Remittances Review
June 2024,
Volume: 9, No: 3, pp.1092-1117
ISSN: 2059-6588(Print) | ISSN: 2059-6596(Online)

Received: 08 May 2024, Accepted:26 June 2024
DOI: https://doi.org/10.33282/rr.vx9i2.56

EVALUATING THE IMPACT OF EDAPHIC VARIABLES ON VEGETATION DYNAMICS IN THE PROXIMITY OF MANGLA DAM, PAKISTAN: A COMPREHENSIVE GEOENVIRONMENTAL ANALYSIS

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Abstract

Edaphic factors play a significant role in generating and sustaining the different vegetation species in an arid ecosystem and it is also helpful for vegetation restoration and management. The current study is aimed to scrutinize the growth patterns and spatial distribution of herbaceous plant life in response to the existing environmental gradients in the vicinity of Mangla Dam on the Jhelum river, Pakistan. Soil and herbaceous plants were randomly collected using 1*1 square meter quadrat. In total, 37 plant species from 17 distinct families were identified. The Generalized Additive Model, employed through the CANOCO program, is utilized for quantitative predictions of species distribution, and stress condition in vegetation distribution is analyzed using a non-metric multi-dimensional scaling technique. The results showed that only one specie *Cynodon dactylon* has tolerance at all micro and macro-nutrient concentrations, depicting higher predictive values. This study is very helpful in monitoring the complex relationship between the predictors and vegetation in the conservation of biodiversity.

Keywords: GAM; Ecology; Conservation; Species distribution; Edaphic factor

1. INTRODUCTION

The development serves as the foundation of any economy, yet numerous economic advancements have triggered significant environmental challenges. These environmental issues not only pose a substantial threat to the well-being of our ecosystem but also exert a deteriorating impact on human health. Pakistan, primarily as an agrarian country, relies upon agriculture as a backbone of the economy and agricultural production is highly dependent on the availability of water. The Indus River System (IRS) is the major source of water supply for Pakistan (Pappas, 2011) and considered as lifeline. Because it supplies water to about 90% of Pakistan's crops and accounts for more than 25% of the country's GDP. Indus Basin Irrigation System (IBIS) contains six rivers (Sutlej, Ravi, Jhelum, Chenab, Indus, and Kabul rivers) with a total annual 146 MAF flow. About 50–80% of Pakistan's normal river flows come from glacial melt, with the remaining amount coming from the country's seasonal monsoon rainfall. There is 144.91 MAF of water in the three rivers in the West, the Indus, Chenab, and Jhelum, and 9.14 MAF in the two rivers in the East, the Ravi and Sutlej. 39.4 MAF of the available water is used for irrigation, out of 104.73 MAF. Pakistan's dependency on rivers is evident that's why three main reservoirs, i.e., Mangla (1967), Tarbela (1978), and Chashma (1971), have been designed with a total capacity of 15.75 MAF, to store and manage water resources within the country (Haidar & Dilawar, 2022). The construction of dams bears paramount importance for Pakistan's development and its long-term prospects.

Dam construction affects the river ecosystem. It brings prominent physical and biological changes in watershed areas such as hydrology, sediment transportation, water quality, dynamics of producers, riparian vegetation, wildlife habitat and community of consumers, etc. (Silva et al., 2010; Grumbine, 2011; Schmutz & Moog, 2018). The presence of vegetation surrounding the dam plays a crucial role in safeguarding water quality by mitigating soil erosion and sedimentation. Vegetation cover helps to infuse organic matter into the soil, hold the soil particles together, and provide protective cover from surface runoff. Otherwise, soil erosion causes the loss of top fertile soil, turbid streams, clogged ponds, reservoirs, damaged aquatic life, roads, and buildings.

Edaphic factors are important in determining vegetation patterns because different plant species have different requirements in soil. To quantify this relationship, statistical methods are gaining worldwide recognition to understand non-Gaussian species response curves (Miller & Franklin, 2002; Austin & Smith, 1989). Vegetation relationship with edaphic factors can be assessed using multivariate or ordination techniques in which species showed positive or negative significant growth at different ranges of nutrient concentrations (Ahmad et al., 2014).

The Generalized Additive Model (GAM) is a statistical tool that predicts the attitude of species to grow on particular ranges of mineral concentration. The outcome variable of GAM is assumed to have a distribution from the exponential family i.e. normal distribution, binomial distribution, and poison, etc. This is particularly useful when the relationships between the predictors and outcome variables are non-linear or when there are interactions between predictors that are difficult to capture with traditional linear models. They can also handle missing data and can be used for both continuous and categorical outcome variables. It is also commonly used in fields such as ecology, epidemiology and finance but can be applied in any area where flexible modeling of complex relationships is required.

Generalized Additive Model (GAM) have become prominent tools in ecological research, offering a powerful means to comprehend intricate relationships between environmental parameters and plant responses. Their fundamental strength lies in the capacity to capture nonlinear associations between environmental parameters and plant responses. Cardoso et al. (2020) showcased the superiority of GAM in modeling complex ecological relationships, emphasizing their adaptability in handling nonlinearities, a critical aspect when investigating plant responses to environmental gradients.

In ecological studies, understanding the temporal dynamics of plant responses to environmental parameters is crucial. Clark & Wells (2023) highlighted the effectiveness of GAM in modeling phenological responses, enabling the identification of pivotal periods in plant development influenced by factors such as temperature, precipitation, and photoperiod. Additionally, GAM have proven valuable in addressing spatial variation and habitat heterogeneity in plant-environment relationships. Dormann (2007) demonstrated the application of GAM in spatially explicit models, enabling researchers to discern how environmental parameters impact plant responses across diverse habitats, contributing to a more nuanced understanding of ecological processes.

Given the complex interactions of environmental factors, GAM provide a framework for capturing these intricacies. Khan et al. (2023) delved into the role of soil nutrients and water availability in shaping plant communities, showcasing the effectiveness of GAM in modeling interactive effects and identifying critical thresholds beyond which plant responses undergo significant changes. The incorporation of covariates in GAM enhances the precision of plant-environment models. Pioneering the development of GAM, Wood (2001) emphasized their ability to handle multiple covariates, facilitating the inclusion of additional ecological context into models and enhancing the interpretability of the relationship between environmental parameters and plant responses.

Ensuring the robustness of ecological models involves addressing uncertainty and validating GAM. Zuur et al. (2010) provided comprehensive guidance on model validation techniques, stressing the importance of assessing model fit, predictive performance, and potential overfitting when applying GAM to ecological datasets.

Recent advancements in remote sensing and the availability of extensive ecological datasets have expanded the application of GAM. Ahmed et al. (2021) demonstrated the integration of remote sensing data with GAM to model vegetation responses to environmental parameters at large scales, highlighting the potential for these models in addressing ecological questions on a broader spatial and temporal scale. Overall, the literature underscores the versatility and effectiveness of Generalized Additive Models in unraveling the intricate relationships between environmental parameters and plant responses, offering a robust statistical framework for gaining deeper insights into the dynamics of plant-environment interactions as ecological research navigates the complexities of natural systems.

This study was designed to determine the growth of different plant species under present edaphic factors in the vicinity of Mangla dam using the Generalized Additive Model.

The significance of the study lies in its focus on understanding the growth patterns of various plant species in the vicinity of Mangla Dam, utilizing the Generalized Additive Model in relation to present edaphic (soil-related) factors. The study not only helps in identifying the key factors influencing plant growth, which is crucial for understanding the overall health and dynamics of the ecosystem around Mangla Dam. But also, by using the Generalized Additive Model, the study aims to provide a comprehensive assessment of how edaphic factors influence plant growth. This information is crucial for assessing the impact of the Mangla Dam on the surrounding environment. The use of the Generalized Additive Model is significant. This statistical modeling approach allows for the exploration of complex relationships between variables. The study not only contributes to understanding plant growth but also showcases the application of advanced statistical techniques in ecological research. Understanding the growth patterns of various species can contribute to the conservation of biodiversity by identifying areas where certain species thrive or face challenges. This knowledge is essential for designing effective conservation strategies. The study holds significance for environmental science, biodiversity conservation, water resource management, and agricultural practices. It contributes valuable information for decision-makers and stakeholders involved in the sustainable development and conservation of the region around Mangla Dam (Figure 01).

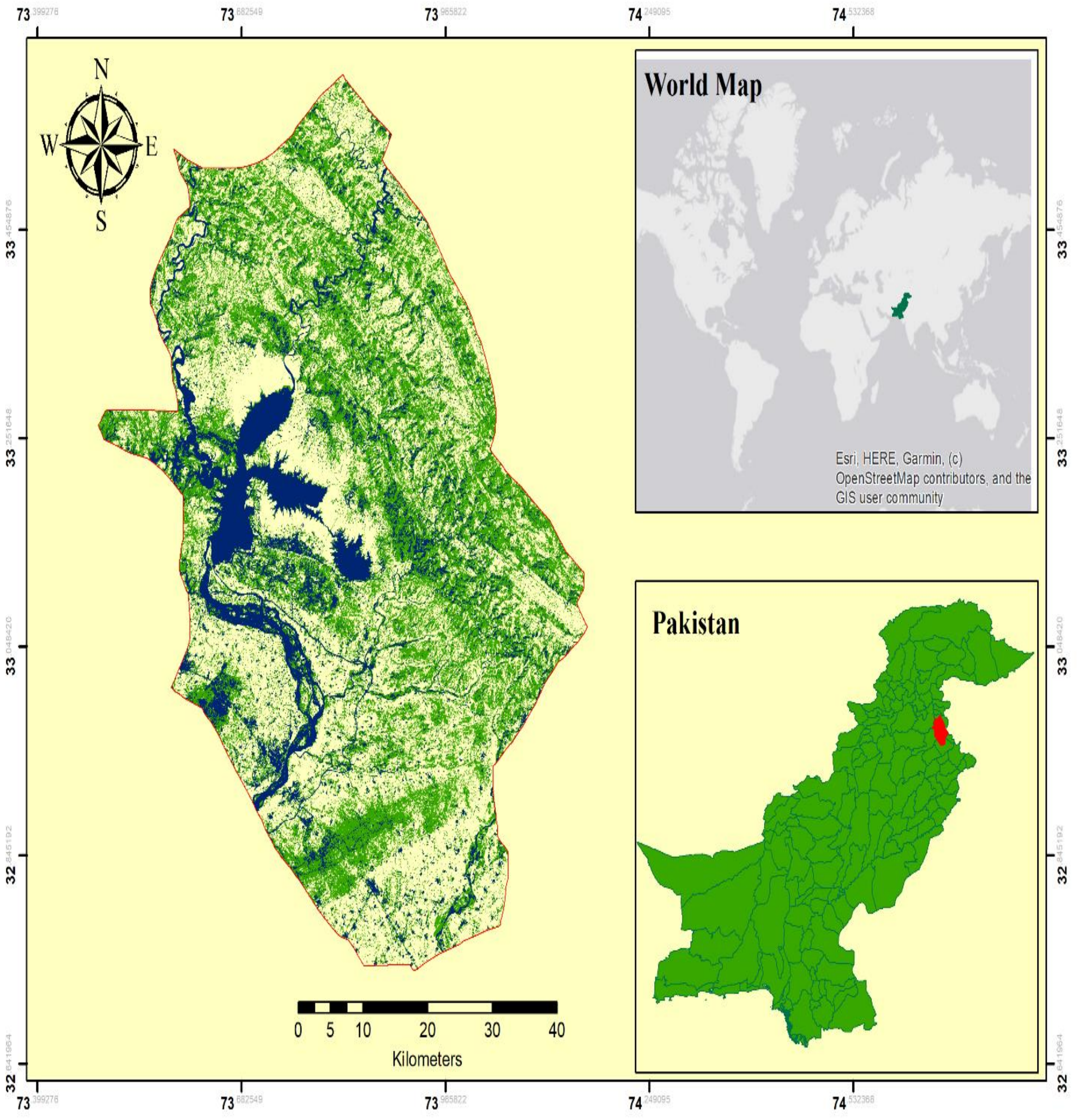

Figure 1. Study Area Map

2. MATERIALS AND METHODS

2.1. Sampling site: Mangla Dam is situated in Mirpur district of Azad Jammu and Kashmir. It is an earth-filled dam built on river Jhelum in 1967 and the 7th largest dam in the world in terms of reservoir capacity, covering 26500 ha total area. It is a large body of water that supports aquatic life. The reservoir created by the Mangla Dam does provide important habitat for a variety of species.

