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YIELD AND QUALITY OF MAIZE GROWN ON A LOAMY SOIL AMENDED WITH NATURAL CHABAZITE ZEOLITITE

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Abstract

The agronomic use of natural zeolite is widely supported by several works. However, almost all are focused on the application of the clinoptilolite as slow plant-nutrient fertilizer and soil conditioner. Our study describes the first comprehensive study on the effects of a Italian chabazite-bearing zeolitite (rocks containing more than 50% of zeolites) on a maize cultivation. The objective was to determine the effects of applying zeolitite on (i) *Zea mays* yield and quality, under two irrigation regimes and (ii) check if it can improve the efficiency of urea fertilization on a loamy soil in an open experimental field of Italy. The production and quality of the corn grown in the traditional way was compared with that of the plots treated with two different amounts of zeolitite (4 and 8 Kg/m^2) and each treatment was monitored both in irrigated and not-irrigated conditions. The measurements of chlorophyll and those related to the morphological features of the plants show suffering conditions of the corn plants in not-irrigated conditions. Furthermore we show that the plants grown with zeolitite and fertilized with less urea have produced the same amounts of corn plants fertilized with traditional contents of urea.

Keywords: *reduction of fertilization; not-irrigated conditions; SPAD; plant morphology measurement.*

Introduction

A more efficient use of water and soil nutrients for sustainable food production is fundamental to face the increasing food demand. Modern agriculture has taken on the new challenge to find innovative strategies which allow an increase in crop production without endangering the health of the environment and mankind. One of the most advanced and natural-based technique is the use of rocks and minerals as a slow plant-nutrient fertilizer and soil conditioner (Van Straaten, 2002; Latifah et al., 2011; Coltorti et al., 2012; Gholamhoseini et al., 2013; Colombani et al., 2015; Zareabyaneh and Bayatvarkeshi, 2015). Natural zeolites, pioneering "mineral

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fertilizers", are minerals with peculiar physical and chemical properties like high and selective cation exchange capacity (CEC), molecular sieving and reversible dehydration (Bish and Ming, 2001). Natural zeolites charged with nutrient cations (NH_4^+, K^+, Ca^{2+} etc.) are considered one of the best slow-release fertilizers for plants, which substantially increase nutrient use efficiency and crop yield (Barbarick and Pirela, 1984; MacKown and Tucker, 1985; Ferguson and Pepper, 1987; Iskenderov and Mamedova, 1988; , Ming and Allen, 2000; Andronikashvili et al., 2007; Sepaskhah and Barzegar, 2010; Omar et al., 2011; Prisa et al., 2011; de Campos Bernardi et al., 2013, Gholamhoseini et al., 2013, Li et al., 2013, Moraditochaee et al., 2013).

The improvement of soils' physical and chemical properties through the use of zeolites has been widely described in literature. Zeolites maintain soil buffering and indirectly regulate soil pH (Polat et al., 2004), as well as improve water retention (Durukan et al., 2014). Colombani et al. (2014) showed the reducing of loss in nitrogen and water in soils amended with natural zeolites with respect to those treated with chemical fertilizer. Conditioning soils with zeolites improve their CEC and favours the development of helpful microorganisms, such as nitrogen-fixing bacteria (Andronikashvili et al., 2007, Ferretti et al., 2015) and allow the dissolution of phosphates (, Pickering et al., 2002; Lancellotti et al., 2014).

Notwithstanding the great amount of works on this topic, almost all of them are related to the use of clinoptilolite, the most abundant and diffused zeolite in the world (Faghihian et al., 2008, Malekian et al., 2011). In this paper we therefore focus the attention on the natural chabazite-bearing zeolitite (Malferrari et al., 2013). Zeolitites are rock containing more than 50% of zeolites (Galli and Passaglia, 2011, Passaglia and Laurora, 2013) characterized by high CEC and remarkable selectivity for low ionic potential cations (NH_4^+, K^+, Pb^{2+}, Ba^{2+}; Passaglia, 2008). The uptake of ammonium from solutions in various environments (Faccini et al., 2014) and its slow release upon plants requirement (Colombani et al., 2014, Faccini et al., 2014) is a key feature of the chabazite-bearing zeolitite.

