European Journal of Ecology, 9.1, 2023, pp. 23-30

ENVIRONMENT FACTORS INFLUENCING ABUNDANCE AND GROWTH OF WILD YAM IN BROADLEAVED FOREST, TSIRANG DISTRICT, BHUTAN

Hem Kumar Subba[1], Yogeeta Dahal[2], Bala Ram Mafchan[3], Sheto Kumar Ghalley[4], Bhakti Sharma Koirala[5*]

[1,4,5]Department of Forest Science, College of Natural Resources, Royal University of Bhutan
[2]Department of Environment and Climate Studies, College of Natural Resources, Royal University of Bhutan
[3]Department of Forest and Park Services, Ministry of Agriculture and Forest, Bhutan
**Corresponding author: bhakti65sharma@gmail.com (Bhakti Sharma Koirala)*

Abstract.

Yams (Dioscorea) consist of approximately 600 species in the world. Yams are considered as staple food in Asia, tropical and sub-tropical regions. The genetic erosion and unsustainable harvesting practices are among the main problems associated with wild yam plants. This study was conducted with the objectives to enumerate wild yam species composition and environmental parameters affecting its growth and abundance. Systematic sampling of the study site was carried out based on different land aspects. Line transect were laid out in selected land aspects within the elevation range of 825 – 1935 m. Five plots in each transects with 100 m plot interval comprising seven transects were laid out in the study area. Each plot was divided in sub-plot of 20 x 20 m, 5 x 5 m and 1 x 1 m to enumerate trees, shrubs and herbs respectively. Seven species of yams was found from the broadleaved forest and spearman correlation showed negative association of yam abundance with tree counts and canopy closure. The areas with higher density of trees had low count of yam abundance. Yam grows well in open canopy in lower altitudes comparing to high altitudes. Yam abundance was positively related with shrubs, herbs, soil moisture, soil organic matter, soil organic carbon and nitrogen content. Analysis of Variance (ANOVA) showed significant difference of yam abundance in 7 different transects due to different ecological parameters influencing the abundance in different transects though transect being in a broadleaved forest.

Key words: Abundance; altitude; dominance; environmental parameters; vegetation

Introduction

Yam plants are vines belonging to Dioscoreaceae family that is cultivated as staple food in tropical, sub-tropical and in Asian regions (Garedew et al. 2017). Yam is a deeply rooted, tuberous, twining, dioecious, perennial vine with distinctly veined cordate (heart-shaped) leaves (Garedew et al. 2017). Yam plant have long growth cycle, flowers borne in different plants (dioecy), poor flowering and mostly vegetative propagation (Wu et al. 2019). Degefa & Anbessa (2017) reported, it bear single to numerous tubers of varying shape and most of them bear bulbils in the leaf axils. It has more than 600 species worldwide and considered as earliest angiosperms originated in Southeast Asia (Tamiru et al. 2008). However it had a divergent evolution and reached to West Africa and tropical America (Tamiru et al. 2008).

Yam plant has high cultural value for about 155 million people in West Africa (Frossard et al. 2017). Degefa & Anbessa (2017) stated yam plant is subsistence as well as cash crop in West Africa. In Bhutan especially in southern and east central region, yam tuber has an important socio-cultural role as an offering to local deity in annual ritual and new year celebration (Ugyen & Gurung, 2015). Yam plants are a source of food and have many pharmaceutical precursors, proteins, vitamins and minerals (Wu et al. 2016).

Yam species are threatened by genetic erosion from pest attacks and farming practices (Ngwe et al. 2015; Muthamia et al. 2016). Harsh weather conditions like flooding, drought and declining soil fertility are some factors for loss of yam diversity (Aboagye et al. 2015).

Information on genetic structure, diversity, distribution pattern and future crop improvement program are important for species conservation (Padhan et al. 2019). Numerous wild crops are unexplored in this world and yam plants got little intervention (Kumar et al. 2017).Thirteen species of yam plants are recorded in the book flora of Bhutan (Noltie, 1994). Ugyen & Gurung (2015) recorded seven species in Zhemgang district of Bhutan. However, there is scanty information on growth pattern of yam and the environment factors affecting its growth. Therefore, the present study aims to investigate the wild yam species and environmental factors affecting the growth and abundance of yam species in broadleaved forest.

Materials and Methods

Study Area

Tsirang district located in central-south of Bhutan has 12 gewogs. The district lies between 300 m to 4200 m above sea level covering an area of approximately 637.83 km^2. Annually Tsirang receives rainfall between 1000 - 3000 mm per year. Approximately 87.50% of area is under forest cover of which 77.64% is broadleaved forest. The climate and altitude range provide a wide potential for supporting wide range of vegetation growth (MoAF, 2017).

