Kuwait J. Sci. **44 (4)** pp 119-128, 2017

Modeling some plant species distribution against environmental gradients using multivariate regression models

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Abstract

This study was done to formulate the predictive models of plant species distribution against environmental gradients in Wah Cantt region of Pakistan. From along the roadsides of Wah Cantt, data was collected using braun-blanquet approach which identified total 36 species belonging to 18 different families. Generalized additive model (GAM) was employed for plotting non-linear relationship between plant species distribution against environmental gradients, while non-metric multi dimensional scaling (NMS) application was carried out to highlight the stress in plant species distribution against selected environmental gradients (Zn^{2+}, Cu^{2+}, Fe^{2+}, Mn^{2+}, O.M, EC, pH). Results obtained from GAM had shown that species of *Cynodon dactylon* had higher values of predictive variables and had ability to survive in stress conditions of environmental gradients. Similarly, results obtained from NMS confirmed that stress rate was uniform for higher values of selected environmental gradients and *Cynodon dactylon* to be most resistant species against stress. Stress was found as function of plant response against extreme conditions of selected environmental gradients depending upon change, interval and causing change in system. These results can be helpful in proper management of herbaceous flora growing at Wah Cantt region of Pakistan.

Keywords: Edaphic factors; generalized additive model; non-metric multidimensional scaling; plant species distribution; species abundance.

1. Introduction

The investigation of relationship between plant species distribution and environmental gradients is of immense importance in ecology, because it reflects about general pattern of species diversity (Gusian & Zimmermann, 2000). With the changing environment, shift in species distribution pattern is becoming common. Most of the species are under stress. Stress is observed in the form of droughts, salinity, floods and temperature fluctuations, which is making natural ecosystem unstable (Lisar *et al*., 2012). Researchers have identified the development of anti-stress mechanism in plant species against changing environment pattern (Zhang *et al*., 2006; Al-turki, 2004) thus supporting survival of well adapted species against environment (Yordanov *et al*., 2003). During last years, among the variety of statistical regression models, generalized additive model (GAM) has gained much importance. GAM was proposed for plotting species response against natural ecosystem but some researches had shown that bell shaped response of generalized linear model (Gaussian Curve) cannot be true for some species (Miller & Franklin, 2002; Austin *et al*., 2006; Austin, 2007) which leads to misinterpretation of distribution patterns (Austin *et al*., 2006; Barry & Welsh, 2002). GAM, is preferred due to its flexibility and better handling of non-linear relationship between plant species distribution against environmental gradients, as it produces response curve on the basis of non-parametric analysis (Austin, 2002; Gusian *et al*., 2002).

For predicting stress between the plant species distribution and environmental gradients, non-metric multidimensional scaling (NMS) is an influential tool for extorting nonlinear gradients in species composition (Ahmad & Quratulainn, 2011). The study was carried out to formulate the predictive models of plant species distribution against environmental gradients and to evaluate the stress between some plant species and selected environmental gradients in Wah Cantt region of Pakistan.

1. Materials and Methods

1.1. Study area:

Wah Cantt is s located in Rawalpindi district (at latitude 31.57ºN and longitude 74.31º E having total area of 92 km^2) in Pakistan and 50 km away from the capital Islamabad. Recorded weather pattern indicated hot summers and cold winters. Maximum rainfall has been recorded during monsoon season from month of July to September (Riaz & Javid, 2009).

1.2. Collection of plant and environmental gradient samples:

The physicochemical analysis was carried out in March-April 2014. Quadrat method was used for collection of herbaceous plant species (Urooj *et al*., 2016). Total 50 quadrats were laid down and the cover values were recorded using Domin Cover Scale (Urooj *et al*., 2015). NMS was carried out for fifty samples. Soil samples were collected from 115-cm depth for pH, organic matter, electrical conductivity (EC) and micronutrients (Zn^{2+}, Cu^{2+}, Fe^{2+}, Mn^{2+}) testing. Soil pH and EC were analyzed by preparing extract of soil solution in 1:2 ratios (Urooj *et al*., 2016). Four micronutrients Zinc, Iron, Copper and Manganese were analyzed by taking 1 g soil from each collected soil sample and digested in 12 ml of freshly prepared aqua regia (containing acid solution of 9 ml HCl and 3 ml HNO_3 in 3:1 ratio). Digested samples were analyzed by using atomic absorption spectrophotometer (Ehi-Eromosel *et al*., 2012; Urooj *et al*., 2016).

