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Reduction of Global Warming Potential from rice under alternate wetting and drying practice in a sandy soil of northern Italy

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Abstract: *Methane (CH_4) is the dominant greenhouse gas (GHG) implicated in global warming from paddy fields, with emissions largely controlled by water and residue management practices. The permanent flooding-based conventional cultivation system is an important anthropogenic source of atmospheric CH_4. However, rice fields also emit N_2O, especially in relation to N fertilization, and N_2O emissions tend to increase when management practices are implemented to reduce CH_4 emissions, through the use of alternate wetting and drying (AWD). Reducing CH_4 and N_2O emissions from rice cropping systems with less water input without compromising the grain yield is a challenge that requires a better understanding of the key processes involved, in particular under Mediterranean pedo-climatic conditions. This work aimed to assess the effect of AWD application on CH_4 and N_2O emissions, global warming potential (GWP) and grain yield in selected Italian rice fields. The GWP was larger under permanent flooding (PF) than AWD both during the whole growing season and the flooding period. However, a significant yield decrease was observed under AWD system, suggesting that site specific management options should be carefully planned taking into account the main drivers affecting mitigation potential under AWD water-saving rice production.*
Keywords: *CH_4 emissions, N_2O emissions, alternate wetting drying (AWD), paddy fields, mitigation.*

Riassunto: *Il metano (CH_4) è il principale gas serra (GHG) implicato nel riscaldamento globale prodotto dalle risaie. Le emissioni di CH_4 sono fortemente controllate dalla gestione idrica ed il sistema di coltivazione convenzionale basato sulla sommersione permanente delle risaie è un' importante fonte antropogenica di CH_4 emesso in atmosfera su scala mondiale. Le risaie costituiscono anche un'importante fonte di emissione di protossido di azoto (N_2O), in particolare in relazione alla fertilizzazione azotata. Le emissioni di N_2O tendono ad aumentare con l'applicazione di metodi implementati per la riduzione del CH_4, quali ad esempio i cicli alternati di sommersione ed asciutta (AWD). Una migliore comprensione dei processi coinvolti nei flussi di CH_4 e N_2O al fine di ridurre sia le emissioni di tali gas che il consumo idrico mantenendo buoni livelli di produttività, costituisce una importante sfida soprattutto in ambiente mediterraneo. In questo lavoro viene analizzato l'effetto della gestione idrica AWD sulle emissioni potenziali di CH_4 e N_2O, sul* "global warming potential" *(GWP) e sulla produttività in una risaia nel nord Italia. Sia durante l'intera stagione vegetativa che durante il periodo di sommersione, il GWP è risultato maggiore nelle parcelle sottoposte a sommersione permanente; tuttavia, nelle parcelle sottoposte ad AWD è stata osservata una significativa riduzione della produttività. Questi risultati suggeriscono l'importanza di un'attenta pianificazione basata sulle caratteristiche specifiche del sito, considerando i principali fattori che influenzano le potenzialità di mitigazione.*
Parole chiave: *Emissioni di CH_4, Emissioni di N_2O, ciclo alternato di sommersione ed asciutta (AWD), risaie, mitigazione.*

INTRODUCTION

Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are the most important greenhouse gases (GHG) emitted from agricultural soils, contributing 60, 15 and 5%, respectively, to enhanced global warming. CH_4 and N_2O have a large global warming potential (GWP) that is respectively 34 and 298 times greater than CO_2 over a 100 yr period (Myhre *et al.*, 2013).

Agricultural activities are significant producers of GHGs, largely deriving from soil and nutrient management (IPCC, 2014). In agricultural systems under temperate climate, net emissions of CO_2, CH_4 and N_2O from the soil surface are of particular interest because they are the major components of the net global warming potential (GWP) of cultivated land (Robertson and Grace, 2004). It is estimated that agriculture accounts for 10–12% of

