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Destruction phase of perennial rhizomatous grasses: response of giant reed (*Arundo donax* L.) and *Miscanthus* (*Miscanthus* × *giganteus* Greef *et* Deu.) to mechanical and chemical strategies

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Summary

The destruction phase of perennial rhizomatous grasses (PRGs) is a key aspect affecting the environmental and economic sustainability of PRG agricultural systems. Different practices have been evaluated during the LogistEC project for reverting perennial crops with the aim to evaluate the capacity of giant reed and *Miscanthus* crops to regrow after land clearing carried out using mechanical and chemical means. The CO_2 emissions were monitored for 2 years after crop destruction. The adopted strategies seem to be more suitable for giant reed than for *Miscanthus* and, in particular the combination of soil tillage and herbicide applications showed the highest effectiveness. However, perennial grasses destruction need to be optimized taking into account also environmental and economic aspects.

Key words: Land clearing, crop regrow, carbon dioxide emissions

Introduction

The destruction phase of perennial rhizomatous grasses (PRGs) is a key aspect affecting the environmental and economic sustainability of these species. In general, the reluctance of the farmers to include PRGs in the current cropping systems is due to the limited knowledge concerning the amount of time and means needed to clear lands after their long-term cultivation. The adoption of different strategies in the crop destruction phase can strongly influence not only the cultivation costs, but also the environmental impact of the cropping systems (e.g. GHG emissions). For this reason, an experiment was conducted within the LogistEC project in Central Italy with the general objective to identify the optimal management of land clearing for giant reed (*Arundo donax* L.) and *Miscanthus* (*Miscanthus* × *giganteus* Greef *et* Deu.), In addition, two sub-objectives were identified: (i) to evaluate the capacity of these crops to regrow after land clearing carried out using mechanical and chemical means; (ii) to monitor the amount of CO_2 emissions for 2 years after crop destruction.

Materials and Methods

A field trial was set in 2003, comparing the productive and environmental performances of giant reed and *Miscanthus* in Central Italy. The trial was conducted at the Enrico Avanzi Agro-Environmental Research Centre of the University of Pisa (CIRAA), located in the Pisa coastal plain. The soil was a typical Xerofluvent, representative of the lower Arno River plain (sand 41.0%, silt 38.5%, clay 20.5%, pH 8.2, organic matter 2.0%, total nitrogen 1.1 g kg^{-1}, assimilable phosphorus 6.2 mg kg^{-1}, exchangeable potassium 138.8 mg kg^{-1}).The experimental design was a randomised block with four replications (plots 10 m × 10 m each). Tillage was conducted in the autumn of 2002, after wheat harvesting, and consisted of medium-depth ploughing (30–40 cm). Seedbed preparation was conducted in spring, immediately before planting. For both crops, establishment was performed using rhizomes with a couple of buds weighing 500 g. The rhizomes were planted at 10–20 cm of soil depth, at 0.50 m × 1.0 m spacing (20,000 plants ha^{-1}). Fertilisers were distributed at a rate of 100 kg N ha^{-1}, 100 kg P_2O_5 ha^{-1} and 100 kg K_2O ha^{-1}. Nitrogen fertiliser was applied in the establishment year 50% as preplant and 50% as side dressing, when plants were 0.30–0.40 m tall. The following years, P_2O_5 and K_2O fertiliser were applied during winter, while N was applied in spring at the beginning of growth. Plots were kept weed-free by hoeing. No crop diseases were detected during the experimental period and irrigation treatment was never necessary. Both crops were harvested once per year from 2003 to 2012. In 2013, 10 years after establishment, the *Miscanthus* and giant reed biomass yield could be considered homogeneous with an above ground dry yield of about 30 t ha^{-1}. That year, both crops were destroyed testing the following strategies: (i) three herbicide applications (glyphosate-based herbicide dose 3,600 g ha^{-1} a.i.), after spring sprouting, when the plants reached 20–30 cm in height (May), at the beginning of summer and at the end of summer (H3); (ii) ploughing at 0.30 m and disk harrowing carried out before spring sprouting, followed by two herbicide applications (glyphosate-based herbicide, dose 3,600 g ha^{-1} a.i.) at the beginning and at the end of summer (PH2). Efficacy of the treatments was assessed by visual sampling, counting the number of new shoots after destruction. Observations were carried out in: (i) May 2013 after soil tillage only for PH2; (ii) July 2013 after soil tillage and the first herbicide application in PH2 and after the second herbicide application in H3; (iii) July 2014, after 10 months from the last herbicide application in both PH2 and H3 and (iv) May 2015, after 19 months from the last herbicide application in both PH2 and H3. At each sampling date, data from treated areas (PH2 and H3) were compared with the untreated ones managed ordinarily (10 years old *Miscanthus*/giant reed-control = C). The efficiency of the treatments was calculated as reduction percentage of H3 and PH2 respect to C.

