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THE POREM BIO-ACTIVATOR AS A SOLUTION FOR DEGRADED SOILS: RESULTS OF FIRST ITALIAN TRIAL

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Abstract

Recent studies have highlighted those European soils are subject to high rates of degradation. Therefore, new strategies to contrast the soil depletion are required. The European project related to POREM (POREM_LIFE17-ENV/IT/333) aims to be a valid solution to the problem with the production of an innovative bio-activator, named just POREM, cheap and based on two main natural raw materials, widely available: poultry manure and a natural enzymatic preparation, derived from plants. Indeed, POREM recycles the main waste of the poultry productions and hence represents a new idea of green fertiliser, which can provide nutrients and organic matter to the soil for their rehabilitation, placing itself in a circular economy strategy.
In this work, the outcomes of physico-chemical characterisations and field application tests, related to the first-year Italian campaign of POREM production at pilot scale, were presented. The characterisation results show the bio-activator maturation over the time and the struvite presence which is a nitrogen compound, useful for N retention and for reducing environmental impact. POREM activity under field conditions on several soils was studied by field tests in Northern and Southern Italy both on vegetable and arable crops. The outcomes demonstrated a significant fertility improvement. Indeed, there are a decreasing of the needed mineral fertiliser and an increase in the yield and crops quality. The field tests planned for the upcoming year campaign will focus on the soil restoration to reduce degradation.

Key words: bioremediation, bio-activator, industrial symbiosis, poultry manure, soil restoration

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1. Introduction

Over the past decades, global climate change and human activity have led to global soil degradation (DeLong et al., 2015; Oldeman, 1991). Considering that about 45 % of the European land was at potential risk of degradation (Cerdan et al., 2010; Hill et al., 1995; Montanarella, 2007), it is crucial to found new solution to protect the soil, preserve its function and restore degraded soil (EUR-Lex, 2006). Soil degradation is understood as a set of mutually dependent factors leading to land degradation: biological, chemical, physical degradation and erosion (Johnson et al., 1997). The main consequence of this is the decline in soil fertility (Hartemink, 2006; Soil Science Society of America, 1997) that is defined as ''the quality of a soil that enables it to provide nutrients in adequate amounts and in proper balance for the growth of specified plants or crops''. The main causes of soil erosion are wind, ice, water and movement related to gravity.

Water erosion can be natural or accelerated by human activity phenomena depleting the soil structure by the action of water. The rate of erosion is not equal

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in all the lands and it is affected by several parameters depending on the soil, local landscape, and weather conditions. In particular, wind erosion is ascribable to strong winds which blow over the soils with a light texture when the drought comes. In the case of ice erosion, it means the abrasion of the land by movement of a glacier onto the ground. Physical degradation includes very different processes and morphometric forms. One of them is the deformation of the inner soil structure by compaction, caused by tracking with heavy agricultural machinery. Also, it includes the formation of crusts at the soil surface by water and wind erosion (Blum, 2011). Biological degradation of soil refers to the decrease or elimination of one or more "significant" populations of microorganisms in soil, often with a resulting change in biogeochemical processing within the associated ecosystem (Sims, 1990).

Chemical degradation is due to changing the elemental concentration of soil thus altering salinification, acidity and toxicity. The main causes of solid acidification are the use of acid-forming nitrogenous fertilisers, the deforestation and the effects of acid precipitation. Soil salinization is the accumulation of free salts; accumulation can extend so much leads to degradation of the agricultural value of vegetation and soils. It is carried out by a combination of both natural and human-caused processes. Another important phenomenon of chemical degradation involves the decrease of carbon concentration which is highly relevant to cultivated fields.

A key soil component is organic matter (SOM), which affects plant growth both indirectly and directly (Bongiovanni and Lobartini, 2006). The main SOM benefits are that it acts as a storehouse for nutrients, it is a source of soil fertility and contributes to soil aeration reducing soil compaction (Jones et al., 2005). Also, it determines the improvement of infiltration rates and the increase in storage capacity for water. Another important contribution is that SOM is a buffer that preserves the soil from rapid acid changes and it is an energy source responding to the needs of soil microorganisms (Van-Camp et al., 2004). As far as Europe is concerned, several areas have low levels of SOM; the European commission report estimates that the 74% of land in Southern Europe has "very-low/low" carbon concentration in soil (Van-Camp et al., 2004). The common strategy is to use compost to mitigate soil carbon loss associated with crop harvesting/agricultural production. (Zheng et al., 2020). However, the aim of the work is focused on the production of soil bio-activator - an association of organic matter for soil fertility and nutrients for plants/crops. The applied technique and the LIFE project are coherent with the research direction of composting technology: integration of mineral/nutrients with organic matter. But, in this case, mineral/nutrients are already inside the substrate (poultry manure) and the technique is addressed to reduce gaseous losses, both for C and N, and develop the autochthone microbial part. (Dall'Ara et al., 2019). Indeed, the simplified treatment can be performed also on farm and static process can reduce volatile compound emissions. Nitrogen is another important element needed for crops and life cycles of the ground. It is used in agronomy in order to stabilise the ground nitrogen concentration, fertilisers base on it. Phosphorus is considered of great importance during the first stage of plant development. The only soluble form of phosphorus that can be assimilated by plants is the orthophosphate ion, with a negative charge. Moreover, the concentration of magnesium, potassium, calcium and sodium determines the Cation-exchange capacity (CEC) and it affects soil fertility. The so called "microelements of soil" (Fe, Mg, Mb, Zn, Cu and B) have an essential role in the plant growth, but an excessive concentration of Zn, Mb and Cu is considered a potential pollutant and toxic for the crops.