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total global anthropogenic emissions of GHG, which amounts to 60% and 50% of global N_2O and CH_4 emissions, respectively (Smith *et al.*, 2007). Very similar figures were obtained for GHG emissions in the European Union (Weiske and Petersen, 2006).
Rice systems have a particular strong impact on CH_4 emissions, being 90 % of the world's harvested rice area is cultivated under flooding conditions for the major part of the year (Neue, 1997). The annual CH_4 emission from rice paddies has been estimated to be 36 Tg year^{-1}, contributing approximately 18% of the total anthropogenic CH_4 emission to the atmosphere (Stams and Plugge, 2010; Kirschkle *et al.*, 2013). In the EU, Italy is the largest rice producer, contributing for 3.7 % to the total CH_4 emissions of Italy (FAO, 2012). Rice systems are also unique from other systems in that the majority of CH_4, as well as some N_2O, are emitted through the plant rather than the soil (Yu *et al.*, 1997). Increasing the sustainability of rice cropping systems will require the identification of agricultural practices that mitigate GHG emissions while sustaining production levels. This issue is based on a better understanding of the scientific link between management practices and key processes involved in the production of GHG. In addition, water scarcity is estimated to globally represent a major constraints, thus increasing water use efficiency will be essential for rice production in the future (Mahender *et al.*, 2013). In this context, a sustainable intensification of rice production, ensuring sufficient yields for the world population and reducing at the same time the negative impacts for the environment, is needed.
CH_4 is the dominant GHG produced and emitted from rice fields, with emissions being largely controlled by water and residue management practices (Yagi *et al.*, 1997; Wassmann *et al.*, 2000). Flooding rice fields promotes anaerobic fermentation of C sources supplied by the rice plants and other incorporated organic substrates, which results in CH_4 production. Subsequent CH_4 emission is the result of its transport from soil to atmosphere through rice plants aerenchima, diffusion and ebullition mechanisms (Krüger *et al.*, 2001). The rate of CH_4 production and emission largely depend on the morpho-physiological parameters like growth characteristics and photosynthetic efficiency of the rice plant, which in turn influence the supply of substrate for CH_4 production (Sass and Cicerone, 2002) and its subsequent release into the environment (Gogoi *et al.*, 2005).
Alternate wetting and drying (AWD) irrigation (as opposed to permanent flooding in conventionally managed rice production system) is one practice in rice systems that has been shown to reduce CH_4 emissions and water use (Rejesus *et al.*, 2011).
Reducing the period during which a soil is flooded through AWD or mid-season drains typically reduces CH_4 emissions. For instance, Lu *et al.* (2000) reported that CH_4 emission in southeast China was reduced by 44 % by a midseason drainage and 61 % by alternating wetting and drying at 10-day intervals compared to continuously flooded plots. Itoh *et al.* (2011) demonstrated that prolonged midseason drainage in Japan suppressed CH_4 emission as much as 69.5 %. Towprayoon *et al.* (2005) reported that CH_4 emission from rice fields in the central plain of Thailand was reduced by 35 % by draining paddy fields twice.
However, rice systems also emit N_2O, especially in relation to N fertilizer rate (Zou *et al.*, 2007). In rice systems, there is often an inverse relationship between CH_4 and N_2O emissions (Hou *et al.*, 2000), mainly in relation to water management. Indeed, N_2O emissions tend to increase when management practices are implemented to reduce CH_4 emissions, through the use of AWD irrigation or mid-season drainage (Cai *et al.*, 1997; Zou *et al.*, 2007). In general, draining paddies create suitable oxygen (O_2) availability in the soil for N_2O production as an intermediate product of either nitrification or denitrification, while flooding creates strict anaerobic condition and restricts N_2O formation and emission (Cai *et al.*, 1997; Zheng *et al.*, 2000). Therefore, in addition to significantly reducing CH_4 emissions, field drainage may actually increase N_2O emissions (Forster *et al.* 2007).
However, AWD and other water reducing practices while potentially mitigate GHG emissions and GWP, have been reported in some cases to reduce rice productivity (Bouman and Tuong, 2001; Towprayoon *et al.*, 2005).
Most studies assessing the impact of AWD on rice productivity and GHG emissions have been performed in Asia, while few data are available for European conditions and practices. In particular, a previous study conducted in Italy (Lagomarsino *et al.*, 2015) highlighted the *need of site specific farming options, considering soil physico-chemical properties and water quality as drivers of GHG mitigation potential*. The importance of pedo-climatic conditions and water saving harshness in determining CH_4 and N_2O emissions and their response to water saving has been hypothesized.
The aim of this work is to assess the effect of the alternate wetting and drying practice on fluxes and

annual budgets of CH_4 and N_2O emissions from a paddy soil in the Italian rice belt, calculating the GWP of each management practices with respect to grain yields.

