Progetto RedAFI

Forested Infiltration Areas Project and reduction of nitrogen from digestates

OBJECTIVES

The three-year project promoted study, research and experimental activities to foster eco-compatible environmental innovation in agriculture, focusing specifically on reducing agricultural nutrient loads in the Venice Lagoon drainage basin. The study was conducted in a zone containing a forested infiltration area (FIA), which was created with two priority objectives: water infiltration for groundwater recharge and woody biomass production for energy use. There was an interest in determining if a third objective could be added – the reduction of a significant portion of the N and P content of the liquid fraction of cattle manure digestate (produced by biogas plants that use livestock waste) by spreading the digestate in the inter-row spaces of the tree plantations. Through the calibration and validation of models that simulate hydrological behaviour and nutrient dynamics, the project has provided results that are valid not only for the test sites but also for other similar settings.

PROJECT DESCRIPTION

Over the course of the project, the following activities were conducted:

1. measurement of the nitrogen and phosphorous dynamics in a mature FIA system (5-7 years) in which two different loads of nitrogen originating from the liquid fraction of cattle manure digestate were applied (170 kg N/ha/year, the current legal limit, and 250 kg N/ha/year, the derogation limit in the Nitrates Directive 91/676/EEC);
2. comparison between the phytoremediation capacity of a mature FIA and a field of ryegrass-maize cultivated with conventional farming methods;
3. measurement of the woody biomass production of sites where digestate was applied and unfertilized sites;
4. measurement of gaseous emissions (greenhouse gases) after digestate application;
5. measurement of the groundwater recharge capacity of the FIA.

RESULTS

Consistent with the project objectives, several scenarios were tested in parallel: the control scenario (A0), test scenarios in a FIA (A1, A2) and test scenarios in a ryegrass-maize system (M0 and M1) (Table 1).

Table 1 – Test scenarios monitored in the experiment.

Type of crop	Description	Code	Theoretical load of applied digestate (kg N/ha/year)
FIA with *Platanus hybrida*	Control AFI	A0	0
FIA with *Platanus hybrida*	Scenario with application at the established legal limit. Application of the liquid fraction of cattle manure digestate.	A1	170
FIA with *Platanus hybrida*	Scenario with application at the derogation limit. Application of the liquid fraction of cattle manure digestate.	A2	250
Ryegrass-maize	Control ryegrass-maize	M0	0
Ryegrass-maize	Ryegrass-maize using conventional farming methods (liquid fraction of cattle manure digestate + chemical nitrogen fertilizer)	M1	170 (+170 of chemical fertilizer)

1. N AND P DYNAMICS IN FORESTED INFILTRATION AREAS

In the two FIA scenarios, digestate was applied in the only inter-row space (2.5 m).

Variations in the nitrogen concentrations in the groundwater at different depths, measured and simulated (Hydrus 1D) taking into consideration the digestate applications and precipitation, reveal similar trends in scenarios A1 and A2, while the peak values are almost double. The mass balances for N and P are reported in Table 2.

It was observed that, despite the stand's maturity, significant N leaching into the groundwater occurred: 35.9% and 37.5% of the applied N in scenarios A1 and A2 respectively during the two growing years of the experiment.

In both scenarios, concentrations decreased significantly between the first two layers (30 and 60 cm) and the third layer (90 cm). This indicates the processes occurring in the rhizosphere of the FIA acquire the ability to transform nitrogen (uptake by vegetation and denitrification). The effect, however, is not sufficient to completely prevent leaching into the groundwater after involvement in rapid hydrological dynamics.

Compared to the initial phase (see RiduCaReflui Project), vegetation uptake increased significantly as the trees matured, with N_{tot} storage of approximately 80 kg/ha/year in the woody biomass in the sixth year after planting, compared to 20 kg/ha/year in the third year after planting. In addition, the amount of N contained in the foliar biomass, which is partially removed during channel maintenance activities and partially returned to the cycle, albeit with slower dynamics, is significantly higher.

Table 2 – N_{tot} leached into groundwater during the experimental period for scenarios M1, A1 and A2 and associated quantifications for the two growing years monitored. The Hydrus 1D model was used to determine leaching data.