Measurement of soil CO_2 flux

To compare soil CO_2 flux rates (g C m^{-2} day^{-1}) in the treatments (C, PH2 and H3), a portable dynamic closed-chamber infra-red gas analyzer (IRGA) system (Li-820, LiCor Inc., USA) was used. In each plot, soil CO_2 flux was measured every 1 to 3 weeks for 2 years (Febraury 2013 – Febraury 2015). At every sampling point the non-steady-state through-flow chamber (WEST Systems s.r.l., Pontedera, Italy. Inner diameter 200 mm, inner height 198 mm, net inner volume 6.186 $m^3 \times 10.3$ m^3, covered area 3.140 $m^2 \times 10.2$ m^2) was placed on an open-ended stainless steel collar (70 mm height, 200 mm diameter) as an interface between the soil and the chamber. One collar was placed at a randomly selected point within the central inter-row of each plot. Each collar was pressed firmly onto the surface layer (20 mm depth) in order to avoid cutting of any root, according to Heinemeyer *et al*. (2011). To guarantee a tight seal with the collars, the chamber had a rubber ring that fits into the collar lip. The chamber closure time was around 120 seconds. The short duration of the closure time allowed reducing the impact of the chamber on the soil environment (Rochette *et al*., 1997; Davidson *et al*., 2002). An internal fan allowed the homogeneity of the air mixture inside the chamber during the measurement. During the closure time, the CO_2 concentration was measured per second, while the increase in the headspace (mg L^{-1} s^{-1}) was checked for linearity for