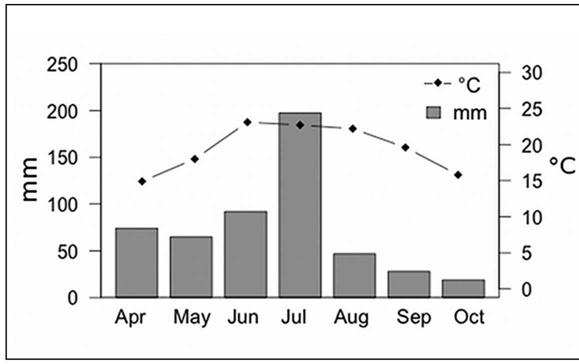

Fig. 2 - Mean monthly temperature and total monthly precipitation during the study period.
Fig. 2 - Temperatura media mensile e precipitazioni totali mensili durante il periodo di studio.

MATERIALS AND METHODS

Site description and experimental design

The experiment was conducted from May to October 2014 in experimental dry-seeded rice fields (Fig. 1), located at CREA-Rice research unit in the municipality of Vercelli (45°19' 25" N, 8° 22' 25" E) (north-western Italy). Mean monthly temperature and precipitation during the experiment are reported in Fig. 2. The fields were planted with the rice cultivar Opale, an Italian rice variety with a long A grain type released in 2008.

Crop management events are listed in Tab. 1. Spring tillage consisted of ploughing, then disk harrowing, followed by final seedbed preparation. Fertilization was applied one month before seeding with organic fertilizer Verdazoto ® (N 12.5 %). Two fields, approximately 1 ha in size each, were selected and subjected to two different water managements: one under permanent flooding (PF) and the other under alternate wetting and drying (AWD) (both on 4 replicates). PF was applied when rice plants were at three leaflets stage, 30 days after sowing, with a water level of 5 cm, increased to 10 cm at 65 days after sowing. PF field was dried at 57 days after sowing to allow herbicide treatments. AWD treatment is a water-saving technology in which water is applied to a field to flood it with 3-5 cm of field water depth and then the water is left to subside through evapotranspiration and percolation until the soil reaches a particular moisture content

Fig. 1 - Experimental site and gas sampling devices.
Fig. 1 - Sito sperimentale e strumentazione di campo per il campionamento dei gas.

Crop Management	PF	AWD
Disc harrowing, land leveling	02/04/2014	02/04/2014
Dry seeding	07/05/2014	07 /05/2014
Herbicide treatment	1° - 13/06/2014 2° - 03/07/2014	1° - 13/06/2014 2° - 03/07/2014
Water flush	13/06/2014	13/06/2014
Organic fertilization (kg N ha^{-1})	50	50
Flooding	Yes	Not
Field drainage	Not	Yes
Days of flooding (PF)	69	0
Harvest	30/09/2014	15/10/2014
Crop cycle (days from sowing to harvest)	146	161
Rice yield (t ha^{-1})	8.08	5.23
Water input (m^3 ha^{-1})	11900	0

Tab. 1 - Crop management events and rice productivity during the vegetative season 2014. PF: permanent flooding; AWD: alternate wetting and drying.
Tab. 1 - Interventi di gestione colturale e produttività del riso durante la stagione vegetativa 2014. PF: sommersione permanente; AWD: ciclo alternato di sommersione ed asciutta.

at which time the field is re-flooded. In this study, AWD was implemented using piezometers to monitor the depth of water, following the International Rice Research Institute protocol (Siopongo *et al.*, 2013). Piezometers were installed in AWD and PF fields in three replicates. In addition, tensiometers were applied to the AWD field and water potential was recorded during the growing season to allow a flood supply when the water potential was lower than -30 kPa.

Yield and water balance
Yield was evaluated on plots of 1.44 m^2 realized in four replicates for each water management conditions (PF and AWD). Analysis of variance (ANOVA) of yield data was performed to test the significance of differences between replications and treatments using SYSTAT v.9 software (Systat Software Inc., CA, USA).
The PF field was flooded on June 13, and the water was removed one time for four days (from June 26 to June 30) to allow the herbicide treatment. In the PF field, water was definitely removed on August 25th. In the AWD, irrigation water was never provided since, as indicated by the tensiometers data, water potential in the field never reached the fixed critical threshold.
Water balance was evaluated with a Bazin Weir, recurring to manual daily measurement and applying the following formula: $Q = 2/3\ C_q\ b\ (2g)^{1/2}\ h^{3/2}$, where Q is the water discharge (m/s), C_q is a run-off coefficient (equals to 0.60-0.62), b is the weir length (m), g is the constant of gravity (m/s^2) and h the height of water on the weir; usually $2/3\ C_q = 0.41$ is assumed.