Year*	Scenario	N_{tot} applied kg/ha	N_{tot} leached kg/ha	%	P_{tot} applied kg/ha	P_{tot} leached kg/ha
2012-2013	M1	382.7	221.9	58.0	66.8	5.3
	A1	177.7	17.6	9.9	27.5	0.7
	A2	260.4	17.6	6.8	40.3	0.6
2013-2014	M1	414.3	119.2	28.8	64.2	3.4
	A1	161.0	104.1	64.7	22	3.8
	A2	237.0	169.0	71.3	32.4	2.0
TOTAL	M1	797.0	341.2	42.8	131	8.7
	A1	338.7	121.8	35.9	49.5	4.5
	A2	497.4	186.7	37.5	72.7	2.6

* 1 October - 30 September

The measurements and in particular the hydrogeological characterization of the system clearly demonstrated that the channel system and the soil system in the inter-rows are undoubtedly separate. Since the water moves only vertically and not horizontally in the soil, the infiltration water (which migrates from the channels to the groundwater) and the percolation water from the digestate application areas (inter-rows) move along parallel paths. This prevents the risk of contaminating the water intended for groundwater recharge.

It follows that the inter-row spaces in the FIAs can be used for cultivation, including activities involving digestate application within the legal limits.

Looking at the FIA system in its entirety, just under 800,000 m^3/ha/year of water with N_{tot} concentrations of 1 mg/L can infiltrate into the groundwater in a hectare of FIA. In the worst case scenario, approximately 5,000 m^3/ha/year of water with average N_{tot} concentrations of 25-30 mg/L could percolate from the inter-row spaces where digestate is applied. The average N concentration of the aquifer is 6 mg/L (ARPAV data). Overall, the FIA system tends to dilute the N concentration in the aquifer. It brings significant benefits to the aquifer, restoring not only the quantity but also the quality of the water.

With respect to phosphorous, it should be noted that the soil of the experimental site has high levels of assimilable phosphorous (84 mg/kg). This was confirmed by the average values measured for the groundwater in the two control scenarios (0.2 mg/L in M0 and 0.39 mg/L in A0) and especially by peaks that reached values close to 2 mg/L. In terms of balance, the slightly higher amount applied (ranging from 20-40 kg/ha/year) than removed (ranging from 15-25 kg/ha/year) explains P leaching at values of less than 5 kg/ha/year.

2. COMPARISON OF FIA AND MAIZE-RYEGRASS

In addition to testing different scenarios in the FIA, testing was also conducted in a conventionally cultivated field of maize, with ryegrass as a winter cover crop.

With respect to nitrogen leaching in terms of mass balance, significant differences in average annual leaching were recorded, with N_{tot} of approximately 170 kg/ha in maize-ryegrass and Ntot of 61 and 94 kg/ha in scenarios A1 and A2 (derogation) respectively (Table 2). These differences are considerably lower, but remain significant, when leaching is calculated as a percentage of the amount applied.

It was found that in soils having a poor protective capacity, like those studied, N leaching into the groundwater closely corresponds to the amount applied, regardless of the type of crop and farming methods. In the maize-ryegrass scenario, despite the crops' elevated capacity to utilize nitrogen (N_{tot} of approximately 300 kg/ha/year), chemical fertilizer must be applied in addition to the livestock waste to achieve sustainable production. In contrast, the production yield of the trees is not strictly correlated to nitrogen availability, so nitrogen application solely from livestock sources is sufficient. In terms of limiting leaching, this key factor favours the use of FIAs over maize-ryegrass fields.

3. WOODY BIOMASS

With respect to production yield, Paulownia was clearly the most productive with 30 t/ha/year of f.m., even taking into consideration the lower moisture content of the woodchips produced (47%). Narrow-leafed ash had the lowest production, with 7.5 t/ha/year of f.m. which was practically half of the yield of the plane tree (15 t/ha/year f.m.) and a quarter of that of the Paulownia. The willow had a production of 13 t/ha/year f.m. In addition to intrinsic genetic characteristics, it can be theorized that the lower productivity of the native species may derive from the fact that they prefer soil with greater water availability. In fact, no water was released into the channels during the summer since it was needed to irrigate agricultural crops, leaving the gravelly alluvial soil dry. With respect to the experimental plane tree stand, despite the higher average biomass produced in scenario A2 (94 kg compared to 83.5 and 83 kg f.p. in A1 and A0 respectively), the differences were not considered significant (Table 3).

Table 3 – Characteristics and yields of biomass obtained from the different species.

