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MORPHOLOGY AND YIELD OF SOYBEAN GROWN ON ALLOPHANIC SOIL AS INFLUENCED BY SYNTHETIC ZEOLITE APPLICATION

AMIR ZAMAN KHAN[1], H. KHAN[1], R. KHAN[1], S. NIGAR[2], B. SAEED[1], H. GUL[1], AMANULLAH[1], S.WAHAB[3], A.MUHAMMAD[3], M. AYUB[3], N. MATSUE[4] AND T. HENMI[4]

[1]*Faculty of Crop Production Sciences, KPK Agricultural University, Peshawar, Pakistan*
[2]*Institute of Development Studies, KPK Agricultural University, Peshawar, Pakistan*
[3]*Food Science Department, KPK Agricultural University, Peshawar, Pakistan*
[4]*Faculty of Agriculture, Ehime University, 3-5-7 Tarumi, Matsuyama 790-8566, Japan*

Abstract

Our objective was to assess the effect of synthetic zeolite application on morphology, yield and yield components of soybean grown on allophanic soils. A greenhouse experiment was carried out using three zeolite levels and three soils (two allophanic and one paddy) with two soybean cultivars. One determinate (Enrei, [MG] 1V) and indeterminate cultivar (Harosoy [MG] 11) were grown in pots on April 20th and harvested on 15th September at the Faculty of Agriculture, Ehime University, Matsuyama, Japan during 2007. Zeolite levels of 0, 20 and 40 (g) were used to determine the growth behavior of soybean cultivars. Different morphological parameters including grain yield were significantly affected by various zeolite levels and soil type. Maximum leaf area and plant height were obtained from 40 (g) zeolite applications with KnP and KyP allophanic soils. Harosoy grew taller than Enrei. Yield and yield contributing attributes were affected significantly by zeolite levels and soil type. Both cultivars gave highest grain yield at 20 (g) zeolite applications and thereafter, the grain yield declined. Application of 20 (g) zeolite applications favored most of the yield contributing characters that contributed maximum grain yield at this level of zeolite application. The allophanic soils gave similar trend of increase in both morphological and yield components parameters of soybean cultivars. A decrease in morphological and yield components were observed, when soybean were grown on a paddy soil with zero(g) zeolite application. Enrei cultivar out yielded Harosoy at all levels of zeolite application and soil type.

Introduction

Plant nutrition of crops are essential for producing sufficient and healthy food for the world's expanding population and are therefore a vital component of any system of sustainable agriculture. Moreover, agricultural intensification requires increased flows of plant nutrients to crops and higher uptake of these nutrients by crops. The depletion of nutrients from soil is a major but often hidden form of land degradation in many developing countries. On the other hand, excessive application of nutrients/inefficient management can cause environmental problems, especially if large quantities of nutrients are lost from the soil/crop system into water or the air. Balanced use of plant nutrients improves soil fertility; increases nutrient and water use efficiency, enhances crop yields and farmer's income and improve environmental quality. To reap the benefits of balanced use of plant nutrients, it is important to have better agronomic practices with greater emphasis on timeliness and precision in farm operations. Nutrition of plants has a substantial impact on the predisposition of plants, by affecting the growth pattern, the anatomy, morphology and the chemical composition of plants (Graham & Webb, 1991). Allophane has a large propensity of sorbing organic substances. 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. In addition, the location of most Andisols occurs in climates that are very suitable for agriculture.

Zeolites are microporous, crystalline aluminosilicates of alkali and alkaline materials that have a high internal surface area. The unique cation exchange, adsorption, hydration-dehydration, and catalytic properties of natural zeolites have prompted slow-release fertilizers and other materials (Pond & Mumpton, 1984). The poor utilization of fertilizers by crops is largely caused by N losses through denitrification, ammonia volatilization, runoff and leaching (Craswell & Vlex, 1979). Natural compound such as zeolite minerals have been reported as ameliorants for coarse soils to modify soil cation exchange capacity (CEC) to decrease N leaching and to increase fertilizer recovery. Zeolite improves soil structure by coupling high CEC with a selective affinity for ammonium and potassium ions (Curkovic *et al*., 1997). Zeolite is very porous with incredibly large surface area. The selectivity of zeolite for ammonium helps to buffer the soil and prevents toxicity, which occurs when excess Ammonium is applied. This property allows the grower to use this less costly form of nitrogen in larger and less frequent applications during the growing season. The retention and timely release of needed nutrients by zeolite improves overall crop yield (Nommik & Vahtras, 1982). There is an environmental bonus from the product as well. Unlike commonly used fertilizers, the plant-growth material dramatically reduces loss of nutrients to ground water and the environment (Pansini, 1996). Increased utilization of manure and biosolids as a rich source of nutrients is gaining popularity. As application rates increase there is a concern about the additive effects of toxic components. Salt and heavy metals are the main problems, although fugitive losses of ammonia to atmosphere and nitrogen and phosphate loss to ground water are also a concern. Zeolites hold nitrogen in the soil, moderate nitrification of ammonia and make it available to plants as needed. Proper nutrition of soybean 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. The question of optimum level of zeolite application and its influence on morphology, yield and yield components of soybean grown on allophanic soil is imperative to be investigated because of the economic and industrial importance of soybean and easier availability of zeolite as source of medium for plant growth. Work on zeolite applications, as fertilizer/soil conditioner on allophanic soil is limited. Thus, this study was designed to evaluate the effect of synthetic zeolite application on morphology, yield and yield components of soybean grown on allophanic soil.

