Pak. J. Bot., 45(3): 1063-1068, 2013.

INFLUENCE OF SYNTHETIC ZEOLITE APPLICATION ON SEED DEVELOPMENT PROFILE OF SOYBEAN GROWN ON ALLOPHANIC SOIL

AMIR ZAMAN KHAN[1*], S. NIGAR[2], SHAD. K. KHALIL[1], S.WAHAB[3], A. RAB[1], M. K. KHATTAK[1] AND TERU HENMI[4]

[1]Faculty of Crop Production Sciences, [2]Institute of Development Studies,
[3]Department of Food Science and Technology, University of Agriculture, Peshawar, Pakistan
[4]Faculty of Agriculture, Ehime University, 3-5-7 Tarumi, Matsuyama790-8566, Japan
[*]Corresponding author e-mail: drazkhan2021@yahoo.com

Abstract

The aim of the present study was to characterize the pattern of seed development in precociously mature soybean seeds during its progression from germination to seedling growth and maturation as affected by synthetic zeolite application and allophanic soil. Changes in seed quality i.e. viability and germination were monitored from seed initiation to physiological maturity (Growth Stage R5 to R7) of soybean under different zeolite level and allophanic soil during 2007. A pot experiment was conducted to study the influence of zeolite nutrition and allophanic soil on seed developmental traits of one determinate (Enrei, [MG] 1V) and indeterminate cultivar (Harosoy [MG] 11) of soybean cultivar. Seeds were harvested at 12 days interval from 60 to 120 days after anthesis (DAA) from zeolite and allophanic soil treatments. Enrei cultivar planted on KyP and KnP allophanic soil and treated with 20 and 40 (g) zeolite gave maximum fresh, dry seed weight and germination as compared to Harosoy. A decrease in fresh and dry seed weight, and germination were observed with zero (g) zeolite application to paddy soil. Moisture content seed^{-1} was maximum (100%) at DAA. Moisture content declined for the whole seed, from above 75 and 65% at 95 DAA to 65 and 50% at 120 DAA in both cultivars. Decrease in seed moisture content during development was accompanied by increase in desiccation tolerance and germination, reaching maximum at physiological maturity in both cultivars. Fresh and dry seed germination increased linearly in both varieties. Mean rate of change in fresh seed weight, moisture content and germination was more pronounced in Enrei than Harosoy. Immature seeds in both cultivars during early developmental stage did not germinate in all treatments of zeolite and allophanic soil.

Introduction

Zeolites have been increasingly used in various application areas such as industry, agriculture, environmental protection, and even medicine (Pond & Mumpton, 1984). Different zeolites or clinoptilolites are present in nature and characterized by a very complex three-dimensional structure, with a high specific surface (Anderson, 2001) and a high cation exchange capacity. The internal cavities of zeolites and in particular, clinoptilolite for sterical reasons can host calcium, magnesium, and sodium ions, exchangeable with ammonium or potassium. Zeolites are good absorbents, due to the elevated electrical charge of their mineral alumino-silicate surface they can behave as “molecular sieves (Ramôa, 1993). For this reason, they have been used in water purification (Valentukeviciene, 2002) as catalysts in petrochemical industry or O_2 generators in medicine and applied in agriculture (Boettinger & Ming, 2002). Clinoptilolite has been used as fertilizer, being a source of potassium (Emadi *et al*., 2001) and a nitrogen slow-release compound, if previously treated with ammonium ions (Mackown & Tucker, 1985; Ando & Mihara, 1996). The influence of zeolite on soil properties and humic matter characteristics was deeply studied by Filcheva & Tsadilas (2001) who verified that zeolite increases soil pH and exchangeable potassium. Zeolite can be also utilized as plant growing medium (Guo *et al*., 2004), when added or coated with mineral fertilizers and/or selected micronutrients (Ferguson *et al*., 1986). Recently, zeoponic substrates made by K exchanged clinoptilolite are under development for use in advanced life support system test-beds and microgravity experiments (Ming *et al.,* 2001). The zeolites has already been used as soil amendment with satisfactory results (Li *et al*., 2000; Al-Busaidi *et al*., 2008), but also as component of growing media in containerized seedlings propagation (Ayan & Tillki, 2007) Zeolites are, therefore, used as a promoter for better plant growth by improving the value of fertilizers; retaining valuable nitrogen and improving the quality of resulting manures, sludge and improve crop yield and quality (Ayan *et al*., 2006). Allophanic clay stabilizes the microbial biomass and its metabolites (Saggar *et al*., 1996). Andisols are often very fertile and their physical properties make them suitable for agricultural use. Proper nutrition of plants is not only important for proper emergence but also important to have the crop in the field when environmental conditions are conducive for proper growth and development (Khan *et al*., 2011). The aims of the present investigation were to characterize the pattern of seed development in precociously mature soybean seeds grown on various levels of zeolite and KyP and KnP allophanic soil during its progression from viability, germination to seedling growth and maturation.

