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D2.2. Design and performance of Microfiltered Digestate to Fertigation (MDF).

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EXECUTIVE SUMMARY

The integrated Microfiltered Digestate to Fertigation (MDF) system, developed by CRPA Foundation in collaboration with Saveco Wamgroup (microfiltration) and Netafim Italia (fertigation) aims at distributing the digestate/slurry, mixed with water, through a drip irrigation system. To this aim it is necessary, by means of the microfiltration at 50 µm, to exclude particles that can clog the drippers.

A pilot plant was installed at CAT Correggio cooperative, Emilia-Romagna (Italy), and both microfiltration and subsurface drip irrigation trials were conducted using digestate, with rather encouraging results both at the biogas plant and in the fields.

The raw digestate is first separated into a palatable solid fraction and a liquid fraction and the latter is subjected to microfiltration to obtain the microfiltered digestate to be used on growing crops, mixed with irrigation water, through drip lines. The microfiltered represents the largest portion of the incoming raw digestate, and the others are the solid fraction deriving from horizontal screw press and the dense fraction from the microfilter. Both of the latter can be used at soil tillage.

Considering 100% the raw digestate as it enters the treatment, approximately 5% by weight is separated as a palatable solid fraction while approximately 70% by weight becomes the microfiltered fraction that can be used in fertigation; the remaining 25% by weight is the dense fraction discharged from the microfilter.

The microfiltered digestate presents Total Solids values between 3.5 and 4.5%, with a reduction of 25-30% compared to the raw digestate, while the total N content remains close to that of the raw digestate, with a ratio of ammoniacal to total N always close to 60%. Phosphorus concentrations, on the other hand, were reduced by 10-15% compared to the raw digestate.

While the raw digestate entering the solid-liquid separation was characterised by 30-40% of the total solids included in the particle size class above 100 µm (>0.1 mm), in the clarified digestate the same particle size class accounted for approximately 6% of the total solids while in the microfiltered it was less than 0.5%. The low viscosity of the microfiltered digestate, compared to that of a raw digestate, improves the operations of injection and use in the fertigation system.

The microfiltered digestate was periodically transferred by means of a tank (total volume of 15 m^3) at the field, so that it could be injected into the subsurface drip irrigation (SDI) plant, mixed with the irrigation water and distributed on maize (summer 2019) and sorghum (summer 2020).

During the two fertigation seasons there were no problems with clogging of the drip lines, as evidenced by the volume flowing through the system, which remained constant.

The trials demonstrated the technical feasibility of microfiltering the digestate and making it usable in drip irrigation through semi-permanent subsurface drip lines on existing crops.

1. Introduction

The digestate is the by-product of anaerobic digestion plants in which biogas is produced. Rich in nutrients such as nitrogen, phosphorus, potassium and other meso- and micronutrients, it appears as a dense liquid matrix that is quite homogeneous with respect to the biomass entering the plant.

In line with the 2030 targets for sustainable food production, as defined by the Farm to Fork Strategy, digestate and livestock manure should increasingly replace mineral fertilisers. To do this, however, it is necessary to maximise their use efficiency, e.g. by treating and distributing them on growing crops, reducing emissions into air and water bodies. In particular, the liquid digestate contains most of the nitrogen in ammoniacal form, which is ready-to-use for plant nutrition.

The integrated Microfiltered Digestate to Fertigation (MDF) system, developed by FCSR in collaboration with Saveco Wamgroup (microfiltration) and Netafim Italia (fertigation) aims at distributing the digestate/slurry, mixed with water, through a drip irrigation system. To this aim it is necessary, by means of the microfiltration, to exclude particles of a size that can clog the drippers. In fact, the particles with a diameter greater than 50 microns (equivalent to three white blood cells) are almost completely excluded by the microfilter.

Digestate microfiltration tests and the use of microfiltered fraction in fertigation (SDI – subsurface drip irrigation) were carried out at CAT Correggio biogas farm (Emilia-Romagna region, Italy). This is a cooperative farm that implements anaerobic digestion of livestock manure, agro-industrial residues and energy crops) in the frame of the BiogasDoneRight model, an example of multifunctional and sustainable agriculture according to objectives of "The Roadmap to a Resource Efficient Europe", that guarantees high soil use efficiency, constant organic matter return, recycling of nutrients and year-long covered soil with lower leaching risk. The biogas plant produces around 25,000 tonnes of digestate per year.

