks directly above bars denote a significant impact of inoculation.

The positive response of green gram to the application of vermi-compost – either alone or in addition to mineral fertilizer – is very encouraging. On the one hand, this shows that soil fertility and health can be improved (short-term) by addition of organic biomass, and that chemical fertilizer alone does not – or no longer – provide this. On the other hand, as most farmers in the region are mixed crop-livestock enterprises and therefore manure is readily available, the production of vermi-compost is a viable strategy to significantly reduce production costs by either completely eliminating the financial expenses for mineral fertilizer, or reducing these expenses significantly (50 % in our case).

The boost in yields by approximately 20 % in response to the use of inoculants at higher yield levels / agronomic performance is likewise promising. We assume – but cannot be entirely sure – that this boost is indeed a combined effect of more efficient biological nitrogen fixation through inoculation with rhizobia and the better availability of phosphate to plants by PSB, which only becomes visible when plant growth and nutrient uptake surpasses a level where the added amounts of N and P, or those residual in the soil from the application of mineral fertilizer in the past, are no longer sufficient to satisfy crop demand. Therefore, rhizobia and PSB inoculations constitutes a smart way of improving agricultural productivity of green gram without increasing the risk of eutrophication of water bodies by excessive use of chemical fertilizers.

N_2O emissions

N_2O fluxes measured *in-situ* in most of the cases were negative (Figure 3). In other words, the soil in this experiment largely constituted a sink for N_2O. Only in one occasion, 11 days after planting (7 July), were the majority of fluxes (8 out of 10) positive. There was no clear seasonable trend visible in any of the treatments.

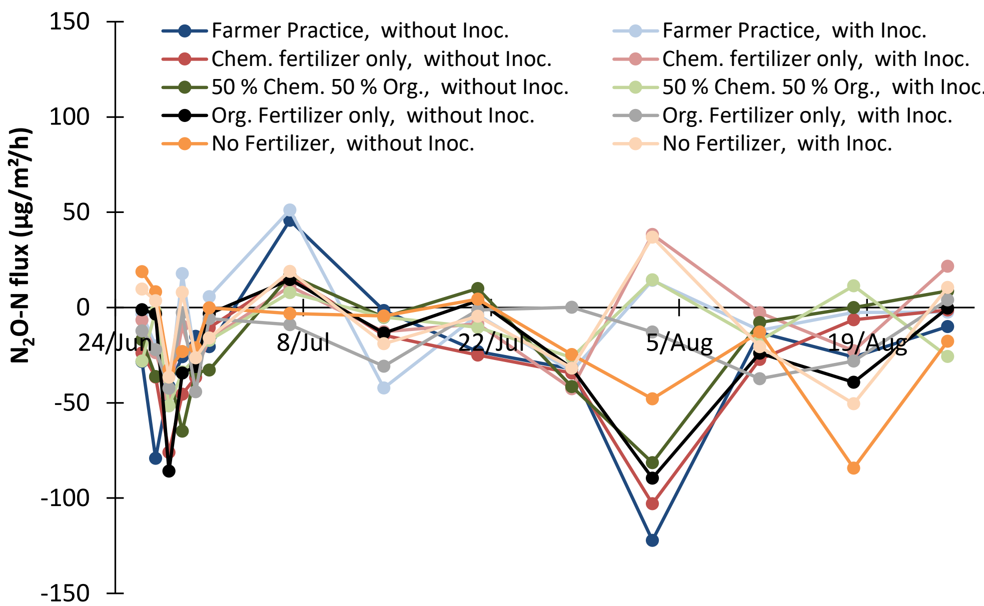

Figure 3: Seasonal measured N_2O fluxes of the various fertilizer treatments

However, fluxes were small altogether, and it could not be ruled out in the majority of cases that the measured increase or decrease of N_2O concentration in the chambers over the 45 minutes of closure where significant, i.e. the slope of the linear regression significantly different from zero (see Appendix Figure A 1). Significant fluxes were detected only in 13 instances, and in all of the cases these were negative (Table 3).

Table 3: Dates and treatments with N_2O fluxes significantly different from zero

DAP	Date	Treatment	Inoculant	N2O Flux (µg/m²/h)
1	27/Jun	50 % Chemical 50 % Organic	Without	-36
2	28/Jun	Farmer Practice	With	-45
2	28/Jun	Chem. fertilizer only	Without	-76
2	28/Jun	Organic Fertilizer only	Without	-86
4	30/Jun	Chem. fertilizer only	Without	-37
5	1/Jul	50 % Chemical 50 % Organic	Without	-33
18	14/Jul	Organic Fertilizer only	With	-31
25	21/Jul	Chem. fertilizer only	Without	-25
32	28/Jul	Farmer Practice	With	-34
46	11/Aug	Farmer Practice	Without	-13
46	11/Aug	50 % Chemical 50 % Organic	With	-17
46	11/Aug	Organic Fertilizer only	Without	-24
53	18/Aug	No Fertilizer	With	-51

Inoculation, but not fertilizer application, significantly increase fluxes – either reducing the N_2O soil sink strength or actually generating (positive) N_2O emissions (ANOVA in the Appendix,

Table A 2).