2.2. Sampling Method: An extensive vegetation field survey was conducted for sample collection during the month of March-April 2019. A total of fifty quadrates of 1×1 square meters were laid down around the Mangla dam area (figure 1).

Flora from each selected quadrate was collected by using the Braun-Blanquet cover abundance scale method. This method is based on the collection of quantitative data about the frequency and cover of plant species within a defined area typically a quadrat. Whereas the domin cover scale was used for estimating the cover value of each species from each quadrate (Urooj et al., 2016). For analysis of vegetation species response towards prevailing soil physical and chemical parameters, statistical regression technique was applied by using multivariate (CANOCO) software.

2.3. Statistical Data Analysis: T-value biplot diagrams are graphical representations with statistical significance, featuring arrows denoting species and arrow symbols representing environmental variables. These plots serve the purpose of illustrating significant pairwise relationships between species and their physicochemical environmental factors. Within the T-value biplot projection, species assume the role of response variables, while environmental variables function as predictors.

The response curve is used to draw the species tolerance against edaphic factors in order to estimate their optimum and stress condition and determine the most prevalent and generalized species in an area. It has been widely assumed that species response on certain gradients is indicated by the Gaussian curve of bell shape symmetry by statistical method. The bell shape curve shows an optimum, tolerance and stress response by species in the Gaussian model. Two models are used for species response curves in ecology i.e.Generalized Linear Model and Generalized Additive Model (Ahmad et al., 2020; Bashir et al., 2017). Generalized Additive Model (GAM) is a statistical regression technique for the prediction of species distributions quantitatively in order to understand the niche of species. So, conservation of these species can be possible in ongoing global changes. GAM is a semi or nonparametric extension of the Generalized Linear Model (GLM). In GAM components are considered smooth and functions are additive. Whereas the relationship between the mean of response variables, and functions of the explanatory variables is established using link function. GAM curves are highly non-linear and non-monotonic relationships between the response and variables (Gelman et al., 2019; Yee & Mitchell, 1991) based on the following equation:

$$y = \beta 0 + f1(x1) + f2(x2) + ... + fp(xp) + \varepsilon \qquad \text{Eq. 01}$$

where y is the response variable (growth response), β0 is the intercept term, f1(x1), f2(x2), ..., fp(xp) are the smooth functions of the predictor variables x1, x2, ..., xp, respectively.

These functions are usually modeled using splines or other smoothing techniques. ε is the error term, which is assumed to be normally distributed with mean 0 and constant variance.

The GAM allows for non-linear relationships between the response variable and the predictor variables by modeling the functions f1(x1), f2(x2), ..., fp (xp) as smooth curves. The smoothness of these curves is controlled by tuning parameters that can be estimated from the data. The GAM can be fitted using various optimization techniques, such as maximum likelihood or penalized likelihood.

3. Results and Discussions

A total of 37 herbaceous species from 17 different families were identified in the vicinity of the Mangla Dam. Among these, *Cynodon dactylon*, *Desmostachya bipinnata*, and *Rhynchosia minima* were the most abundant species, with a higher presence in all surveyed quadrants. In contrast, *Amaranthus spinosus* and *Medicago polymorpha* were the least abundant species in the study area, indicated by a logarithmic sum abundance value of 0.698.

The positioning of an environmental variable arrow's tip in relation to the line coinciding with a particular species arrow indicates valuable information. If the tip of the environmental variable arrow extends beyond the arrow of a specific species and moves farther away from the origin of the species arrowhead, it suggests that the T-value for the corresponding regression coefficient exceeds 2. Conversely, a similar situation in the opposite direction reveals a T-value less than -2.

Species arrows enclosed within circles signify T-values greater than 2, signifying a positive relationship with the environmental variable. On the contrary, species arrows confined within opposite blue circles indicate T-values less than -2, implying a negative relationship with the specified environmental variables. The circles, known as Van Dobben Circles, possess equal diameters, and in this study, they were plotted for both zones, representing the relationship between species as response variables and environmental variables as independent predictors (Leps, 2003).

3.1. Correlation with soil pH: Soil pH is a physical property that influences the availability of nutrients to plants and can also help identify sodic soil conditions. Species within Zone-I exhibited no discernible response to the soil pH, whether positive or negative. In contrast, species in Zone-II demonstrated both positive and negative correlations with the soil pH, as illustrated in Figure 2.

Specifically, *Pupalia lappacea*, *Rhynchosia minima*, *Dactyloctenium aegyptium*, *Euphorbia prostrata*, *Lantana camara*, *Aristida adscensionis*, and *Artemisia scoparia* exhibited a positive relationship with the soil pH. Notably, *Rhynchosia minima*, *Aristida adscensionis*, and *Pupalia lappacea* displayed particularly robust responses to the prevailing soil pH in Zone-I near Mangla Dam.

Conversely, *Brachiaria decumbens*, *Malvastrum coromendelianum*, *Parthenium hysterophorus*, *Euphorbia hirta*, *Desmostachya bipinnata*, and *Solanum surrattense* manifested a negative response to the pH levels. Interestingly, *Launaea procumbens* and *Cynodon dactylon* did not exhibit any noticeable reaction to the soil pH conditions.

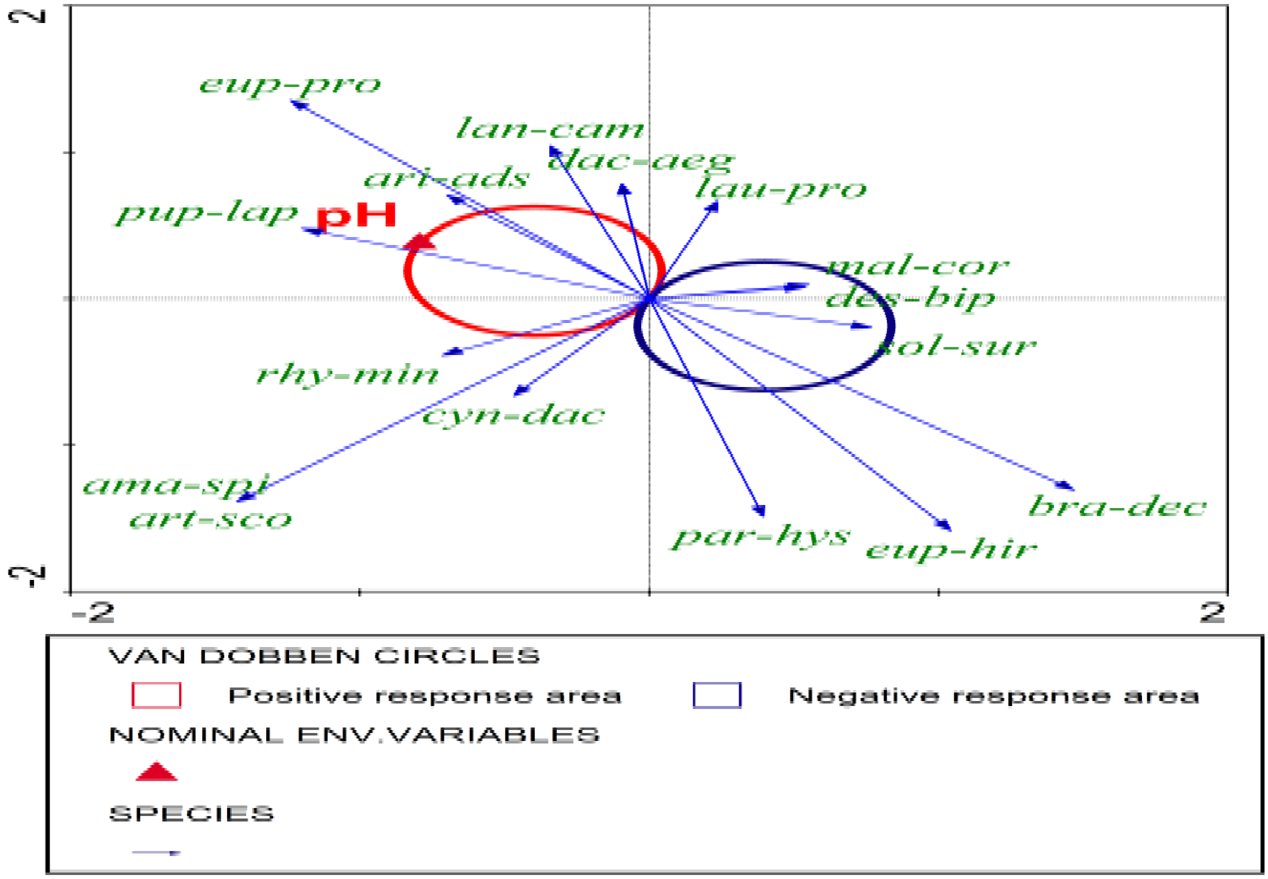

Figure 2. T-value biplot for Species response to pH In Zone-II

Generalized Additive Models (GAM) results shown in Figure 3 demonstrated that *Cynodon dactylon* exhibited significant tolerance to pH levels within the range of 7.3-7.8, with an upper quartile value of 60 and a lower quartile value of 10. This robust tolerance explains its abundance and ability to thrive even in stressful conditions, with the optimal pH range for its growth predicted to be 7.6-7.7. In contrast, *Medicago polymorpha* and *Amaranthus spinosus*, the least abundant species, displayed upper and lower quartile values of 0, indicating their struggle to thrive in the area's conditions.