We report for the first time, the results of an experiment based on the use of agronomic zeolitites in plots without irrigation and with reduction of fertilization. The production and quality of the corn grown in the traditional way has been compared with that of plots treated with two different amounts of zeolitite (4 and 8 Kg/m^2) and each treatment was monitored in "normal" irrigation regimes and not-irrigated conditions.

Our work describes the effects of a Chabazite-bearing zeolitite amendment on maize cultivation in order to verify if this natural material, very abundant in Italy, can improve water and nutrients use by plants, for a more sustainable maize production. The objective was to determine the effects of applying zeolitite on (i) maize yield and quality under two irrigation regimes and (ii) check if it can improve the efficiency of urea fertilization on a loamy soil in an open experimental field of Italy.

Yield and quality of maize grown in each plot were determined by plant morphology measurement, and determination of the greenness (chlorophyll content) of corn thought the Soil Plant Analysis Development (SPAD, Wood *et al.*, 1992) chlorophyll meter.

Materials and methods

The natural K-rich, Na-poor zeolitite (Ø=3-6 mm) used in this study has been quarried from Sorano village (Vulsini Mountains, Lithic Yellow Tuff body; Central Italy) and provided by the Verdi Firm. Actually it is a granular byproduct of the quarrying activity in a large zeolitized pyroclastic deposit whose total zeolitic content is on average 70% (Chabazite, 68.5%; Phillipsite, 1.8%; Analcime, 0.6%; Malferrari *et al.*, 2013). The total CEC of the zeolitite is 2.17 meq/g, 1.46 of which is due to Ca, 0.6 to K, 0.07 to Na and 0.04 to Mg. Apparent density and water retention are 0.56 g/cm^3 and 34.2%, respectively; heavy metal and radiogenic element contents are very low. For detailed mineralogical and chemical characterization of the used zeolite refer to Malferrari et al. (2013).
Field experiment was conducted during the 2014 growing seasons on the loamy soil of the Foundation for Agriculture Fratelli Navarra, near Ferrara (44°51'27.60"N, 11°39'37.68"E). One week before field preparation, zeolite was transported from Sorano to the study site and was incorporated into the top of the soil by tillage. Figure 1 shows the parcels subdivision and the different types of treatment used for the maize cultivation.

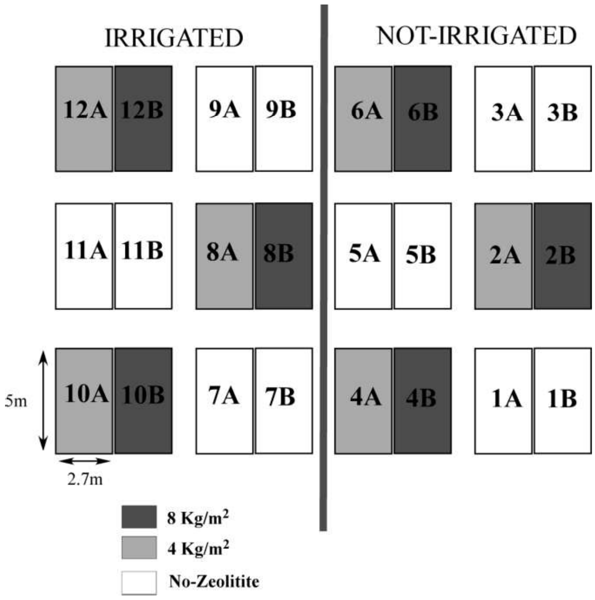

Figure 1
Schematic parcel subdivision of the experimental field.