Materials and Methods

To assess the effect of zeolite application on morphology, yield and yield components of determinate and indeterminate soybean grown on Japanese two allophanic soils (KnP & KyP) and a paddy soil (Table 1), 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 greenhouse environment. Ceramic cylinders pots (h = 20 cm, Ø = 10 cm) were filled with 2 kg of air-dried sieved soil samples. A 3 factor (3x3x2) factorial experiment of three soils and zeolite amendments on two soybean cultivars were used. Paddy soil was collected from Ehime University Agriculture Research Farm, Hojo and was used as control. The pumice grains for KyP having low Si/Al ratio were collected from Kurayoshi, Tottori prefecture, near Mt. Daisen. While for KnP having high Si/Al ratio was collected from Kakino, Kumamoto Prefecture, near Mt. Aso. Three zeolite levels of 0, 20 and 40 (g) were applied one day before sowing of the crop. The zeolite was obtained from Maeda Kensetsu Co. Ltd. Synthetic zeolite species was Na-P1 with a CEC of 260 cmol kg^{-1}. Determinate cultivar (Enrei, [MG] 1V) and indeterminate cultivar, Harosoy [MG] 11) were planted at 30 mm depth. Maximum seed were planted to obtain the required planting 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 ground and sieved through a 2 mm 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 20 cm 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. Irrigation was applied at weekly intervals. A set of basic plant measurements were recorded during the course of study to evaluate the crop progression toward maturity and to asses the vegetative/reproductive balance of the crop as described by Fehr & Caviness (1977). The following sets of data were recorded on morphology, yield and yield components of soybean according to standard procedure.

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

Leaf Area Index (LAI): Leaf Area Index was calculated using the following formula:

$$LAI = \frac{\text{(Surface area of the sample leaf)}}{\text{(Ground area occupied by the sampled plants)}}$$

Data regarding plant height was recorded on two plants in each treatment randomly selected and measured (cm) from the soil surface to the tip of the plant at maturity. For yield attributes of soybean, two plants were selected from each treatment and pods $plant^{-1}$, seeds pod^{-1} was counted to record the number of pods $plant^{-1}$, and seeds pod^{-1}. All the treatments were harvested by hand, cleaned, air-dried and weighed with a balance to record biological yield.The material were threshed separately; the seed was cleaned, dried and weighed to record seed yield. For the determination of seed weight, 100 grains were counted at random from each treatment and weighed with the help of a sensitive electronic balance to record 100 grain weight.

Statistical analysis: Data were subjected to analysis of variance (ANOVA) according to the methods described by Steel *et al*., (1996), and means between treatments were compared by least significant difference (LSD) at $p \leq 0.05$.

Results and Discussion

Leaf area development: Crop growth depends on adequate formation of leaf area for efficient interception of light (Wilson, 1981). Leaf area $plant^{-1}$ as influenced by zeolite application level and soil type is shown in Fig. 1. Leaf area $plant^{-1}$ in both cultivar increased sharply after emergence reaching peak at pod filling stage and then decreased especially in Enrei. The reduction of leaf area $plant^{-1}$ at later growth stage might be due to senescence of older leaves associated with the remobilization of the stored metabolites from the leaf to the developing pods of soybean (Egli & Jian, 1993). Similar trends were reported by Matsunaga *et al*., (1989) and Singh *et al*., (1985) in mungbean, Ferdous (2001) in edible podded pea, Hossain (1999) and Misra *et al*., (1994) in groundnut. Among the cultivars, Enrei consistently produced more leaf area per treatment than Harosoy. Zeolite levels significantly influenced leaf area development upto pod filling stage. Leaf area responded positively up to 40 g zeolite application in both cultivars. Maximum leaf area was obtained at pod filling stage with 40g zeolite application followed by plants with 20 g zeolite application. Higher dose of zeolite application maintained higher leaf area through out the crop growth period. Plants grown with zero zeolite application gave the lowest leaf area. Enhanced leaf area development with highest dose of zeolite application was also reported for horticultural crops (Munir *et al*., 2007). Kavoosi (2007) concluded that increase in zeolite application improved nitrogen uptake, increased nucleic acid, amides and amino acid and hence cell multiplication, which increased leaf area. However, it is evident from Fig. 1 that despite the magnitude of differences in leaf area due to treatment differences, the trend of leaf area development per treatment remains identical for both varieties.

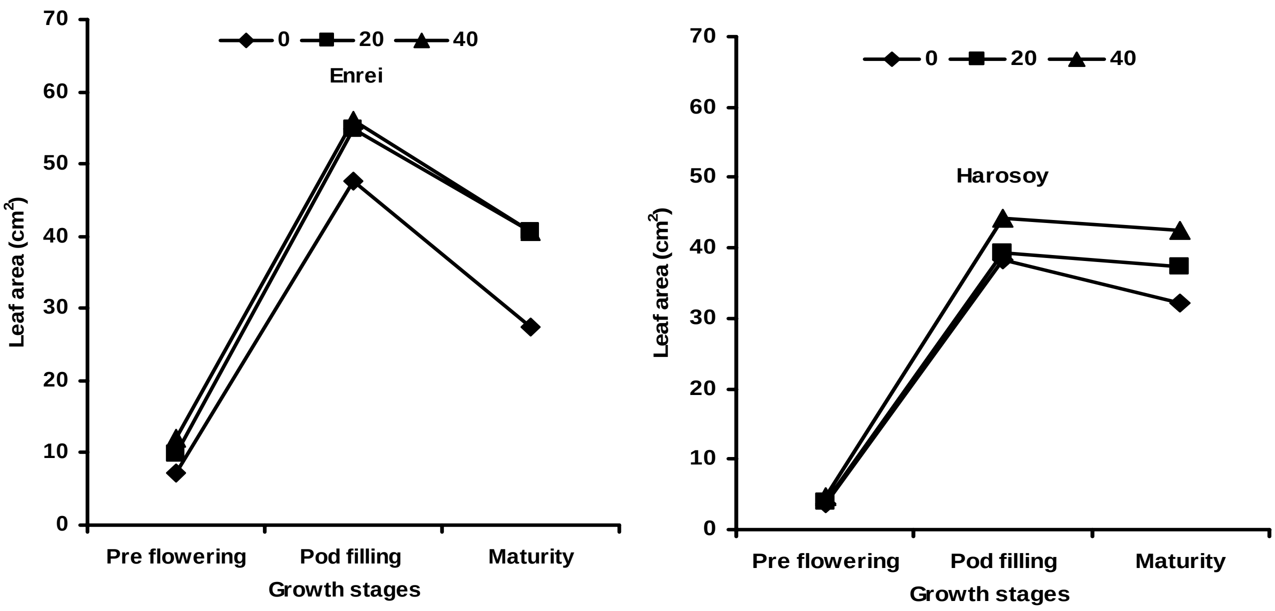

Fig. 1. Leaf area of Harosoy and Enrei at different growth stages as affected by zeolite levels.