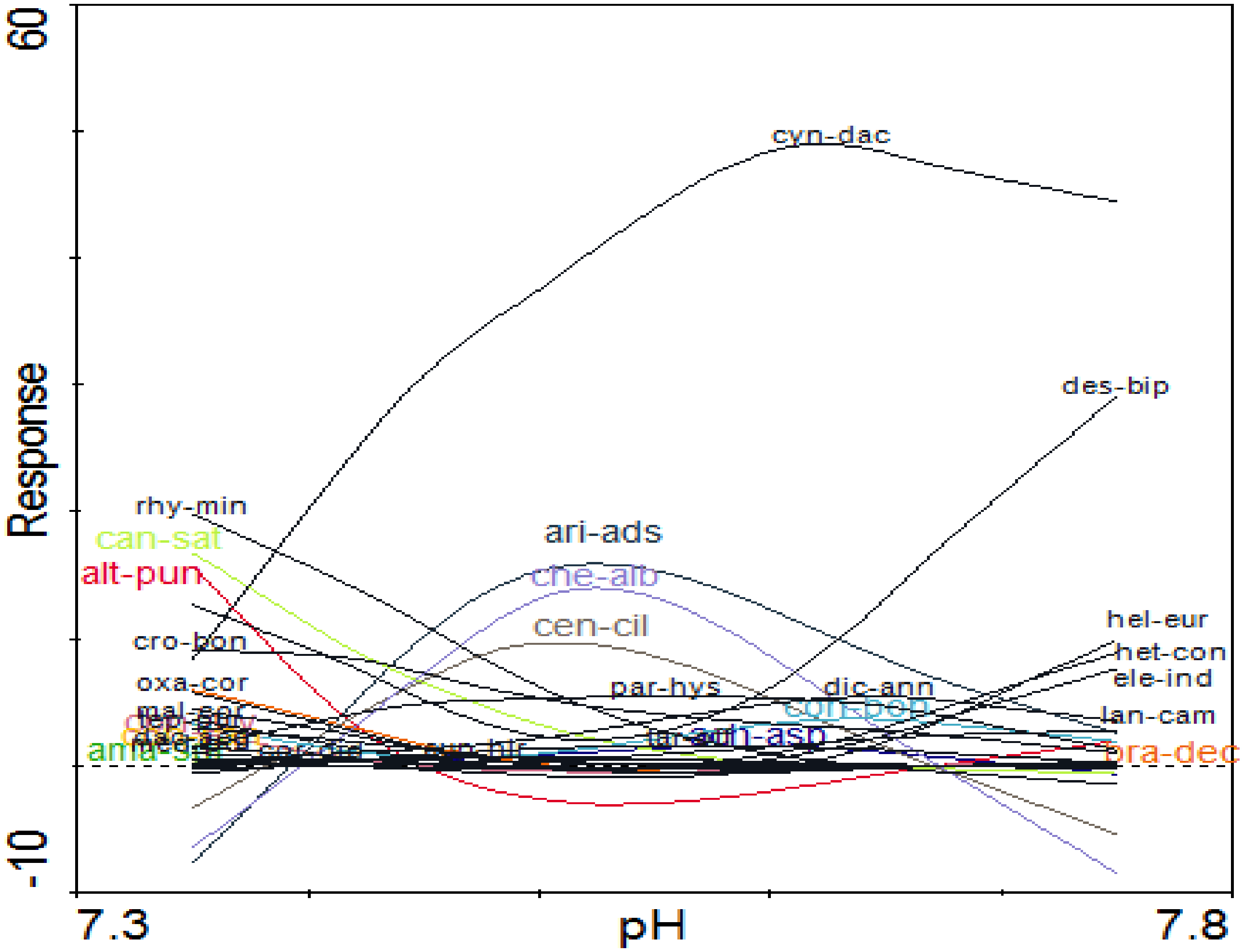

Figure 3: GAM response curve for pH

3.2. Correlation with Electrical conductivity (EC): It is another important soil property for vegetation growth is electrical conductivity (EC), which can assess mineral content in the soil. The presence and types of minerals significantly impact plant growth, with high soil EC indicating a greater mineral presence. *Cynodon dactylon* demonstrated tolerance and positive response to an EC range of 0.6-1.6 dS/m, with peak growth occurring at 0.8 dS/m, 1.4 dS/m, and 1.6 dS/m. *Parthenium* *hysterophorus* also responded well to an EC range of 1-1.2 dS/m, although it could tolerate an EC range of 0.6-1.6 dS/m (Figure 4). Several other species, such as *Conyza bonariensis*, *Cenchrus ciliaris*, *Desmostachya bipinnata*, and *Aristida adscensionis*, exhibited growth and positive responses to an EC range of 0.6-1 dS/m, while *Cannabis sativa*, *Rhynchosia minima*, and *Croton bonplandianus* were predicted to respond only at an EC range of 1.2-1.6 dS/m.

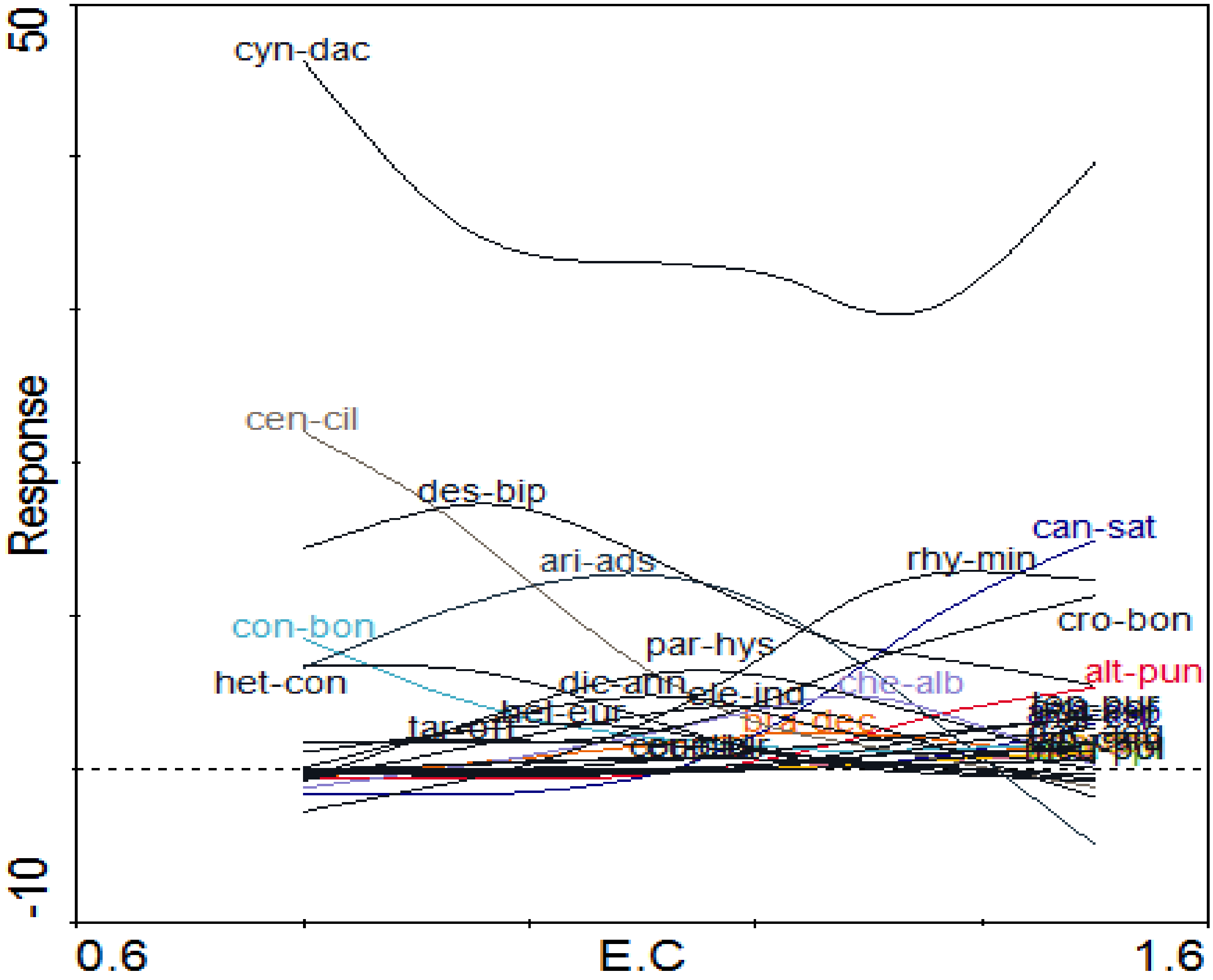

Figure 4: GAM response curve for EC

3.3. Correlation with Organic matter

In Zone-I, *Croton bonplandianus*, *Chenopodium album*, *Coronopus didymus*, *Desmostachya bipinnata*, *Lantana camara*, *Heliotropium europaeum*, and *Eleusine indica* exhibited a positive relationship with organic matter and thrived abundantly in the Zone-I area (Figure 5). On the other hand, *Conyza canadensis* and *Cynodon dactylon* displayed no noticeable response to the availability of organic matter, whether rich or scarce. *Conyza bonariensi*, *Amaranthus spinosus*, and *Medicago polymorpha* demonstrated a robust negative correlation with organic matter in the soil.

T-value Biplot (Figure 6) showed a minimal response by species toward organic matter in Zone-II. Van Dobben Circles shown that *Desmostachya bipinnata*, *Solanum surrattense*, and *Malvastrum coromendelianum* revealed a positive response towards organic matter, but this relationship was not significantly influenced by the presence of organic matter in the soil. In comparison, prevailing species such as *Cynodon dactylon* and *Parthenium hysterophorus* did not exhibit any visible response to organic matter. However, several species, including *Lantana camara*, *Euphorbia prostrate*, *Pupalia lappacea*, *Rhynchosia minima*, and *Aristida adscensionis*, revealed a negative relationship with organic matter.