Materials and Methods

To assess the effect of zeolite nutrition on seed developmental traits of determinate and indeterminate soybean grown on allophanic soil, a pot experiment was carried out at the Faculty of Agriculture, Ehime University, Matsuyama Japan, during 2007. The experiment was carried out in completely randomized design under natural green house environment. Ceramic cylinders pots (h = 30 cm, Ø = 20 cm) were filled with 3 kg of air-dried sieved soil samples. A 3 factor (3x3x2) factorial experiment of three zeolite and soil amendments on two soybean varieties were used. Paddy soil was collected from Ehime University Agriculture Research Farm Hojo and was used as control. KyP having low Si/Al ratio were collected from Kurayoshi Tottori prefecture near Moutain Daisen.KnP having high Si/Al ratio were collected from Kakino Kumamoto Prefecture near Moutain Aso. Selected characteristics of the three experimental soils are listed in Table 1. Three zeolite levels of. 0, 20 and 40 (g) were applied a day before sowing of the crop. Determinate cultivar (Enrei, [MG] 1V) and indeterminate cultivar, Harosoy [MG] 11) were planted at 30mm depth in the above soils. Maximum seed were planted to obtain the required plant population density that should be quite enough to study the required parameters. A basal dose of 5 (g) N and 10 (g) each of P_2O_5 and KCL were applied one day before starting the experiment. All soils samples were sieved through a 2mm sieve before application. The 18 combinations were replicated 3 times so there were 18 x 3 = 54 experimental units. The 54 pots were arranged within 18 x 3 arrays of rows with 20cm distance between pots. Normal cultural practices for raising a successful crop were applied uniformly to all the experimental units. The plots were hand weeded at different growth stages and were irrigated as and when required. A set of basic plant measurements were recorded during the course of study to evaluate the crop progression toward maturity and also to asses the vegetative/reproductive balance of the crop as described by Fehr *et al*., (1977). Two plants per treatment were sampled at 12 days interval starting at R5 (Beginning seed 3 mm long in the pod at one of the four uppermost nodes on the main stem) to R7 (Beginning Maturity when one major pod has changed to brown color on the main stem). The following observations were recorded on seed samples harvested at 10 days interval after anthesis (DAA).

1. Fresh seed weight (mg),
2. Fresh seed moisture content (%),
3. Fresh seed germination (%),
4. Dry seed weight (mg),
5. Dry seed moisture content (%)
6. Dry seed germination (%)

Table 1. Some physical and chemical properties of the different soils used in the experiment.

Soil type	pH (H_2O)	pH (KCl)	CEC	Na	K	Ca	Mg
					(cmol kg^{-1})		
Paddy soil	6.0	5.1	13.8	0.6	0.5	7.0	1.4
Allophanic soil (KyP)	5.7	5.0	17.2	1.8	0.3	0.3	0.2
Allophanic soil (KnP)	6.2	4.8	30.1	1.3	1.9	7.2	2.6

Determination of fresh seed weight (mg): With in 6 h of pod collection at each sampling date, 25 fresh seeds per treatment were obtained by hand removal from randomly selected pods and were used to determine seed fresh weight on wet basis.