Plant height: Plant height is an important morphological character that acts as a potent indicator for availability of growth resources in its vicinity. The height of a plant depends on nutrients especially on nitrogen (Ferdous, 2001). Irrespective of zeolite application, plant height increased over time. Plant height increased progressively and attaining its maximum height at physiological maturity (Fig. 2). The effect of zeolite application on plant height of the two varieties was significant from pod filling stage to physiological maturity. In the beginning between pre-flowering and pod filling stage, the rate of increase in plant height was not statistically significant and thereafter tendered to flatten regardless of zeolite treatment differences. Among the two soybean cultivars the increasing rate of plant height was more pronounced between the two stages in Harosoy than Enrei. Maximum plant height of 42.48 and 42.05 (cm) was recorded with 40 and 20g zeolite application and the lowest in control treatment at all the growth stages. This trend was similar with the result reported for pea (Naik, 1989), mung bean (Akhtaruzzaman, 1998) and for edible oil pea (Ferdous, 2001). The KyP and KnP allophanic soils gave similar trend of increase with respect to plant height as compared to paddy soil. The KnP and KyP soils gave 12.77 & 7.11% more taller plants than the paddy soil. On an average, plants from allophanic soils were 13.44 % taller than the paddy soil. Maximum plant height from KyP and KnP allophanic soils may be due to less competition among plants for space and availability of nutrients for growth and development. Kavoosi (2007) reported that plant height increased significantly in rice crop under proper utilization of zeolite application. Significant differences were observed between plant heights of the two cultivars. Harosoy grew taller and attain maximum plant height of 18 cm as compared to Enrei. The differences in plant height of the two cultivars may be due to their growth habit, which is genotypic in nature.

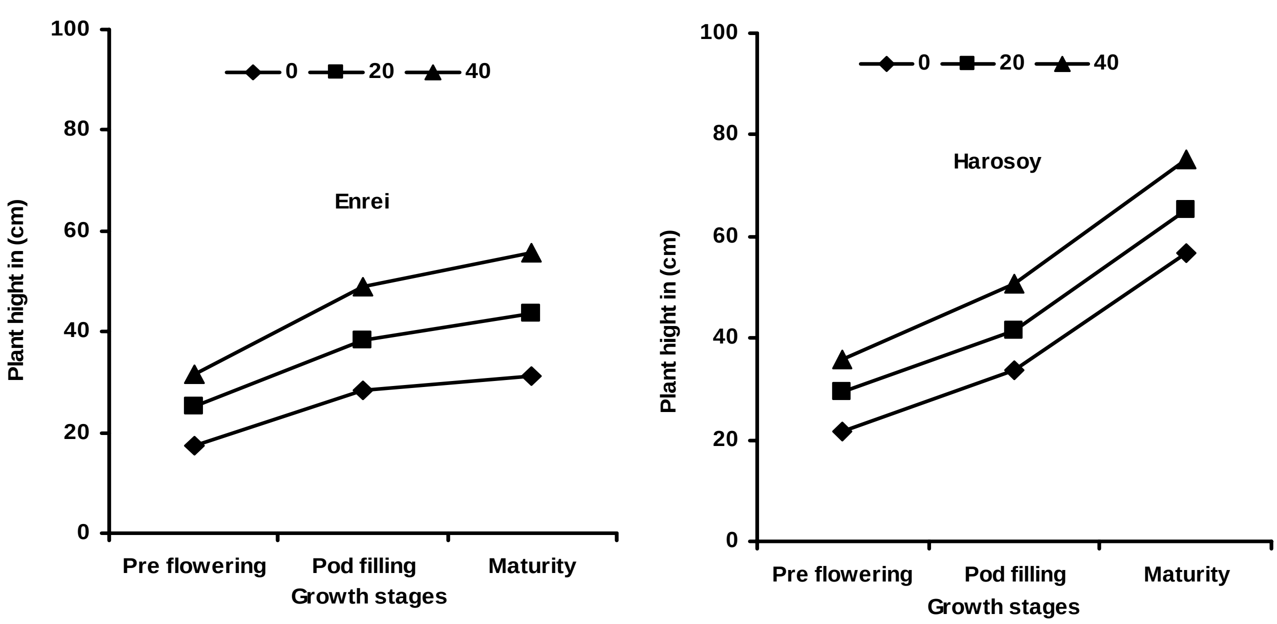

Fig. 2. Plant height of Harosoy and Enrei at different growth stages as affected by zeolite levels.