All the country patterns of the project related to POREM, Italy (Basso et al., 2003), Spain (Van-Camp et al., 2004) and Czech Republic (Žížala et al., 2019, 2017), have a direct national interest in soil degradation. The definition of *soil degradation* is different for each country: for the Spanish soils, it is related to the plant's absence caused by erosion (rain, flood); for Czech soils to the abiotic and biological immobilization and leaching, which caused structural damage, soil compaction, surface run-off; finally, for Italian soils it is ascribable to the soil's exploitation and the resulting Low Organic Carbon percentage. In particular, our research is based on two Italian locations for field testing: Forlì-Cesena Province (Emilia Romagna region, Northern Italy) and Loc. Tertiveri, Biccari, Foggia Province (Puglia region, Southern Italy). These soils are degraded as shown by their poor carbon concentration. Indeed, the average carbon percentages reported in the data of ARPA Emilia-Romagna maps at (44.166095, 12.267886) are in the range of 1.1 - 1.3 % (Staffilani et al., 2015). Soil samples of each location were collected and analytic experimental measurements of carbon (total and organic) were carried out by Elemental Analyser LECO C, N, S technique in CEBAS CSIC Certified laboratory. The tests showed respectively a value of 1.62 ± 0.06 % of total carbon soil for the Cesena field and in the Biccari location an amount 1.4 ± 0.2 % of percentage of carbon soil. These quantities do not guarantee an appropriate grade of fertility for the crops as described in the report of ARPA Veneto (Giandon and Bortolami, 2007; Van-Camp et al., 2004). In the present work, the physico-chemical characteristic of POREM bio-activator will be analysed during its maturation. Moreover, the effect of POREM as sustainable fertiliser for degraded land will be evaluated by field tests.

2. Material and methods

2.1. POREM bio-activator production at pilot scale

According to EP1314710 (Memmi and Ridolfi, 2002), the POREM bio-activator production is carried out forming three piles of poultry manure (3ton)

whose was added the Vegetable Active Principles, that is an enzymatic preparation based of plants. The piles were made under a roof, but not isolated in a room, to ensure the natural air recycling. It is an innovative, simplified and static process which allows the POREM maturation, along 120 days, with oxygen available from natural convection. For these characteristics, the process can be considered an "energy saving biotreatment" and then it is a low-cost technology. Moreover, POREM bio-activator derives from waste product of the poultry industry, widely available, which is reused, in accordance with a circular economy strategy. All these aspects influence the bio-activator cost, which is lower than other technologies (e.g. compost needs the oxygen supply and the overturning of the pile, procedure which increases the cost of technology).

The POREM bio-activator were produced in two different Italian production sites, Puglia and Calabria (hereinafter referred to as ITP and ITC respectively), to test the replicability of the bio-activator production process. ITP samples derive from poultry raised in litter and whose diet only includes seeds, while ITC samples derive from poultry whose diet provides additional calcium to help them in the eggshell formation.

2.2 POREM bio-activator sampling procedure

The POREM properties were evaluated at different maturation time: thirty (t30), sixty (t60), one hundred and twenty (t120) days and also the as prepared POREM (t0) was analysed as reference starting point. Moreover, each sample consisted of the mixing of sub-samples collected by different pile positions. Specifically, three samples were collected for each pile (e.g. samples 1.1, 1.2 and 1.3 from pile 1) and each represented a portion of the pile (i.e. 1.1➔A, 1.2➔B, 1.3➔C; see Fig. 1). Each individual sample consisted of six subsamples, collected at three different points of the same part (top, bottom and middle) and two different depths (20cm and 50cm). This sampling procedure was followed for each selected maturation time and each pile. Therefore, for each sampling time, nine samples were obtained (Fig. 2, ITP production case). Subsequently, the samples were dried and grinded by CEBAS-CSIC in order to obtain homogeneous samples. The analyses were carried out on individual sample and the final properties were calculated as the mean of the measured values.