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During the experimentation, control plots, with no addition of Chabazite-bearing zeolitite, in both irrigated and not-irrigated conditions (hereafter NoZeoW and NoZeoD) were compared with those treated with zeolitite, using: 1) 4 Kg/m^2 of zeolitite and absence of irrigation (hereafter 4KgD); 2) 8 Kg/m^2 of zeolitite, and absence of irrigation (hereafter 8KgD); 3) 4 Kg/m^2 of zeolitite with irrigation (hereafter 4KgW); 4) 8 Kg/m^2 of zeolitite, with irrigation (hereafter 8KgW).
300 kg/ha of urea was applied on both NoZeoW and NoZeoD plots. Following the guidelines of the Zeolife project (www.zeolife.it) in which the zeolitite is coupled to a reduction of the fertilizer, in the zeolitite treated parcels we applied a reduction of urea of 20%, lowering until 240 kg/ha. *Zea mays* L. (FAO 600 maturity class; Jugenheimer, 1958) was sown on 30/03/2014 and harvest on 24/09/2014. Maize sowing was made using a inter row spacing of 45 cm and seeding density of 8.55 $seed/m^2$. The drip system has been used as method of irrigation, setting a water flow of 0.57 l/h. Table 1 shows the total of water used for irrigation and the amount of rain fall on the experimental field for each month.

Month	Irrigation (mm)	Rain (mm)
September		55
August		83
July	42	45
June	63	20
May		52
April		65
Total	105	320

Table 1
Total of water used for irrigation and the amount of rain fall on the experimental field for each month.

Determination of chlorophyll contents of leaves were made one month before the harvest, at phenological growth stages 79 of the BBCH-scale (Meier, 2001). The determination of the relative amount of chlorophyll in the leaf was measured by chlorophyll meter SPAD-502Plus (Konica Minolta). Measurements and calibrations have been made by applying the methodology defined by Markwell et al. (1995).

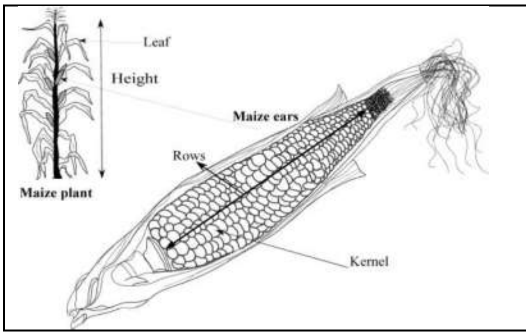

Figure 2
Schematic representation of the physiognomy of the corn plant

Maize morphology measurements were performed on the corn cobs at milk maturation stages (phenological growth stages 85). The parameters that have been taken into account are the number of rows, number of kernels in the row, number of the corn ears, humidity, yield, height and number of plants per unit area (Fig. 2). The One Way ANOVA test (Webster, 2007) has been performed in order to verify any significant variation in the dataset due to the different treatments.

Results

The results of SPAD measurements and those of the ANOVA test are shown in Table 2 and Table 3 respectively. As a whole two main features can be highlighted: i) chlorophyll content is inversely correlated to the contents of zeolitite in the soils (this is more evident in the not irrigated plots) and ii) all the not-irrigated plots present a significant deficiency in chlorophyll when compared to the irrigated plots.

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Analysis of variance		
Groups		Significance level
A	B	
ZeoW	NoZeoW	0.32
ZeoD	NoZeoD	0,02 (B)
NoZeoW	NoZeoD	0,02 (A)
ZeoW	ZeoD	<0,01 (A)
4 kgW	4 kgD	0.1
8 KgW	8 KgD	<0,01 (A)
4 kgD	8 KgD	0.11
4 kgW	8 KgW	0.83

Table 3
Result of ANOVA test for SPAD values. When the significance level value is smaller than 0.05, the ANOVA test demonstrates that there is a significant difference between the compared values.