Number of pods plant^{-1}: Both remobilization of N and biological N_2 fixation during reproductive growth are important sources of N for developing pods (Neves *et al.*, 1982). Number of pods plant^{-1} depends on the number of flowering nodes plant^{-1} and number of flower per node and its retention. Greater photosynthesis enhanced by more nutrients uptake helps to initiate more flowering bud, which ultimately developed as pods. Nutrients requirement of a plant especially nitrogen depends on its demand and is controlled genetically or by the nutrients status present in the soil. The number of pods plant^{-1} significantly increased with increasing levels of zeolite (Fig. 3). Plots treated with 20 and 40 g zeolite gave the highest number (32.96 & 30.79) of pods plant^{-1}, whereas the lowest number of pods plant^{-1} (25.90) was recorded from the control plots. Zeolite application gave 7.06% more pods as compared to the control treatment. Maximum number of pod plant^{-1} from zeolite treated plots may be due to greater partitioning of nutrients to reproductive sink in zeolite treated plots, resulting in maximum number of pods plant^{-1} from pods initiation period to physiological maturity. The same trend of increase in number of pods plant^{-1} was observed when the crop was sown on KyP and KnP allophanic soils. KyP and KnP allophanic soils gave 9.08% more pods plant^{-1} than paddy soil. Maximum number of pods plant^{-1} from KyP and KnP allophanic soil is attributed to the high fertility status of these soils plus the nutrients supplement through zeolite application. Therefore, these soils have high potential to provide nutrients for optimum plant growth and development. The minimum number of pods plant^{-1} from paddy soil and control treated plots of zeolite is attributed to the poor fertility status of these soil, where, greater interplant competition for light, water and nutrients leading to smaller plants with less branching and minimum pods plant^{-1}, which is in agreement with Beatty *et al.*, (1982), who reported that non- fertilized treatment reduced pod number. These results were similar to those reported by Singh *et al.*, (1992) and Ferdous (2001).Cultivars differed in number of pod plant^{-1} with Harosoy having 12% more pods plant^{-1} than Enrei.

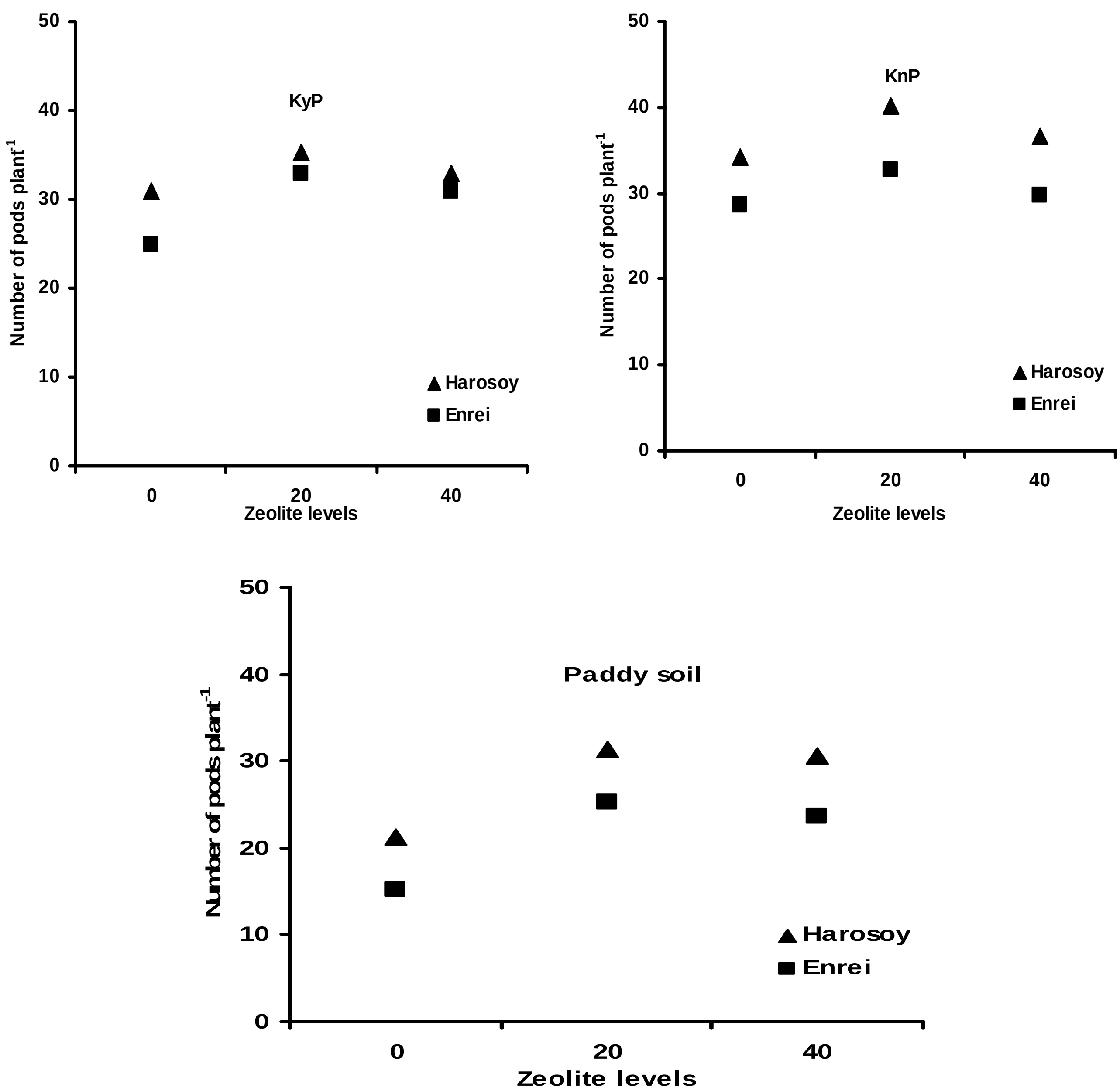

Fig. 3. Number of pods plant^{-1} of determinate (Enrei) and indeterminate (Harosoy) soybean cultivars as affected by zeolite levels and soil type.