Fresh seed moisture content determination (%): Seed moisture content was determined by loss in weight of the seeds using the air oven method at 105°C for 24 hours on a fresh weight basis. Twenty-five seeds replicated four times from each treatment at every sampling date were placed in a weighed container and weighed before and after drying. Calculation was made up to 2 decimal using the following formula:

Percent moisture: $[(W_2-W_3)]/[(W_2-W_1)] \times 100$

where
W_1= Weight of the empty container
W_2= Weight of the container plus wet seed
W_3= Weight of the container plus dry seed

Fresh and dry seed germination (%): Standard germination test were made in accordance with the method prescribed in the Rules for Testing Seeds (Anon., 2002). Four replications of 25 fresh and dry seeds from each treatment were placed on two sheets of standard germination paper and covered with an additional sheet and was folded 2.50 cm from the bottom and rolled loosely and secured with a rubber band. Each group of rolls was placed upright in wire basket covered with a plastic bag. The rolls were then placed in a germinator at 25°C. Seeds samples were evaluated at 7th day after incubation and germination were described as radicle protrusion through the testa of the seed.

Dry seed weight (mg): Determination of dry seed weight were made on 25 randomly selected pods treatment^{-1}, kept in paper bags and were placed in the drier at 35-40°C until a seed moisture content of 12-14% were obtained and after that the seeds were removed by hand from the pods and weighed.

Dry seed moisture content determination (%): For the determination of dry seed moisture content, the same method was used as described earlier for fresh seed moisture content determination.

Statistical Analysis: The data recorded on different seed developmental traits were statistically analyzed according to Steel & Torrie (1980). Data were regressed on zeolite levels and allophanic soil to quantify the effect of zeolite and allophonic soil on soybean cultivars. Means were separated by using LSD test at 0.05 level of probability.

Results and Discussion

Fresh seed weight: Data on fresh seed weight from R5 to R7 of the two soybean varieties grown on KyP and KnP of allophanic soil with various zeolite levels are presented in Figs. 1 and 2. Zeolite application and allophanic soil significantly affected the fresh seed weight of soybean cultivars. Maximum fresh seed weight increased in both varieties with increase in zeolite levels. Both KyP and KnP of allophanic soil gave maximum fresh seed weight as compared to paddy soil. The mean fresh seed growth rates calculated from the regression equations (Table 2) shows that 20 and 40 gm zeolite application rate of Enrei has higher mean seed growth rate than Harosoy. A steady decrease in mean fresh seed growth rate was observed in control treated plots of 0 (g) zeolite applied to paddy soil. Maximum fresh seed weight from 20 and 40 (g) zeolite treated plots grown on KyP and KnP allophanic soil may be due to the fertility of soil and availability of nutrients for optimum plant growth and development, especially during seed filling duration, which lead toward maximum dry matter accumulation or may be due to sink capacity and sink strength of the seed growth habit. The demand for nitrogen is determined by the growth rate and the nitrogen composition of the new tissues. Both growth rate and tissue composition vary with nitrogen and water supply, plant competition and other environmental factors. In aerated soils, nitrate is the dominant form in plant nutrition and is absorbed first into the free-space of roots and then across membranes into the plant cells themselves. The maximum demand for nitrogen will be achieved under non-limiting conditions for photosynthesis when growth rate approaches its genetic potential. The decrease in seed developmental rate in control treated plots of 0 (g) zeolite applications and paddy soil in both cultivars may be due to low bulk density and porosity which lead toward its low fertility. The differences among the seed growth rates of determinate and indeterminate varieties may be the patterns of seed development and its assimilate requirements. These finding are in line with those of Egli (1975), Beaver & Cooper (1982) who found that Corsoy 79 have a higher seed fill rate than Williams 79 and concluded that this advantage gave Corsoy 79 its higher yield potential, which may be due to variation in rates of dry matter accumulation in different varieties.