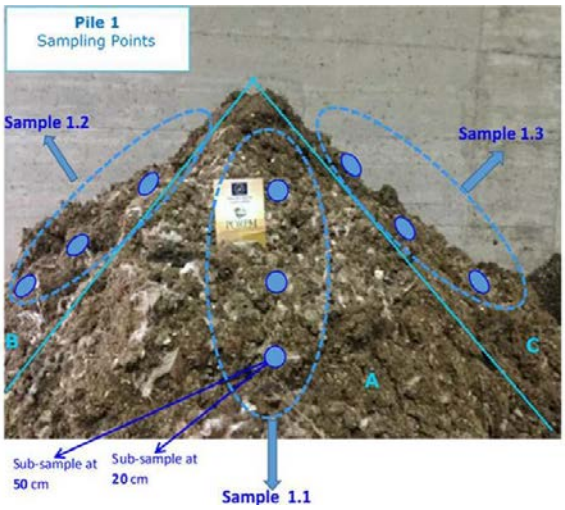


Fig. 1. Diagram of POREM bio-activator sampling (pile 1)

2.3 Physico-chemical characterisation methods

Using the Simultaneous Thermal Analyser (STA 409C, Netzsch), in Thermogravimetric Analysis (TGA) mode, the mass loss and the differential of mass loss were measured to detect decomposition phases and evaluate the thermal stability of the samples. The TGA were carried out under the following conditions: inert dynamic atmosphere (argon, 100 mL/min), heating rate of 10 ° C / min, final temperature of 1000 °C and initial mass of the sample of 850 mg.

Scanning Electron Microscopy (SEM, LEO 438 VP) was used to observe the morphology of the POREM bio-activator. Moreover, a compositional semi-quantitative analysis was carried out by Energy Dispersive X-Ray spectroscopy (EDS, ISIS 300), through the specific detector the SEM is supplied with. The average composition was acquired and, in localised areas of particular morphology, the specific composition was also obtained. All samples were characterised as received, without any pre-treatments and, therefore, avoiding any possible contamination or damage. Different areas were analysed by SEM-EDS in each sample to have more reliable and representative results.

The X-Ray Diffraction analysis (XRD, Philips PW1710, Bragg–Brentano geometry) was performed for the identification of the crystalline phases in POREM samples (CuKα 40 kV-30 mA, scan step time 3 s, step size of 0.02°).

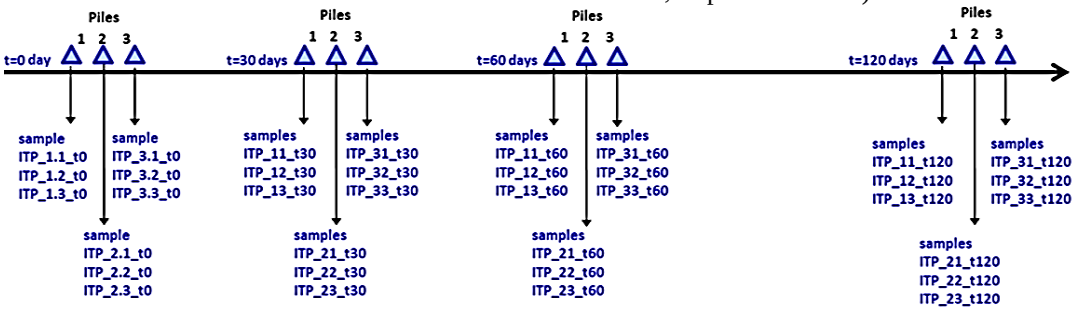


Fig. 2. Flow chart of ITP experiment

2.4 Parameters of field tests and related agricultural index

POREM bio-activator was tested on two Italian soils (Forlì-Cesena, Emilia-Romagna region and Foggia, Puglia region), described in Table 1. The aim of the experimental field tests was the evaluation of yield quantity and quality improvement obtained from crops grown in soils treated with POREM bio-activator or with standard fertilisers in comparison to crops grown in untreated soil.