Both a solid-liquid separator and a new microfilter specially developed by Saveco Wamgroup were installed in December 2018 (Figure 1). The raw digestate was first separated into a palatable solid fraction and a clarified fraction through the common solid-liquid separation by horizontal screw press. Then the clarified fraction was subjected to microfiltration at 50 µm with the innovative equipment that allowed to obtain the microfiltered digestate to be transferred to the fields and used on growing crops, injected in a SDI plant with drip lines buried 25 cm deep (Figure 2).

Figure 1: The solid/liquid separator + microfilter installation (left), the screen of the microfilter (centre) and the microfiltration of digestate (right)

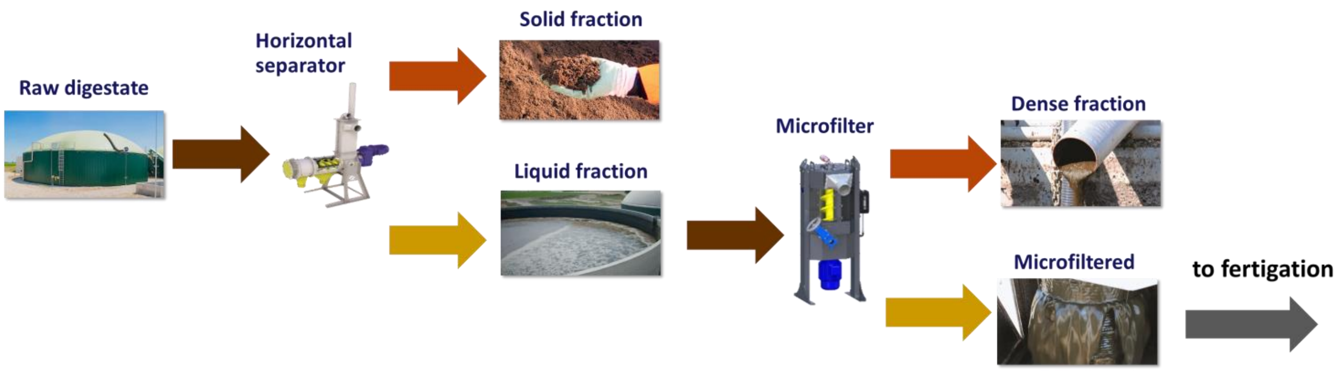

Figure 2: Treatment scheme with the solid-liquid separation and microfiltration of digestate

The activity carried out in Subtask 2.2.2 has set up and validated an innovative integrated system for the use of digestate in fertigation, the so-called Microfiltered Digestate to Fertigation (MDF), applicable to digestate obtained from crops and their residues plus livestock manure, which represents the most important type in terms of quantities available on the Italian territory.

2. Performance verification of the separation and microfiltration plant

The new microfilter exploits the action of a polymer screw tool spinning at high speed inside a filter screen with very low spacing (50 micrometers), to obtain a microfiltered fraction that can be used in fertigation without the risk of clogging nozzles or drippers. The figure below illustrates the installation scheme of the separation and microfiltration system.