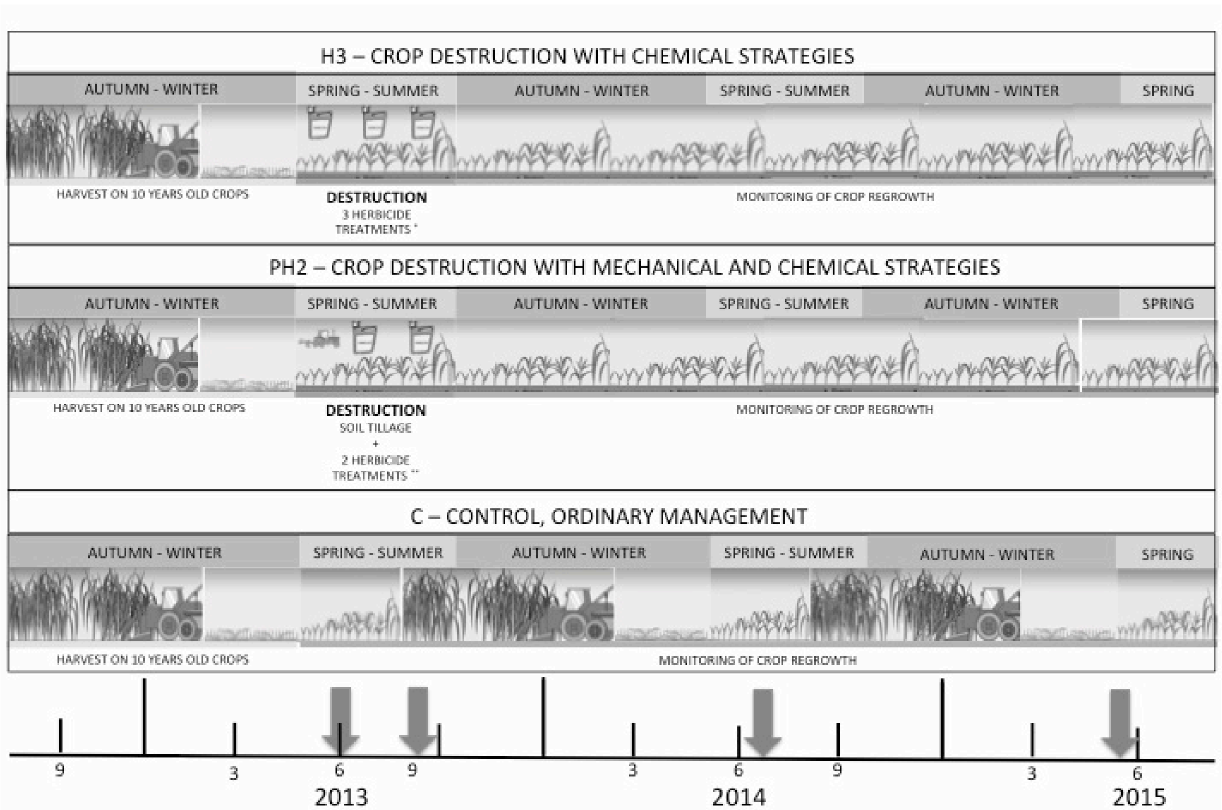

Fig. 1. Description of study performed from 2013 to 2015 comparing different strategies of crop destruction (H3, PH2 and C) on giant reed and *Miscanthus*. In the H3 treatment the herbicide applications were performed on 2 May, 19 June and 13 September 2013. In respect to H3, in PH2 the first herbicide application was substituted by soil tillage. On the bottom, arrows indicate the sampling dates (23 May 2013, 25 July 2013, 22 July 2014 and 13 May 2015).

a period of 2–3 min, and calculated and recorded in the field by a palm top computer connected via Bluetooth. CO_2 flux was calculated by performing linear regressions on the logged CO_2 data (R^2>0.95), which were corrected for atmospheric pressure and air temperature.

Cumulated annual soil carbon flux (∑Cflux, Mg C ha^{-1} yr^{-1}) was calculated for years 2013 and 2014. The approach for the calculation was based on the linear interpolation of two consecutive measurements and the numerical integration over time as:

$$\sum C_{flux} = \sum_{i}^{n} \left[(x_i + x_{i+1}) * \frac{N}{2}\right] + \ \dots + \left[(x_{n-1} + x_n) * \frac{N}{2}\right]$$

where *i* is the date of the first measurement, *n* is the date of the last measurement, *x* is the soil CO_2 flux at each sampling point, and *N* represents the number of days between two consecutive soil CO_2 flux measurements.

Data analysis

The R software was use to perform statistical analysis. A two factor ANOVA was performed to determine the effect of the species, the treatments and their interaction on all the measured parameters. The number of shoots after destruction was analyzed separately for each sampling date. The CO_2 flux was analyzed on an annual basis in the first and in the second year of monitoring.

Results

Data reported in Table 1 showed the number of shoots after crop destruction and the percentage of reduction due to the applied treatments (PH2 and H3) respect to the control (C). In all the dates of observation, our results on the shoot regrowth after the treatments, highlighted significant differences between the species, among the treatments and in the interaction between these two factors. In general, giant reed response to the treatments was more efficient than that of *Miscanthus*. Moreover, among the strategies, the combination of mechanical and chemical methods seemed to perform better than herbicide only applications. In fact, in PH2 giant reed rhizomes were almost completely dead in July 2014 and re-sprouting was not observed in the following year (2015). On the contrary, *Miscanthus* showed a destruction efficiency of around 90% in July 2014, decreasing to 70% in May 2015. A lower destruction efficiency of H3 respect to PH2 was observed in both species. In giant reed, H3 determined stable reduction (around 80%) from July 2014 onwards. In *Miscanthus*, H3 reduced crop sprouting of about 50% in July 2014, while in May 2015 the number of shoot of H3 was not significant different from the control (C).