1.3. Monte Carlo permutation tests:

It is a statistical significance test repeatedly performed by shuffling samples to find relation between species and environmental variables. It is done with known probability and outcome, to evaluate the results of unknown outcome. It is performed repeatedly. Its validity is dependent upon type of permutation for specific research (Ter braak & Smilauer, 2002).

1.4. Generalized additive model:

Generalized additive model is the extension of generalized linear model. It is a statistical package that helps in plotting co-relational graphs between species and predictor variables. It enables step wise model selection including species and environmental variable (Austin, 2007).

2. Results

2.1. Generalized additive model (GAM):

GAM was done to evaluate the relationship between the plant communities and selected environmental gradients (Lehmann *et al*., 2002; Munoz & Felicisimo, 2004). For planning and conservation of plant communities in any area, spatial analysis of species distribution is very important (Tutz & Kauermann, 2003). For EC, the upper quartile of *Cynodon dactylon* was 40 and lower quartile was -10. The species *Cynodon dactylon*, *Rumex dentatus*, *Cucumis meloagrestis*, *Taraxacum officinale*, and *Oxalis Corniculata* were unaffected by EC and species *Medicago polymorph*, *Malvastrum coromandelianum (L.) Garcke, Euphorbia heliscopia, Lepidium sativum* were slightly affected by EC while the species of *Coronopus didymus, Amaranthus spinosus, Dicliptera roxburghiana, Euphorbia hirta, Carthamus oxyacantha, Parthenium hysterophorus ,Conyza Canadensis, Cenchrus biflorus Roxb, Euphorbia prostrate and Dichanthium annulatum* were affected by EC content and low EC content were in stress due to low level of EC (Figure 1).

In case of pH, *Vicia sativa* emerged to be most affected species with the upper quartile of 80 and lower quartile of -20. The species of *Silybum marianum* and *Verbena tenuisecta* remained unaffected, while pH showed slight impact on *Cynodon dactylon*, as it was giving smooth curve and other species like *Coronopus didymus, Amaranthus spinosus, Dicliptera roxburghiana, Euphorbia hirta, Carthamus oxyacantha, Parthenium hysterophorus, Conyza Canadensis, Cenchrus biflorus Roxb, Euphorbia prostrate and Dichanthium annulatum* were in stress due to low level of pH (Figure 2).

The upper quartile of *Cynodon dactylon* was 25 and lower quartile had value of -5 and it had smooth curve (Figure 3). The level of organic matter had no effect on species of *Cynodon dactylon*, while stress condition appeared for *Coronopus didymus, Amaranthus spinosus, Dicliptera roxburghiana, Euphorbia hirta, Carthamus oxyacantha, Parthenium hysterophorus, Conyza Canadensis, Cenchrus biflorus Roxb, Euphorbia prostrate and Dichanthium annulatum*, due to low level of Organic matter (Figure 3).

Zinc had no effect on species of *Cynodon dactylon* and had upper quartile of 40 and lower quartile of -10. The species like *Dichanthium annulatum* and *Euphorbia heliscopia* were slightly affected, while stress condition appeared for *Coronopus didymus, Amaranthus spinosus, Dicliptera roxburghiana, Euphorbia hirta, Carthamus oxyacantha, Parthenium hysterophorus, Conyza Canadensis, Cenchrus biflorus Roxb* and *Euphorbia prostrate* due to low level of Zinc (Figure 4).

Cannabis Sativa and *Cynodon dactylon* were impassive against Copper, while low level of copper created stress condition for species *Coronopus didymus, Amaranthus spinosus, Dicliptera roxburghiana, Euphorbia hirta, Carthamus oxyacantha, Parthenium hysterophorus, Conyza Canadensis, Cenchrus biflorus Roxb, Euphorbia prostrate* and *Euphorbia heliscopia* (Figure 5).

Cynodon dactylon, *Malvastrum coromandelianum (L.) Garcke* and *Medicago polymorpha* were unaltered by Iiron content, while species *Taraxacum officinale* was slightly impacted and resulted in smooth curve. The species *Coronopus didymus, Amaranthus spinosus, Dicliptera roxburghiana, Euphorbia hirta, Carthamus oxyacantha, Parthenium hysterophorus, Conyza Canadensis, Cenchrus biflorus Roxb,* *Euphorbia prostrate* and *Euphorbia heliscopia* had revealed stress condition, due to low level of Iron (Figure 6).