GHG measurements
Gas sampling was conducted following the UCDavis protocol described in Adviento-Borbe *et al.* (2013) and Pittelkow *et al.* (2013). PVC vented, closed opaque chambers 30 cm in diameter, with a base inserted into the soil, a chamber extension to follow rice plants during growth and an air-tight chamber lid have been used in four replicates (Fig. 1). Chamber lids were covered with a reflective insulation and equipped with: vent tubes, fans to mix headspace air, gas sampling ports and thermocouple wires to measure air temperature (Fig. 1). Wooden boardwalks were installed in the rice field to prevent soil disturbance while gas sampling. During each gas sampling event, chambers were closed for 63 min and four gas samples were collected at 0, 21, 42, and 63 min. Headspace gas samples were obtained with air-tight

30 ml propylene syringes and immediately pressurized into pre-evacuated 12 ml glass Exetainer® vials (Labco Ltd., Buckinghamshire, UK). Gas fluxes were monitored during all phases of the annual cropping cycle which included preseason tillage and land preparation, crop establishment through harvest. Measurements were performed weekly to bimonthly from May to October 2014 depending on the climate conditions, for a total of 15 sampling events. Gas sampling occurred between (10:00 a.m. – 12:00 a.m.), when fluxes were expected to represent average daily values (Alves *et al.*, 2012). Concentrations of CH_4 and N_2O were analyzed using a GC-2014 gas chromatograph (Shimadzu Scientific) with a ^{63}Ni electron capture detector (ECD) for N_2O and flame ionization detector (FID) for CH_4. The GC detection limits were 11.6 ng l^{-1} for N_2O and 84.8 ng l^{-1} for CH_4. Gas samples were analyzed within four weeks of collection. Chamber gas concentrations were converted to mass per volume units using the Ideal Gas Law and measured chamber air temperatures and volumes. Fluxes of N_2O and CH_4 were calculated using the slope of linear regression of gas concentration versus chamber closure time and the enclosed soil surface area. Fluxes were set to zero if the change in gas concentration during chamber enclosure fell below the minimum detection limit determined for the GC, and flux values were rejected (i.e. treated as missing data) if they passed the detection test but had a $r^2 < 0.80$.

Data analysis

Estimates of cumulative CH_4 and N_2O emissions for each field replicate were based on linear interpolation, with the sum of cumulative growing season and fallow period emissions representing the annual cropping cycle. The growing season covered the period from seeding through harvest (see Table 1). The CH_4 and N_2O cumulative emissions were calculated separately for the growing season and flooded period, and expressed in g C-CO_2 eq m^{-2} using the climate warming factor on 100-year horizon equal to 34 and 298 for CH_4 and N_2O, respectively (Forster *et al.*, 2007). By using this data, the GWP for the growing season (5 months) has been computed, which normalized to the yield gives the yield-scaled global warming potential (GWPY), obtained from the ratio of GWP and grain yield.
Variance components and mixed model ANOVA module of Statistica package (StatSoft Inc.) was performed to evaluate the effects of water management on CH_4 and N_2O fluxes, GWP and GWPY, soil and water parameters.

RESULTS

Water management and yield Consumption of irrigation water for the whole growing season was evaluated as 11900 m^3/ha for the PF and 0 m^3/ha for the AWD condition. These parameters have of course been affected by the relevant level of rain recorded.
The yield recorded in the PF condition for the rice variety Opale was of 8.08 t/ha, while in the AWD the paddy rice yield was of 5.23 t/ha, showing a significant decrease of 34.6 % ($p<0.05$).