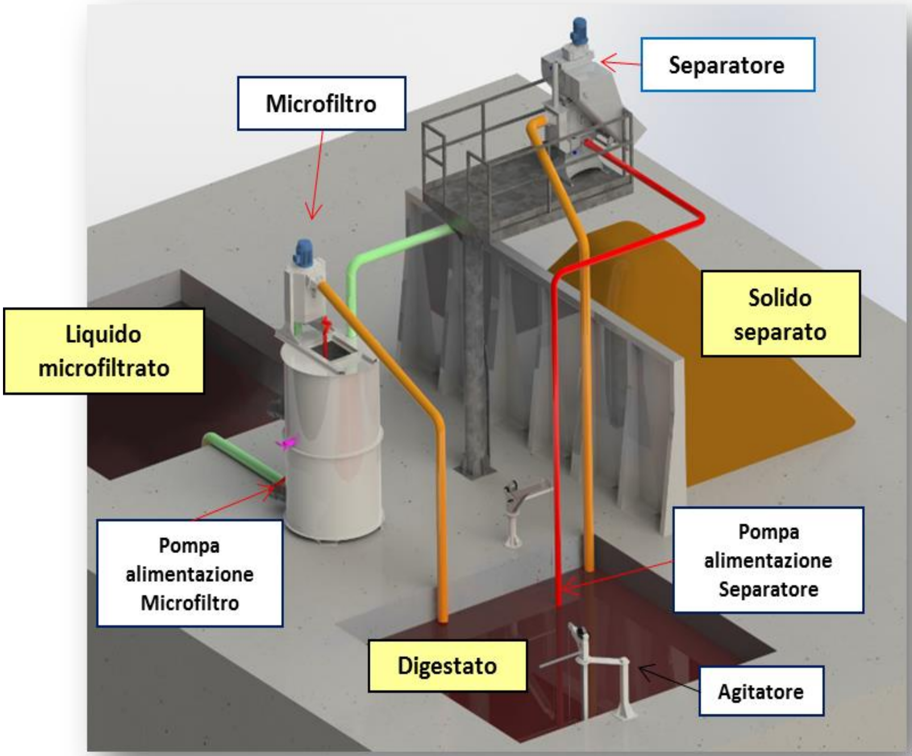

Figure 3: Scheme of installation with solid/liquid separator and microfilter

The tests in Subtask 2.2.2 were carried out at the CAT Correggio biogas plant, in Correggio (RE), on digestate from crops, agro-industrial residues and livestock manure.

The performance of the separation/microfiltration system was verified during two complete monitoring sessions in which the inlet flow rates to the separator and microfilter and the relative quantities of the different fractions obtained were determined. For each monitoring session, the following flows were sampled:

- the raw digestate entering the system;

- the palatable solid fraction from the solid-liquid separator;

- the clarified liquid fraction from the solid-liquid separator (and entering the microfilter);

- the dense and microfiltered fractions at the outlet of the microfilter.

In particular, the two monitoring sessions were carried out during the first year of work, the first in February 2019, following the installation of the microfilter, and the second in July 2019, while the microfiltered digestate used in the fertigation trials was being produced, again with a 50-micron filter, the one that proved most suitable for microfiltration of the digestate following laboratory tests.

Analyses of the parameters Total Solids (TS), Volatile Solids (VS), Total Suspended Solids (TSS), Total Kjeldahl Nitrogen (TKN), Ammoniacal Nitrogen ($N\text{-}NH_4^+$) and Phosphorus (P) were carried out on each sample.

Particle size analysis was also carried out on 6 samples taken during the measurement sessions (2 raw digestate, 2 clarified and 2 microfiltered), to which was added a further particle size analysis carried out on the microfiltered stored for a day in a tank for use in fertigation.

The measurements carried out made it possible to assess the separation efficiency by weight of the total solids and the nutrients nitrogen and phosphorus in the various fractions obtained from the separation and microfiltration processes.

On the basis of the results obtained, the most suitable solid-liquid + microfiltration separation system setting was defined to obtain the microfiltered fraction to be introduced into the fertigation system.

1.1. Chemical characteristics of digestate and derived fractions

Table 1 shows the concentrations of the elements analysed on the raw digestate entering the screw press separator and on the fractions produced (palatable solid fraction and liquid fraction); it also shows the concentrations of the elements on the fractions produced by the microfilter (dense and microfiltered).

The raw digestate from the CAT Correggio biogas plant, as confirmed by further analysis, has a normal concentration of total solids of 5-6%, with values of volatile solids over total solids generally in the range of 70-75%, total nitrogen of 3-4 kg/t, sometimes slightly higher, and phosphorus around 0.5 kg/t.

In the two tests, the palatable solid fraction produced by the horizontal screw press separator had quite different dry matter contents of 18 and 28%, which can be related to the setting of the separator. In this fraction, nitrogen tended to concentrate, particularly in organic form (derived from TKN minus ammoniacal N), with values approaching 6 kg/t. Phosphorus was also particularly concentrated in this fraction, with values exceeding 1.5 kg/t.

The liquid fraction, compared to the raw digestate, was clearly lighter in total solids content (approx. 15% lower), while the TKN concentration did not change significantly, with a slight increase in the share of ammoniacal nitrogen on the total N.