Species	Scenario	Aboveground age (years)	Avg. diameter (cm) at breast height	Weight biomass produced f.m. (t)	Weight biomass produced f.m. (t/ha)	Weight biomass produced f.m. (t/ha/anno)	Avg. moisture content (fresh weight)[2]
Paulownia		5	15.93	45.04	151.33	30.27	47%
Narrow-leafed ash		7	-	15.91	53.03	7.58	>55%
Willow		7	-	27.15	90.50	12.93	>55%
Plane tree	A1 row 1	7	10.70	1.95	-	-	>55%
	A1 row 2		10.30	1.85	-	-	>55%
	A2 row 1		11.20	2.51	-	-	>55%
	A2 row 2		10.68	2.13	-	-	>55%
	A0 row 1		9.82	1.66	-	-	>55%
	A0 row 2		10.50	1.89	-	-	>55%
Control plane tree (5 rows)		7	-	10.01			
Plane tree total				22.00	104.76	14.96	

Note[2]: the meter cannot precisely measure moisture content values greater than 55%. In these cases, the value is imprecisely recorded as > 55%.

4. GASEOUS EMISSIONS

The gaseous emissions associated with the application of cattle manure digestate were studied for each scenario. The monitoring method adopted for the project was based on using a dynamic chamber (Figure 1). The primary objective was to measure NH_3 and N_2O emissions, however greenhouse gases (GHG) including carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4) were also monitored.

Figure 1 – Chamber installed in the RedAFI - A2 site, immediately after digestate application.

Maize-ryegrass

Total N emissions ranged from 0.8 to 8.2% of the applied nitrogen, with a significant difference between subsurface application and surface application. The latter resulted in higher emissions despite the lower amount of applied nitrogen.
Total annual N emissions were 9.73 and 2.93 kg/ha (Table 4).

Tabella 4 – Emissioni annuali di azoto dalla tesi M1.

	N-NH_3 (kg/ha)	N-N_2O (kg/ha)	Total N (kg/ha)	N em./N app. % (avg. value)
Year I	8.72	1.01	9.73	4.97
Year II	2.32	0.61	2.93	0.96

In contrast to N emissions, a reverse trend was observed for greenhouse gas (GHG) emissions, with an increase in emissions for subsurface digestate application compared to surface application. The average emission value for the two test years corresponded to a Global Warming Potential (GWP) of 757.9 kg CO_2 eq./ha (Table 5).

Tabella 5 – Emissioni medie di GHG dalla tesi M1 e calcolo del GWP. I valori rappresentano l'emissione totale cumulata fino a 24 ore dalla distribuzione.

	CO_2 (kg CO_2 eq./ha)	CH_4 (kg CO_2 eq./ha)	N_2O (kg CO_2 eq./ha)	Total GWP (kg CO_2 eq./ha)
Year I	443.2	34.7	236.8	714.6
Year II	619.7	39.6	142.1	801.4
Avg. 2 years	**531.4**	**37.1**	**189.4**	**757.9**

FIA

NH_3 emissions accounted for almost all nitrogen emissions (Table 6) and ranged from 2.3 to 16.8 kg N/ha in the different application scenarios. Scenario A2 resulted in higher emissions than scenario A1, with greater differences recorded during the summer when temperatures were high. NH_3 emissions from the final application (05/06/2014) were higher than others (14.1 and 16.8 kg N/ha respectively for scenarios A1 and A2), due to the higher amount applied.
N emissions tended to grow as the amount applied increased, but with a progressively decreasing rate of growth as the amount applied increased.

Table 6 – Total annual N emissions from the plane tree FIA system.

	Scenarios	N-NH_3 (kg/ha)	N-N_2O (kg/ha)	Total N (kg/ha)	N em./N app. % (avg. value)
Year I	A1	9.4	0.39	9.8	6.0
	A2	14.6	0.80	15.4	6.4
Year II	A1	14.1	0.02	14.1	8.8
		16.8	0.03	16.8	7.1

GHG emissions ranged from 200.1 to 492.5 kg CO_2 eq./ha/24h for scenario A1 and from 274.1 to 690.4 kg CO_2 eq./ha/24h for scenario A2. For both scenarios, the highest emission values were recorded following the summer application (29/07/2013) and these emissions contained significant quantities of N_2O, reaching higher values than those measured after other applications.

Table 7 – Annual GHG emissions and GWP calculation for the RedAFI scenarios. The values represent total emissions during the first 24 hours after digestate application.