Pilot field tests in Italy demonstrated improvements in terms of quantitative and qualitative production (yield) of arable and vegetable crops grown on soils treated with POREM. In Forlì-Cesena area (Northern Italy), POREM was tested on industrial tomato production under conventional farming. Crop evaluations were executed comparing the performance of POREM bio-activator (40 nitrogen units per hectare) to that of a conventional mineral fertiliser NPK 26-46-50 (130 nitrogen units per hectare), used as chemical standard reference; in addition, an area not treated (untreated check) was included in order to carry out result comparisons. The standard fertiliser amount was set in order to provide a nitrogen amount calculated on the basis of indications reported by the Emilia-Romagna Region IPM (RER Directive, 2020). This first pilot test on vegetable crops was carried out with four replicates per each treatment. The crop was evaluated by the improvement in marketable fruit production in comparison with the untreated reference and by the quality parameter of Brix degree**,** which assesses the sugar content in marketable fruits. Crop health and vigour Index, which measures the increase in plant growth or foliage volume through time after planting, was also considered. The test was replicated on barley crop and was carried out in the hills near Foggia area (Southern Italy), characterised by poor and degraded soil in organic farming.

Field evaluations and crop production were observed on the two fertilisers (POREM application at 80 kg N/ha and Bioazoto N12 at 80 kg N/ha, used as organic standard reference); an adjacent untreated area was used for comparisons in field data recording.

Table 1. Initial characteristics of Italian soils

Parameters		***FORLÌ-CESENA soil***	***FOGGIA soil***
		mean values	
pH	**-**	6.98	8.35
Electrical Conductivity	**µS/cm**	94.00	121.83
Bulk density	**g/cm^3**	1.16	1.15
Aggreggates	**%**	69.17	44.51
B-Glucosidase	**µmoles PNF/g*h**	0.43	1.19
Phosphatase	**µmoles PNF/g*h**	1.48	3.45
MACROELEMENTS			
Calcium	**g/100g**	1.19	13.43
Assimilable calcium	**meq/100g**	24.89	24.34
Potassium	**g/100g**	0.76	0.86
Assimilable potassium	**meq/100g**	0.55	1.19
Magnesium	**g/100g**	0.95	0.49
Assimilable magnesium	**meq/100g**	2.82	1.12
Sodium	**g/100g**	0.04	0.05
Assimilable sodium	**meq/100g**	0.26	0.22
Phosphorus	**g/100g**	0.05	0.06
Assimilable phosphorus	**meq/100g**	21.67	8.97
Sulfur	**g/100g**	0.03	0.09
MICROELEMENTS			
Boron	**mg/kg**	36.03	24.70
Iron	**g/100g**	3.43	2.44
Manganese	**g/100g**	1076.30	1212.82
Cadmium	**mg/kg**	0.73	0.51
Lead	**mg/kg**	56.07	32.11
Cooper	**mg/kg**	40.57	29.55
Chrome	**mg/kg**	106.70	43.45
Nickel	**mg/kg**	67.17	26.25
Zinc	**mg/kg**	85.83	51.79
Total nitrogen	**%**	0.15	0.13
Total nitrogen water soluble	**ppm**	20.13	0.53
Total organic carbon	**%**	1.08	1.37
Water soluble carbon	**ppm**	167.67	237.48

In this case, each treatment was evaluated in two different field parts (upper and lower, for a total of six replicates), characterised by two different soil structure based on gravel and stone quantity. The crop was evaluated by plants improvement in number and vigour, at crop-emergence and pre-flowering, and production improvement in grain weight at harvest, in comparison to the crop grown in the untreated land. All field results were evaluated with ANOVA analysis which was performed with the ARM Software.

3. Results and discussion

The analysis of the bio-activator POREM has foreseen two phases: the characterisation to establish its intrinsic physico-chemical properties, both of Calabria and Puglia samples, and the field tests to evaluate its activity on the crop. The measures also include the error due to adverse climatic conditions, as in the case of ITC POREM samples around 120 days.

3.1. Physico-chemical characterisation of POREM bio-activator

The TGA results clearly suggested four main steps of mass loss which characterise the ITC and ITP samples (Cimò et al., 2014; Lee et al., 2017). Indeed, in the temperature range 25-220°C, water removal occurred. At around 220°C, the pyrolysis of organic matter began and ended at 550°C. This degradation occurred in two steps: the first, between 220°C and 380°C, corresponds the to the thermal decomposition of aliphatic fraction, that is the alkyl labile and carbohydrates systems; the second (380-550°C), to the decomposition and thermal transformation of aromatic moieties.

Finally, between 550-1000°C, the inorganic components of poultry manure have degraded with the thermal transformation of biogenic salts (i.e. calcium carbonate) and mineral. Table 2 summarises the TGA main results of Italian samples, over the time; each result is the mean of the samples collected from the three different piles. The comparison of the results highlighted a reduction of the organic matter over the time, particularly in the 220-380°C range, which is related to the aliphatic compounds of organic part (e.g. straw decomposition). Consistent with expectations, this trend is probably due to the bio-activator maturation: during this process, the organic fraction decreases, up to stabilise itself to the value which characterises the material.