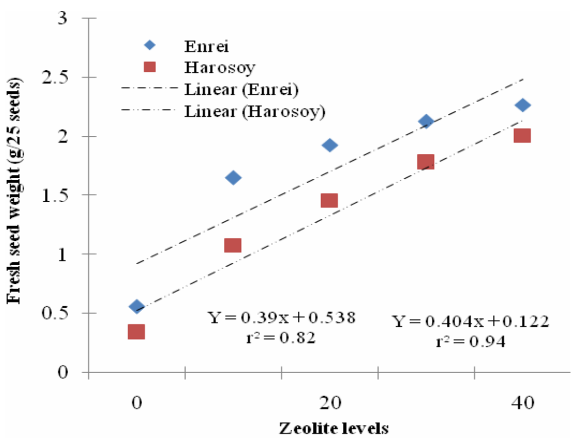

Fig. 1. Fresh seed weight of Enrei and Harosoy cultivars of soybean planted under different levels of zeolite.

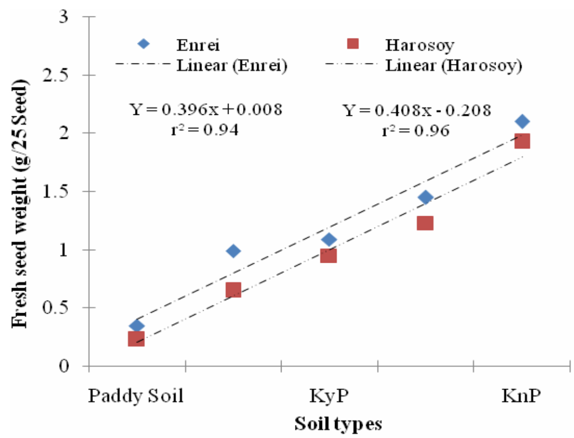

Fig. 2. Fresh seed weight of Enrei and Harosoy cultivars of soybean grown on different soil types.

Table 2. Mean fresh seed growth rate (g/day/100seeds) of soybean varieties as affected by zeolite application and soil types.

Variety	Zeolite doses (g)			Soil types		
	0	20	40	Paddy Soil	KyP	KnP
Enrei	0.61	0.73	0.80	0.52	0.61	0.67
Harosoy	0.59	0.64	0.68	0.45	0.58	0.63

Fresh seed moisture: Data regarding fresh seed moisture (%) of the two soybean cultivars as affected by various levels of zeolite and allophanic soil are shown in Figs. 3 and 4. Fresh seed moisture (%) of soybean cultivars was initially the same in all seed samples from various zeolite and allophanic treatments. Fresh seed moisture content decreased as the seed developed and the trend of decrease was about the same in all zeolite and allophanic soil treatments. Mean rate of change in moisture (%) in fresh seed calculated from the regression equations (Table 3) reveals that Enrei treated with 20 and 40 (g) of zeolite application has higher mean rate of change in moisture (%) as the crop stage advanced (Egli, and TeKrony, 1997). Paddy soil treated with 0 (g) zeolite applications gave a slow decreasing trend in the rate of change in fresh seed moisture (%) in both varieties. Speedy rate of change in fresh seed moisture (%) in higher dose of zeolite applied to KyP and KnP allophanic soil may be due to more utilization of water in the metabolism of photosynthates, assimilates and regularization of plant canopy temperature as compared to control treated plots. A loss of water in seeds is essential for changing cell activity from developmental program to germination-oriented program (Prusiński, 1992). The changes in water content in developing seeds are observed as a metabolic loss of water at the beginning and seed desiccation at the end of ripening. Decreasing water content in seeds is accompanied by an increase in dry weight and germination (Jasińska & Kotecki, 1997).

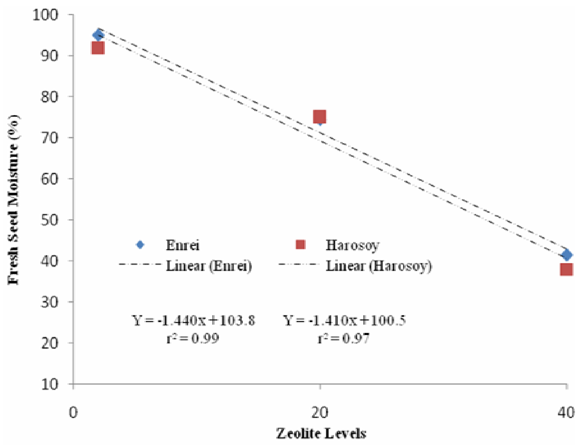

Fig. 3. Changes in fresh seed moisture (%) of Enrei and Harosoy soybean cultivars as affected by zeolite levels.