	Scenarios	CO_2 (kg CO_2 eq./ha)	CH_4 (kg CO_2 eq./ha)	N_2O (kg CO_2 eq./ha)	Total GWP (kg CO_2 eq./ha)
Year I (*)	A1	228.0	24.1	60.2	**312.3**
	A2	307.5	39.2	124.8	**471.5**
Year II (**)	A1	260.2	135.6	9.6	**405.4**
		311.4	244.2	15.6	**571.2**

(*) Year I: annual amount of digestate spread in 3 applications. (**) Year II: annual amount of digestate spread in a single application.

On an annual basis, when the digestate was spread in 3 applications, the average GWPs calculated were 312.3 and 471.5 kg CO_2 eq./ha for scenarios A1 and A2 respectively. These were lower than the GWPs calculated when the digestate was spread in a single application, 405.4 and 571.2 kg CO_2 eq./ha for scenarios A1 and A2 respectively (Table 7).

Conclusions

The digestate application method had more of an impact on NH_3 emissions than the vegetation type, the amount applied and the time of year when applied. In fact, incorporating the digestate into the soil by ploughing within 1 hour of application (scenario M1, RedAFI site) led to emission factors lower than or equal to 2.0%. In contrast, the surface application method in the FIA resulted in higher emission factors, averaging between 11.6 and 17.6%. The lowest levels were recorded when the annual amount of N was spread in 3 applications, as opposed to a single application. In these situations, the slow infiltration of the digestate into the soil proved to be a crucial factor for gaseous emissions.

5. INFILTRATION CAPACITY

The groundwater infiltration rates in the FIA were calculated using mass balance with the following equation:

$$I = D + P - EVT - E_w$$

where net infiltration (I) includes the sum of the following: diversions (D) from the Remondina irrigation channel (Brenta River), precipitation (P), evapotranspiration (EVT) and evaporation (E_w). The discrepancy between the cumulative D flux and the other components is notable, since D is more than 80 times greater than all of the other cumulative fluxes (Figure 2 and Table 8). In fact, after three years of monitoring, cumulative D equalled 2,330,265 m^3/ha while cumulative P equalled 65,504 m^3/ha, providing a total input to the system of 2,395,768 m^3/ha. The cumulative outflow from the system was equal to 37,403 m^3/ha, with only 4,391 m^3/ha resulting from E_w from the small channels and 33,012 m^3/ha deriving from EVT from the forested area. Finally, no flux was measured exiting the artificial groundwater recharge system during the entire three years of monitoring.

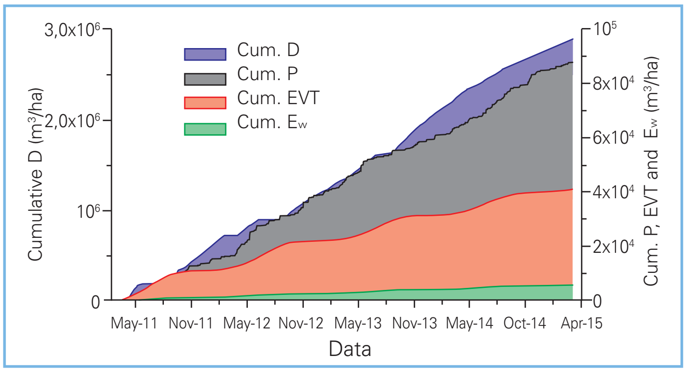

Figure 2 – Cumulative fluxes of the different components of the hydrological balance. Note the difference in scales on the y-axis.

Table 8 – Components of the hydrological balance (m^3/ha) for the artificial groundwater recharge system during the three years of monitoring: diversion (D), precipitation (P), evapotranspiration (EVT), evaporation (E_w) and infiltration (I).

Monitoring year*	D	P	EVT	E_w	I
Year I	745.636	20.049	12.940	1.520	751.225
Year II	660.719	26.546	10.536	1.186	675.543
Year III	923.910	18.909	9.537	1.685	931.597
Avg. value	776.755	21.835	11.004	1.464	786.122

**From April to March*

This document is an informative summary of the activities and results of "REDAFI – Forested Infiltration Areas and reducing nitrogen from digestates"

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For further information on the project, see the publication "Progetti REDAFI e FLOROBASCO: Valorizzare i nutrienti, produrre biomassa da energia" www.venetoagricoltura.org (Formazione, convegnistica, editoria / catalogo editoriale / agricoltura sostenibile) and the website http://riducareflui.venetoagricoltura.org/

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Printed April 2016 by Adle Edizioni sas - Padova

Funded by the Region of Veneto – Agri-Environment Division
"Promoting eco-friendly environmental innovation in agriculture in the Venice Lagoon drainage basin – Project profile C5.1.5".