CH_4 emissions

Because of the frequent rain input during rice growing period, soil water potential measured by the tensiometers never reached values selected as thresholds for re-flooding (Fig. 3). The effect of water management was highly significant for methane emissions, discriminating the two treatments PF and AWD. In the whole flooding period, under PF, two different methane emission rates were measured, with the first one showing an initial peak immediately after the flooding event (Fig. 4). CH_4 emissions were then higher from maximum tillering, when the highest value was recorded, through panicle initiation, after which they declined until field drainage. Low CH_4 emissions were also measured during the maximum tillering period in the AWD water management system. Frequency distribution of average CH_4 fluxes ranged from 5.4 to 1514.4 g ha^{-2} d^{-1} in PF (Fig. 4), while in AWD the highest peak reached 85.6 g ha^{-2} d^{-1}.

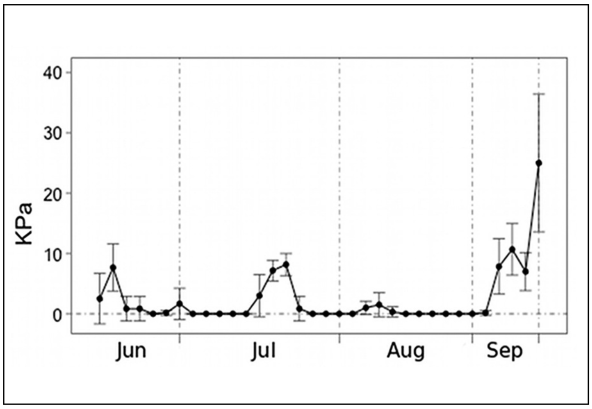

Fig. 3 - Soil water potential measured by tensiometers. Vertical bars indicate standard deviations of the means (n = 6).
Fig. 3 - Potenziale idrico del suolo misurato attraverso tensiometri. Le barre verticali indicano le deviazioni standard (n = 6).

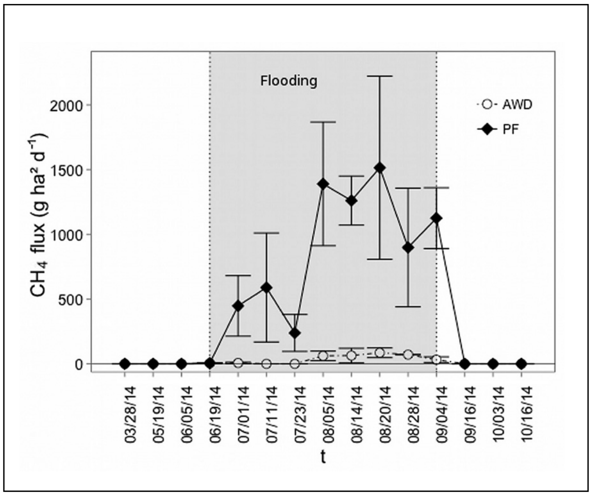

Fig. 4 - Potential CH_4 fluxes (g ha^2 d^{-1}) in PF and AWD fields during the study period. Vertical bars indicate standard deviations of the means (n = 4). The shaded area indicates the flooding period.
Fig. 4 - Flussi potenziali di CH_4 (g ha^2 d^{-1}) nelle parcelle PF and AWD durante il periodo di studio. Le barre verticali indicano le deviazioni standard (n = 4). L'area ombreggiata indica il periodo di sommersione.

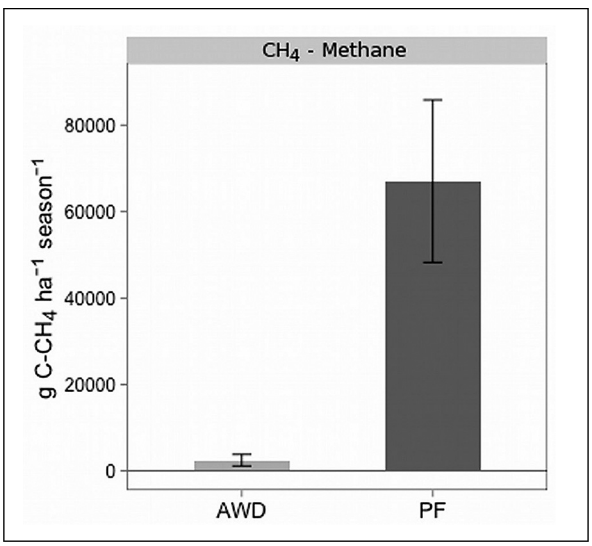

Fig. 5 - Total methane emissions (g C-CH_4 ha^{-1} season^{-1}) in PF and AWD fields during the flooding period. Vertical bars indicate standard deviations of the means (n = 4).
Fig. 5 - Emissioni totali di metano (g C-CH_4 ha^{-1} season^{-1}) nelle parcelle PF and AWD durante il periodo di sommersione. Le barre verticali indicano le deviazioni standard (n = 4).