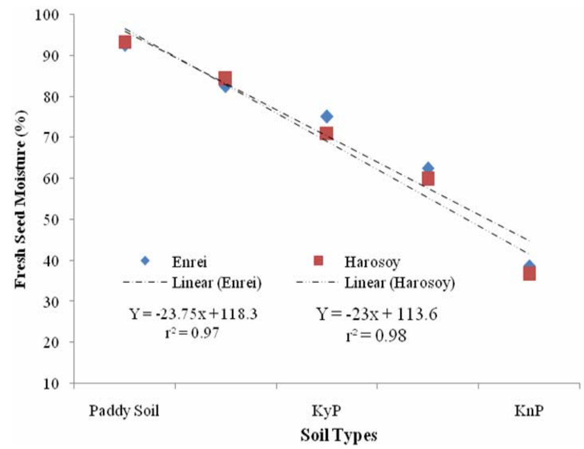

Fig. 4. Changes in fresh seed moisture (%) of Enrei and Harosoy soybean cultivars as affected by soil types.

Table 3. Mean rate of change of percent moisture (Percent/Day) in seed of soybean varieties as affected by zeolite application and soil types.

Variety	Zeolite doses (g)			Soil types		
	0	20	40	Paddy Soil	KyP	KnP
Enrei	-1.24	-1.34	-1.36	-1.34	-1.38	-1.44
Harosoy	-0.72	-0.85	-0.88	-1.02	-1.07	-1.10

Fresh seed germination: Data on fresh seed germination of Enrei and Harosoy of the two soybean cultivar as affected by zeolite levels and KyP and KnP allophanic soil are presented in Figs. 5 and 6. Which reveals that both zeolite levels and allophanic soil significantly affected fresh seed germination of soybean. Germination was zero in the beginning and increased steadily as the stage of seed development advanced in all treatments. Maximum fresh seed germination was obtained in both varieties as zeolite level increased from 20 to 40 (g) grown on KnP allophanic soil (Huang & Petrovic, 1994). Mean rate of change in fresh seed germination during seed development, calculated from the regression equations (Table 4) indicates that change in germination rate was sluggish in both cultivars in control treated plots of zeolite and paddy soil. A steady increase in rate of fresh seed germination was observed with advance in stage of seed development in both cultivars with 20 and 40 (g) zeolite application. The same trend of increase in fresh seed germination was observed in both cultivars when planted on KyP and KnP allophanic soil. Maximum rate of change in fresh seed germination in both cultivars from maximum zeolite levels and KyP and KnP of allophanic soil may be due to proper availability of nutrients, water and its metabolism, which helped in the accumulation of dry matter and vigor of soybean varieties as compared to control treated plots (Saggar *et al*.,1996).

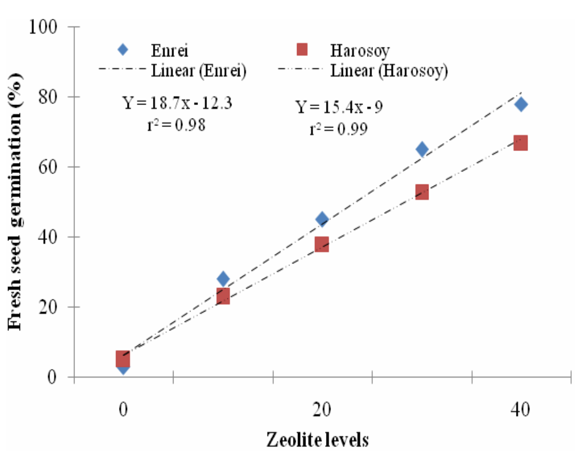

Fig. 5. Fresh seed germination of Enrei and Harosoy cultivars of soybean grown on different levels of zeolite.