Beteni and Mendrelgang gewog is located at 26°57’9.23”N 90°9’40.15”E and 26°57’8.09”N 90°7’57.28”E respectively. Both gewogs harbours wide range of floras and faunas (MoAF, 2017). Broadleaved forest from both gewogs is selected to study the wild yam species (Fig. 1).

Sampling methods

Transects were laid out in different land aspects within elevation range from 825 - 1935 masl applying systematic sampling method. Total of 7 transects were laid out in study sites. Systematic method was adopted to lay out the plots. Each transect comprise of 5 plots with 100 m plots interval comprising 35 plots in total were laid. Each plots had sub-plots; 20 x 20 m quadrat for tree, 5 x 5 m for shrubs and 1 x 1 m for herbs (Fig. 2). Yam plants were enumerated in whole plots (20 x 20 m) to assess associations with vegetation (Byarugaba et al. 2006).

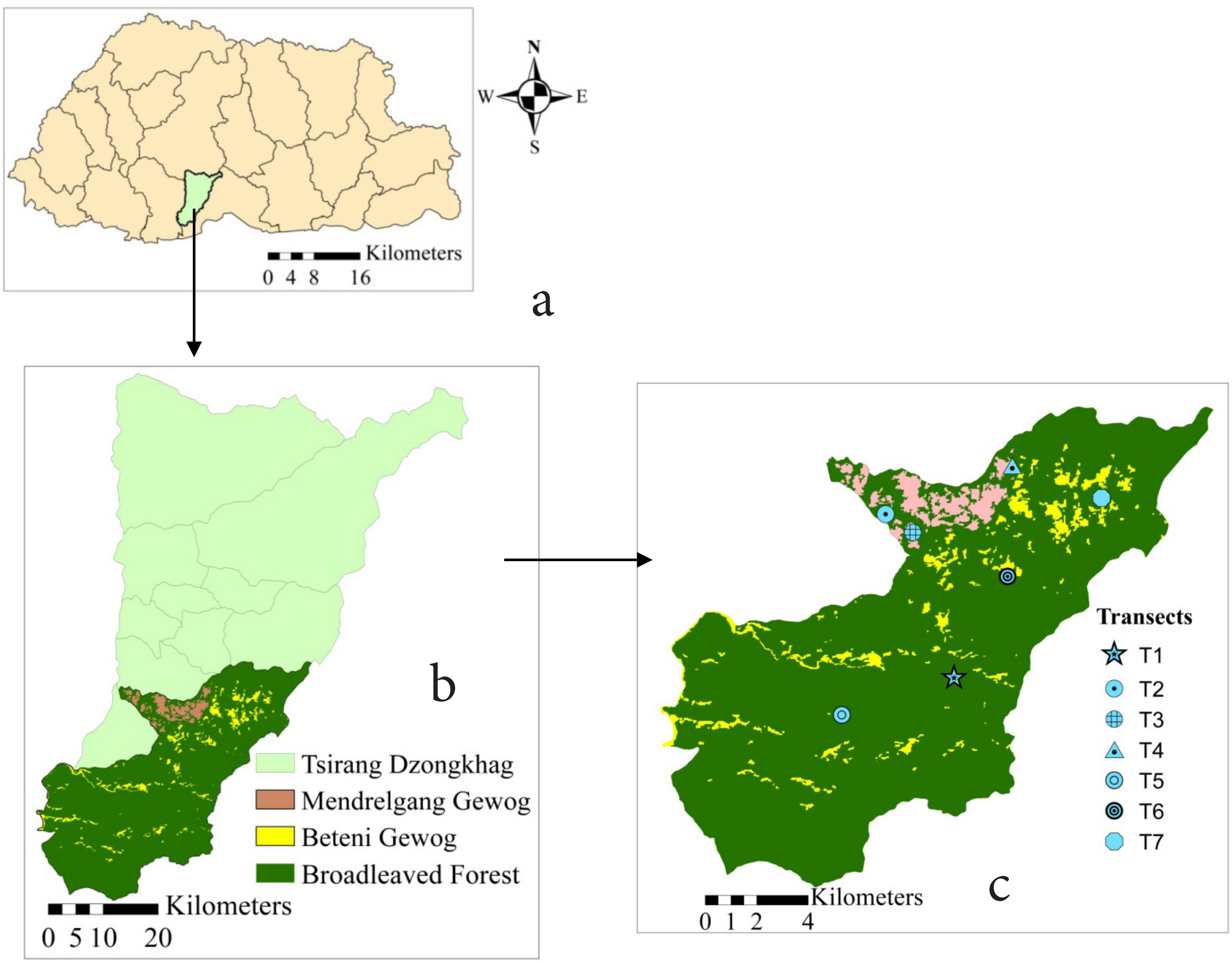


Figure 1. a) Bhutan map showing whole district, b) Tsirang district showing Beteni and Mendrelgang gewog, c) Beteni and Mendrelgang gewog showing study transects