The GAM of Mn had shown no consequences for species *Cynodon dactylon* and *Malvastrum coromandelianum (L.) Garcke*. The species *Taraxacum officinale, Euphorbia hirta, Medicago polymorpha, Euphorbia heliscopia* and *Cannabis sativa* had documented slightly effected by Manganese, while the species *Dicliptera roxburghiana, Capsella bursa patoris (L.) Medic, Opuntia monacantha, Ranunculus muricatus* and *Tribulus terrestris* showed stress conditions for low level of Manganese (Figure 7).

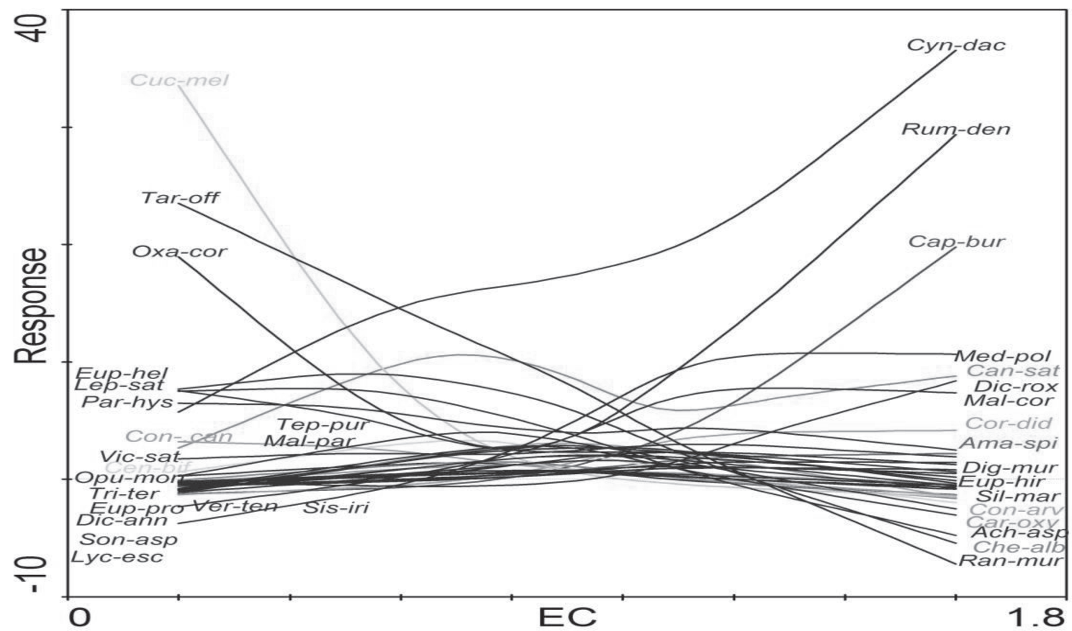

Fig. 1. GAM of EC

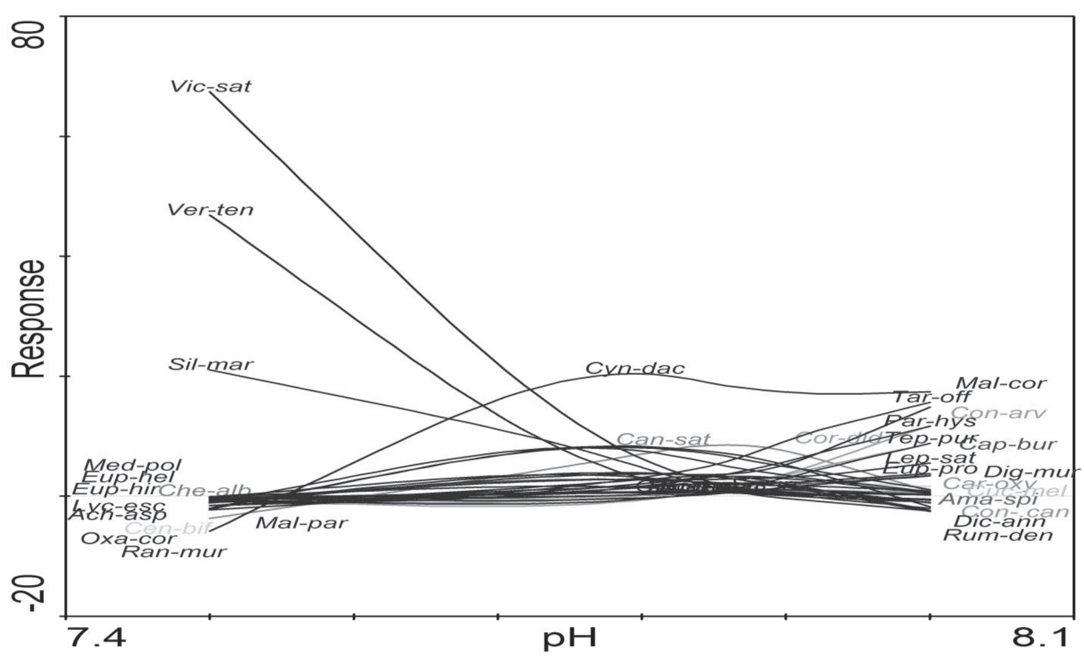

Fig. 2. GAM of pH

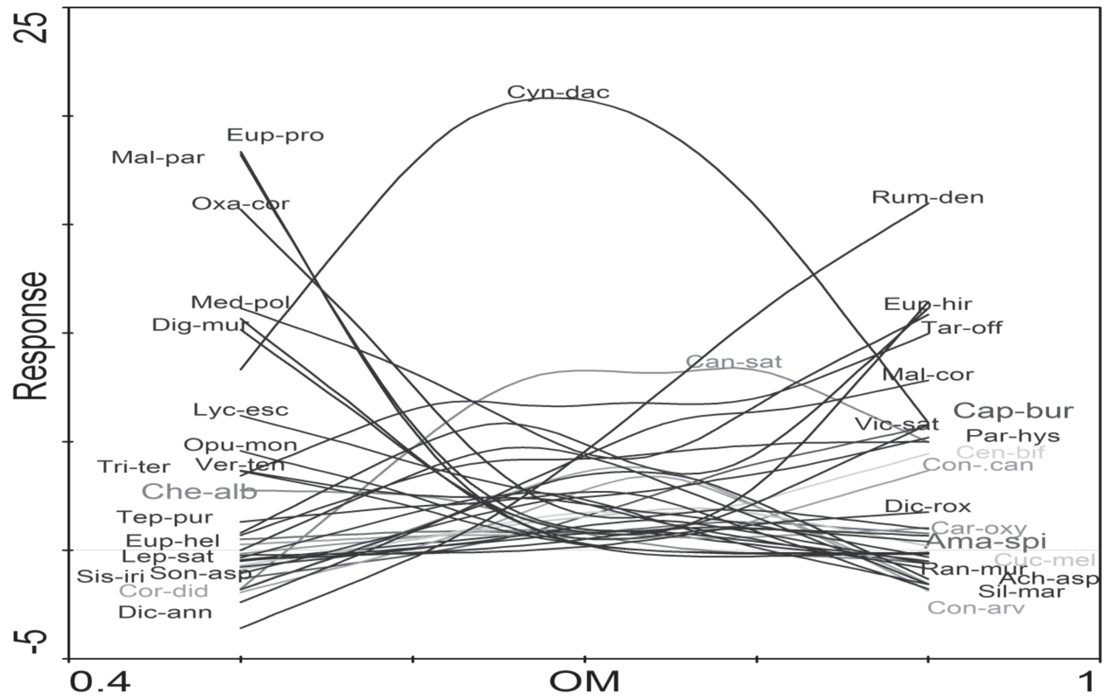

Fig. 3. GAM of OM

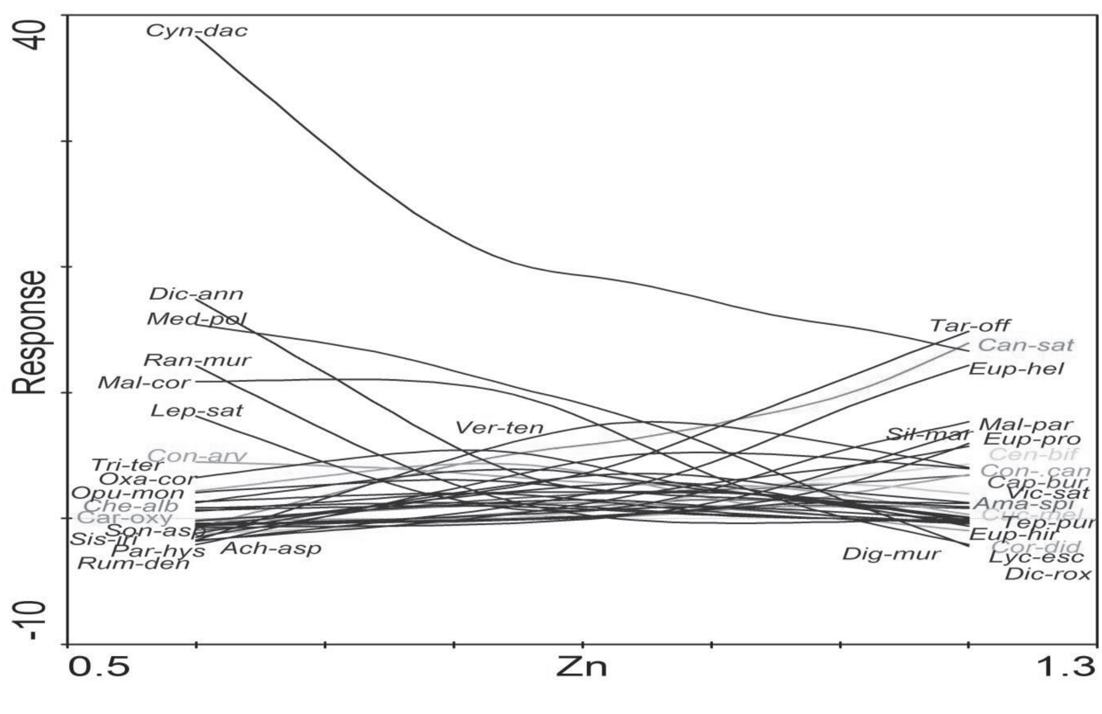

Fig. 4. GAM of Zn

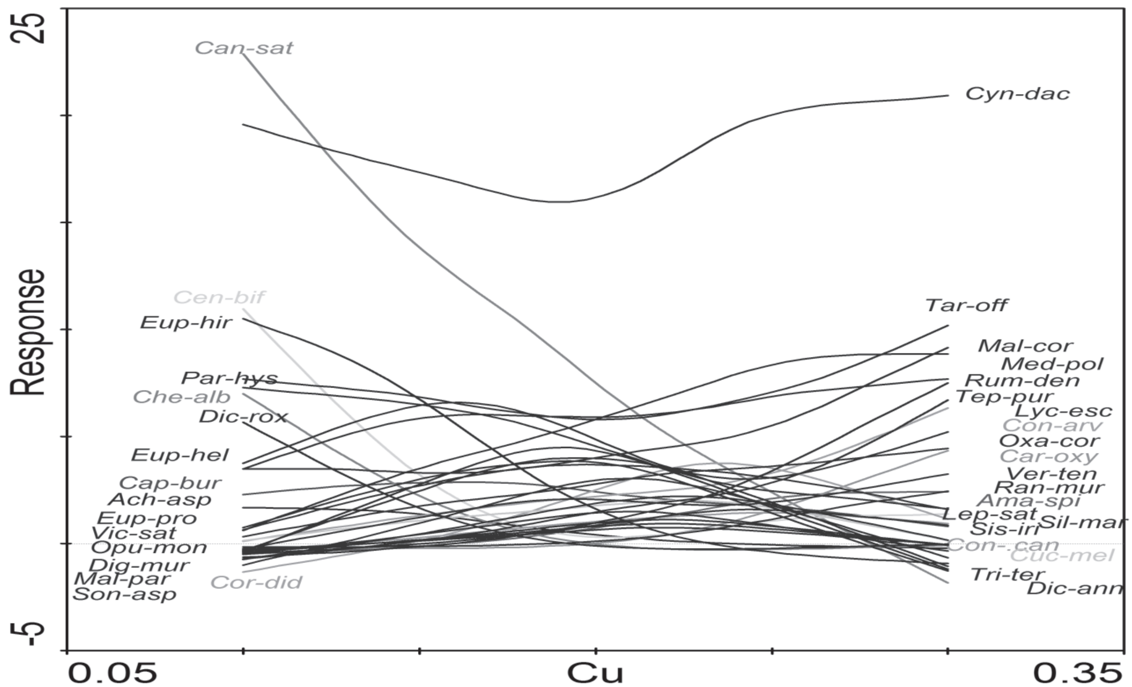

Fig. 5. GAM of Cu

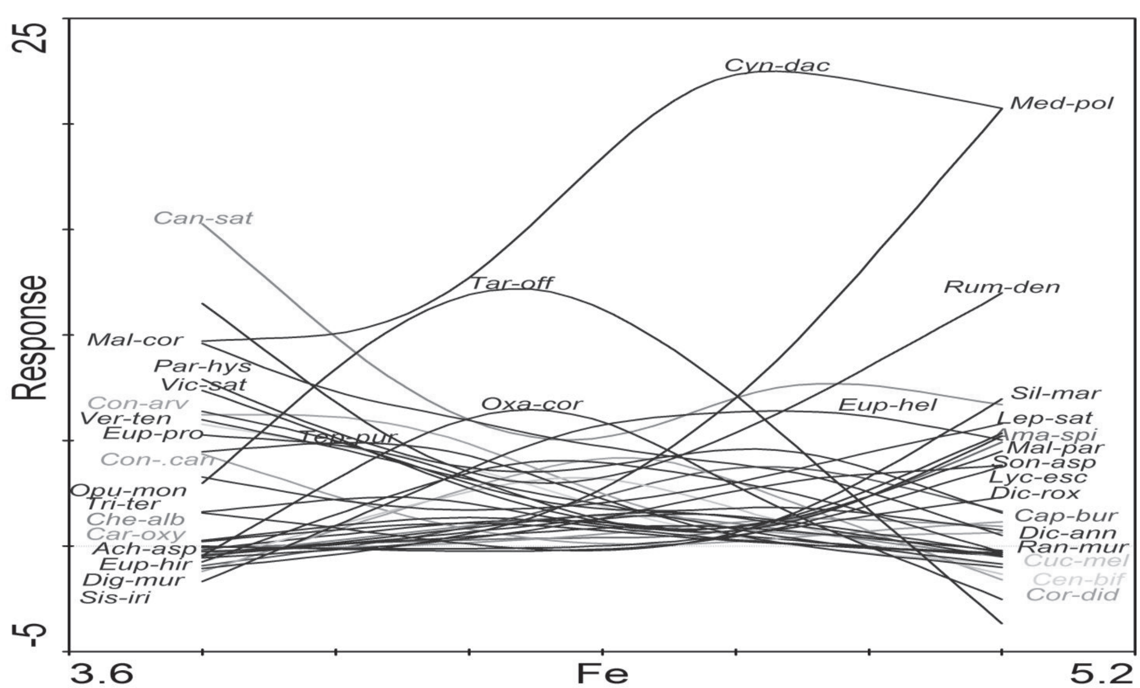

Fig. 6. GAM of Fe

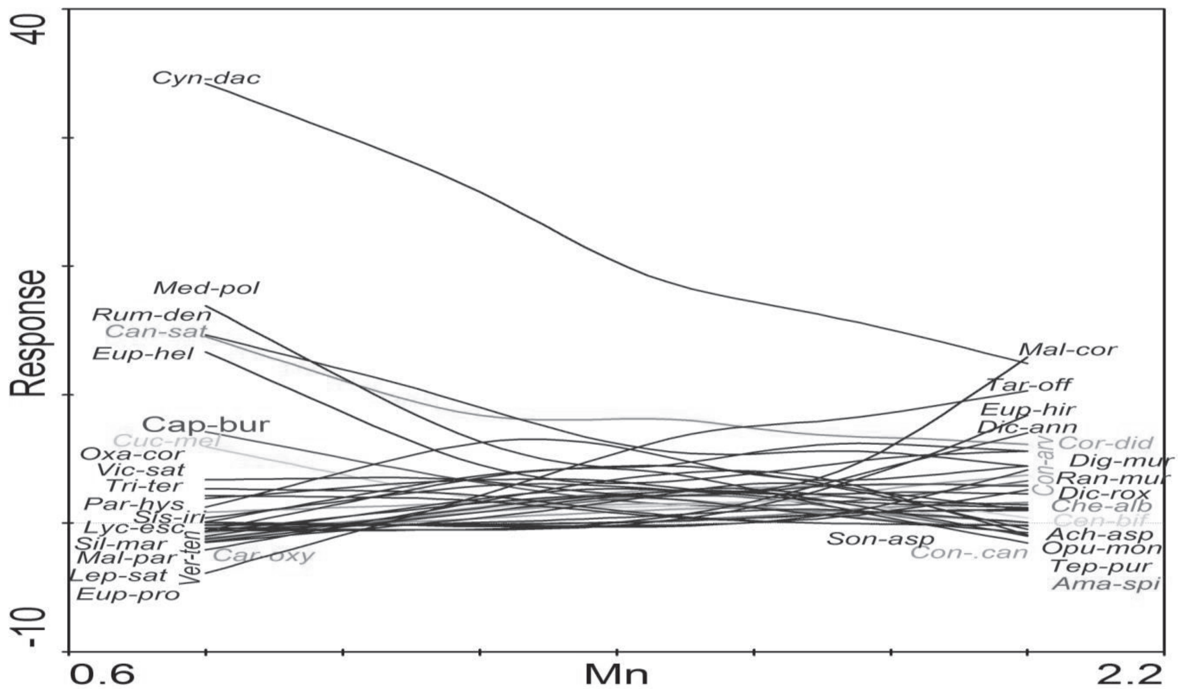

Fig. 7. GAM of Mn

2.2. Non-metric multidimensional scaling (NMS):