The action of the microfilter is evident on the characteristics of the two output materials. The microfiltered fraction is in fact made lighter in terms of total solids content, which are significantly concentrated in the dense fraction, that reaches (in the case of February) or abundantly exceeds (in the case of July) the value of total solids of the raw digestate.

As confirmed by other additional analyses conducted during field use, the microfiltered digestate presents TS values between 3.5 and 4.5%, with a reduction of 25-30% compared to the raw digestate, while the total N content remains close to that of the raw digestate, with a ratio of ammoniacal to total N always close to 60%. Phosphorus concentrations, on the other hand, were reduced by 10-15% compared to the raw digestate.

TSS values between 25 and 35 g/l in the microfiltered, allowed it to be used in the drip line fertigation system.

Table 1: Results of chemical analyses carried out on different materials as input and output from treatment (CAT Correggio)

Monitoring session of 02 February 2019							
Parameters		**TS**	**VS**	**TKN**	**$N\text{-}NH_4^+$**	**P**	**TSS**
Unit of measurement		*[g/kg]*	*[g/kg]*	*[mg/kg]*	*[mg/kg]*	*[mg/kg]*	*[g/l]*
	Raw digestate	58.3	42.5	4077	2458	505	46.1
	Solid fraction	182.4	155.5	5772	2346	1628	-
	Liquid fraction	49.5	33.6	4070	2492	515	38.9
	Thickened	59.9	42.3	4278	2514	589	-
	Microfiltered	42.5	28.1	4038	2422	453	33.0

Monitoring session of 29 July 2019							
Parameters		**TS**	**VS**	**TKN**	**$N\text{-}NH_4^+$**	**P**	**TSS**
Unit of measurement		[g/kg]	[g/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[g/l]
	Raw digestate	49.4	36.1	3192	1822	476	35.9
	Solid fraction	285.1	257.4	5921	1756	1730	-
	Liquid fraction	41.6	28.4	3144	1843	412	31.1
	Thickened	77.0	59.7	3477	1852	600	-
	Microfiltered	36.8	24.2	3016	1746	407	26.2

Average values of the two monitoring sessions							
Parameters		**TS**	**VS**	**TKN**	**$N\text{-}NH_4^+$**	**P**	**TSS**
Unit of measurement		*[g/kg]*	*[g/kg]*	*[mg/kg]*	*[mg/kg]*	*[mg/kg]*	*[g/l]*
	Raw digestate	53.8	39.3	3635	2140	491	41.0
	Solid fraction	233.8	206.5	5847	2051	1679	-
	Liquid fraction	45.5	31.0	3607	2168	464	35.0
	Thickened	68.4	51.0	3878	2183	595	-
	Microfiltered	39.6	26.2	3527	2084	430	29.6

1.2. Separation efficiencies and rheology of the materials

Despite the high residual dry matter content (almost 5%) of the liquid fraction that was sent from the horizontal screw press separator to the microfilter, under the conditions tested (with a 50-micron filter), the equipment produced an average of 4.2 m^3/hour of microfiltered digestate, with values varying between 3.8 and 4.5 m^3/hour; the corresponding average flow rate for the dense fraction was 1.6 m^3/hour, with values varying between 0.6 and 2.6 m^3/hour. Therefore, the microfilter was able to treat more than 5 m^3/hour of liquid fraction of digestate, on average.

The measurement of the flow rates, together with the analysis of the chemical characteristics of the raw digestate and the different fractions produced, made it possible to calculate the separation efficiencies by weight of materials as they are and for solids and nutrients, which are presented in Figure 4.

Considering 100% the raw digestate as it enters the treatment, approximately 5% by weight is separated as a palatable solid fraction while approximately 70% by weight becomes the microfiltered fraction that can be used in fertigation; the remaining 25% by weight is the dense fraction discharged from the microfilter.

Nitrogen shows a percentage distribution among the three fractions very much in line with the weight partition, while both solids (total and volatile) and phosphorus tend to be more concentrated in the palatable solid fraction, at the expense in particular of the microfiltered fraction, which is accordingly expected to be lightened.