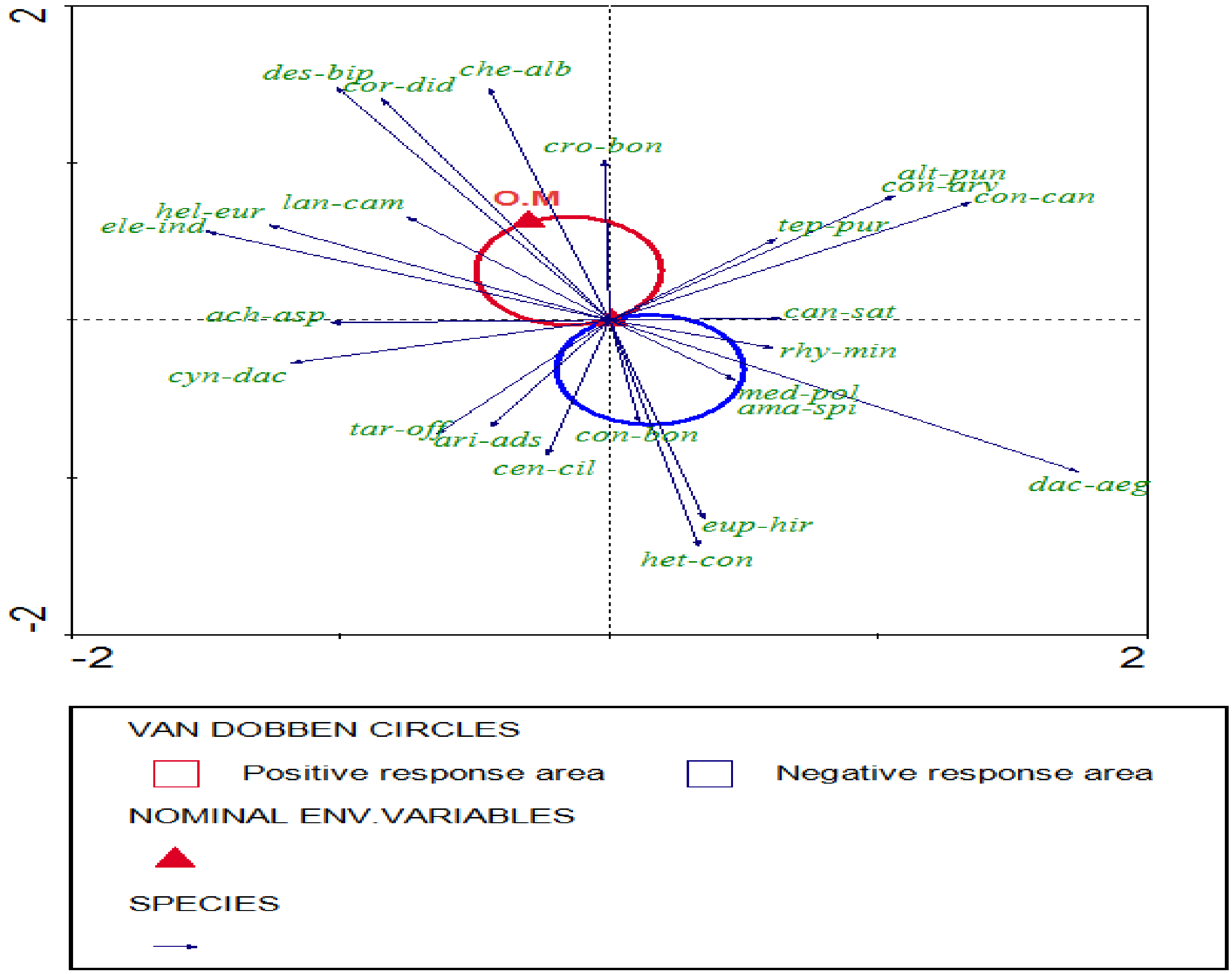

Figure 5: T-value biplot for Species response to OM In Zone-I

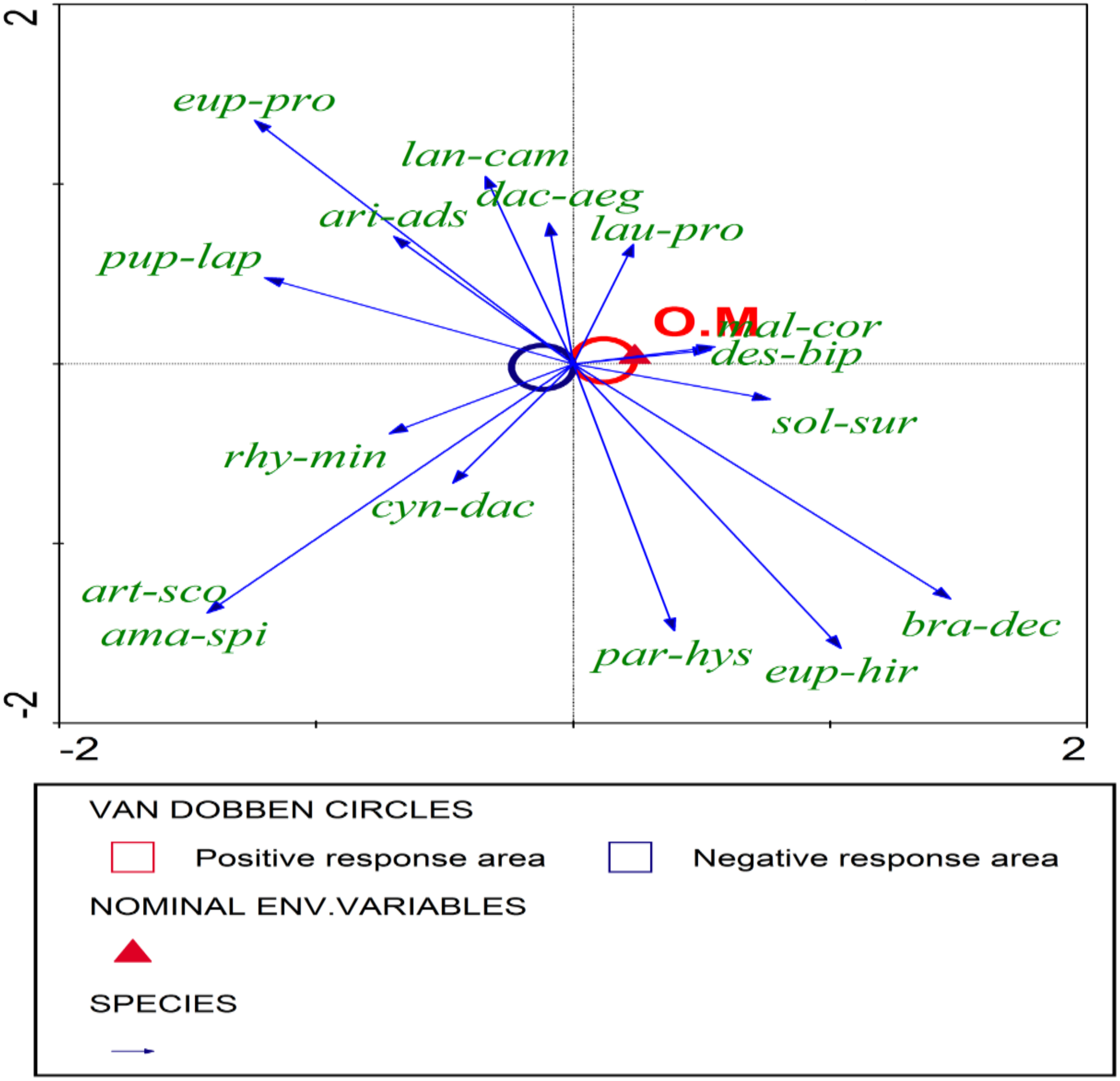

Figure 6: T-value biplot for Species response to OM In Zone-II

3.4. Correlation with Potassium

Conyza bonariensis showed a healthy relationship with the available potassium in the soil of Zone-I, found abundantly in the area. Furthermore, *Cenchrus ciliaris* and *Aristida adscensionis* also revealed a positive correlation with the presence of potassium as a macro nutrient. Conversely, several species including *Croton bonplandianus*, *Tephrosia purpurea*, *Conyza Canadensis*, *Alternanthera pungens*, *Chenopodium album*, *Desmostachya bipinnata*, *Coronopus didymus*, *Lantana camara*, *Eleusine indica*, *Heliotropium europaeum*, and *Convolvulus arvensis* displayed a negative relationship with potassium in Zone-I. Notably, *Cynodon dactylon*, *Achyranthes aspera*, and *Cannabis sativa* exhibited no discernible response to potassium in Figure 7.

In Figure 8, *Launaea procumbens*, *Desmostachya bipinnata*, *Solanum surrattense*, and *Malvastrum coromendelianum* demonstrated a positive response to the presence of potassium. Conversely, *Lantana camara*, *Parthenium hysterophorus*, *Euphorbia hirta*, and *Dactyloctenium aegyptium* exhibited no response to potassium, while *Cynodon dactylon*, *Euphorbia prostrate*, and *Pupalia lappacea* displayed a strong negative correlation with potassium, indicating their sensitivity to this nutrient in Zone-I.