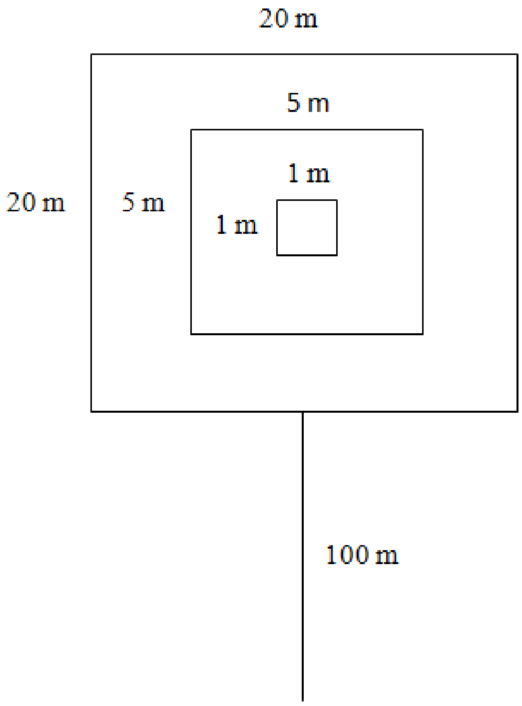


Figure 2. Design for sample plots; 400 m^2 = Yams & trees, 25 m^2 = shrubs, 1 m^2 = herbs.

The soil samples were collected from each plot from centre of every plot (1 x 1 m) with soil auger (15 cm) comprising to 35 samples in total. 100 g of sample from each plot were tested for nitrogen, phosphorus, potassium, soil carbon, soil organic matter and pH (Diby et al. 2011).

Yam specimen collection and identification

Stem with leaves were collected as specimen and made herbarium. The collected herbarium were levelled, pressed and taken to National Biodiversity Centre (NBC) for identification and consultation. The herbariums were identified consulting experts and tally the existing herbarium and database. Herbariums of all species were handed over at National Biodiversity Centre: Thimphu for future reference.

Data analysis

Soil pH was determined by maintaining 1:5 (20 g of soil sample in 100 ml water) using pH meter (Maikhuri et al. 2000). Soil phosphorus was measured using Bray no 2 extract method (Watham et al. 2014). Soil nitrogen (N) was calculated using Kjeldahl method (Bremner, 1960). Soil potassium was determined by flame photo-metric method (Jankowski & Freiser, 1961). SOM and SOC were determined by loss of ignition method (Konare et al. 2010)

Shapiro-Wilk test was conducted to check normality of data. One-way ANOVA and correlation was done in SPSS version 23. Canonical Correspondence Analysis (CCA) was done in PC-ORD version 5.1 between the yam species and environmental parameter.

Results

Relationship between vegetation and wild yam

The total of 1223 individual counts of yam plants were recorded. Among the total count, the area had a seven different types of yam species (Table 1). Spearman rho correlation coefficient result showed an inverse relationship between yam abundance and trees count (r_s = -.59, $p < 0.05$), indicating more trees cause closed canopy which hinder light penetration to the ground affecting the growth and abundance of yam plants.

However, yam abundance have significant positive relationship with shrubs (r_s = .52; $p < 0.05$) and herbs (r_s = .51; $p < 0.05$) indicating that yam plants prefers to grow associated with shrubs and herbs

Table 1. Dioscorea species and the individual count in different transects

Species	T1	T2	T3	T4	T5	T6	T7	Total count
Dioscorea belophylla	42(+)	36 (+)	45 (+)	18 (+)	27 (+)	50 (+)	20 (+)	238
Dioscorea sp.	32 (+)	37 (+)	53 (+)	0 (-)	34 (+)	35 (+)	33 (+)	224
Dioscorea bulbifera	36 (+)	26 (+)	48 (+)	14 (+)	27 (+)	27 (+)	23 (+)	201
Dioscorea pentaphylla	39 (+)	37 (+)	44 (+)	15 (+)	27 (+)	19 (+)	12 (+)	193
Dioscorea hispida	28 (+)	25 (+)	41 (+)	17 (+)	36 (+)	17 (+)	25 (+)	189
Dioscorea deltoidea	15 (+)	24 (+)	19 (+)	5 (+)	15 (+)	12 (+)	0 (-)	90
Dioscorea prazeri	30 (+)	0 (-)	0 (-)	17 (+)	32 (+)	9 (+)	0 (-)	88