Moreover, the fourth ITP step percentage of mass loss (i.e. the inorganic part) has grown slowly than ITC samples. This is related to the raw poultry manure composition: ITC showed a higher inorganic fraction than ITP samples due to the relevant calcite presence in the initial poultry manure, related to the hens' diet rich in Ca for the eggshell formation. The initial absence of Ca in ITP samples justifies the lower percentage of mass loss in this temperature range and the slow growth over the time, which is probably due only to mineralization. It can be assumed that the presence of $CaCO_3$ (or Ca) in ITC samples acted as an adjuvant for mineralization which, however, also occurred in ITP samples resulting in a slow growth of mass loss over the time. This effect is important because the mineralization and the related compounds can be considered a basin of soil nutrients.

As shown in Table 2, from the comparison among the samples collected from the different piles, the standard deviation is less than 1% for all the mass losses steps of ITC samples and less than 0.5% for about all the mass losses steps of ITP samples. Finally, the Table 2 shows how, at around 60 days, the mass tended to stabilise.

The main differences between ITC and ITP thermograms are well summarised and shown in Fig. 3(a) which depicts the mass loss and DTG (first Derivate of TG) of these POREM samples at t0: between 550-1000°C, the higher percentage of inorganic compound (i.e. calcite) in ITC sample compared to ITP sample; in the range 200-380°C, the double peak in ITP sample DTG, due to the litter straw, which was absent in ITC. Indeed, this region is typical of hemicellulose and cellulosic components. Finally, to demonstrate the homogeneity of POREM production, the replicability was also studied at piles and samples level.

Table 2. Comparison among the Italian POREM mass losses [wt%], over time

Sample Name	*Mass Losses [wt%]*		
	[220-380] °C region	*[380-550]°C region*	*[550-1000]°C region*
ITC t0	36.6 ± 0.6	13.7 ± 0.8	9.5 ± 0.4
ITC t30	28.8 ± 0.7	11.6 ± 0.4	13.7 ± 0.9
ITC t60	27.3 ± 0.4	12.5 ± 0.8	13.1 ± 0.8
ITC t120	19.9 ± 0.2	8.7 ± 0.3	16.9 ± 0.5
ITP t0	37.7 ± 0.1	10.6 ± 0.4	6.8 ± 0.2
ITP t30	36.0 ± 0.5	11.2 ± 0.1	7.6 ± 0.3
ITP t60	35.7 ± 0.3	11.9 ± 0.2	7.7 ± 0.1
ITP t120	33.0 ± 0.4	11.0 ± 0.1	7.5 ± 0.2

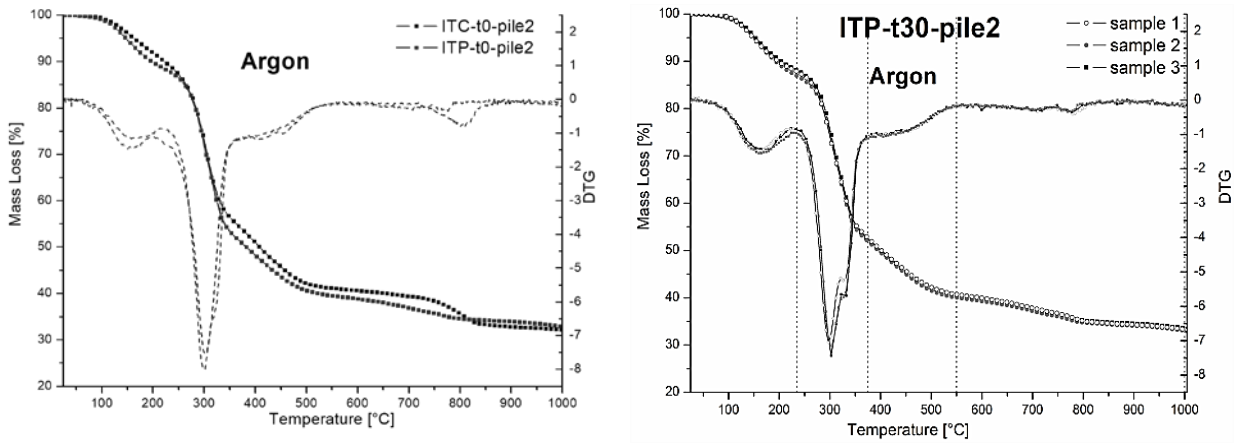
As depicted in the typical comparison between the three samples collected from the same pile shown in Fig. 3(b), the thermograms are well overlapped. Therefore, the properties showed a great level of replicability. The bio-activator morphology was heterogeneous and the micrographs showed several residues such as fibres and different shaped particles (Fig. 4a). Moreover, it was possible to identify specific particles performing localised microanalysis, as shown for calcium salt in Fig. 4b.