Table 1. *Number of shoots (± standard deviation) in giant reed and* Miscanthus *crops managed following the H3, PH2 and C itineraries. Last column indicate the reduction percentage of H3 and PH2 respect to C. For each date different letters indicate significant differences among the treatments*

Date*	Species	Treatment	Number of shoots N° m^{-2}	Destruction efficiency %
23 May 2013	Giant reed	PH2	32 (±8.5) d	45.8
		H3		
		C	59 (±9.7) c	
	Miscanthus	PH2	79 (±13.4) b	38.8
		H3		
		C	129 (±16.4) a	
25 July 2013	Giant reed	PH2	20 (±5.2) c	67.7
		H3	32 (±3.4) c	48.4
		C	62 (±3.5) b	
	Miscanthus	PH2	14 (±4.5) c	89.9
		H3	36 (±12.9) bc	74.1
		C	139 (±11.0) a	
22 July 2014	Giant reed	PH2	2 (±1.3) c	96.9
		H3	12 (±4.2) c	81.5
		C	65 (±6.7) b	
	Miscanthus	PH2	8 (±4.6) c	92.9
		H3	56 (±4.9) b	50.0
		C	112 (±12.3) a	
13 May 2015	Giant reed	PH2	0 (±0.0) b	100.0
		H3	8 (±6.5) b	78.4
		C	37 (±4.7) b	
	Miscanthus	PH2	29 (±7.9) b	72.9
		H3	107 (±10.7) a	
		C	86 (±11.9) a	

*on 25 May 2013 shoots were counted when only soil tillage was performed. On 22 July 2013 we tested the effect of soil tillage and one herbicide application in PH2 and the effect of two herbicide applications in H3. From July 2014 onwards were determined the effect of the whole strategies described for PH2 and H3.

Significant differences were recorded in CO_2 emissions between the species. *Miscanthus* showed a cumulative value (of 1350 g C m^{-2} yr^{-1} (mean 2014–2015), while values around 680 g C m^{-2} y^{-1} were recorded in giant reed. In 2014, the crop destruction using PH2 strategy determined an increase of CO_2 emissions of +130% and +47% in giant reed and *Miscanthus* respectively. In 2015, the equivalent changes were lower in both species (+ 60% in giant reed and 24% in *Miscanthus*). H3 increased CO_2 emissions by 75% in giant reed in 2014 and 2015, while a reduction in respect to the mature crop was observed in *Miscanthus* when H3 strategy was applied (-11% and -32% in 2014 and 2015, respectively).

Discussion

Our results, on the destruction of perennial grasses showed that removing giant reed can be easier than removing *Miscanthus*. Our results on giant reed are in agreement with Boland (2006) reporting that giant reed could be grown as a low weed risk crop in non-riparian zones, since it does not produce viable seeds and the expansion via rhizomes has been found to be slow. On the contrary, Dufossé *et al*. (2014) reported an almost complete destruction of *Miscanthus* managed with glyphosate application and soil tillage operations. This difference could be probably due to the different period of the year in which these agricultural operations were performed and to the different operative sequence (soil tillage before herbicide application *vs* the opposite). Then, the tested strategies (PH2 and H3) seem to be suitable for giant reed destruction while they need to be improved for *Miscanthus*. Although, the combination of mechanical and chemical means showed high destruction efficiency (almost 100% in giant reed and 80% in *Miscanthus*), the use of herbicides with three applications (May, June and September; H3) lead to a partial reduction of giant reed sprouting, while it is not suitable for *Miscanthus* destruction.

This paper reports a comparison on CO_2 emissions from soil in giant reed and *Miscanthus* for the first time. In general, perennial rhizomatous grasses are cited as low-emission crops, however a substantial difference was observed between the two species with values being two fold in *Miscanthus* with respect to those of giant reed. Soil tillage operations for crop destruction determined an increase in cumulative CO_2 annual values in both species. However, the sole use of herbicide determined differing responses in the studied crops (-75% in giant reed and +20% in *Miscanthus*). While the H3 treatment controlled regrowth in giant reed, in *Miscanthus* H3 induced only a temporary stop of crop regrowth leading to a slightly inhibition of soil respiration with respect to the mature crop. Thus, the CO_2 emissions seem to be affected by the amount of live rhizomes and by their contribution to above-ground yield accumulation.

In conclusion, both strategies need to be further optimized. Although, the combination of mechanical and chemical means gave the best results on both crops, it was based on the use of glyphosate, a non-selective herbicide, and further studies are necessary on the assessment of the environmental impact of this phase. Concerning this last point, while the destruction phase by mechanical means has been demonstrated to increase CO_2 emissions from soil, the evaluation of GHG emissions from soil needs to be extended to other GHGs gas, such as N_2O and to the whole crop cycle (from crop establishment to crop destruction).

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