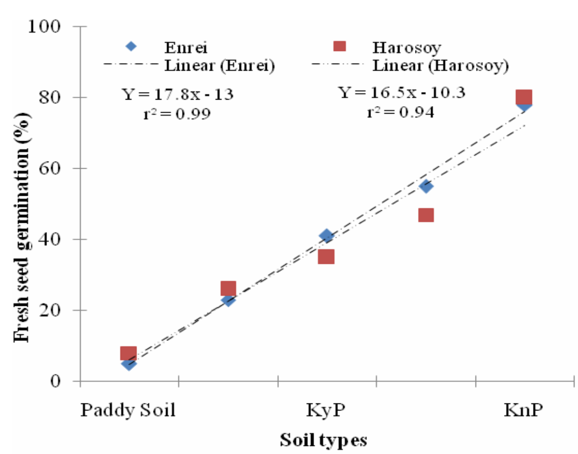

Fig. 6. Fresh seed germination of Enrei and Harosoy cultivars of soybean grown on different soil types.

Table 4. Mean rate of change in fresh seed germination (percent/Day) of soybean varieties as affected by zeolite application and soil types.

Variety	Zeolite doses (g)			Soil types		
	0	20	40	Paddy Soil	KyP	KnP
Enrei	2.43	2.57	2.63	1.99	2.22	2.33
Harosoy	1.31	1.65	2.20	1.26	1.56	1.87

Table 5. Mean dry seed accumulation rate (g/day/100seeds) of soybean varieties as affected by zeolite application and soil types.

Variety	Zeolite doses (g)			Soil types		
	0	20	40	Paddy Soil	KyP	KnP
Enrei	0.28	0.30	0.32	0.23	0.25	0.29
Harosoy	0.23	0.27	0.30	0.17	0.21	0.25

Dry seed weight: Data on dry seed weight of Enrei and Harosoy as affected by zeolite application KyP and KnP of allophanic soil are presented in (Table 5). The table shows that both zeolite levels and allophanic soil significantly affected the dry matter accumulation in soybean cultivars. The mean dry seed accumulation rate indicates that 20 and 40(g) zeolite application and KyP and KnP of allophanic soil had higher dry matter accumulation rate as compared to zero (g) zeolite application grown on paddy soil. Dry seed weight decreased in both varieties, when sowing was done on paddy soil with zero dose of zeolite application. Minimum dry seed weight from paddy soil treated with zero (g) zeolite may be due to low fertility and non availability of nutrients to the plants in paddy soil, which resulted in minimizing the seed filling duration and its growth. The rate of dry weight and nutrient accumulation increase in seed weight depends on development phase and genetic properties of cultivars and micro environment around the plant. Over plant ripening considerable chemical changes occurred in seeds, mostly a decrease in the amount of water and readily-soluble compounds, and the formation and accumulation of hardly-soluble and macromolecular compounds (Khan et al., 2011).

Dry seed moisture: Keeping the seed moisture content at proper level is a pre-requisite for proper storage to maintain vigor and viability of a seed lot. Data on dry seed moisture (%) of the two soybean cultivars as affected by zeolite levels and KyP and KnP of allophanic soil are reported in (Table 6). The table reveals that zeolite application and allophanic soil had non-significantly affected the air dry seed moisture (%) of the soybean. Dry seed moisture decreased as both cultivars were sown on paddy soil treated with 0(g) zeolite application. Mean rate of change in dry seed moisture (%) indicates that Enrei had higher rate of moisture change at 40(g) zeolite applied to KnP allophonic soil as compared to Harosoy. The change in moisture (%) in dry seed from paddy soil treated with zero (g) was slow. The variation among the two cultivars may be due to their genetic make-up and variation in seed coat characteristics.

Dry seed germination: Data on dry seed germination of the two soybean cultivars as affected by zeolite application and KyP and KnP on allophonic soil are reported in (Table 7). Zeolite application had significantly affected the dry seed germination of the soybean cultivars (Table 7). In both cultivars, dry seed germination increased with increase in zeolite levels from 20 to 40 (g) with maximum germination of seeds from KnP of allophanic soil. The mean rate of change in dry seed germination with advance in stage of crop shows that in both varieties, 0 (g) zeolite treated plots grown on paddy soil have slow rate of change in percent dry seed germination. A steady increase in rate of change in dry seed germination was observed in both varieties as planting was done with 20 and 40 (g) zeolite was applied to KyP and KnP of allophanic soil. The rate of change in dry seed germination was more pronounced in Enrei than Harosoy. Maximum dry seed germination from 20 and 40 (g) zeolite application grown on allophanic soil may be due to the availability and utilization of nutrients, which directly helped in its development, maturation and final yield (Muhammad et al., 2012).