In the whole growing season, cumulative average daily CH_4 emissions were 262.8 and 9.7 g C-CH_4 ha^{-2} d^{-1} for PF and AWD, respectively, with a percentage reduction of 96 % under AWD (Fig. 5). The effect of flooding increased cumulative average daily emissions up to 893.6 and 33.0 g C-CH_4 ha^{-2} d^{-1} in PF and AWD, respectively.

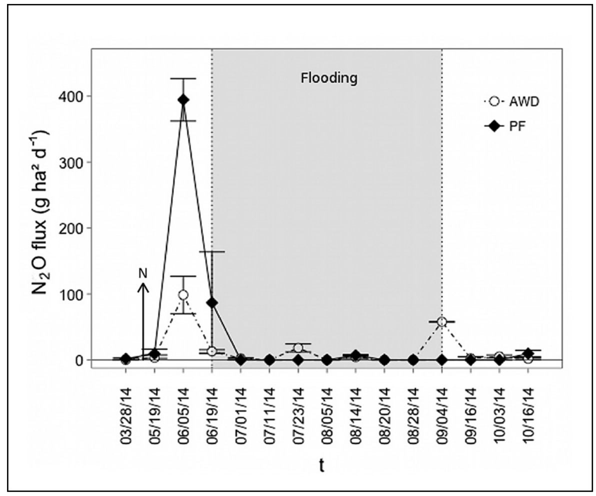

Fig. 6 - Potential (N_2O) fluxes (g ha^2 d^{-1}) in PF and AWD fields during the study period. Vertical bars indicate standard deviations of the means (n = 4). The shaded area indicates the flooding period. The vertical arrow indicates the fertilization event (N).
Fig. 6 - Flussi potenziali di N_2O (g ha^2 d^{-1}) nelle parcelle PF and AWD durante il periodo di studio. Le barre verticali indicano le deviazioni standard (n = 4). L'area ombreggiata indica il periodo di sommersione. La freccia verticale indica il momento in cui è stata applicata la fertilizzazione (N).

N_2O emissions

Nitrous oxide emissions trend was characterized by few peaks, accounting for 76% and 94% of total N_2O emissions in AWD and PF treatments, respectively. The highest N_2O peaks (394.6 g ha^{-2} d^{-1}) was measured in PF field before the flooding period and 1 month after N fertilization (Fig. 6). Under AWD, in the month of September, a significant peak was found after previous rainfall followed by dry conditions. Unexpectedly, the PF field accounted for a cumulative higher N_2O emission (Fig. 7a) and the flooding treatment led to a low reduction in N_2O emissions, indeed no significant difference was found during the flooding period between the two treatments (95.4 and 94.0 g ha^{-2} d^{-1} for AWD and PF, respectively, Fig. 7b).

Global warming potential

The GWP was larger under PF than AWD both during the whole growing season and the flooding period (+ 67 % and + 80 %, respectively, Fig. 8). The largest contribution to GWP during the growing season was ascribable to N_2O emissions (93% and 61%, respectively for AWD and PF treatments). This result was mainly related to N_2O emission peaks, significantly influencing the total amount of Kg CO_2 eq produced, due to the highest N_2O peak founded under PF treatment. On the other hand, the largest contribution of CH_4 to GWP was strictly related to