NMS is a flexible and powerful tool that allows integration of different data sets into multivariate patterns. Selection of sample size and specie/variable make NMS easy. NMS relates the balance "noise" against statistical significance (Urooj *et al*., 2015). NMS ordination was done to obtain a Scree plot which helped in determination of amount of stress in ordination structure and helped in testing monotonicity. Stress was defined as the measure of distance of departure from monotonicity (Urooj *et al*., 2015). The level of stress is high, when the real data fall above 20 within randomized data, and the data do not meet the postulation of monotonicity. McCune & Grace (2002) warned that stress reduction of more than 20 indicates that the ordination contains too much noise (Table 1).

Table 1. Stress in relation to function of dimensionality by using Monte Carlo test

n=50	**Stress in real data**			**Stress in randomized data**			
Axes	Minimum	Mean	Maximum	Minimum	Mean	Maximum	P
1	46.513	54.284	56.569	46.855	50.856	75.006	0.0196
2	28.877	30.648	40.328	28.237	30.618	32.498	0.0588
3	20.412	21.378	30.924	20.022	24.444	76.041	0.0392
4	15.629	16.452	25.392	16.017	19.944	76.465	0.0196

p = proportion of randomized runs with stress < or = observed stress that is;

p = (1 + no. permutations <= observed) / (1 + no. permutations)

1- Unrestricted

2- Restricted for spilt plot design, time series, line and grids

3- Unrestricted (as 1) within block

4- Restricted (as 2) within blocks (Ter braak & Smilauer, 2002).

The minimum value of real data line was less than 20 on y-axis while the maximum value was higher than 20. The leveling of line showed the points of stress and where stress was reduced to more than 20 i.e. group of species had noise in it. This could be proved by probability of second axis 0.058, which was more than 0.050, thus generating noise in the data. In this study, a Scree plot was obtained to discover the pressure in the structure of dataset for monotonicity. The Scree plot was suitable after major diminution in stress to occur with leveling off in two or three dimensions. In the Scree plot, the real data remained within randomized data, which means stress was neither so high nor too low for the ordination to contain noise, thus showing the data to be uniform. This revealed that *Cynodon dactylon* is most suitable growing plant under examined environment.