Table 6. Mean rate of change in air dry seed moisture content (Percent change/Day) of soybean varieties as affected by zeolite application and soil types.

Variety	Zeolite doses (g)			Soil types		
	0	20	40	Paddy Soil	KyP	KnP
Enrei	-0.11	-0.12	-0.12	-0.10	-0.12	-0.12
Harosoy	-0.10	-0.11	-0.11	-0.10	-0.11	-0.11

Table 7. Mean rate of change in air-dry seed germination (Percent/Day) of soybean varieties as affected by zeolite application and soil types.

Variety	Zeolite doses (g)			Soil types		
	0	20	40	Paddy Soil	KyP	KnP
Enrei	2.81	2.96	3.04	2.22	2.30	2.50
Harosoy	2.55	2.72	2.91	1.89	2.15	2.32

Conclusion and Recommendations

In this paper we have compared the effect of synthetic zeolite application on two soybean cultivar grown on KyP and KnP allophanic soil during its seed developmental processes of viability, germination and growth. It was concluded that zeolite application exerts positive effect on seed growth rate of soybean and improve the agronomic attributes of soybean cultivar grown on KyP and KnP allophanic soil. Allophanic soil shows its high potentive efficiency/fertility for crop cultivation. Further research is needed to ascertain the beneficial effects of synthetic zeolite application on different crops in a wider range of environment under diverse ecological conditions.

Acknowledgments

Thanks are extended to "Higher Education Commission, of Pakistan" for Financial Support of this Project. I am thankful to the "Administration, University of Agriculture-Peshawar" for providing me an opportunity for a Postdoctoral Fellowship at the Faculty of Agriculture, Ehime University, Matsuyama, Japan.

References

Al-Busaidi, A., T. Yamamoto, M. Inoue, A.E. Eneji, Y. Mori and M. Irshad. 2008. Effects of zeolite on soil nutrients and growth of barley following irrigation with saline water. *J. Plant Nutr*., 31(7): 1159-73.

Anderson, M.W. 2001.Surface microscopy of porous materials. *Curr. Opin. Solid State Mat. Sci*., 5(5): 407-415.

Ando, H. and C. Mihara.1996. The fate of ammonium nitrogen applied to flooded rice as affected by zeolite addition. *Soil Sci*., 42: 531-538.

Anonymous. 2002. *Seed vigor testing handbook*. No. 32. Assoc. Official Seed Analysts, Las Crucas, NM

Ayan, S. and F. Tillki. 2007. Morphological attributes of oriental spruce seedlings grown in peat based amended with natural zeolite. *Acta Agr. Hung*., 55: 363-373.

Ayan, S., Z. Yahyaoglu, V. Gerçek and A. Ahin. 2006. Utilization of zeolite as a substrate for containerized oriental spruce (*Picea orientalis* L.) seedlings propagation. *Acta Horticult*., 779: 583-590.

Beaver, J.S. and R.L Cooper. 1982. Dry matter accumulation patterns and seed yield components of two indeterminate soybean cultivars. *Agron. J*., 74: 380-383.

Boettinger, J.L. and D.W. Ming. 2002. Zeolites. Soil mineralogy with environmental applications. Soil Science Society of America, Madison,WI, USA: *SSSA Book Series*, 7(19): 585-610.

Egli, D.B. 1975. Rate of accumulation of dry weight in seed of soybeans and its relationship to yield. *Can. J. Plant Sci*., 55: 215-219.

Egli, D.B. and D.M. TeKrony. 1997. Species differences in seed water status during seed maturation and germination. *Seed Sci. Res*., 7: 3-11.

Emadi, H., J.E. Nezhad and H. Pourbagher. 2001. *In vitro* Comparison of zeolite and activated carbon as ammonia absorbants in fish culture. In: (Ed.): Y. Naga. Penang, Malaysia: *The ICLARM Quarterly*, 24(1-2): 18-20.