The not-irrigated plots are characterized by significant differences between the amount of chlorophyll and the treatment of the plots. The leaves of the 4KgD have an average value of chlorophyll of 498 mmol/m^2; those of the parcels with more zeolitite (8KgD) have an average of 462 mmol/m^2, while that of the leaves belonging to the parcels that do not contain zeolitite is 517 mmol/m^2.

Among the irrigated plots no correspondence is found between chlorophyll content and the different treatments. The leaves of 4KgD have an average value of chlorophyll of 538 mmol/m^2, while in the leaves of 8KgD parcels and in the NoZeoW the averages are 532 mmol/m^2 and 552 mmol/m^2 respectively. The leaves of maize plants of NoZeoD plots have more chlorophyll than the NoZeoW parcels.

The results of the morphological analysis are reported in Tables 4 and 5, and in Table 6 the results of the ANOVA test. On the whole, number of Kernels and number of row (Tab. 4 and Tab. 6) are similar in all the plots. The ZeoD and NoZeoD plots have grain humidity and height higher than the ZeoW and NoZeoW plots.

At the same time ZeoD and NoZeoD yield is lower than that of ZeoW and NoZeoW plots. Comparing the irrigated plots with and without zeolitite, no differences can be observed (Tab. 5 and 6).

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Table 2. *Content (μmol/m^2) of chlorophyll in the leaves of irrigated and not-irrigated parcels.*

Not-irrigated											
NoZeo D	**NoZeo D**	**4KgD**	**8KgD**	**NoZeo D**	**NoZeo D**	**4KgD**	**8KgD**	**NoZeo D**	**NoZeo D**	**4KgD**	**8KgD**
1A	**1B**	**2A**	**2B**	**3A**	**3B**	**4A**	**4B**	**5A**	**5B**	**6A**	**6B**
650	652	727	518	686	638	563	594	622	542	652	526
540	755	932	556	744	626	408	310	604	246	497	565
380	596	460	720	561	489	444	278	493	406	436	446
486	400	577	511	686	417	432	300	340	384	537	396
546	374	409	283	636	561	451	330	422	444	535	493
539	470	427	616	760	640	539	376	387	357	579	329
365	537	552	539	411	529	475	342	351	465	526	448
520	580	395	417	711	559	441	401	385	353	414	446
363	522	479	484	584	461	449	396	456	408	431	454
369	608	429	524	552	722	522	385	475	390	548	524
533	569	507	527	498	531	294	348	465	612	529	451
382	482	348	432	567	604	396	441	515	598	320	382
393	385	559	626	524	590	421	371	502	458	509	584
488	431	602	522	522	516	461	620	495	461	604	409
650	439		484		751	602		612			400
434	638				550						569
579											388
											638

Irrigated											
NoZeo W	**NoZeo W**	**4KgW**	**8KgW**	**NoZeo W**	**NoZeo W**	**4KgW**	**8KgW**	**NoZeo W**	**NoZeo W**	**4KgW**	**8KgW**
7A	**7B**	**8A**	**8B**	**9A**	**9B**	**10A**	**10B**	**11A**	**11B**	**12A**	**12B**
557	634	682	796	751	414	408	468	680	817	632	688
724	542	596	707	714	735	477	342	577	610	580	714
548	414	546	663	624	489	780	382	522	573	354	626
661	439	354	497	520	343	740	669	550	648	513	511
652	439	416	351	504	606	624	395	401	573	610	479
673	417	348	460	502	573	404	577	724	659	636	588
550	451	356	416	582	620	400	308	436	542	598	789
544	354	437	484	539	548	714	577	671	565	495	348
453	424	544	396	718	546	600	363	588	590	340	317
498	413	524	563	575	622	467	244	622	526	771	350
398	461	260	509	550	500	489	598	518	426	606	488
467	577	561	598	640	542	403	443	655	535	659	622
511	419	586	667	688	575	650	327	477	441	596	622
542	305	640	642	493	385	540	515	544	718	377	762
507	446	552	648	540	479	515	646	648	652	393	789
682	600	659		594		537		474	791	669	
628	640	474				427		488	413	722	
449		701				392				648	
598						584					