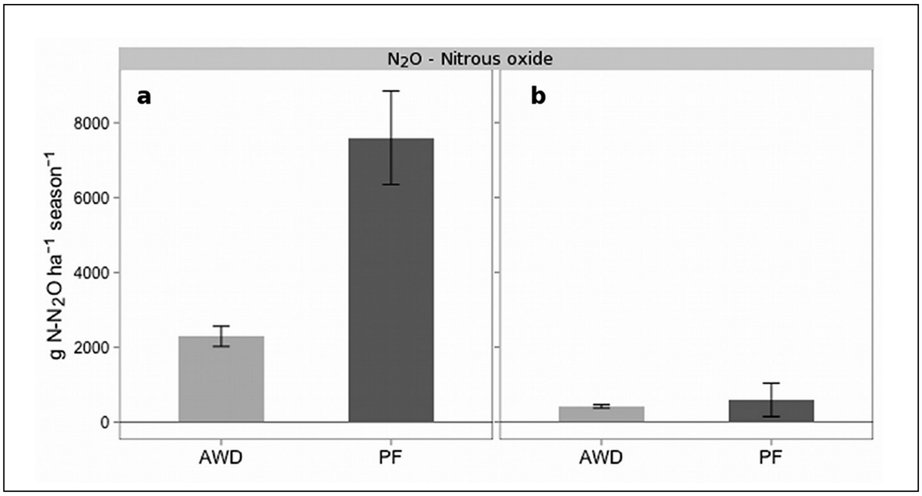

Fig. 7 - Total nitrous oxide emissions (g N-N_2O ha^{-1} season^{-1}) in PF and AWD fields during the growing (**a**) and flooding (**b**) periods. Vertical bars indicate standard deviations of the means (n = 4).
*Fig. 7 - Emissioni totali di protossido di azoto (g N-N_2O ha^{-1} season^{-1}) nelle parcelle PF and AWD durante l'intera stagione vegetativa (**a**) ed il periodo di sommersione (**b**). Le barre verticali indicano le deviazioni standard (n = 4).*

the flooding effect, passing from 39 % during the whole growing season to 89 % of the total Kg CO_2 eq produced during the flooding period.

DISCUSSION

Our results showed the large contribution of CH_4 to GWP during the flooding period (89%), as expected by the classical rice cultivation practice (Wassmann *et al.*, 2000; Kruger *et al.*, 2001; Kirschkle *et al.*, 2013), although the radiative forcing of N_2O is much higher than that of CH_4 (Linquist *et al.*, 2012; Pittelkow *et al.*, 2013). During flooding anaerobic conditions lead to methanogenesis and CH_4 transport through the plant is the dominant form of methane release into the atmosphere and can account for up to 90% of total emissions (Holzapfel-Pschorn and Seiler, 1986; Butterbach-Bahl *et al.*, 1997). In fact, maximum rates of CH_4 emissions were observed during the maximum development of rice plants, confirming rice plants important conduits of GHGs (both CH_4 and N_2O) from the soil to the atmosphere (Yu *et al.*, 1997). Also, a correspondence between increase of CH_4 emissions and higher water level was observed, confirming findings reported in Lagomarsino et al. (in press).
AWD is commonly applied to reduce CH_4 emissions, decreasing GWP too (Yu *et al.*, 2004; Zou *et al.*, 2005), because the major contributor to GWP from rice paddies is usually CH_4 and our results confirmed a reduction up to 96% during the flooded period.
Moreover, the total CH_4 emission in terms of GWP during the whole growing season was reported to be greater than the cumulative N_2O emissions from drained soils, although intermittent flooding usually strongly increases N_2O emissions (Itoh *et al.*, 2011). Surprisingly, in our case the highest N_2O peaks, that significantly influenced the total amount of Kg CO_2 eq during the growing season, was recorded under PF before the flooding and may be related to the previous N fertilization. N_2O is typically emitted

