EFFECT OF IRRIGATION AND FERTILIZATION ON METHANE AND CARBON DIOXIDE EMISSIONS FROM PADDY SOIL DURING THE SEEDLING STAGE IN NE SPAIN

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1. Introduction

Methane (CH_4) and carbon dioxide (CO_2) are the most important greenhouse gases (GHGs), respectively contributing 15% and 60% to the anthropogenic greenhouse effect. Rice paddy is an important source of atmospheric CH_4, about 50 to 100 Tg yr^{-1}, accounting for 10%-20% of the total CH_4 emissions (IPCC 2007). Many measurements and models have focused on CH_4 and CO_2 emissions from rice paddies (Sampanpanish 2012; Li et al. 2013), but information from Spanish environments has lacked behind. The rice seedling stage (the first 35 days after sowing) significantly contributes to CH_4 and CO_2 emissions from rice paddies (Sampanpanish 2012). In China rice seedlings are cultivated in a separate paddy nursery under intensive management for approximately 1 month and transplanted to a paddy field, while in Spain rice is sown directly on site and flooded. Environmental factors, irrigation regime and fertilizer management are determinant factors of CH_4 and CO_2 emissions (Li et al. 2013). The main objectives of this study are to evaluate the effect of different irrigation regimes and different rates of mineral and organic fertilizers on CH_4 and CO_2 emissions during the seedling stage.

2. Materials and methods

Field trials were carried out in 2011 and 2012 on 3 experimental fields at 2 different sites. Treatments were (Table 1): (I) irrigation frequency (continuous irrigation –CI- and intermittent irrigation –II-) in 2011 at Amposta-1; (II) 4 doses of chicken manure (9.5, 19.1, 15.2, and 28.7 t ha^{-1}), mineral fertilizer (150 kg N ha^{-1}) and control in 2011 and 2012 at Amposta-2; (III) 2 doses of pig slurry (30 and 50 m^3 ha^{-1}), mineral fertilizer (120 kg N ha^{-1}) and control, in 2012 at Alcolea de Cinca. Rice (*Oryza sativa* L.*)*, cv. *Gleva* at Amposta-1 and -2 (150 kg seed ha^{-1}) and cv. *Guadiamar* at Alcolea (170 kg seed ha^{-1}) was sown directly on site and flooded. The fluxes of CH_4 and CO_2 were sampled weekly from sowing to harvest using the semi-static closed chamber method. Samples of air inside the chambers were withdrawn in duplicate by adapted plastic 100 ml syringes. CH_4 and CO_2 were quantified using the photoacoustic technique (Innova Multi-gas Photoacoustic Monitor 1412). Soil temperature and soil Eh were recorded on site. Soil water content was used to estimate water filled pore space (WFPS).

3. Results and discussion

At Amposta-1, the dynamics of CH_4 emission for both treatments was similar during the seedling stage of rice. CH_4 emissions were not significantly affected by irrigation type nor by soil temperature. The negative cumulative emissions of CH_4 (soil acts as a sink) (Table 1) in both treatments may be due to soil salinity (measured in the soil saturated paste extract) and to a high soil SO_4^{-2} content (not measured) according to Datta et al. (2013).
Intermittent irrigation during the rice seedling stage significantly increased CO_2 emission compared to CI. The cumulative CO_2 emissions in the II treatment during the rice seedling stage represent more than 45% of the cumulative CO_2 emissions of the whole crop season, while in CI only the 23% (Table 1). The present study made it clear how flooding and drainage affect CO_2 emissions at rice paddies in the short term.
At Amposta-2, the fertilizer treatments had a significant effect on CH_4 emissions in both years. In the control and mineral fertilizer treatment the soil acts as a sink for CH_4 (Table 1). In the same

way as in Amposta-1, soil salinity and the high SO_4^{-2} content of soil explain CH_4 emission inhibition. The SO_4^{-2} reducing bacteria and the methanogenic bacteria compete for the same substrate, since C mineralization through SO_4^{-2} reduction is higher than that of CH_4 production (Datta et al. 2013). In both years, CH_4 emissions were significantly ($P<0.05$) affected by the amount and type of fertilizer applied (Table 1). In 2011, CH_4 emission increased when increasing the rate of chicken manure applied, while in 2012 decreased (Table 1). Probably the highest dose applied (29 t ha^{-1}) might have caused a saturation effect for the production and release of CH_4, so that this increase in organic fertilizer rate has not further increased CH_4 emission.