Where, T= Transect, Sp. present (+), Sp. absent(-)

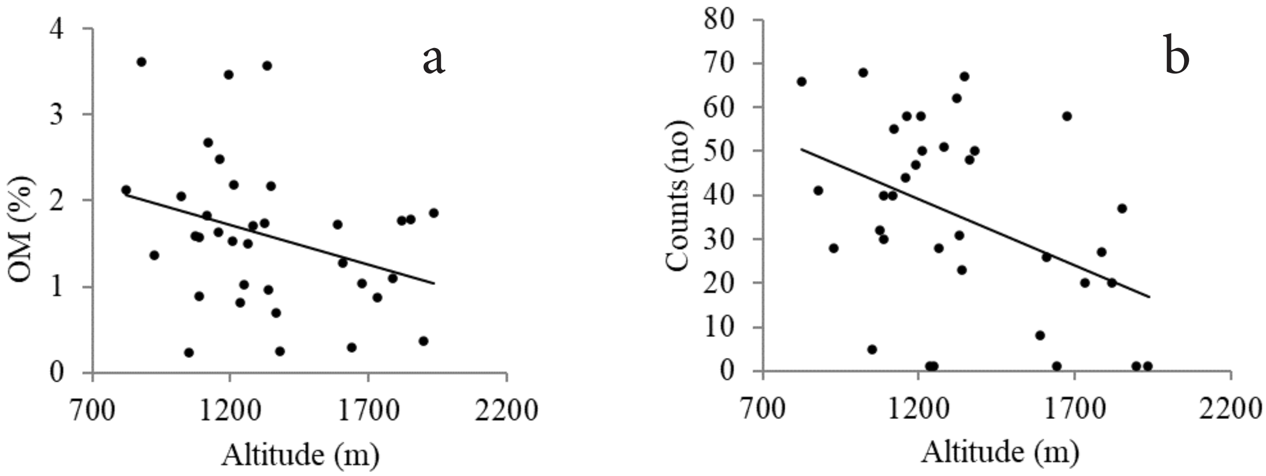


Figure 3. a) Abundance of yam along the altitude; b) Soil organic matter along altitude

competing for the same nutrient contents. The abundance of yam was negatively related with the altitude (r_s = -.581, $p < 0.05$) (Fig. 3).

Factors influencing growth and abundance of yam

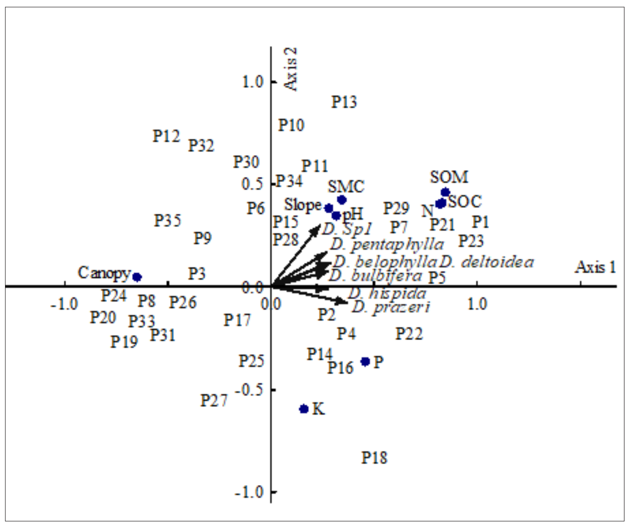
The lowest altitude range between 825 – 1211 m recorded more individual count of yam (n = 662) whereas highest altitude range (1235 – 1934 m) recorded fewer counts of yam (n = 561) individuals. Similarly, there was significant negative relationship of altitude with soil organic matter (r_s = -.53, p < 0.05) leading to unequal distribution and growth in low and high altitudes (Fig. 3).

Canonical correspondence analysis (CCA) showed that the yam abundance has a close relationship with environmental conditions (Fig. 4). The eigenvalues of axis 1 (0.043) was greater than axis 2 (0.020) (Table 2). Eigenvalue measures the most affecting environmental parameters of yam growth and abundance. Soil organic matter (r_s = 0.500; $p < 0.05$), organic carbon (r_s = 0.501; $p < 0.05$) and nitrogen (r_s = 0.500; $p < 0.05$) are the most determining factor for yam abundance (Fig. 4). However yam abundance has inverse relationship with canopy closure (r_s = -.479, $p < 0.05$) (Fig. 4). There was no significant relationship of yam abundance with soil phosphorus (r_s = 0.007; $p > 0.05$) and potassium (r_s = 0.005; $p > 0.05$) resulting that phosphorus and potassium did not influence on yam growth and abundance.