The production process of the POREM bio-activator was replicated at different level (sample and pile), showing similar composition with no significant variations. All samples are mainly composed of C and O, but also soil nutrients (Ca, P, K, Mg, S, etc.) are present in small quantities. The analysis of the three piles in both sites at any maturation time was averaged to show more clearly the composition trend of each element over the process.

The composition trend during the POREM maturation was shown in Table 3. The reported values were very stable over time, highlighting a remarkable process uniformity (the only data slightly out of range, Si in ITC sample at 120 days, may have been caused by the adverse conditions that occurred in Calabria around 120 days. Presumably, the rain could have dragged small percentages of sand, close to the pile, which may have been detected in the analysis). The results showed similar composition during the maturation process in both the sites, except for some differences due to the farm and hen's type.

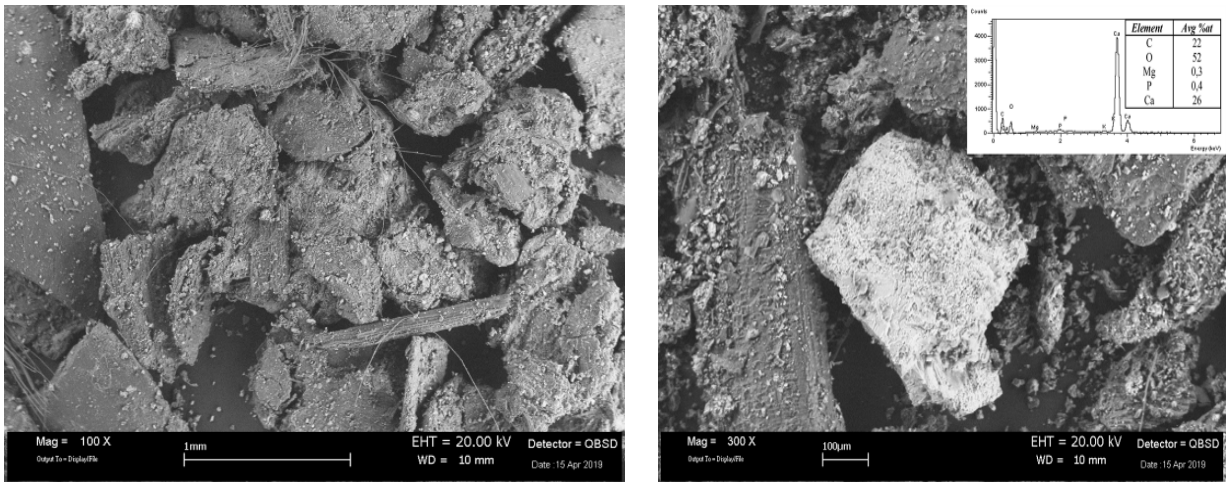
In general, the inorganic fraction increases with time. More specifically the carbon amount does not exhibit too remarkable variation. This observation, combined with the stability of calcium content, could be also an indication of calcite ($CaCO_3$) formation and C retention with consequent CO_2 evolution reduction and therefore benefits from an environmental point of view. Moreover, nitrogen is unfortunately not detectable because its EDS peak energy is between those of C and O and their high intensity completely hides that of N. However, the persistence of P and Mg contents could be an indirect sign of the struvite ($NH_4MgPO_4 \cdot 6H_2O$) formation. If so, the precipitation of N into struvite crystals would not allow a large amount of nitrogen to be released into the environment as ammonia or nitrates with a gain for the environmental impact also in this case. Finally, the presence of other elements, such as S, K, Na, Cl still at the end of POREM maturation process, is promising for its application as soil bio-activator.

The POREM bio-activator samples were composed from both amorphous and crystalline phases (Fig. 5). ITP XRD patterns shown a considerable presence of the amorphous, ascribable to the litter straw derived from the origin manure. The high content of amorphous phase hid peaks of the crystalline phases and calcite and struvite were recognised as main phases, as showed in Fig.5 (a). Instead an amorphous phase decreasing was evident for ITC samples at maturation time increasing; the crystalline main phase consisted of calcite and struvite while weddellite ($Ca(C_2O_4) \cdot 2H_2O$) was recognised as secondary phase, probably due to a manure derived by calcium rich diet (Fig. 5b).