In 2011, though not significative, the addition of fertilizer increased CO_2 emission rates. This may need further study. The plots with chemical fertilizer emitted more CO_2 than the plots with organic fertilizer, because applying mineral fertilizer increases soil density (Sampanpanish, 2012), while the application of organic one decreases it (Karami et al. 2012).

In 2012, the effect of fertilization was not significant (Table 1). Both years, the same effect as with CH_4 was observed: increasing chicken manure dose increased CO_2 emission up to a point; at the highest tested dose emission remained constant or decreased. The organic compounds applied with the fertilizer react with soil particles to form complexes that are hardly decomposed into CO_2 (Sampanpanish, 2012). The slow decomposition of organic compounds may be inhibiting enzymatic microbial activity (Cheng, 1999). The highest dose of manure may also have temporarily disrupted microbial activity.

Table 1. Average cumulative CH_4 and CO_2 emissions from paddy soil during the seedling stage per site, year, and treatment plus minus the standard error. Percentage from the CO_2 emitted during the whole rice growth that the cumulative losses of CO_2 during the seedling stage represent. Different letters in a column mean significant differences at $\alpha=0.05$ level. Negative values of CH_4 mean that soil acts as a sink.

Site and year	Irrigation type/ N applied (kg ha^{-1})	CH_4 (kg ha^{-1})	CO_2 (kg ha^{-1})	% CO_2 of the whole crop season emission
Amposta-1 (2011)	CI	-2.07±0.2a	1167.49±233.08b	23
	II	-5.29±0.38a	4077.24±310.61a	49
Amposta-2 (2011)	0 kg N ha^{-1}	-2.37±0.51c	167.67±8.36b	20
	150 kg N ha^{-1} (urea)	-0.64±0.04c	418.88±36.18a	39
	170 kg N ha^{-1} (9.5 t chicken manure)	9.35±0.24ab	238.71±31.02b	23
	340 kg N ha^{-1} (19.1 t chicken manure)	29.62±0.71a	257.11±8.6b	18
Amposta-2 (2012)	0 kg N ha^{-1}	-44.82±7.98c	871.23±158.33a	8
	150 kg N ha^{-1} (urea)	-19.91±0.76c	1290.72±253.23a	13
	425 kg N ha^{-1} (15.2 t chicken manure)	169.91±31.14a	1257.76±81.24a	25
	803 kg N ha^{-1} (28.7 t chicken manure)	48.16±4.66b	1492.35±37.36a	16
Alcolea (2012)	0 kg N ha^{-1}	60.71±3.47a	122.34±4.96a	2
	120 kg $(NH_4)_2SO_4$-N ha^{-1}	73.65±5.61a	114.30±37.78a	1.1
	120 kg N ha^{-1} (30 t pig slurry)	39.81±2.33b	190.14±18.87a	2.3
	170 kg N ha^{-1} (50 t pig slurry)	65.04±6.77a	197.14±54.87a	2.3

At Alcolea de Cinca, CH_4 emission appeared shortly after sowing in all the treatments, probably due to mineralization of native or added organic matter. There was no significant difference between CH_4 emission from the mineral fertilizer treatment and 50 t pig slurry ha^{-1} (Table 1). This result can be explained because the dry matter content of slurry was low and consequently, this very liquid slurry was able to infiltrate and interact with soil microorganisms and be affected by soil conditions, e.g. aeration/moisture status (Chadwick and Pain, 1997).

The highest CO_2 emission occurred with pig slurry addition. Increasing the dose of pig slurry increased emission, due to the input of additional available C substrates to the soil. Mineral fertilizer did not increase emission with respect to the control (Table 1) probably because fertilizer was applied as a sulphate.
There was CH_4 emission during the seedling stage of rice (35 days) in all the experimental fields, though in most of them the whole rice crop resulted in soil acting as a sink of CH_4 (negative cumulative whole crop emission). This result is in accordance with Chinese results, where approximately 75% of the CH_4 emissions of the whole crop occurred during the rice seedling stage (40 days) (Ma et al. 2011; Wang et al. 2013).

4. Conclusions

Intermittent irrigation significantly increases CO_2 emissions compared with CI, but has no effect on CH_4 emissions. Soil salinity and high soil SO_4^{-2} inhibit CH_4 flux (soil acts as a sink). Mineral fertilization may increase soil density and therefore increase CO_2 emission with respect to no fertilization or organic fertilization. High doses of chicken manure do not increase CH_4 or CO_2 emission. CO_2 emissions tend to increase with increasing doses of pig slurry

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