Number of seeds pod^{-1}: Insufficient nutrient supply to the plants during developmental stage may cause lesser number of seeds pod^{-1}. During pod development the supply of sufficient nutrient and photo-assimilates are essential for increasing pod length as well as grain number in pod. Seeds pod^{-1} was significantly influenced by zeolite application level and soil type (Fig. 4). Irrespective of varieties, seeds pod^{-1} increased with increasing zeolite levels. Maximum number of seeds pod^{-1} was obtained from plots treated with 20 g zeolite. A decreasing trend in the number of seeds pod^{-1} was observed with maximum dose of zeolite application. Maximum number of seeds pod^{-1} from 20 g zeolite application may be due to greater reproductive growth and greater partitioning to reproductive sink in these plots, which resulted in maximum number of seed pod^{-1}. Higher dose of zeolite produced larger canopy which created shading effect that reduced photosynthesis to the developing grain. Roy *et al*., (1995) obtained maximum seeds pod^{-1} at moderate levels of nitrogen and beyond that seed pod^{-1} were reduced in pea and sesame respectively. KyP and KnP allophanic soils gave maximum number (2.55& 2.77) of seeds pod^{-1} as compared to paddy soil. Maximum number of seeds pod^{-1} from KyP and KnP allophanic soils may be due the availability of nutrients and water during its reproductive growth and greater partitioning to reproductive sink in these plots, which resulted in maximum number of seeds pod^{-1}. Seeds pod^{-1} differed between cultivars with Enrei having 5% less seeds pod^{-1} than Harosoy. Differences between cultivars for seeds pod^{-1} were small as expected (Egli & Yu, 1991) and did not correlate with seed yield. The number of seeds produced by a soybean community is a function of the amount of photosynthate available for seed growth since soybean seed number is associated with crop growth rate during flowering and pod set Egli *et al*., (1993). Differences in seeds plant^{-1} could therefore be derived from a more efficient utilization of assimilate in seed. Our data correspond well with those of Woodward & Begg (1976), who stated that reduced seed mass of soybean resulted in greater pod and seed number.

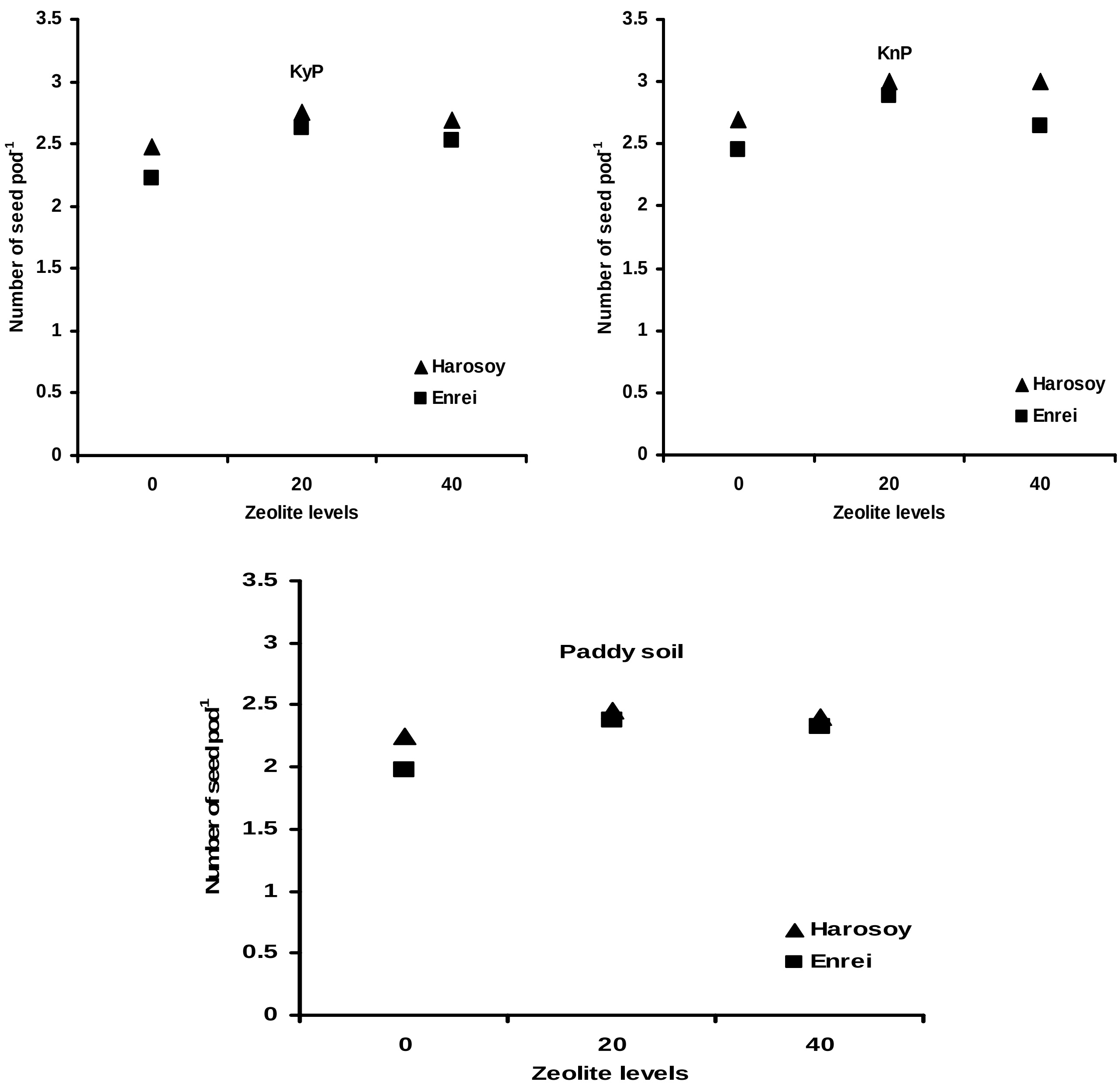

Fig. 4. Number of Seed Pod^{-1} of determinate (Enrei) and indeterminate (Harosoy) soybean cultivars as affected by zeolite levels and soil type.