Cumulative seasonal fluxes estimated by linear interpolation of mean observed fluxes for days without actual measurement, yielded negative total N_2O emissions in all 10 cases (Figure 4).

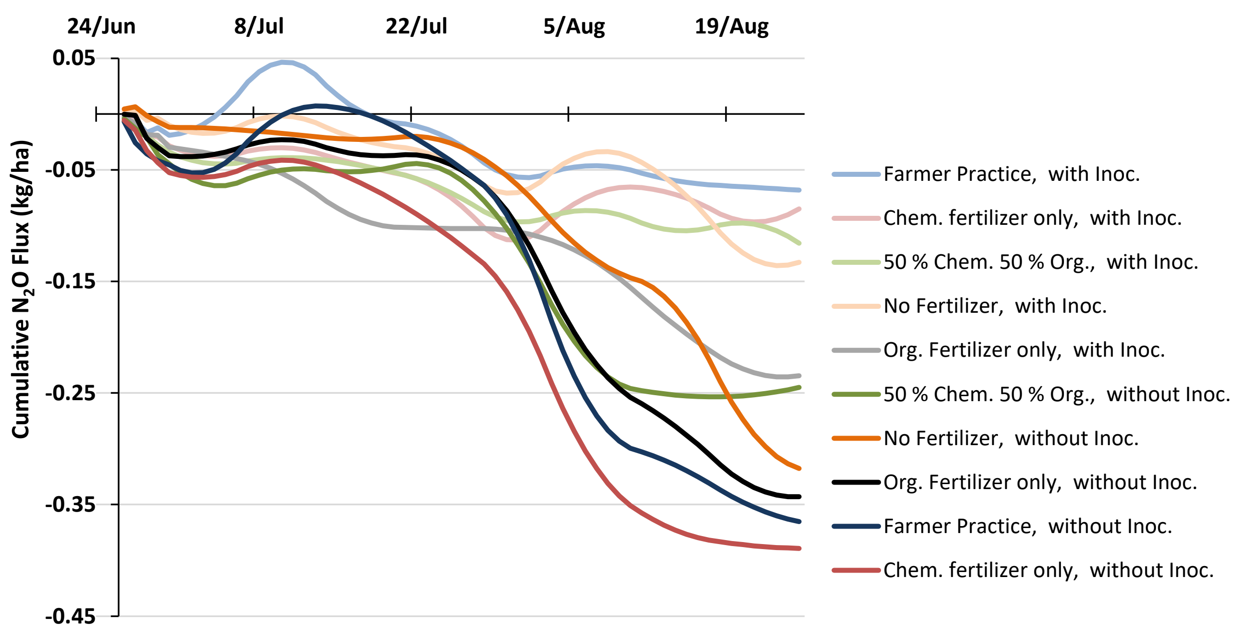

Figure 4: Cumulative N_2O fluxes of the various tested fertilizer treatments

Following the trend outlined above, cumulative N_2O fluxes of the inoculated treatments were higher ("less negative") than fluxes of those without inoculation.

Over the observed 60 days, total N_2O sinks however were very low ranging between -0.07 (farmer practice with inoculation) and -0.39 kg N_2O-N/ha (chemical fertilizer only, without inoculation; Table 4).

Table 4: Seasonal N_2O emissions of the 10 treatments

Treatment	Inoculant	Cumulative N_2O Flux	
		(kg N/ha/60 d)	(kg CO_2e/ha/60 d)
Farmer Practice	Without	-0.37	-109
	With	-0.07	-20
Chem. fertilizer only	Without	-0.39	-116
	With	-0.09	-25
50 % Chem. 50 % Org.	Without	-0.25	-73
	With	-0.12	-35
Org. Fertilizer only	Without	-0.34	-102
	With	-0.23	-70
No Fertilizer	Without	-0.32	-95
	With	-0.13	-40

Converted into carbon dioxide emission equivalents (CO_2e) – whereas N_2O is 298 times more potent than CO_2 over a 100 year time horizon – the mitigation potential did not surpass 116 kg CO_2e/ha/60 d.