(a) (b)

Fig. 3. Typical POREM bio-activator thermograms and relative derivate: Comparison between ITC and ITP, piles 2, at t0 (a); Comparison among the three samples of ITP piles 2, at t30 (b)



(a) (b)

Fig. 4. Typical POREM bio-activator morphology (a) and specific particle with localised microanalysis (b)

Table 3. Average elemental composition of POREM bio-activator during the maturation

	Calabria				*Puglia*			
Element	***t0***	***t30***	***t60***	***t120***	***t0***	***t30***	***t60***	***t120***
C	49±2	52±1	52±4	40±8	54±4	49.1±0.5	47.2±0.8	51±3
O	45±1	41.3±0.7	41±3	48±5	40±3	43.15±0.04	44.8±0.7	43±2
Na	0.29±0.05	0.25±0.04	0.30±0.03	0.4±0.1	0.48±0.08	0.52±0.04	0.51±0.02	0.51±0.07
Mg	0.5±0.2	0.56±0.01	0.58±0.08	0.9±0.3	0.48±0.06	0.60±0.07	0.59±0.01	0.5±0.1
Al	nd	0.02±0.02	0.08±0.05	0.3±0.3	0.2±0.1	0.22±0.08	0.11±0.06	0.11±0.04
Si	nd	nd	nd	0.2±0.2	0.5±0.1	0.8±0.2	1.0±0.1	0.6±0.1
P	1.1±0.2	1.35±0.09	1.2±0.1	1.9±0.6	1.0±0.1	1.2±0.1	1.24±0.02	1.0±0.2
S	0.29±0.02	0.30±0.02	0.29±0.03	0.4±0.06	0.35±0.01	0.38±0.01	0.43±0.04	0.45±0.06
Cl	0.14±0.04	0.17±0.05	0.21±0.01	0.25±0.03	0.5±0.1	0.60±0.07	0.54±0.05	0.54±0.06
K	1.2±0.2	1.12±0.07	1.2±0.1	1.8±0.1	1.3±0.1	1.55±0.08	1.56±0.04	1.5±0.2
Ca	3.2±0.8	3.4±0.4	3.6±0.6	5±2	1.5±0.3	1.9±0.2	1.9±0.1	1.6±0.3

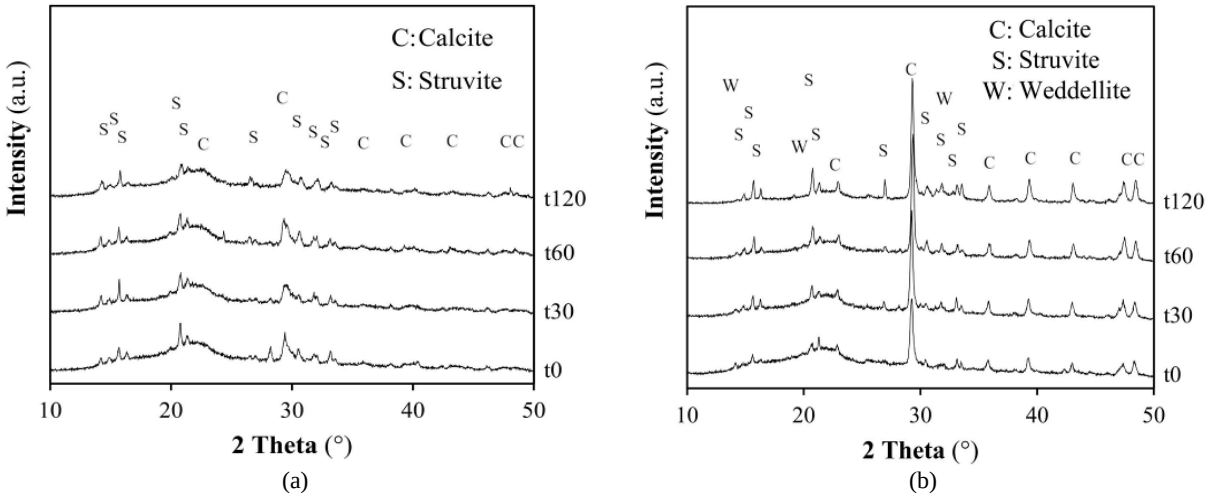


Fig. 5. Typical POREM bio-activator XRD patterns of ITP (a) and ITC (b) samples at different maturation time

3.2. Effect of POREM bio-activator application: field tests

On the vegetables pilot test in Forlì-Cesena area, the industrial tomato crop treated with POREM obtained a significant increase of marketable crop production and quality, overall crop status and biomass (Normalised Difference Vegetation Index) with respect to that of plants grown without fertiliser. The field assessments were carried out in all replicates per treatment and each parameter data are summarised in a table as overall mean (only significant parameters are presented, Table 4; please note: in ANOVA method, the same letter ("a" or "b") is used to identify values not significantly different; P=.05, Student-Newman-Keuls). Field data proved that the tomato crop treated with POREM obtained a yield statistically comparable to that treated with a mineral fertiliser commonly used in the area.