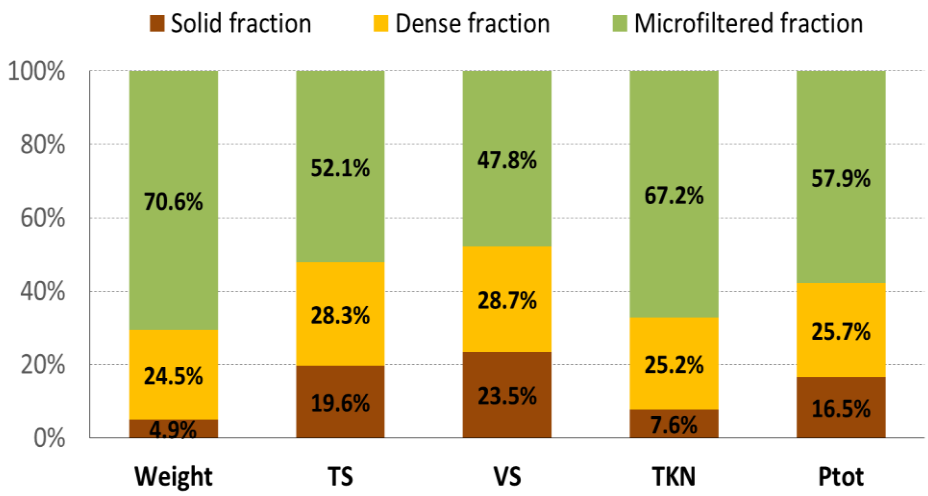

Figure 4: Average separation efficiencies derived from monitoring sessions

The evaluation of the Particle Size Distribution made it possible to verify the efficiency of the solid-liquid separation and microfiltration processes in the selection of particles of different diameters.

The results of the particle size measurements carried out for each of the two complete monitoring sessions are shown in Table 2 below, with total solids and volatile solids contents of the materials and the frequencies measured for the different particle size classes.

While the raw digestate entering the solid-liquid separation was characterised by 30-40% of the total solids included in the particle size class above 100 µm (>0.1 mm), in the clarified digestate the same particle size class accounted for approximately 6% of the total solids while in the microfiltered it was less than 0.5%. In particular, a particle size of less than 100 µm (< 0.1 mm) was measured for 99.7% of the total solids remaining in the microfiltered digestate.

Table 2: Solids content of the three materials and percentages of Total Solids (TS) in the different particle size classes

Monitoring session of 02 February 2019										
	TS [g/kg]	VS [g/kg]	>5mm [%]	<5mm >3.15mm [%]	<3.15mm >2mm [%]	<2mm >1mm [%]	<1mm >0.5mm [%]	<0.5mm >0.3mm [%]	<0.3mm >0.1mm [%]	<0.1mm [%]
Raw digestate	58.3	42.5	5.10	6.73	9.38	5.88	5.77	3.30	5.87	57.97
Liquid fraction	49.5	33.6	0.02	0.07	0.03	0.07	0.42	1.24	4.19	93.95
Microfiltered	42.5	28.1	0.07	0.03	0.06	0.04	0.07	0.03	0.02	99.68

Monitoring session of 29 July 2019										
	TS [g/kg]	VS [g/kg]	>5mm [%]	<5mm >3.15mm [%]	<3.15mm >2mm [%]	<2mm >1mm [%]	<1mm >0.5mm [%]	<0.5mm >0.3mm [%]	<0.3mm >0.1mm [%]	<0.1mm [%]
Raw digestate	49.4	36.1	3.11	3.67	4.23	4.18	3.83	2.53	4.58	73.87
Liquid fraction	41.6	28.4	0.00	0.03	0.13	0.44	1.78	1.91	5.10	90.61
Microfiltered	36.8	24.2	0.02	0.00	0.02	0.04	0.07	0.04	0.19	99.62

Viscosity measurements were carried out on microfiltered digestate (sample of 29 July 2019) using a rotational Brookfield LV DV-E viscometer (Brookfield Engineering Laboratories Inc., USA), at 25°C. Measurements were performed using the disc spindle #61. Since the standard disc-type spindles provided with the viscometer do not have direct definable shear rate and shear stress values, viscosity at different revolution speeds (50-60-100 RPM) were evaluated. Values were determined by triplicate analyses and averaged.