Fehr, W.R. and C.E. Caviness. 1977. Stages of soybean development. Spec. Rep. 80. Iowa State Univ. Coop. Ext. Serv., Ames.

Ferguson, G.A., I.L Pepper and W.R. Kneebone.1986. Growth of creeping bentgrass on a new medium for turfgrass growth: clinoptilolite zeoliteamended sand. *Agron J*., 78: 1095-1098.

Filcheva, E.G. and C.D. Tsadilas. 2001. Influence of zealite and compost on soil properties. *Commun. Soil Sci Plant Anal*., 33(3-4): 595-607.

Guo, S.S., C.J. Zhao, L.J. Han and J.X. Wang. 2004. Selection of rootzone media for higher plant cultivation in space. *Space Med Eng*., 17(2): 93-97.

Huang, Z.T. and A.M. Petrovic. 1994. Clinoptilolite zeolite influence on nitrate leaching and nitrogen use efficiency in simulated and based golf greens. *Journal of Environmental Quality*, 23: 1190-1194.

Jasińska Z. and A. Kotecki. 1997. Effect of sowing date and threshing method on the dynamics of changes in maturing plants of two pea morphotypes. Part I. Plant development and dry matter accumulation]. Zesz. Nauk. AR we Wrocławiu, Rolnictwo LXIX, 173-189.

Khan, A.Z., H. Khan, R. Khan, S. Nigar, B. Saeed, H. Gul, Amanullah, S. Wahab, A. Muhammad, M. Ayub, N. Matsue and T. Henmi. 2011. Morphology and yield of soybean grown on allophanic soil as influenced by synthetic Zeolite application. *Pak. J. Bot*., 43(4): 2099-2107.

Khan, A.Z., P.Shah, H. Khan, S.Nigar, S. Parveen, Amanullah and S. K. Khalil. 2011. Seed quality and vigor of soybean cultivars as influenced by canopy temperature. *Pak. J. Bot*., 43(1): 643-648.

Li, J.K. N.E. Christians and D.D. Minner. 2000. Inorganic soil amendment effects on sand-based sports turf media. *Crop Sci*., 40: 1121-1125.

Mackown, C.T., T.C. Tucker. 1985. Ammonium nitrogen movement in a coarse-textured soil amended with zeolite. *Soil Sci. Soc. Am. J*., 49(2): 225-238.

Ming, D.W., J.W. Gruener, K.E. Henderson, D.J. Barta and C. Galindo Jr. 2001. Production of fresh vegetable crops in zeoponic substrates: preliminary results. Paper presented at the Annual Meeting of ASGSB; p. 99.

Muhammad, A., S.K. Khalil, A. Z. Khan and S.M. Wazir.2012. Seasonal and Cultivar effects on nodulation potential of soybeans. *Pak. J. Bot*., 44(1): 317-320

Pond, W.G. and F.A. Mumpton. 1984. *Zeo-agriculture: Uses of Natural Zeolites in Agriculture and Aquaculture*. Westview Press, Boulder, Co, USA.

Prusiński, J. 1992. Some aspects of seed legumes maturation. *Biul. branż. Hod. Ros. Nas*., 26-30.

Ramôa, R.F. 1993. Adaptation of the porosity of zeolites for shape selective reactions. *Chem. Mat. Sci*., 22(1-2): 107-121.

Saggar, S., A. Parshotam, G.P Sparling, C.W. Feltham and P.B.S. Hart. 1996. 14C-Labelled rye grass turnover and residence times in soils varying in clay content and mineralogy. *Soil Biology and Biochemistry*, 28: 1677-1686.

Steel, R.G.D. and J. H. Torrie. 1980. *Principles and Procedures of Statistics*. New York: McGraw-Hill.

Valentukeviciene, M. 2002. Removal of organic matter during groundwater treatment using powdered natural adsorbents (zeolites). Kavnas, Lithuania: Transactions of the

Lithuanian University of Agriculture and Lithuanian Institute for Water Management, 18(40): 1392-2335.

(Received for publication 20 March 2012)