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Table 4 *Number of kernels and number of row in the plants of irrigated and not-irrigated parcels.*

Irrigated				Not-irrigated			
Treatments	**Parcels**	**Kernels**	**Row**	**Treatments**	**Parcels**	**Kernels**	**Row**
4KgW	12A	38	18	**4KgD**	6A	45	14
		42	18			47	16
		48	16			48	14
		50	14			45	16
		45	18			40	16
4KgW	8A	41	18	**4KgD**	2A	40	16
		46	16			48	18
		42	18			47	16
		45	18			48	14
		41	18			44	20
4KgW	10A	48	16	**4KgD**	4A	38	16
		45	14			39	16
		42	16			47	16
		48	16			40	18
		46	18			39	16
8KgW	12B	46	14	**8KgD**	6B	40	14
		37	16			44	16
		39	16			43	16
		37	18			44	14
		39	16			45	16
8KgW	8B	45	14	**8KgD**	2B	47	20
		42	16			41	16
		48	16			49	16
		34	20			46	16
		47	14			43	14
8KgW	10B	40	16	**8KgD**	4B	34	18
		49	16			35	16
		44	18			47	18
		46	16			37	14
		47	16			42	18
NoZeoW	9A	41	14	**NoZeoD**	3A	47	16
		42	18			43	16
		43	16			46	16
		37	18			44	18
		48	12			44	20
NoZeoW	9B	42	14	**NoZeoD**	3B	45	16
		45	16			45	20
		38	16			46	16
		43	14			38	18
		42	16			34	16
NoZeoW	11A	48	16	**NoZeoD**	5A	47	18
		47	16			49	14
		46	16			50	14
		43	16			50	14
		44	16			43	16
NoZeoW	11B	45	14	**NoZeoD**	5B	45	16
		43	16			47	18
		49	16			44	14
		42	18			45	18
		49	16			46	18
NoZeoW	7A	47	20	**NoZeoD**	1A	46	18
		49	16			47	16
		52	16			46	18
		52	18			49	14
		48	18			48	16
NoZeoW	7B	40	16	**NoZeoD**	1B	37	18
		46	18			44	16
		41	16			44	18
		38	18			43	16
		46	14			43	16

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The same can be stated for the not irrigated plots with and without zeolitite (Tab. 5 and 6). Morphological differences exist between irrigated and not-irrigated plots (plant/m^2, ears/m^2 and height; Tab. 5), with and without zeolitite. Regarding the yield values, the only type of treatment that is not affected by the irrigation is the one with 8 kg/m^2 of zeolitite.

Table 5 *Results of the plants morphological analysis for irrigated and not-irrigated parcels.*

Irrigated						
Treatments	**Parcels**	**Umidity (wt%)**	**Yield (Kg/m^2)**	**Plant/m^2**	**Ears/m^2**	**Height (m)**
4KgW	12A	22,70	2,20	8,1	8,7	2,47
4KgW	8A	25,40	2,19	8,3	8,3	2,68
4KgW	10A	24,30	2,26	8,3	8,5	2,57
8KgW	12B	24,30	2,24	8,1	8,7	2,65
8KgW	8B	24,80	2,15	8,0	8,9	2,72
8KgW	10B	24,40	2,37	8,1	8,5	2,52
NoZeoW	9A	25,60	2,31	7,8	8,9	2,27
NoZeoW	9B	24,50	2,09	8,1	8,0	2,57
NoZeoW	11A	24,40	2,15	8,0	8,1	2,49
NoZeoW	11B	23,90	2,28	8,1	8,1	2,59
NoZeoW	7A	25,50	2,46	8,5	8,9	2,46
NoZeoW	7B	25,10	2,30	8,5	8,5	2,70