A constant viscosity was observed with the increase of RPM, indicating a behaviour similar to Newtonian fluid for this kind of digestate. The apparent viscosity of the microfiltered digestate was 12-13 cP. The low viscosity of the microfiltered digestate, compared to that of a raw digestate which can range from 20 and up to over 1000 cP depending both on the TS content and the diameter of the particles, should improve the operations of injection and use in the fertigation system (see next paragraph).

2. Fertigation system based on subsurface drip lines

The microfiltered digestate was used for fertilising purposes in an agronomic trial, which will be reported on in WP1, where three treatments were compared: 1) microfiltered digestate through subsurface drip irrigation (SDI); 2) soluble urea through SDI; and 3) business as usual (BAU) with sprinkler irrigation and granular urea. SDI treatments were coupled with minimum tillage. Total surface of each plot (treatment) was almost 1 hectare (25 m large x 350 m long).

In order to be used as a fertiliser, the microfiltered digestate was periodically transferred by means of a tank (total volume of 15 m^3) at the field, so that it could be injected into the subsurface drip irrigation (SDI) plant, mixed with the irrigation water and distributed on maize (summer 2019) and sorghum (summer 2020). The reason why the subsurface fertigation system with injection of microfiltered digestate was used on maize and sorghum is because these are two spring-summer crops that in the study area need both irrigation and fertilization coincident with their development, in order to be able to express their yields to the maximum. This moreover closed the nutrient cycle, as maize and sorghum grown by CAT Correggio were used for energy purposes in the anaerobic digestion plant, becoming biogas and digestate.

The following are the main features of the fertigation system:

• Drip line type is pressure compensated (flow rate 1 l/hour, spacing 0.50 m)

• Drip lines are buried at a depth of 25-30 cm, the distance between them is 1 meter, total length of each drip line is 350 m

• Flow rate per hectare: 18-20 m^3 /ha/hour for water, 1-2 m^3 /ha/ hour for microfiltered digestate

The irrigation water is taken from an open channel through a motor pump and the microfiltered digestate is sucked from the tank through a connection with the water intake pipe of the irrigation system, thanks to a negative pressure.

The mixture of water and microfiltered digestate then passes through a system of disk filters protecting the drip lines, which periodically cleans itself through backwashing cycles involving one filter at a time, so that irrigation can continue. During the backwashing, which lasts a few minutes and is generally carried out on an hourly basis, the flow of digestate is automatically interrupted so that washing can take place with water only.

Both years, the system had to be fine-tuned and therefore suffered some initial delays and a few setbacks during the season but overall the necessary quantities of microfiltered, to compensate for the mineral fertilisation carried out in the BAU treatment, were injected (table 3). Irrigation supplied a total of 160 mm of water over 80 hours in 2019 and 175 mm over 85 hours in 2020.

Figure 5: The fertigation plant with the microfilterd digestate tank and the disk filtration (A), the motor pum and the injection system for microfiltered digestate (B, C), the disks inside the filters (D), the filtration control unit (E) and a water meter (F).

Table 3: Volume of microfiltered digestate injected in the SDI system in 2019 (maize) and 2020 (sorghum)

N.	*DD.MM.YYYY*	*Volume [m³]**		*N.*	*DD.MM.YYYY*	*Volume [m³]**
1	*04.06.2019*	*1.1*		*1*	*28.05.2020*	*5.1*
2	*11.06.2019*	*7.7*		*2*	*23.06.2020*	*11.0*
3	*18.06.2019*	*10.5*		*3*	*29.06.2020*	*9.9*
4	*25.06.2019*	*11.1*		*4*	*20.08.2020*	*5.6*
5	*11.07.2019*	*11.9*				
6	*19.07.2019*	*2.0*				
7	*25.07.2019*	*9.7*				
	Total	*54.0*			*Total*	*31.6*

* referring to an area of 25 m x 350 m = 0.875 hectares

The following table shows the data from some complete monitoring sessions conducted on the fertigation system, with simultaneous sampling of irrigation water, injected microfiltered digestate and their mixture. In addition, for most fertigation interventions, the microfiltered digestate used was sampled for checking of Total Solids and Total Kjeldahl Nitrogen.