Observed negative fluxes of N_2O were a big surprise, as most studies and publications report emissions rather than sinks, such as for instance for India in rice-wheat systems in the Punjab (Sapkota *et al*., 2017). However, some reports about soils as N_2O sinks have been published, and a review of studies was provided by Chapuis-Lardy *et al.* (2007). They report that "such fluxes are frequent and substantial and cannot simply be dismissed as experimental noise". Even though in our case such experimental noise (fluxes not significant) was abundant, still days and treatments with significant negative fluxes could be identified. Low mineral N in the soil and high soil moisture contents are discussed to favour soil microbes "consuming" N_2O. While the first seems unlikely in our soils given years of application of significant amounts of N-fertilizers to these soils (even more so to non-legume crops), the latter could be a reason for negative fluxes. Under high soil moisture oxygen is becoming quickly scarce. This in turns triggers microbial denitrification of nitrate, where N_2O is an intermediary product (which then can "leak") before complete denitrification where such N_2O is then further reduced to N_2. It has been further hypothesized that soils that provide for only low diffusion of gases seem to enhance N_2O consumption in the soil before leakage, which may apply to our high-clay soil as well. However, as noted earlier "factors regulating N_2O consumption are not yet well understood and merit further study" Chapuis-Lardy *et al.*, (2007).

As our research shows, application of rhizobia and PSB seem to reduce the soil's capacity to consume N_2O even though very little only, which, if proven consistent, would constitute a slight trade-off of the otherwise beneficial effect of such inoculations. However our cumulative emission rather insignificant (negative or positive) altogether.

Conclusions

The observed significant yield increase (+~50 %) of green gram in response to the application of vermi-compost underlines that such agronomic management strategy merits promotion by GIZ and partners in India, and that this technology should also be tested in other countries. Further efficiency and productivity gains could be proven for the vermi-compost treatments when green gram seeds were inoculated with rhizobia and phosphate solubilized bacteria (PSB). Such positive impact of both technologies was achieved without (in the case of vermi-compost), or only a humble increase (inoculants) in N_2O emissions. In fact, the studied soil turned out to be a net sinks for N_2O, even though altogether very little. This means that green gram production in Maharashtra with vermi-compost and inoculation is a climate smart management practice. Further studies should investigate the long-term trends of these improved practices on soil organic carbon contents and carbon dynamics, with the aim to answer the question whether these soils are losing or sequestering carbon and what the importance of such losses or gains are.

Acknowledgement

The training of WOTR staff on GHG sampling provided by CIMMYT scientists Drs. Hanuman Jat, Tek Bahadur Sapkota, Mangi Lal Jat and Balwinder Singh is highly appreciated. We also acknowledge the analysis support given by the team of Dr. Anthony Whitbread at ICRISAT, namely Kumar Mahender, Jana Kholova, and Pradiptaranjan Pradhan, as well the expert feedback on N_2O emissions by Dr. David Rowlings from Queensland University of Technology. We are grateful for funding for this study from BMZ/GIZ. The study is part of the CGIAR Research Program on Water, Land and Ecosystems, WLE.

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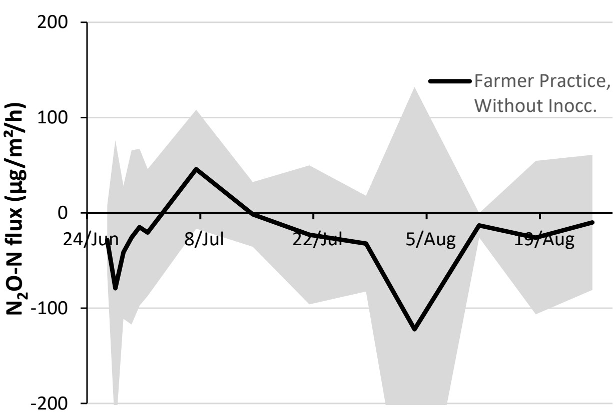
Annex

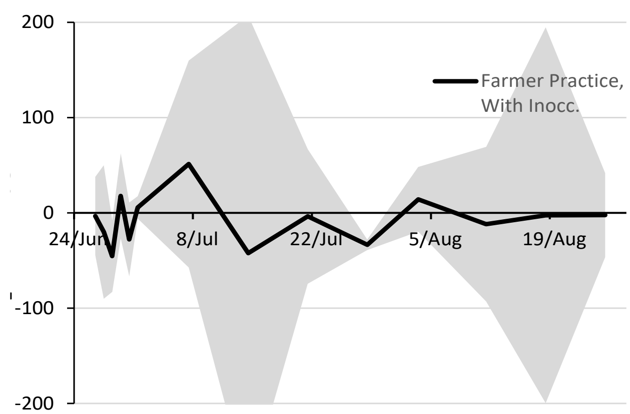
Table A 1: Analysis of variance of green gram yields; *Fertilizer* as the main treatment and *Inoculant* as split-plots