Table 2. CCA representing amount of affecting environmental correlations in axis 1&2

	Axis 1	Axis 2	Total Variance
Eigenvalues	0.043	0.020	0.288
Species-environment correlations (Kendall corr.)	0.468	0.468	
Cumulative percentage	14.9	21.9	

Further, there was no significant relationship between the yam abundance and pH recorded (r_s = 0.220, $p > 0.05$) of study sites. The pH in the study sites varies from 5.31 to 6.78 which were slightly acidic and this range of pH does not show any relationship with yam abundance nor did it indicate any negative effect on growth of yam plants. One way



P1 - P35 are the plots identity. N = nitrogen, P = phosphorus, K = potassium, SMC = soil moisture content, SOM = soil organic matter & SOC = soil organic carbon.

Figure 4. CCA showing the influence of environmental factors in distribution of yam abundance

ANOVA showed significant differences of yam abundance in seven different transects; F (6, 42) = 3.13, $p < 0.05$ indicating that yam abundance depends on elevation and different land aspect (Table 3).

Table 3. ANOVA showing difference within and between yam abundance in seven transects

Source	*df*	MS	*F*	*P*
Between Groups	6	482.46	3.13	.013
Within Groups	42	154.12		
Total	48			

* $p < 0.05$

The abundance was found more in 3rd transect (n = 250, 20%) which was located in north facing aspect (Fig. 5). It was observed that the 3rd transect facing towards north was laid out along the stream with good amount of moisture and organic matters. Leading to significant relationship between soil moisture content and yam abundance (r_s = .447, $p < 0.05$). Thus, it indicated that the soil moisture has the positive effects on the growth and abundance of yam species.

Discussion

Variation in wild yam species in broadleaved forest

The current record of seven yam species (Table 1) from the broadleaved forest showed that the yam species can differ within a similar habitat. Since, the study conducted by Ugyen & Gurung (2015) in broadleaved forest of Zhemgang reported all the yam species present in the current study site including extra three yam species *Dioscorea alata, Dioscorea rotundata* and *Dioscorea cayenensis*. Singh & Kumar (2015) recorded 9 yam species from Khunti district of India including *D. bulbifera* and *D. hispida* that was also recorded from the current study. Despite the study being conducted in broadleaved forest, the ecological and climatic factors affect the diversity of yam species (Singh & Kumar, 2015).

Relationship between associate vegetation and wild yam abundance

The presence of tree species in the plots where transects was laid out for yam species enumeration showed a significantly inverse association. Where ever there was higher density of trees the yam abundance was low. Similarly, Paul & Yavitt (2010) found that trees with big diameter which have closed canopy affects yam vine to gain the vertical growth. Abundance of yam plants decrease with rise in the forest canopy and tree counts (Paul & Yavitt, 2010). Yasuoka (2013) reported that competing trees reduce light intensity on the forest floor which negatively affects the propagation of yams through true seeds (sexual propagation).

But a positive association was shown between yam abundance with shrubs and herbs in an open canopy. It was observed that the yam abundance was high along with higher amount of herb and shrubs where there was less amount of trees leading to open canopy. Yasuoka (2013) explained that shrubs and herbs do not hinder the light intensity at forest floor as it is shorter than 5 m height. Maximum diameters a yam vine can twine around was about 10 cm