3. Discussion

Direct gradient modeling techniques have emerged as the best techniques for modeling plant species response against environmental gradients. In this study, the species of *Cynodon dactylon* emerged as the most resistant species between the ranges of 0.321.06- dS/m of EC. *Cynodon dactylo*n showed similar response for rest of the parameters including pH, OM, CU, Zn, Mn and Fe. Other parameters ranged as pH (7.67.91-), O.M (0.380.98%-), Zn (0.81.16-mg/kg), Cu (4.2-4.87mg/kg), Fe (0.150.29-mg/kg) and Mn (11.9-mg/kg). Species of *Cynodon dactylon* was more resistant as reported in previous researches, because it could grow between the ranges of 4.58.5-. A Species like *Lepidium sativum* grow at pH of 66.5- (Allan & Drast, 2010), so it was under stress at this condition.

Growth of some plant species was suppressed for lower values of selected environmental gradients. As the curve was shifted towards higher value of predictive variable, species were able to survive easily. So, it was found that Cynodon dactylon with upper quartile of 40 and lower of -10 was able to survive easily for the estimated values of predictive variables. *Cynodon dactylon* appeared as most dominant species, which was unaffected by any environmental gradient, while other species recorded stress conditions, which means they could not tolerate excess or lack of selected environmental gradients. Some species also recorded smooth curves, which mean they were showing balance with environmental predictors. Species responses recorded in GAM may be dependent on the nature of selected environmental gradients and ecological processes associated with them. Ejrnaes (2000) applied GAM for studying the response of 146 species against pH as environmental gradient and 20% of the species resulted in formation of unimodal sigmoid curve. It can be said that the scarcity of species varied with the location on dominant environmental variable as similiar to the results of Leathwich & Austin (2001).