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	2	13299	6650	0.83	
Rep.Fertilizer stratum					
Fertilizer	4	460882	115220	14.38	0.001
Residual	8	64083	8010	0.39	
Rep.Fertilizer.Inoculant stratum					
Inoculant	1	153262	153262	7.4	0.022
Fertilizer.Inoculant	4	45626	11406	0.55	0.703
Residual	10	207003	20700		
Total	29	944154			

Table A 2: Two-way analysis of variance of the impact of Fertilizer and Inoculation on observed N_2O fluxes; measurement days as reps (N=14)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Fertilizer	4	951.3	237.8	0.34	0.85
Inoculation	1	4516.3	4516.3	6.48	0.012
Fertilizer.Inoculation	4	2034.8	508.7	0.73	0.573
Residual	130	90659	697.4		
Total	139	98162			





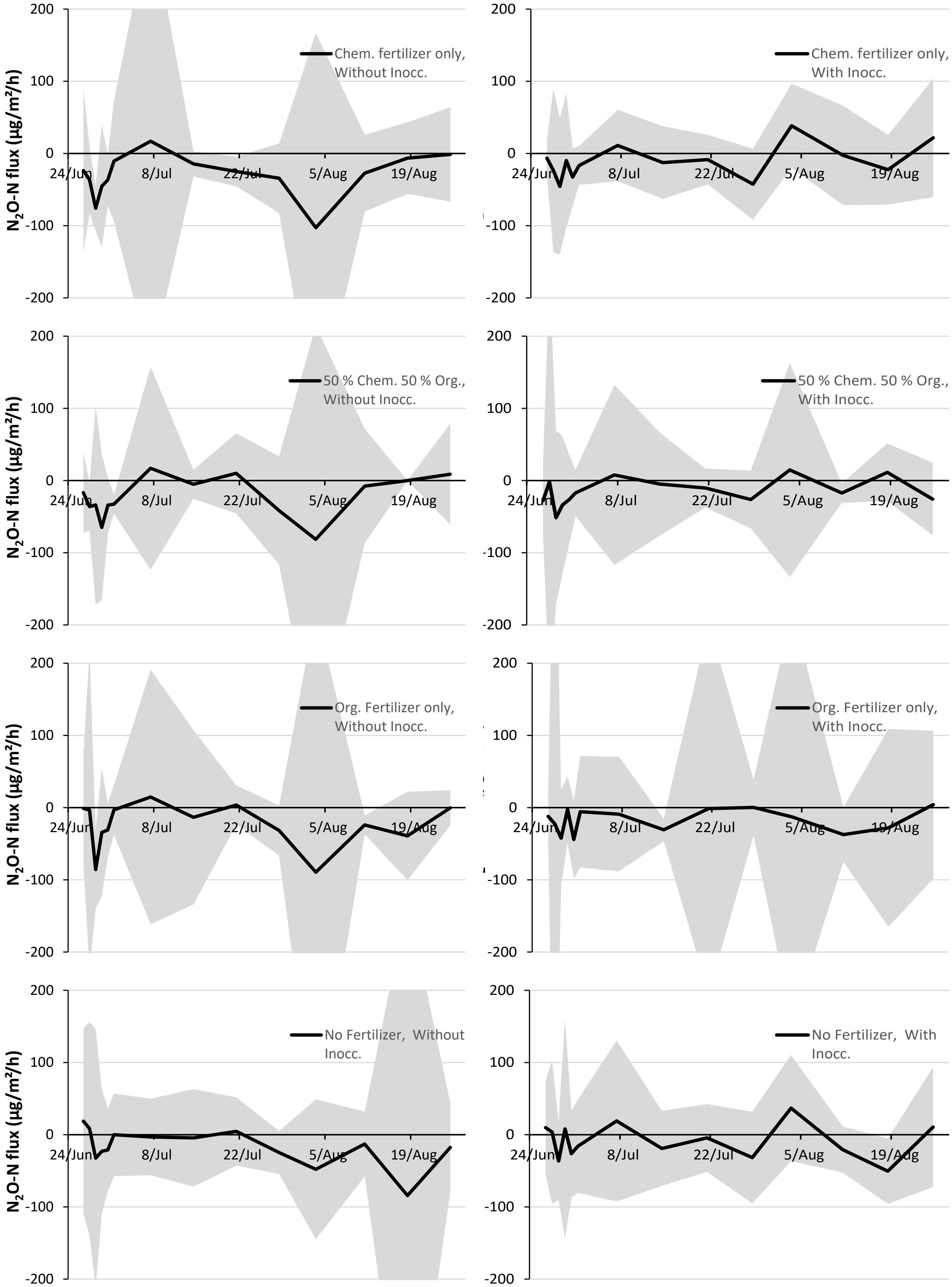


Figure A 1: Individual graphs of N_2O fluxes (thick lines) and 5-95% confidence interval (grey-shaded areas)