Not-irrigated						
Treatments	**Parcels**	**Umidity (wt%)**	**Yield (Kg/m^2)**	**Plant/m^2**	**Ears/m^2**	**Height (m)**
4KgD	6A	27,3	1,85	7,59	8,15	1,95
4KgD	2A	25,6	1,96	7,59	7,78	2,17
4KgD	4A	26,4	2,02	7,59	7,96	2,33
8KgD	6B	28,6	1,59	7,22	7,04	2,03
8KgD	2B	25,9	2,11	8,33	9,07	2,26
8KgD	4B	26,9	1,81	7,78	7,22	2,24
NoZeoD	3A	26,0	2,07	7,41	7,78	2,07
NoZeoD	3B	28,9	1,96	8,33	8,33	2,23
NoZeoD	5A	27,8	1,85	8,15	7,78	1,87
NoZeoD	5B	26,2	1,83	7,22	7,22	2,20
NoZeoD	1A	26,1	2,13	8,15	8,33	2,26
NoZeoD	1B	25,5	2,17	7,78	8,70	2,19

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Table 6. *Result of ANOVA test for plants morphological data. * (A) and (B) indicate the group with the higher average values*

Analysis of variance								
Groups		**Significance level**						
A	**B**	**Umidity**	**Yield**	**Plant/m^2**	**Ears/m^2**	**Height**	**Number of kernels**	**Number of row**
ZeoW	**NoZeoW**	0,29	0,63	1,00	0,33	0,25	0,36	0,42
ZeoD	**NoZeoD**	0,96	0,27	0,53	0,68	0,76	0,08	0,28
NoZeoW	**NoZeoD**	**<0,01 (B)***	**0,01 (A)***	0,15	0,17	**<0,01 (A)**	0,76	0,28
ZeoW	**ZeoD**	**<0,01 (B)**	**<0,01 (A)**	**0,02 (A)**	**0,03 (A)**	**<0,01 (A)**	0,64	0,42
4 kgW	**4 kgD**	0,07	**0,01 (A)**	**<0,01 (A)**	**0,02 (A)**	**0,03 (A)**	0,55	0,24
8 KgW	**8 KgD**	**0,03 (B)**	0,06	0,40	0,23	**0,01 (A)**	0,91	1,00
4 kgD	**8 KgD**	0,49	0,54	0,59	0,79	0,85	0,44	1,00
4 kgW	**8 KgW**	0,67	0,62	0,10	0,29	0,54	0,24	0,24

Discussion and conclusions

For many years, numerous scientific studies have dealt with the actual environmental quality of zeolites, preferring the use of clinoptilolite zeolites. Among all these studies, few have been made in the open field and even fewer have demonstrated the real effectiveness of zeolites in conditions of absence of irrigation. In this study we have described the effects of a Chabazite-bearing zeolitite amendment on maize cultivation in order to verify if this material could improve the plants water's and nutrients' use.

We observed corn plants in suffering conditions in not-irrigated plots by measuring both chlorophyll content and some morphological parameters.

Despite suggestions from previous studies (Xiubin and Zhanbin, 2001; Durukan et al., 2014), zeolitite is not able to counteract the total absence of irrigation. Indeed, data from this study show that the more zeolitite is present in the plot the more the corn suffered from water shortage. Zeolitite is a "reservoir" of water: the way in which these rocks act is storing water from the soil first and successively transfer the water to the plants. This probably happens when there is enough water in the soil to hydrate the zeolitite that only in a second moment will transfer the stored water to the plant. A soil never or scarcely watered cannot moisturize the zeolitite, and in these conditions, the zeolitite may act as a competitor of the plant. Data also show that zeolitites help corn growth with a reduction of urea. Plants grown with zeolitite (4KgW and 8KgW) and fertilized with 240 kg/ha of urea have in fact produced the same amounts of corn plants fertilized with 300 kg/ha of urea.

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