Frescino *et al*. (2001) studied forest composition and structural diversity in Uinta Mountains Utah, for the variables of slope, aspect, geology, temperature, precipitation, and elevation. Unimodal sigmoid curve revealed 88% Pinus Corntorta trees were present in the selected forest depending upon selected predictive variables. The abundance of species was found to be dependent on environmental variables. Similar results were deduced from the current study.

Cynodon dactylon emerged as the most resistant species against stress. Venn *et al*. (2014) reported species with high specific leaf area were abundant and dominant at higher elevation by using NMS to find vegetation composition changes in alpine forest for the years of 2004 to 2011. Results of this study are similar to Venn *et al*. (2014). Non-metric multidimensional scaling (NMS) technique was employed to find correlation between environmental gradients and floristic composition highlighted non significant environmental gradients in species structure and excluded it in final model (Davies *et a.l*, 2007).

Ahmad & Ann (2011) applied Monte Carlo test in Non metric multi dimensional scaling for equating stress in relation to dimensionality. *Adiantum caudatum* and *Hedera nepalensis* emerged as most stress tolerant species against the selected environmental variables of pHand EC Results of present study are similar to Ahmad & Ann (2011).

4. Conclusion

This study identifies the response of plant species distribution against environmental gradients. *Cynodon dactylon* emerged as most resistant species against all the selected variables for both GAM curve and NMS. The predictive curves could be used for studying the complex interactions between plant communities. Predictive curves delineate stress conditions, when the predictive variable goes beyond permissible limit. This study could be used in conservation projects of native herbaceous flora and in conserving the recessive species in study area. Present study can be helpful for understanding the relative response of plants with their edaphic factors. In 2009, dominant species in study area was *Cannabis sativa* (Riaz & Javaid, 2009), but in 2014 dominant species was *Cynodon dactylon*. As a result, it can be be utilized for evaluating changing responses of plant communities against selected environmental gradients and for plant management.

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Submitted **:** 04/01/2016
Revised **:** 21/04/2016
Accepted **:** 24/10/2016

نمذجة توزيع بعض أنواع النباتات مقابل التدرجات البيئية باستخدام نماذج الانحدار متعددة المتغيرات

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خلاصة

أُجريت هذه الدراسة لصياغة النماذج التنبؤية لتوزيع أنواع النباتات مقابل التدرجات البيئية في منطقة واه كانت Wah Cantt في باكستان. فمن على طول جوانب الطرق في واه كانت، تم جمع البيانات باستخدام طرق براون-بلانكيت braun-blanquet التي حددت 36 نوعاً تنتمي إلى 18 عائلة مختلفة. تم استخدام النموذج التجميعي المُعمم (GMA) لتخطيط العلاقة غير الخطية بين توزيع أنواع النباتات مقابل التدرجات البيئية، في حين أنه تم تطبيق مقياس متعدد الأبعاد غير المتري (NMS) لتسليط الضوء على الإجهاد في توزيع أنواع النباتات مقابل التدرجات البيئية المختارة (Zn2+، Cu2+، Fe2+، Mn2+، O.M، Ec، pH). وقد أظهرت النتائج التي تم الحصول عليها من النموذج التجميعي المُعمم (GAM) أن أنواع النباتات من عرق النجيل Cynodon dactylon حصلت على قيم أعلى من المتغيرات التنبؤية وأنها لديها القدرة على البقاء على قيد الحياة تحت ظروف إجهاد التدرجات البيئية. وبالمثل، أكدت النتائج التي تم الحصول عليها من مقياس متعدد الأبعاد غير المتري (NMS) أن معدل الإجهاد كان موحداً بالنسبة للقيم الأعلى من التدرجات البيئية المختارة وأن نبات عرق النجيل Cynodon dactylon من أكثر الأنواع مقاومة للإجهاد. وقد وُجد الإجهاد عندما تعمل وظائف النبات ضد الظروف القاسية من التدرجات البيئية المختارة بناءً على التغيير، الفترة الزمنية وعمل تغيير في النظام. ومن الممكن أن تكون هذه النتائج مفيدة في إدارة النباتات العشبية المتنامية في منطقة واه كانت Wah Cantt في باكستان بشكل مناسب.