Biological yield (kg ha^{-1}): Biological yield was significantly affected by different levels of zeolite application and allophanic soil (Fig. 5). Maximum biological yield was obtained from 40 g zeolite application, followed by 20 g zeolite application. Dry matter yield for various zeolite levels ranged from 507.70 to 545.70 kg ha^{-1}. Enrei produced higher biological yield than Harosoy. Maximum dry matter (502.76 kg ha^{-1}) was obtained from Enrei applied with 40 g zeolite, and minimum (425.44 kg ha^{-1}) from Harosoy grown on paddy soil without zeolite. Seasonal dry matter yield for both cultivars shows that in each cultivar dry matter yield increased when treated with highest dose of zeolite, attained a peak and then declined (Fig. 5). Decrease in dry matter yield was observed from control treated plots of zeolite applied to paddy soil. Dry matter yield progressively increased as sowing was done on KyP and KnP allophanic soils due to the availability of nutrients and its proper uptake and utilization. Dry matter of Enrei increased @ 28.6 kg ha^{-1} day^{-1} from 0 to 40 g zeolite application and Harosoy increased @ 63.6 kg ha^{-1} day^{-1}, with addition of zeolite, which could be due to different rate of dry matter accumulation among cultivars as reported by Egli (1975) and Beaver & Cooper (1982) who found Corsoy 79 to have a higher seed fill rate than Williams 79 and concluded that this advantage gave Corsoy 79 its higher yield potential. Interaction between zeolite, varieties was significant; Enrei produced heavier seeds than Harosoy in all zeolite levels. The percent difference between the two cultivars was maximum (28%) in 20 g zeolite application and minimum (11.5%) in 40 g zeolite application. This could be due to the differential response of varieties to variation in uptake and its utilization. Henderson & Kamprath (1970) have reported dry matter accumulation rates from 106 to 379 kg ha^{-1} day^{-1} between specific periods. Hangway & Weber (1971) reported daily rates of dry matter accumulation from 88 to149 kg ha^{-1} at specific growth stages.

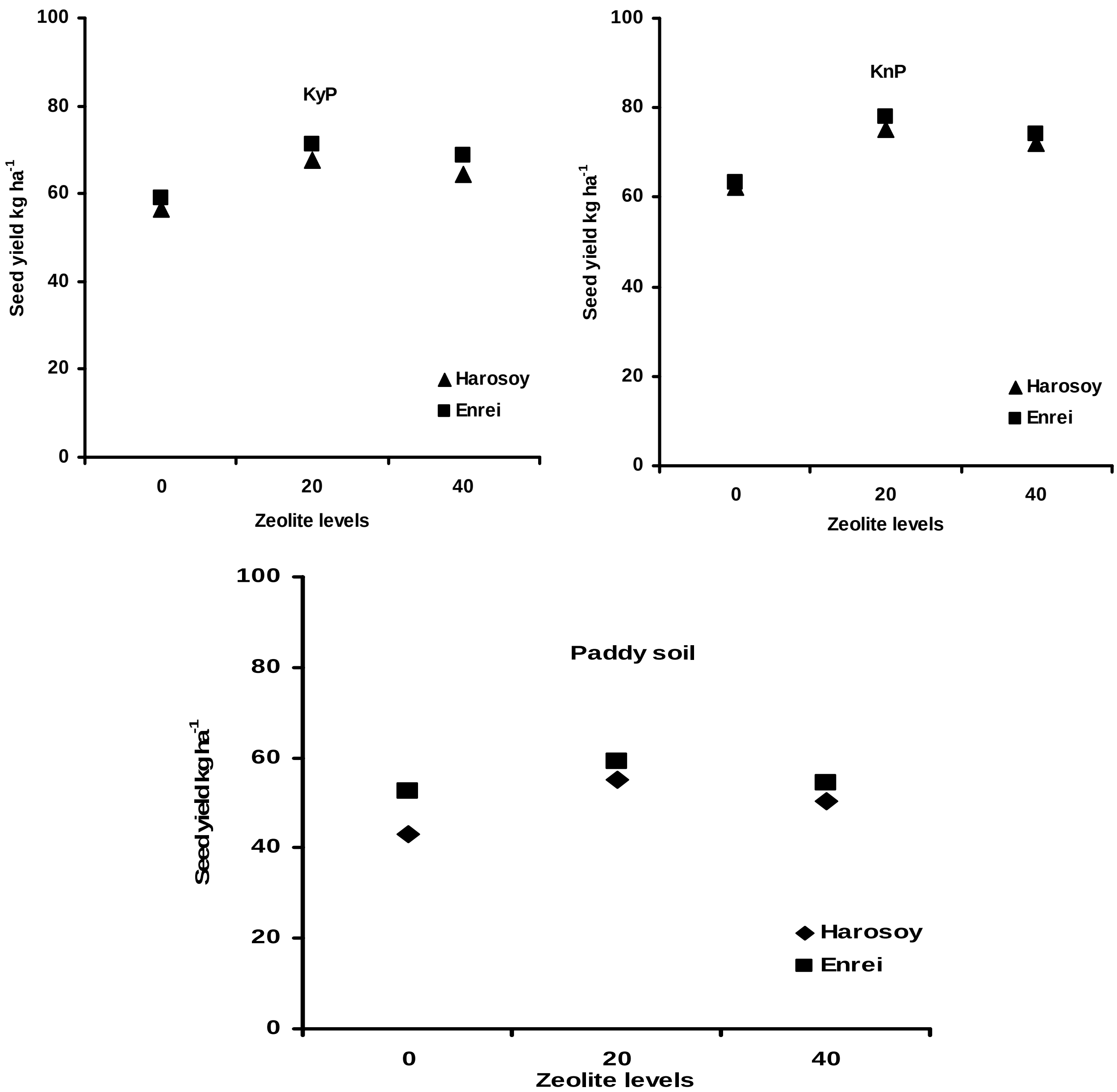

Fig.. 5. Seed yield (Kg ha^{-1}) of determinate (Enrei) and indeterminate (Harosoy) soybean cultivars as affected by zeolite level and soil type.