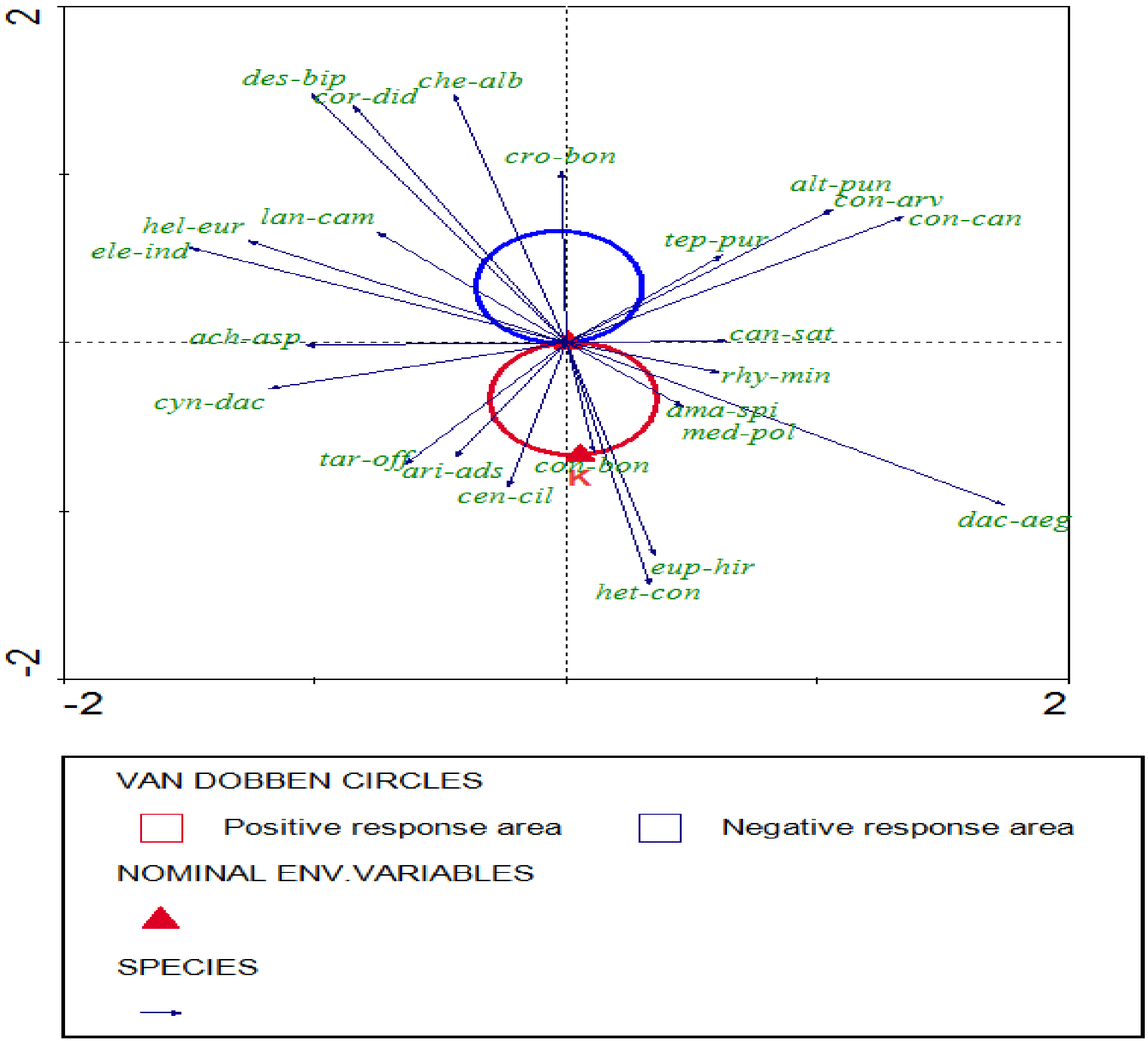

Figure 7: T-value biplot for Species response to K in Zone-I

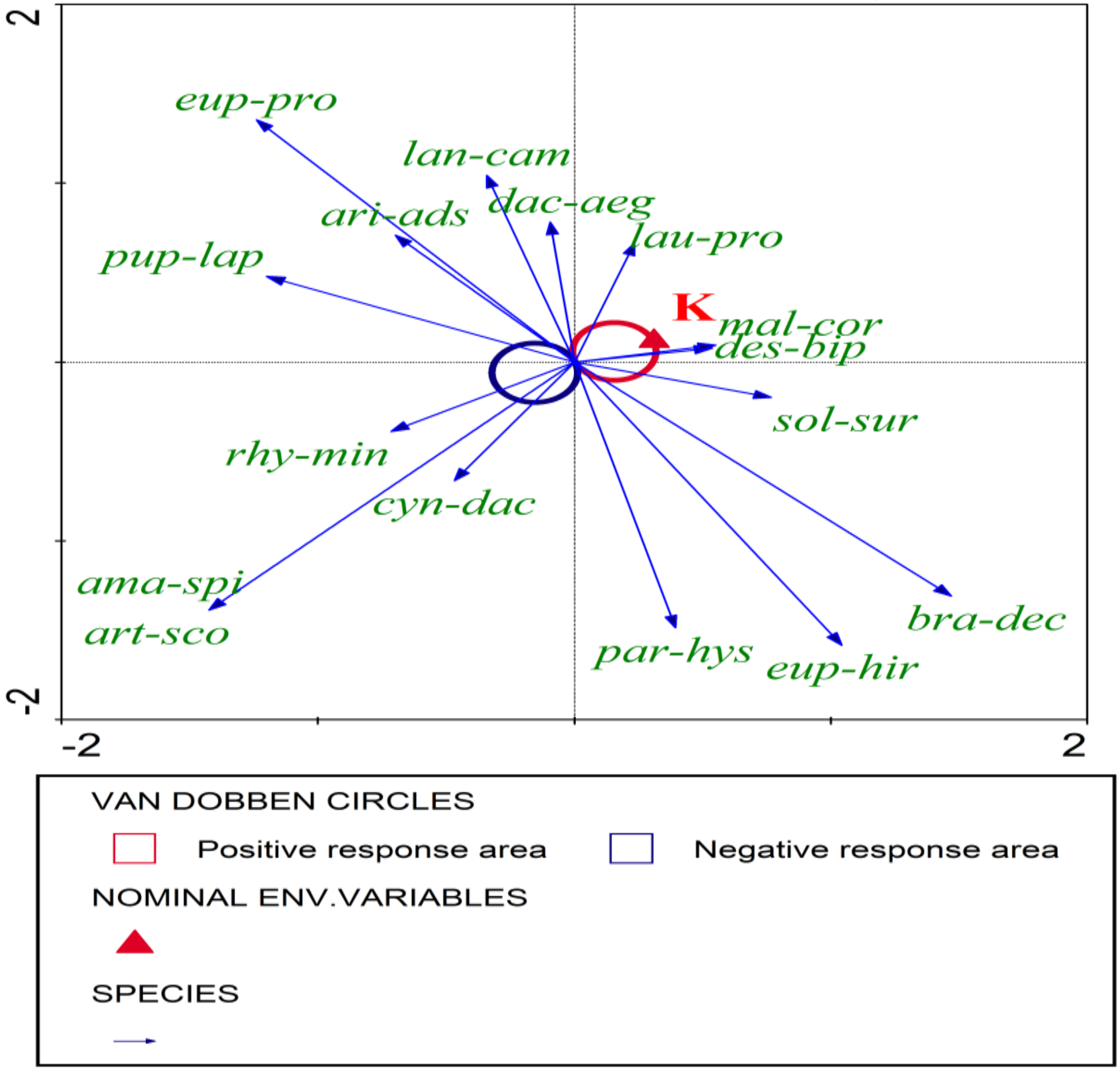

Figure 8: T-value biplot for Species response to K in Zone-II

3.5. Correlation with phosphorous: For healthy plant growth, the soil's phosphorous concentration should ideally exceed 7.1 mg/kg. Soils with phosphorous concentrations below this threshold are less fertile and require additional phosphorous supplementation. GAM results indicated that *Cynodon dactylon* exhibited growth across a range of 0-20 mg/kg of phosphorous, suggesting its adaptability to both less fertile and rich fertile soil. However, *Cynodon dactylon* showed better responses to lower phosphorous concentrations and reduced growth in highly fertile soil with phosphorous levels exceeding 12 mg/kg (Figure 9). In contrast, *Rhynchosia minima* thrived in conditions with high phosphorous concentrations and did not grow well in soils with less than 10 mg/kg of phosphorous. *Desmostachya bipinnata* demonstrated normal growth distribution and positive responses to phosphorous concentrations ranging from 5-15 mg/kg, while other species, represented by straight lines, appeared to be under stress and exhibited poor responses to phosphorous concentrations in the 0-20 mg/kg range.

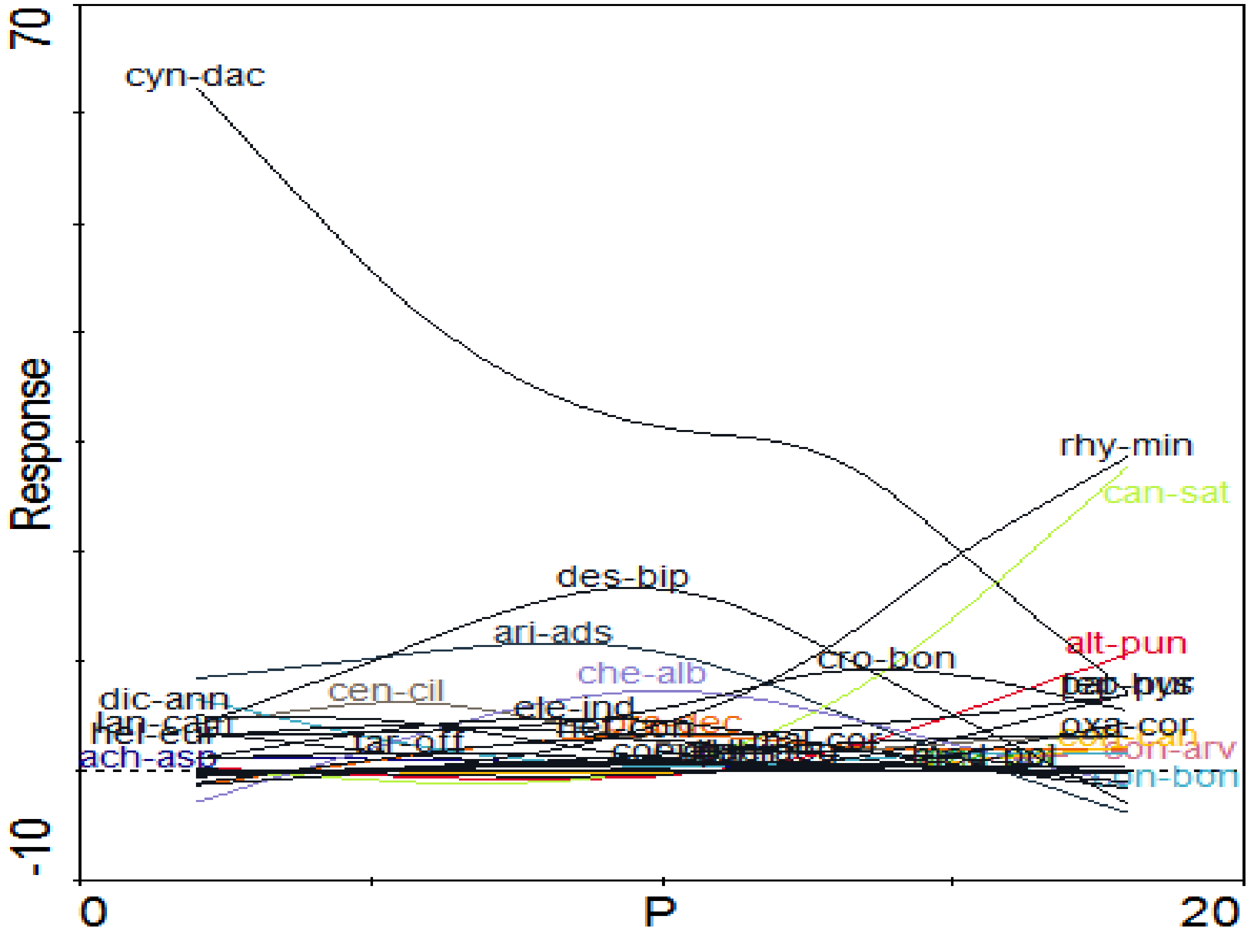

Figure 9: GAM response curve for available soil P

3.6. Correlation with Manganese

Examining the correlation with manganese, four species in Zone-I—*Tephrosia purpurea*, *Conyza Canadensis*, *Cannabis sativa*, *Alternanthera pungens*, and *Convolvulus arvensis*—demonstrated a positive relationship with available manganese as a micronutrient. *Conyza Canadensis* exhibited a particularly strong positive correlation with manganese. However, several species, including *Chenopodium album*, *Desmostachya bipinnata*, *Coronopus didymus*, *Croton bonplandianus*, and

Dichanthium annulatum, displayed no response to the availability or scarcity of manganese in the soil. In contrast, *Euphorbia hirta*, *Eleusine indica*, *Brachiaria decumbens*, *Cynodon dactylon*, *Achyranthes aspera*, and *Aristida adscensionis* exhibited a negative response to manganese in Figure 10.