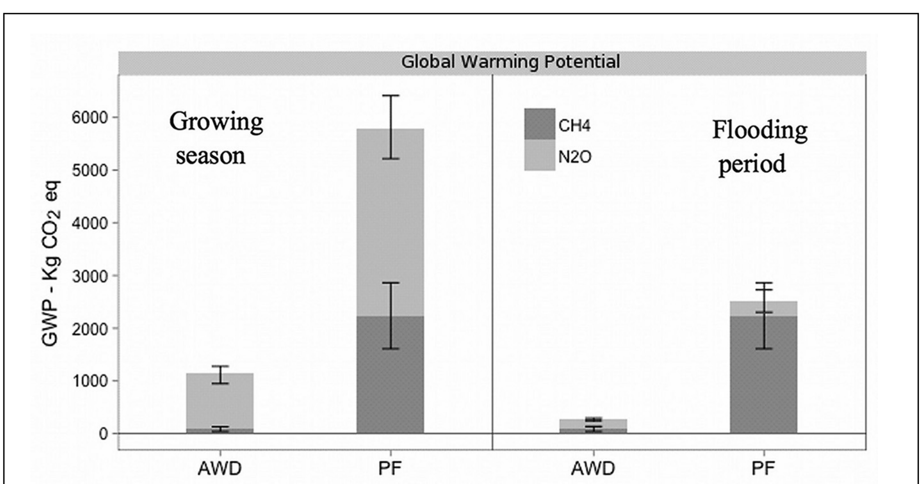

Fig. 8 - Global warming potential (GWP) in PF and AWD fields during the growing and flooding periods. The relative contribution of CH_4 and N_2O is reported. Vertical bars indicate standard deviations of the means (n = 4).
Fig. 8 - Global warming potential (GWP) nelle parcelle PF and AWD durante la stagione vegetativa e il periodo di sommersione, riportando. Il contributo relativo di CH_4 and N_2O. Le barre verticali indicano le deviazioni standard (n = 4).

through peaks, which may account for the largest part of seasonal emissions, varying in time and space and driven mainly by oxygen and substrates availability, as well as by microbial species (Giles *et al.*, 2012).

The peak was absent in AWD although PF and AWD showed similar water soil potential and similar soil characteristics before the flooding. However, 25 mm of precipitation (about 27% of the total monthly amount) was recorded the day before the peak, suggesting a modification of soil conditions that favored N_2O production. Therefore, it could be hypothesized that different soil conditions at microscale between PF and AWD triggered the N_2O peak. Moreover, during the flooding period, the AWD field did not reach very dry and well drained conditions due to the frequent rain input during the whole growing season, explaining the similar trend in N_2O emissions found during the flooding period.

The impact of water saving on GWP and the relative contribution of CH_4 and N_2O strongly differed to the results obtained in a clayey Italian soil. In this last one, AWD reduced CH_4 emissions but triggered N_2O peaks, which accounted for 80% of GWP on average (Lagomarsino *et al.*, in press). Indeed the main difference relied on the contribution of N_2O, much lower in the present experimental site. To explain these difference it was hypothesized a main role of soil physico-chemical characteristics (i.e. texture and pH), which may affect prevalent soil processes and therefore the response of GHG emissions to AWD treatment (Le Mer and Roger, 2001; Huang *et al.*, 2002).

The GWP reduction observed under AWD, coupled with a significant yield decrease under this water-saving rice production system, confirming the main results often showed by many authors (Towprayoon *et al.*, 2005; Farooq *et al.*, 2009; Li et *et al.*, 2011), although there are still contrasting reports on the effect of water management practices for reducing flooding on rice yields (Adhy*a et al.*, 2014). These contrasting results suggest the need to find and adopt site specific management options, taking into account duration of flooding periods, drainage frequency, the capability of soils to retain an acceptable level of moisture, as well as rice variety used.

Varietal characteristics of the rice plants can affect CH_4 emission to the atmosphere because of their gas transport mechanism and the role of root exudates, serving as significant substrates for CH_4 production (Mitra *et al.*, 1999). Rice cultivars having higher photosynthate C allocation capacity to rice grain and lower C translocation towards root for methanogenes might result in lower CH_4 emission from paddy fields, without significant reductions in grain yield (Das and Baruah, 2008).

In the last years rice varieties adapted to growth under dry conditions have been developed, without significant differences in grain yield between AWD and PF (Abbasi and Sepaskhah, 2011; Yao *et al.*, 2012) and wide variability for adaptation to aerobic conditions has been observed in several studies involving rice (Kumar *et al.,* 2014). Further studies are needed to assess rice adaptation to AWD conditions, depending also on site-specific soil physico-chemical characteristics.

CONCLUSION

Water management showed a large influence on GWP of rice paddies, influencing the relative contribution of N_2O e CH_4. Our results showed a decrease of CH_4 emissions and GWP with AWD application, although the frequent rain input during rice growing season led to similar trend in N_2O emissions during the flooding period.

Further mitigation strategies should be evaluated in relation to site-specific conditions and management options, regarding the duration of flooding, the water level, the residues management, the fertilizer type and application. Moreover, screening of existing rice cultivars and initiation of breeding programs for new cultivars better adapted to AWD and with low translocation of C to root for methanogenes might help to reduce CH_4emission from paddy fields, without compromising the grain yield.

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