Seed yield (kg ha^{-1}): The seed that represents economic yield is a mixture of embryonic and maternal tissues. The mature seed is influenced by environmental factors such as temperature, photoperiod and supply of nutrients. Seed yield area^{-1} is attributed to the number of pods plant^{-1}, number of seed plant^{-1}, seed weight and number of plant area^{-1}. All these yield contributing parameters were significantly influenced by the increasing levels of zeolite application and soil types in both cultivars of soybean (Fig. 6). It is evident from the figure that a steady increase in seed yield (kg ha^{-1}) occurs with increase in zeolite level from 20 to 40 g. The highest seed yield from 20 g zeolite application and KyP and KnP allophanic soils may be attributed to greater partitioning of dry matter into the economic portion i.e. to seed and favorable nutrient uptake, which resulted higher number of pods plant^{-1}, seed pod^{-1} and maximum seed weight. The increase in seed yield may also be related to changes in plant architecture like more leaf area, more branching, number of leaves and plant height. Large reduction in branches and stem, vegetative and reproductive development resulted from higher dose of zeolite application and paddy soil. Higher dose of zeolite application produced larger canopy which created shading effect that reduced photosynthesis to the developing grain. The KyP and KnP allophanic soils gave same trend of increase in yield (kg ha^{-1}) as compared to the paddy soil. Minimum yield (kg ha^{-1}) was obtained from plots grown on paddy soil with zero zeolite application. Among the varieties, Enrei gave maximum yield than Harosoy. This is mainly due to better canopy structure that facilitated more light interception and more dry matter production that translocated to the developing grain in Enrei. Whereas, in Harosoy thin leaves influenced distribution of photo-assimilates to the parasitic leaves rather to developing grains. Average data for dry seed yield showed a best-fit linear positive relationship with LAI and zeolite levels (Fig. 1), where the R^2 values are 0.96 and 0.98. These relationships indicate that in case of Enrei, over 61% and 66% variation can be explained from the variation in LAI and zeolite levels. Munir *et al.*, (2007) studied the response of horticultural crops to zeolite application and observed that increase in the dose of zeolite application increased the grain yield and yield components over control.

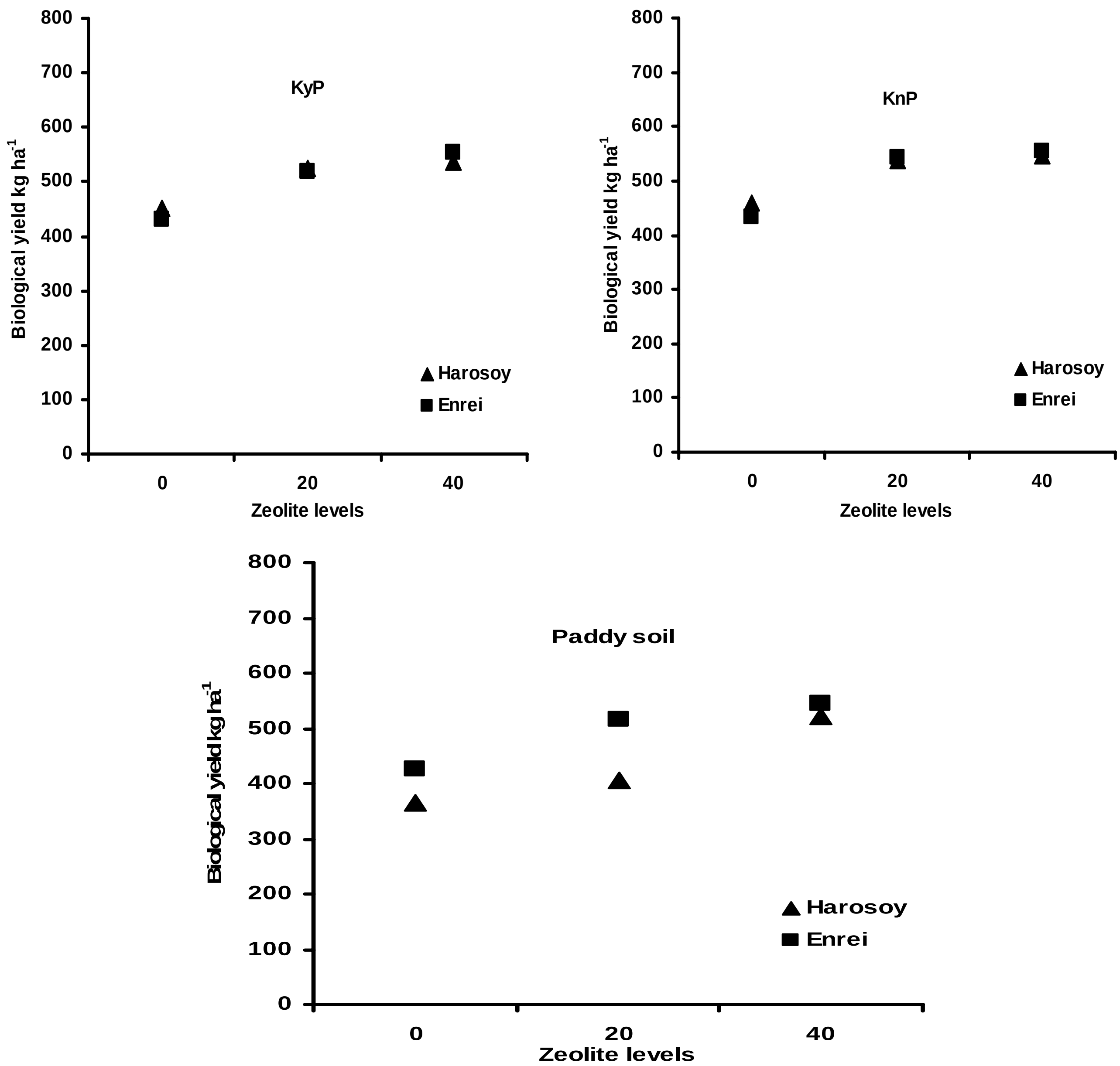

Fig. 6. Biological yield (kg ha^{-1}) of determinate (Enrei) and indeterminate (Harosoy) soybean cultivars as affected by zeolite levels and soil type.