Particularly, the crop production treated with POREM reached values of sugar content of the berries (°Brix) which were significantly higher than that fertilised by a standard fertiliser, with products of mineral origin, resulting in an improvement in the commercial value of fruit production, recognised by processing companies. Overall trend of results on plant observation confirmed the POREM effectiveness in comparison to untreated, with higher leaf development and a superior ground coverage by plants, statistically comparable to that with the mineral fertiliser. In all the parameters assessed at the beginning of crop growth, POREM provided a general better performance ("starter effect") in comparison to the standard fertiliser, with a lower quantity of available applied nitrogen.

On the test on cereals (barley crop), in Southern area (Puglia) plants grown on soil treated with POREM obtained a significant increase of marketable crop production with respect to that of plants grown without fertiliser, and even superior to the conventional organic fertiliser in terms of plants emerged, overall crop status and absence of yellowing on foliage. For barley test, the assessments were carried out in both single field parts; each parameter are summarised as overall mean with six replicates per treatment (Table 5; please note: in ANOVA method, the same letter ("a" or "b") is used to identify values not significantly different; P=.05, Student-Newman-Keuls).

Field data on barley showed a similar or even superior production on soil with POREM in comparison with that obtained with a conventional organic fertiliser in a land area characterised by a high quantity of gravel and stones.

Table 4. Assessments on marketable production on tomato (vegetable crops, Emilia Romagna)

Treatment	*Fruit production [g/plant]*	*Production improvement [%]*	*Brix index [°Brix]*	*Brix index Improvement [%]*
Untreated check	1359.4 [b]	Reference [b]	4.9 [b]	Reference [b]
Standard fertiliser	1926.2 [a]	+42 [a]	5.2 [a]	+7 [a]
POREM	1813.5 [a]	+33 [a]	5.6 [b]	+16 [b]

Table 5. Assessments on ground cover and marketable production on arable crops (barley, Puglia)

Treatment	*crop-emergence [plants/sqm]*	*Plant improvement at crop-emergence [%]*	*pre-flowering [plants/sqm]*	*plant improvement at pre-flowering [%]*	*Production [g/plant]*	*Production improvement [%]*
Untreated check	236 [b]	Reference [b]	257 [b]	Reference [b]	1026.5 [b]	Reference [b]
Standard fertiliser	220 [a]	7 [a]	236 [a]	-8 [a]	1629.0 [a]	+37 [a]
POREM	281 [b]	+19 [b]	300 [b]	+17 [b]	1943.3 [a]	+47 [a]

POREM provided on barley crop an initial general better performance on the parameters observed ("starter effect") in comparison to the standard fertiliser, obtaining better results although with equal amount of available nitrogen. The comparison of results obtained in the lower and upper land parts of the field, showed that the "likely lower fertility", observed in the 'upper' land, linked to the structure of the soil including a higher quantity of gravel and stone, mostly influenced the performance of POREM. Based on these considerations, POREM showed a superior performance since the crop emergence up to harvest than standard fertiliser, providing a more evident bioremediation effect in degraded soils. Finally, the innovative bioremediation fertiliser POREM is proposed as a sustainable fertiliser to be used particularly in degraded land.

The main positive effects of the bioremediation POREM development and application can be resumed as an improvement in the ecologically friendly and sustainable crop production.

4. Conclusions

The first POREM production in Italy and its application have highlighted the intrinsic properties of the bio-activator which potentially made it useful for the plants and the soils. Indeed, it appeared as a product rich in micronutrients and carbon, natural and obtained from an innovative, sustainable and natural process which reuses the by-product of poultry industry.

The physico-chemical properties of POREM bio-activator were time-dependent until around 60 days when they showed a tendency to stabilise; this effect, related to the maturation, can be consider an indirect demonstration of the innovative, static and simplified process efficacy. As well as the stability, the replicability was demonstrated at different levels (sample and pile) and it confirmed the POREM process efficacy.

The mineralization also had an evolution over time. It is important because the mineralization can become a basin of nutrients, i.e. P or N, fundamental for the soils. Indeed, field tests have highlighted that POREM applied to soil provides a bioremediation effect, especially in "poor" and degraded land. POREM provided on both cereal and vegetable crops an initial general better crop performance ("starter effect") in comparison to the standard fertiliser, showing to be generally more efficient with an inferior or equal quantity of available nitrogen applied. The struvite presence constituted a N basin which became available.

Finally, the Italian field pilot tests showed positive results after POREM application to the soil: the crop growth and harvested product quality and quantity were better, compared to unfertilised and standard fertilised soils.

Future developments provide for replication of this experimental campaign, to confirm results and also to evaluate soil quality improvement after repeated POREM applications. Moreover, the comparison and analysis of after-applied results collected from Italy and the other European places will be also the subject of future investigation.

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