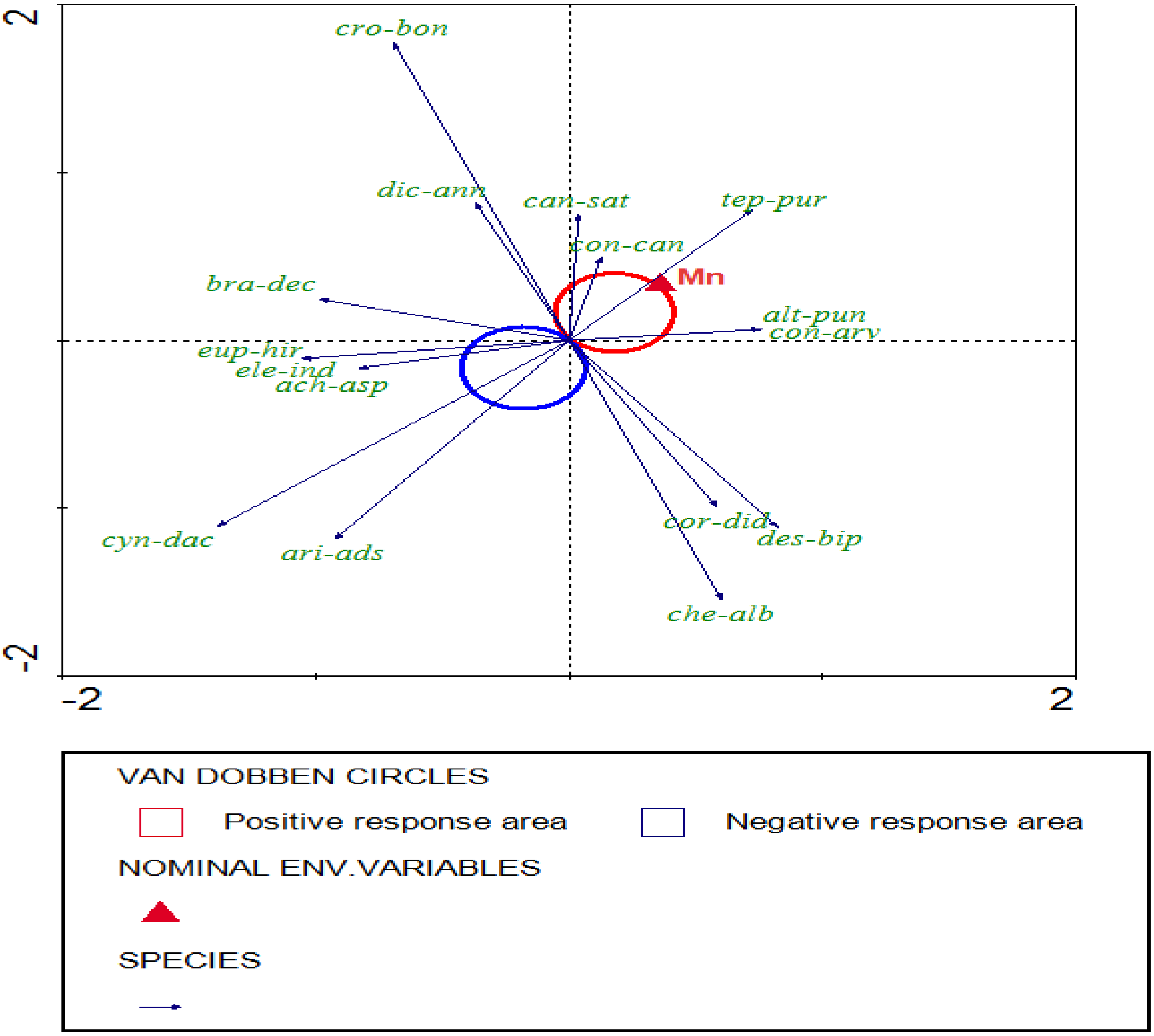

Figure 10: T-value biplot for Species response to Mn^{+2} in Zone-I

However, *Euphorbia hirta, Eleusine indica, Brachiaria decumbens, Cynodon dactylon,* and *Achyranthes aspera, Aristida adscensionis* showed in Figure 3.16 negative response towards Mn^{+2} as predictor. This Figure depicted that *Cynodon dactylon* has very strong positive correlation with Mn^{+2}. In presence of this micronutrients its growth, abundance and scattering get positively influenced. Besides *Euphorbia prostrate* and *Cucumis melo var agrestis* also showed positive regression coefficient, revealed positive influence on growth and abundance in Zone-II of study area (Figure 11). While *Taraxacum officinalis*, *Parthenium hysterophorus* and *Launaea procumbens* did not shown any response towards Manganese presence or absence. However, *Lantana camara*, *Aerva javanica* and *Pupalia lappacea* showed strongly negative correlation with Manganese as their growth gets affected by this micronutrient.

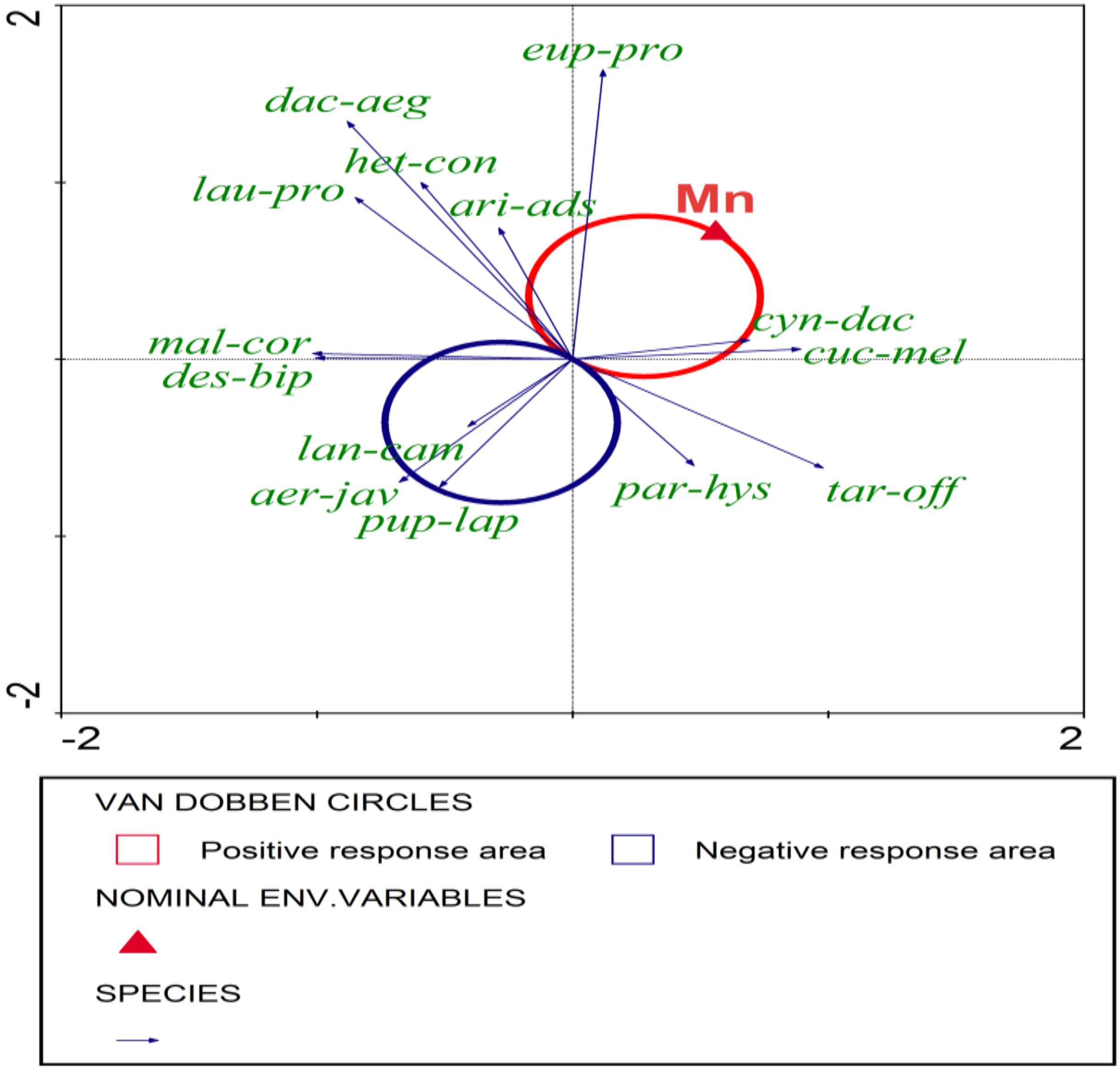

Figure 11: T-value biplot for Species response to Mn^{+2} in Zone-II

3.7. Correlation with Iron and Zinc

Iron and zinc are essential micronutrients for plants naturally present in the soil. Soil iron is vital for chlorophyll formation, while zinc is a component of enzymes that regulate plant growth and carbohydrate formation. GAM analysis revealed that *Cynodon dactylon* exhibited uniform growth within a range of 2.5 mg/L to 5.5 mg/L of iron concentration. *Desmostachya bipinnata* also demonstrated high growth at lower iron concentrations, while *Rhynchosia minima* and *Cannabis sativa* exhibited better growth at higher iron concentrations and stress conditions at lower concentrations (Figure 12). Analyzing the correlation with iron, three species in Zone-I—*Chenopodium album*, *Desmostachya bipinnata*, and *Coronopus didymus*—exhibited a positive response to the available iron concentration in mg/L as a micronutrient in the soil. In contrast, *Conyza Canadensis*, *Cannabis sativa*, *Croton bonplandianus*, *Dichanthium annulatum*, *Euphorbia hirta*, *Eleusine indica*, *Brachiaria decumbens*, *Cynodon dactylon*, and *Achyranthes aspera* showed a negative response to iron content in the soil. Particularly, *Conyza canadensis* acted as a negative response variable in the presence of iron content, affecting its abundance and scattering. *Tephrosia purpurea* and *Aristida adscensionis* exhibited no response to iron content, as seen in Figure 13.

In Zone-II, the correlation between iron content and species depicted that *Parthenium hysterophorus* and *Taraxacum officinalis* showed a positive relationship with iron content, positively influencing their growth and abundance. Conversely, *Lantana camara* and *Cynodon dactylon* exhibited no response to iron content, while several species, including *Launaea procumbens*, *Euphorbia prostrate*, *Dactyloctenium aegyptium*, *Heteropogon contortus*, and *Aristida adscensionis*, displayed a strong negative correlation with iron, indicating that their growth, abundance, and scattering were affected by the presence of iron content in the soil.

The data attribute analysis further assessed the relationship between species and environmental parameters in both Zone-I and Zone-II, considering soil physical characteristics, available micronutrients (Zn+2, Fe+2, Mn+2), and macronutrients (P and K).

In Zone-I, *Cynodon dactylon*, the most abundant species, exhibited strong positive correlations with soil electrical conductivity, available phosphorus, zinc, copper, and iron, indicating that these factors positively influenced the abundance of *Cynodon dactylon* in Zone-I. On the other hand, *Amaranthus spinosus* and *Medicago polymorpha*, the least abundant species, did not show significant associations with environmental variables, resulting in their scattered distribution.

In Zone-II, *Cynodon dactylon*, the dominant species, demonstrated positive correlations with organic matter, moisture, potassium, iron, manganese, and copper, indicating that these environmental factors positively influenced its abundance. Conversely, *Amaranthus spinosus* and *Taraxacum officinalis*, the least abundant species, exhibited a similar pattern of distribution and association with environmental variables, with no significant positive correlations.