100-seeds weight (g): Seed size i.e., seed weight contributes greatly to seed yield. Seed size varies with the variation in zeolite application and soil type. The quality of seed crop depends on the translocation of photosynthates from photosynthesizing organ to seed during the period from pod setting to maturity. Seed weight depends on protein synthesis in it and seed protein increases by nitrogen fertilization (Klalan & Berger, 1963) Among the different zeolite applied, significant variation in 100 seeds weight were observed (Fig. 7) and it varied from 128.35 to 130.05 g. The highest 100-seeds weight was observed at both 20 and 40 g zeolite applications. The same trends of increase in 100-seeds weight were observed in both KyP and KnP allophanic soils. Significant differences were found between cultivars with respect to seed weight. Enrei produced 15% larger seed mass than Harosoy (Fig. 7). Gay *et al.*, (1980) and Woodward & Begg (1976) stated that yield advantages between cultivars were correlated with seed mass, partially as a result of the number of seeds available for filling duration of the seed filling period, and total photosynthate production. Seed mass was overall significantly correlated with yield ($r = 0.33$; $p<0.001$), but the r-value was relatively small. Board, (1987) reported a weak relationship between seed mass and yield. Beaver & Cooper (1982) observed that Corsoy-79 had a higher seed fill rate than William-79 and concluded that this advantage gave Corsoy 79 its higher yield potential.

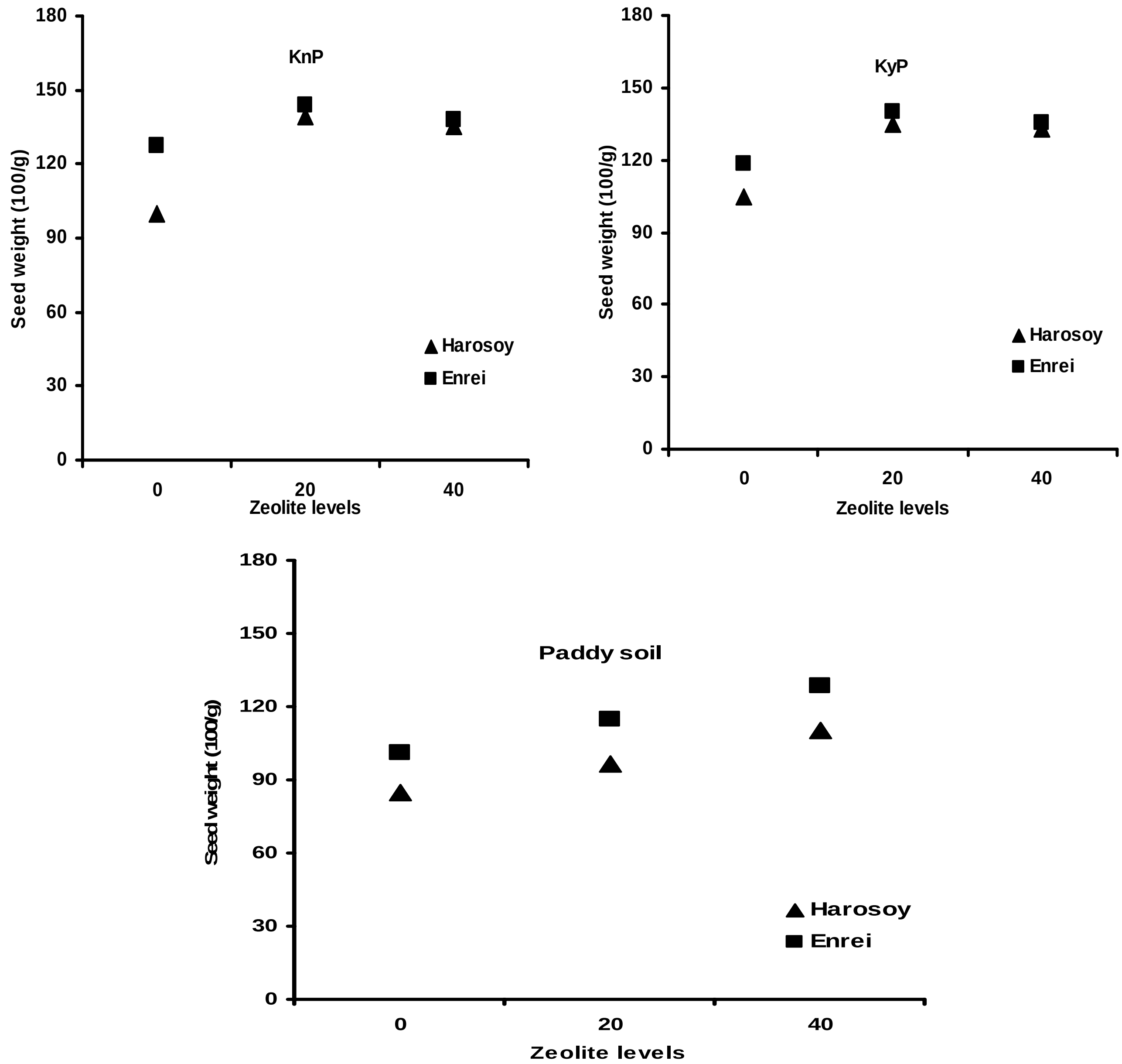

Fig.. 7. Seed weight (g/100) of determinate (Enrei) and indeterminate (Harosoy) soybean cultivars as affected by zeolite levels and soil type.

Conclusion and Recommendations

Results of this experiment reveals that synthetic zeolite application promote plant growth, enhance dry matter accumulation and improve the agronomic attributes such as pods plant^{-1} and seeds pod^{-1}, thereby increasing seed yield of determinate and indeterminate soybean cultivars. KnP and KyP allophanic soils show its fertility and high potentive efficiency for crop cultivation. Further research is needed on different aspects of zeolite application on different crops for ascertaining the beneficial effects in a wider range of environment and under different ecological conditions.

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