Table 4: Results of chemical analyses on inputs to the fertigation system (CAT Correggio)

Monitoring session of 18 June 2019									
	pH [-]	TS [g/kg]	VS [g/kg]	TKN [mg/kg]	$N\text{-}NH_4^+$ [mg/kg]	P [mg/kg]	K [mg/kg]	TSS [g/l]	Conductivity [mS/cm]
Microfiltered digestate	8.2	36.3	23.2	3236	2519	377	4725	25.9	22.6
Irrigation water	7.8	1.3	0.5	11	0.4	6	89	0.04	1.3
Mix water + microfiltered	8.1	3.4	2.0	308	172	27	471	1.7	3.0
Monitoring session of 11 July 2019									
	pH [-]	TS [g/kg]	VS [g/kg]	TKN [mg/kg]	$N\text{-}NH_4^+$ [mg/kg]	P [mg/kg]	K [mg/kg]	TSS [g/l]	Conductivity [mS/cm]
Microfiltered digestate	8.2	44.1	30.1	3667	2074	462	5754	33.4	21.4
Irrigation water	7.6	0.6	0.5	15	2.1	3	81	0.02	1.4
Mix water + microfiltered	8.0	4.8	3.0	519	213	39	727	2.5	3.5
Monitoring session of 23 June 2020									
	pH [-]	TS [g/kg]	VS [g/kg]	TKN [mg/kg]	$N\text{-}NH_4^+$ [mg/kg]	P [mg/kg]	K [mg/kg]	TSS [g/l]	Conductivity [mS/cm]
Microfiltered digestate	7.8	39.5	25.4	3744	2367	451	5164	31.8	24.1
Irrigation water	8.1	1.2	0.4	15	0.3	7	157	0.02	1.6
Mix water + microfiltered	8.1	4.1	1.8	279	186	38	511	1.7	3.4

A particular attention must be paid at the pH of the solution and to the electric conductivity, two major parameters in fertigation, that are crucial for a good agronomic performance. The pH of the distributed solution of water and microfiltered digestate is the same as that of the soil, while the conductivity of the microfiltered digestate is quite high (as that of raw digestate, anyway), but its dilution with irrigation water significantly reduces it to acceptable levels for the two crops.

During the two fertigation seasons there were no problems with clogging of the drip lines, as evidenced by the volume flowing through the system, which remained constant.

To prevent this type of problem from occurring during the fertigation season, each fertigation operation was completed using only water for at least one hour while, with regard to autumn and winter months, with the system switched off, the drip lines were washed with a peroxide acid-based product at the end of the last irrigation operation to ensure greater cleanliness during the period of non-use. Thus, the shelf life of the drip lines fertigation plant is expected to reach or exceed 10 years.

CONCLUSIONS AND RECOMMENDATIONS

The trials demonstrated the technical feasibility of microfiltering the digestate and making it usable in drip irrigation through semi-permanent subsurface drip lines on existing crops.A complete pilot plant at farm scale was developed and validated (TRL 7-8)If the digestate is not subjected to solid/liquid separation and microfiltration, its agronomic use as a raw by-product in most cases does not occur on growing crops and therefore the use efficiency of nutrients and water may result rather low. In fact, the digestate is usually distributed on the soil before ploughing and the fertilization of the crops must be integrated with mineral fertilizers.

The trials demonstrated that it is possible to distribute the digestate in fertigation during the growing season of crops and through drip lines, without causing blockage: the keystone is the new digestate microfiltration equipment. The overall system (screw press separation + microfiltration+ fertigation) allows high nutrients/water/energy use efficiency and therefore can lead to significant savings of resources.

In practical terms, however, it is important to highlight the need for an underground network of pipes for transport the microfiltrate or temporary storages at the field. Otherwise, the alternative is to leave some hours the slurry tanks at the field, for filling the fertigation plant with microfiltrate.

Unique selling points for Microfiltered Digestate to Fertigation (MDF) are:

- Moderate cost and low maintenance equipment, minimising water and energy consumption
- Increase nutrient use efficiency of digestate/slurry, with the possibility of completely (or almost) replacing mineral fertilisers
- Reduction of greenhouse gases and ammonia emissions