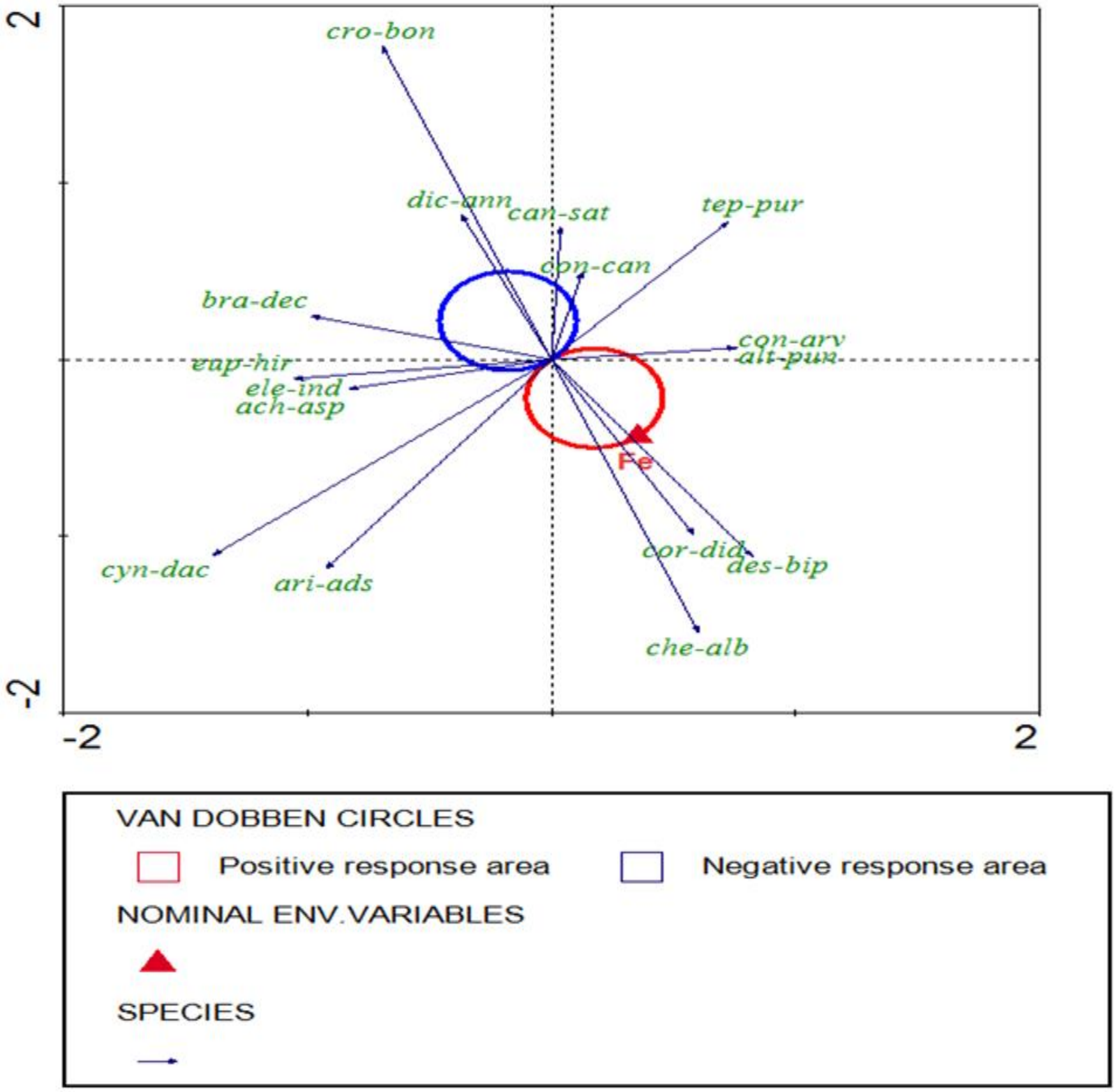

Figure 12: T-value biplot for Species response to Fe^{+2} in Zone-I

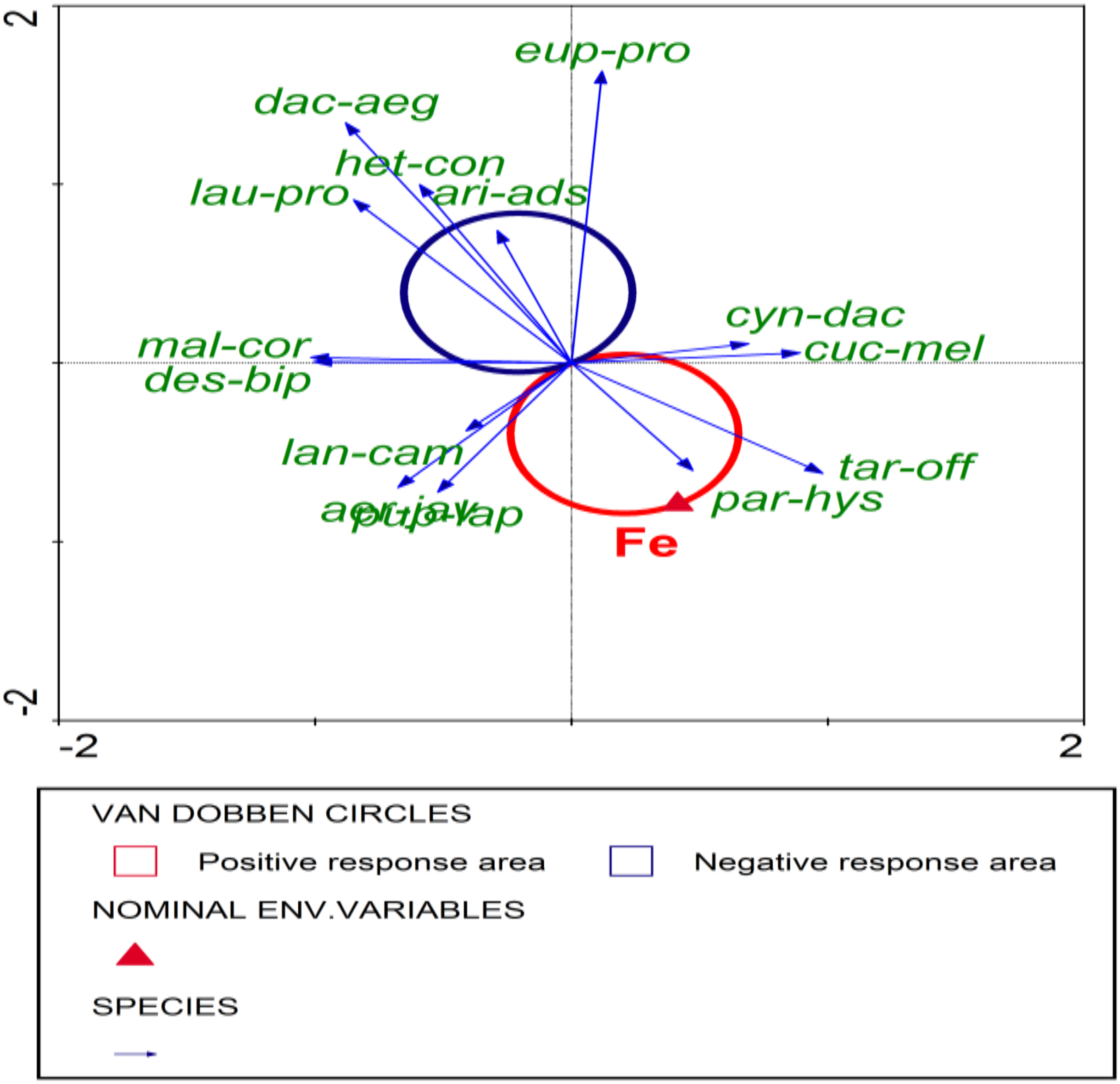

Figure 13: T-value biplot for Species response to Fe^{+2} in Zone-II

Figure 14 and 15 showed correlation between *Amaranthus spinosus* and *Taraxacum officialis* with pH, EC, OM, Moisture, Macronutrients (P, K) and Micronutrients (Mn^{+2}, Zn+2, Fe^{+2}). However, Figures depicted that these least abundant species have negative correlation with environmental gradients as indicated by negative and less values.

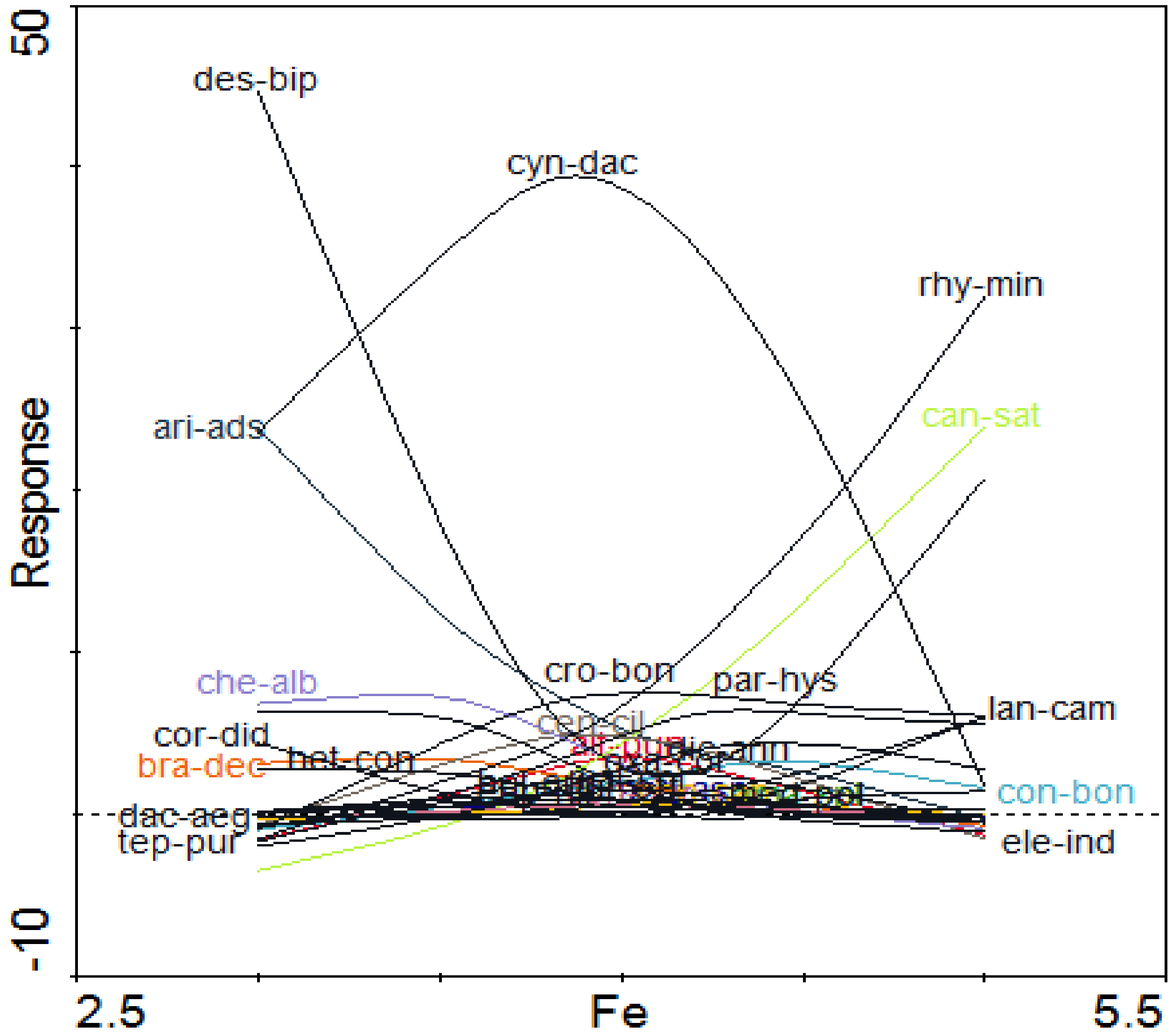

Figure 14: GAM response curve for available soil Fe^{+2}

In the case of zinc (Zn+2), *Cynodon dactylon* displayed average growth at concentrations exceeding 0.7 mg/L in the soil. *Desmostachya bipinnata* and *Rhynchosia minima* also showed consistent growth responses over the observed range of Zn+2 concentrations in the study area, while other species represented by straight lines exhibited unfavorable growth conditions.

The dominant species observed included *Cynodon dactylon*, *Desmostachya bipinnata*, and *Rhynchosia minima*. Ecologists employ multivariate techniques in the analysis of vegetation, as plant ecology, a subfield of ecology, focuses on characterizing species frequency and abundance in relation to their adaptation along environmental gradients (Crawley, 1997).