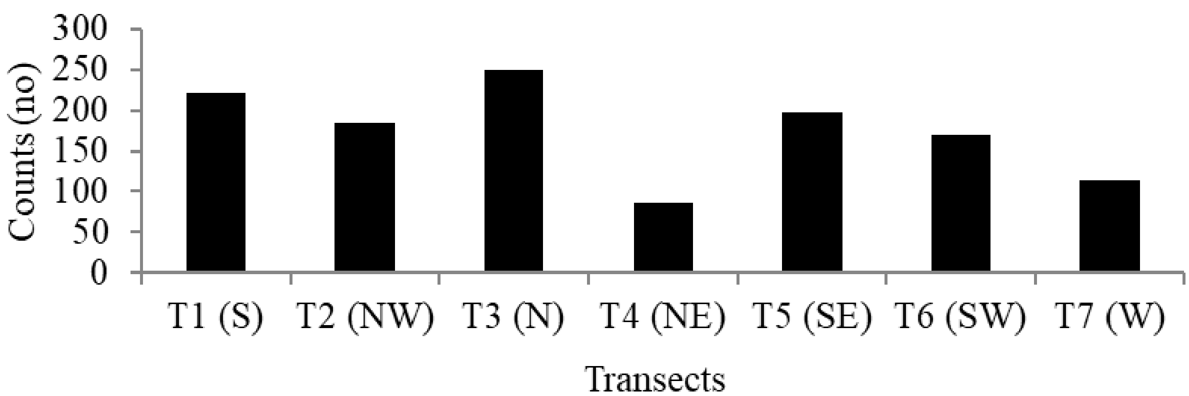


Figure 5. Effect of aspects on yam abundance along transects: T1 = South, T2 = North West, T3 = North, T4 = North East, T5 = South East, T6 = South West & T7 = West

(shrubs) and exposes their leaves towards sunlight (Paul & Yavitt, 2010). In absence of support; yam growth rate reduces and formation of harvestable tubers ceases so it grows well associated with shrubs and herbs (Byarugaba et al. 2006).

Influence of environmental factors on growth and abundance of wild yam

The abundance of yam showed a significant negative relationship with altitude (Fig. 3). Higher count of yam was found in lower altitude. This could be due to higher temperature in lower altitude and lower altitude providing essential growth materials (Diby et al. 2009).

While performing CCA (Fig.4), it was found the canopy closure, soil organic matter, organic carbon and nitrogen were the main factor that lead to the variation of yam abundance in various transects and altitudes. Diby et al. (2009) stated that nitrogen is primary nutrient that is essential for growth of yam plants. Nitrogen helps in growth and development of yam plants but has minimum effect on its yields (Diby et al. 2011). Robert & Cornet (2010) reported that the soil organic matter and organic carbon are required in good quantity for growth of yam plants. Similarly, Siqueira et al. (2014) highlighted that farmers of Brazil usually keep their land fallow for few years to restore soil fertility. Whereas Frossard et al. (2017) experimentally found forest area was good for yam growth than the open land as forest has the capacity to replenish the organic matter. Ehirim & Obike (2017) reported that greater number of yam seedlings observed in soil with rich organic matter content than any other soil. The canopy cover of the tree also influences the yam abundance. There were fewer number of yam vines in the area present with trees. The tree canopy hinders the light penetration to the ground as yam is a light demanding species (Yasuoka, 2013). Paul & Yavitt (2010) reported that the counts of the yam plants decrease with rise in the forest canopy.

It was fascinating to know that yam abundance showed significant poor relationship with soil phosphorus, potassium and pH. It showed that the yam requires such nutrients in low amount and does not influences the yam growth and abundance. Diby et al. (2009) found content of phosphorus in shoot and tubers of yam plants was low. The potassium does not affect the yam growth but increase the tuber yield by increasing tuber bulking rate, bulking phase and earlier tuber initiation (Diby et al. 2011). The pH of soil in the current study site of 5.31 to 6.78 does not influences the yam abundance and growth. Similarly, Diby et al. (2009) recorded pH range of 5.8 to 6.5 of forest soil taking the soil sample from 10 – 20 cm depth had found no relationship with yam growth and abundance. Moreover, Schiwachi et al. (2015) experimentally maintained the alkaline soil (pH = 8), and found no effect on total vine length, number of leaves on the plant and yam growth.

Variation of yam abundance in different transects

The yam abundance was different in different transects. Even though they share a similar vegetation (broadleaved). It could be base on the location of plots in different elevation and aspects (Table 3). Similarly, Gong et al. (2009) found that the differences in chemical properties of soil between the two aspects (north and south) results in variation of vegetation abundance.

Zurich & Adeoluwa (2017) experimentally found exposure of leaves towards sunlight is necessary for growth and higher yield was recorded when expose to sunlight. However, it was found the 3rd transect located in north facing aspect (Fig. 5) had higher abundance. It was mainly due to presence of stream which was providing moisture to the yam. The soil moisture content affects the propagation, shoot development and productivity of yam plants (Diby et al. 2009). However, Nyadanu & Agyeman (2015) found that some accessions of yam species were tolerant to drought. Ehirim & Obike (2017) stated that yam need high soil moisture for growth but with proper drainage system and compacted soil results in low growth due to less water holding capacity.

Conclusion

The ecological aspects of yam abundance in various transects in broadleaved forest gave a insight into its performance with various environmental conditions. Yam abundance was recorded more in lower elevation than higher elevation. Yam is the light demander species and recorded growing more in south facing than north facing aspects. Yam plants had negative relationship with tree abundance and canopy. Yam species grows well when associated with shrubs and herbs due to open canopy and more light intensity. Yam species had the positive correlation with the organic matter, organic carbon and moisture content. Nitrogen had positive relation with yam growth as it was essential for stem and crown development. However there is need to study the influence of phosphorus and potassium on yam plants mainly through the tuber yield assessment as this nutrient affects the tuber development. Although an ecological study was conducted by this research in winter season, the study of yam plants in other seasons are strongly recommended to associate with wide range environmental conditions. More over this study assessed only the wild yam species in the broadleaved forest thus assessment of domesticated yam species is still strongly recommended. There is need to study human perception on yam species diversity trends (species richness & abundance) over the past to the present. The study of human perception of yam plants will record the social, cultural and economic benefits of yam to the farmers. Furthermore, the human perception will aids in implementation of conservation strategies.

Acknowledgement

The authors would like to express their immense gratitude to Department of Forest and Park services, Ugyen Wangchuk Institute for Conservation and Environment Research, and National Biodiversity Center, Bhutan for rendering support throughout the completion of this research.

References

Aboagye, M., Nyadanu, D. & Opoku, O. (2015) Survey of diversity and production of yams in four communities in Southern Ghana. African Journal of Agricultural Research. 10(24): 2453-2459. DOI: 10.5897/AJAR2014.9468.

Bremner, J. (1960) Determination of Nitrogen in soil by the Kjeldahl method. The Journal of Agriculture Science.55(1): 11-33. DOI: https://doi.org/10.1017/S0021859600021572.

Byarugaba, D., Ndemere, P. & Midgley, J. (2006) The vulnerability and resilience of Dioscorea species in utilized and nonutilized zones of Bwindi Impenetrable National Park. Journal of Ecology. 45(1): 258–264. DOI: 10.1111/j.1365-2028.2006.00700.x.

Degefa, I. & Anbessa, B. (2017) Traditional Agronomic Practices of Yam (*Dioscorea* Species) in Abaya Woreda, Southern Ethiopia. International Journal of Chemical and Natural Science. 5(1): 499-503.

Diby, N., Hgaza, K. & Tie, B. (2009) Productivity of yams (*Dioscorea* spp.) as affected by soil fertility. Journal of Animal and Plant Sciences, 5(2): 494-506.

Diby, N., Hgaza, K. & Tie, B. (2011) 'How does soil fertility affect yam growth?. Acta Agriculturae Scandinavica, Section B - Plant Soil Science. 61(5): 448-457. DOI: 10.1080/09064710.2010.505578.

Ehirim, C. & Obike, K. (2017) The Effect of Soil Types on the Growth Rate of Yam Seedlings Inferred from 2-D Electrical Resistivity Tomography. Journal of Environmental Science, Toxicology and Food Technology. 11(3): 81-86.

Frossard, E., Aighewi, B. & Ake. (2017) The Challenge of Improving Soil Fertility in Y a m Cropping Systems of West Africa. Frontiers in Plant Science. 8(1953): 1-8. DOI: org/10.3389/fpls.2017.01953.

Garedew, B., Haile, B. & Ayiza, A. (2017) Distribution, Diversity and Potential Production of Yams (*Dioscorea*species) in Sheko District, Southwest Ethiopia. American Journal of Life Sciences.5(3): 86-92.

Gong, J., Chen, L. & Fu, B. (2009) Integrated effects of slope aspect and land use on soil nutrients in a small catchment in a hilly loess area, China. International Journal of Sustainable Development & World Ecology. 14(3): 307–316.

Jankowski, S. & Freiser, H. (1961) Flame Photometric Methods of Determining the Potassium Tetraphenylborate. Analytical Chemmistry. 33(6): 773-775. DOI: https://doi.org/10.1021/ac60174a034.

Konare, H., Yost, R. & Doumbia, M. (2010). Loss on ignition: Measuring soil organic carbon in soils of the Sahel, West Africa. African Journal of Agricultural Research. 5(22): 3088-3095.

Kumar, S., Das, G. & Shin, H. (2017) Dioscorea spp. (A Wild Edible Tuber): A Study on Its Ethnopharmacological Potential and Traditional Use by the Local People of Similipal Biosphere Reserve, India. Frontiers in Pharmacology. *8*(52): 1-17. DOI: 10.3389/fphar.2017.00052.

Maikhuri, R., Semwal, R. & Rao, K. (2000) Growth and ecological impacts of traditional agroforestry tree species in Central Himalaya, India. Agroforestry Systems. 48(3): 257-271. DOI: https://doi.org/10.1023/A:1006344812127.