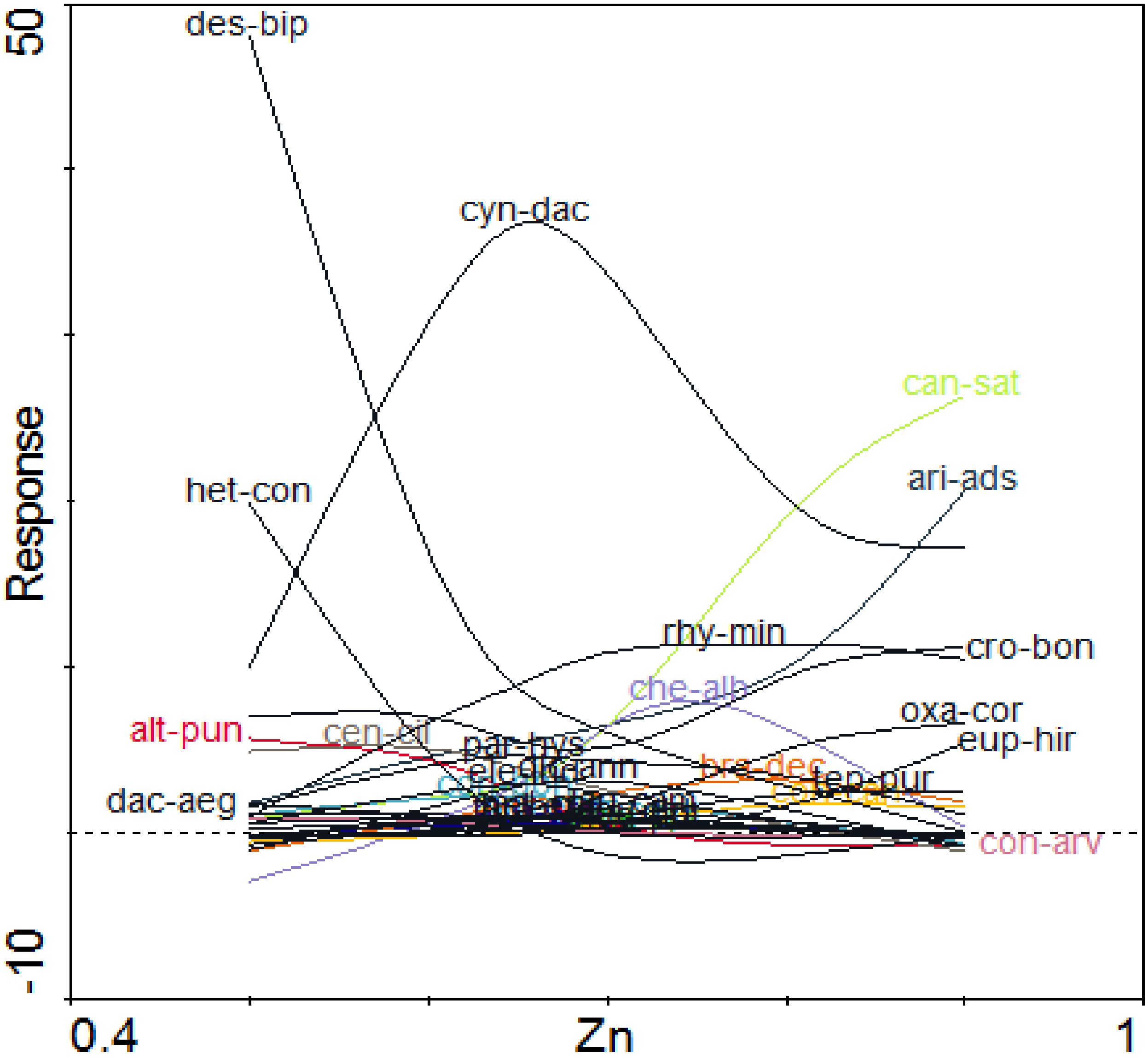

Figure 15: GAM response curve for available soil Zn^{+2}

The Generalized Linear Response (GAM) Curve illustrates how a species responds to a specific environmental gradient, shedding light on the interplay between various species in their quest for survival. In the GAM framework, species serve as the response variable, while environmental parameters act as the explanatory variables or predictors (Ter Braak, 2002).

Few species were shown humped shaped curve in GAM curves and other species were indicated by straight lines which depicted their growth in stress conditions, envisaging their inferiority against dominant species response abundance (Grime, 1979).

GAM curves predicted that *Cynodon dactylon* has tolerance over wide ranges of physicochemical concentrations examined. Due to its potential to tolerate and grow under stress condition, *Cynodon dactylon is* found in the study as the most abundant species.

One identified species in the present study was *Cannabis sativa* which is an environmentally friendly species and also used as low-cost feedstock. This specie has unique morphology and require about 13 hours to grow at 6.3-6.8 optimum pH soil. Whereas most abundant species in the area around Mangla Dam was *Cynodon dactylon* belonged to the family Poaceae.

The fact of its abundance is the prevailing optimum condition like temperature above 15°C, necessary for its growth. But another fact revealed in research by Guertin in 2003 is that *Cynodon dactylon* adapted to a wide range of climates i.e. arid to rainy climates and did not show dormancy in any season. Some other researchers found that *Cynodon dactylon* existed in association with *Malvastrum coromandelianum* without having preferences for a specific habitat (Ahmad, 2010).

5. CONCLUSIONS

The present study was undertaken to forecast species responses in light of existing edaphic factors such as pH, electrical conductivity (EC), phosphorous (P), zinc (Zn^{+2}), and iron (Fe^{+2}), utilizing the Generalized Additive Model as a versatile multivariate statistical technique. The outcomes revealed that *Cynodon dactylon* exhibits remarkable resilience across a broad spectrum of soil physicochemical factors, encompassing both micro and macronutrient concentrations. This species is prevalent and evenly distributed throughout the dam's vicinity.

It is worth noting that GAMs can incorporate considerations of spatial or temporal autocorrelation, a common feature in ecological data. By accounting for these dependencies, GAMs enhance prediction accuracy while mitigating the risk of generating spurious results.

An inherent strength of GAMs lies in their adaptability to model non-linear relationships between response and predictor variables, a valuable attribute in ecology where many associations defy linear modeling through conventional regression techniques. In summary, Generalized Additive Models serve as a robust tool for modeling vegetation responses to environmental variables, offering valuable insights into the underlying ecological processes governing these intricate relationships.

REFERENCES

Ahmad, A., Ahmad, S.R., Gilani, H., Tariq, A., Zhao, N., Aslam, R.W., Mumtaz, F. (2021). A Synthesis of Spatial Forest Assessment Studies Using Remote Sensing Data and Techniques in Pakistan. *Forests*, *12*(9):1211.

Ahmad, S.S. (2010). Detrended Correspondence Analysis of vegetation along Motorway (M-2), Pakistan. *Pakistan Journal of Botany, 42* (4): 2473-2477.

Ahmad, S.S., Murtaza, R., Shabir, R., Ahmed, M.N., Shah, T.A. (2014). Environmental Diversification and Spatial Variations in Riparian Vegetation: A Case Study of Korang River, Islamabad. *Pakistan Journal of Botany*, *46*(4): 1203-1210.

Austin, M., Smith, T. (1989). A new model for the continuum concept. *Vegetation*, 83:35-47.

Bashir, H., Ahmad, S.S., Urooj, R., Nawaz, M. (2017). Modeling Some Plant Species Distribution Against Environmental Gradients Using Multivariate Regression Models, 44(4):119-128.

Cardoso, P., Branco, V.V., Borges, P.A.V., Carvalho, J.C., Rigal, F., Gabriel, R., Mammola, S., Cascalho, J., Correia, L. (2020). Automated Discovery of Relationships, Models, and Principles in Ecology. *Frontiers in Ecology and Evolution,* 8:530135.

Clark, N., Wells, K. (2023). Dynamic Generalized Additive Models (DGAM) for forecasting discrete ecological time series. *Methods in Ecology and Evolution*.

Crawley, M.J. (1997). *Aliens: The ecology of non-indigenous plants.* Oxford, Oxford University Press.

Dormann, C. (2007). Effects of incorporating spatial autocorrelation into the analysis of species distribution data. *Global Ecology and Biogeography*, *16*:129 - 138.

Grime, J. (1979). Evidence for the existence of three primary strategies in plants and its relevance to ecological and evolutionary theory. *The American Naturalist*, *111*:1169-1194.

Grumbine, R.E., Xu, J. (2011). Mekong hydropower development. *Science*, *332*(6026): 178–179

Guertin, P. (2003). *USGS weeds in the west project: Status of introduced plants in southern Arizona parks factsheet for: Cynodon dactylon* (L). Pers.

Haidar, K., and Dilawar, I. (2022). *UN chief seeks aid as Pakistan flood losses exceed $30 billion*. New York, NY: Bloomberg.Com. Available at: https://www.bloomberg.com/news/articles/2022-09-09/un-chief-seeks-aid-as-pakistan-flood-losses-exceed-30-billion.

He, D.M., Zhao, W., Chen, L.H. (2004). The Ecological Changes in Manwan Reservoir Area and Its Causes. *Journal of Yunnan University,* 26(3):220–226.

Kent, M., Coker, P. (1992). *Vegetation description and data analysis*. London, Belhaven press.

Khan, F., Siddique, A.B., Shabala, S., Zhou, M., Zhao, C. (2023). Phosphorus Plays Key Roles in Regulating Plants' Physiological Responses to Abiotic Stresses. *Plants*, *12*(15):2861.

Miller, J., Franklin, J. (2002). Modeling the distribution of four vegetation alliances using generalized linear models and classification trees with spatial dependence. *Ecological Modelling*, *157*:227-247

New, T., Xie, Z. (2008). Impacts of Large Dams on Riparian Vegetation: Applying Global Experience to the Case of China's Three Gorges Dam. *Biodiversity and Conservation*, *17*(13): 3149-31634

Pappas, G. (2011). Pakistan and water: New pressures on global security and human health. *American Journal of Public Health*, 101 (5), 786–788

Schmutz, S., Moog, O. (2018). Dams: ecological impacts and management. *Riverine ecosystem management: Science for governing towards a sustainable future*, 111-127.

Silva, D., Marco, P., Resende, D.C. (2010). Adult Odonate Abundance and Community Assemblage Measures as Indicators of Stream Ecological Integrity: A Case Study. *Ecological Indicator*, 10(3): 744–752

Ter Braak, C.J.F., Smilauer, P. (2002). *CANOCO Reference Manual and CanoDraw for Windows User's Guide: Software for Canonical Community Ordination* (version4.5). Ithaca, NY: Microcomputer Power, 1-500.

Urooj, R., Ahamd, S.S.,Ahamd, M.N., Khan, S. (2015). Ordinal Classification of vegetation along Mangla Dam, Mirpur, AJK. *Pakistan Journal of Botany*, *47*(4): 1423-1428.

Urooj, R., Ahamd, S.S.,Ahamd, M.N. (2016). Ordination study of vegetation analysis around wetland area: a case study of Mangla Dam, Azad Kashmir-Pakistan. *Pakistan Journal of Botany*, *48*(1): 115-119.

Wood, S.N. (2001). Partially Specified Ecological Models. Ecological Monographs, 71, 1-25

Yee, T. W., Mitchell, N.D. (1991). Generalized Additive Models in Plant Ecology. *Journal of Vegetation Science*, 2(5):587-602.

Zuur, A., Ieno, E.N., Elphick, C.S. (2010). A protocol for data exploration to avoid common statistical problems. Methods in Ecology and Evolution, 314.