Ministry of Agriculture and Forests. (2017) Atlas of Bhutan. Retrieved from http://www.dofps.gov.bt/wp-content/uploads/2018/05/Atlas_LULC2016.pdf on 4 January 2020.

Muthamia, Z., Morag, F. & Nyende, A. (2016) Estimation of genetic diversity of the Kenyan yam (Dioscorea spp.) using microsatellite markers.

African Journal of Biotechnology.12(40): 5845-5851. DOI: 10.5897/AJB2013.12362 .

Ngwe, M., Omokolo, D. & Joly, S. (2015) Evolution and Phylogenetic Diversity of Yam Species (Dioscorea spp.): Implication for Conservation and Agricultural Practices. 10(12): 1-13. DOI:10.1371/journal.pone.0145364.

Noltie, H. (1994) *Flora of Bhutan*. Edinburgh: Royal Botanical Garden Edinburgh.

Nyadanu, D. & Agyeman, M. (2015) Survey of diversity and production of yams in four communities in Southern Ghana. African journal of agricultural research. 10(24): 2453-2459. DOI: 0.5897/AJAR2014.9468.

Padhan, B., Mukherjee, A. & Mohanty, S. (2019) Genetic variability and inter species relationship between wild and cultivated yams (Dioscorea spp.) from Koraput, India based on molecular and morphological markers. Physiological Molicular Biological Plants. DOI.org/10.1007/s12298-019-00691-3.

Paul, G. & Yavitt, J. (2010) Tropical Vine Growth and the Effects on Forest Succession: A Review of the Ecology and Management of Tropical Climbing Plants. Tropical Vine Ecology and Forest Succession. 77 (2010): 11–30. DOI: 10.1007/s12229-010-9059-3.

Robert, A. & Cornet, D. (2010) Review of soil fertility management for yam-based systems in West Africa. African Journal of Root and Tuber Crops. 8(2): 1-17.

Schiwachi, H., Kikuno, H. & Ohata, J. (2015) Growth of Water Yam (*Dioscorea alata* L.) under alkaline soil conditions. Tropical agriculture development. 59(2): 76-82.

Singh, G. & Kumar, J. (2015) Diversity of wild edible yams and its traditional knowledge among munda tribe of district Khunti, Jharkhand, India. International Journal of Bioassays.4(10): 4440-4442.

Siqueira, M., Nascimento, W. & Silva, L. (2014) Distribution, management and diversity of yam local varieties in Brazil: a study on *Dioscoreaalata* L. BrazilJournal of Biology. 74(1): 52-61. DOI: org/10.1590/1519-6984.17112.

Tamiru, M., Becker, H. & Maass, B. (2008). Diversity, distribution and management of yam landraces (*Dioscorea* spp.) in Southern Ethiopia. Genetic Resource Crop Evolution. 55(1): 115–131.

Ugyen, J. & Gurung, T. (2015) Assessment of Yam *(Dioscorea spp.)* Diversity at Community Level in Nangkor Gewog under Zhemgang Dzongkhag. Retrieved from https://pdfs.semanticscholar.org/976d/a1f2afd40c0174d568f509d142e41d63531e.pdf on 7 September 2019.

Watham, L., Athokpam, H. & Meitei, W. (2014). Evaluation of some soil test methods for available phosphorus and its critical limits for black gram in acid soils of Imphal west district, Manipur (India). The Ecoscan. *8*(3): 199-202.

Wu, J., Ding, Z. & Jiao, Z. (2016) Analysis of Genetic Diversity of *Dioscorea japonica* Germplasm in China Using Inter-simple Sequence Repeat Markers. International Journal of Current Research in Biosciences and Plant Biology. *3*(11): 36-42. DOI: http://dx.doi.org/10.20546/ijcrbp.2016.311.006.

Wu, W., Chen, C. & Zhanga, Q. (2019). A comparative assessment of diversity of greater yam (*Dioscorea alata*) in China. Scientia Horticulturae. *243*(2019):116–124.DOI:org/10.1016/j.scienta.2018.08.016.

Yasuoka, H. (2013) Dense Wild Yam Patches Established by Hunter-Gatherer Camps: Beyond the Wild Yam Question, Toward the Historical Ecology of Rainforests. *Human Ecology*. *41*(3): 465–475. DOI: 10.1007/s10745-013-9574-z.

Zurich, E. & Adeoluwa, O. (2017) Yam (Dioscorea spp.). Encyclopaedia of Applied Plant Sciences.3(2017): 435–441. DOI: 10.1016/B978-0-12-394807-6.00177-5.