International Journal of Applied Social Science *RESEARCH PAPER*
Volume 5 (11&12), November & December (2018) : 921-933 ISSN : 2394-1405 (Print)
Received : 05.05.2018; Revised : 19.05.2018; Accepted : 05.06.2018

Cultivation of *brahmi* (*Bacopa monniery* Linn.) in Haryana: An agroecological approach

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ABSTRACT

Brahmi (*Bacopa monniery* Linn.) is being cultivated in many states of north India but there is a gap between demand and supply. This gap can be filled by bringing more and more suitable areas under its cultivation by studying its agroecological requirements. This plant is used in many medicines and health products and its market demand is also growing consistently. It provides opportunity for further expansion of the cultivable land under this plant. Wetlands, ponds and damp areas may also be suitably used for the cultivation of this plant. Irrigation facilities in the state are also well developed. These factors in combination with agroecological suitability of cultivating this plant in the state of Haryana have prompted this investigation. In the present research agroecological approach has been adopted for scientific investigation of the areas as well as agricultural condition which support the cultivation of this plant. The basic assumption underlying this approach is that every region with its unique natural and geographic conditions has potential to supports different species and varieties of crops and plants. These potentials should be properly understood and utilised for the benefit of society and natural environment. In the present paper, agroecological conditions (climatic, pedological and agricultural) of cultivating *brahmi* in Haryana have been studied. For this purpose agroecological requirements or sets of potentials and constraints (land, soil and environmental characteristics) for the cultivations of *brahmi* have been used to identify zones/regions of varying suitability in GIS environment using IDW interpolation method of spatial analysis kit in ArcGIS 10.3 software. This exercise has yielded four zones of different levels of suitability on the basis of average expected yield of the plants in different locations of the state. Around 15 per cent area of the state has been found to be more than just suitable for the cultivation of this plant. Around 54 per cent area in the western part of the state is not suitable for this plant. Wetlands, ponds, lakes, river banks, canal sides form special areas for the cultivation of this plant.

Key Words : Agroecological approach, Agroecological regions, Agroecological zones, Crop suitability, Cultivation of *brahmi*, Aromatic plants cultivation

INTRODUCTION

Conservation of medicinal and aromatic plants (MAPs) in the state of Haryana has been a long tradition. Recently, due to the efforts of state and central governments and increasing market demand many farmers and practitioners have adopted the cultivation of these plants. But, an analysis of total areas under these plants shows that the cultivation of these plants has been an infrequent practice in the state as the total area under these plants was 3,035 hectares in 2003-04, which has

How to cite this Article: Zaidi, Tasawwur Husain (2018). Cultivation of *brahmi* (*Bacopa monniery* Linn.) in Haryana: An agroecological approach. *Internat. J. Appl. Soc. Sci.,* **5** (11&12) : 921-933.

come down to 290 hectares only in 2015-16. One of the reasons for it may that farmers and practitioners are not aware about the agroecological requirements of these plants (Horticulture Department, Government of Haryana 2018). *Brahmi* is also a much sought after medicinal plant in India and abroad due to its extensive use in different medicinal and health products. Therefore, there is a need of proper cultivation of this plant to meet the growing demand and conserve this species. Present research addresses the same concern with agroecological approach. The approach of agroecological zoning includes identification and demarcation of suitable area for cultivating crops and plants based on agricultural resources developed by humans superimposed upon natural conditions of the area. Thus, an agroecological zone may be defined as the land unit carved out of agroclimatic zone superimposed on agricultural resources developed by humans and landforms which act as modifier to climate, availability of moisture and length of growing period. It is a homogeneous land unit in terms of climate, length of growing period (LPG), soil properties and physiographic conditions which are suitable for certain group of plants with agricultural resources developed by humans (Food and Agriculture Organization FAO, 1978, FAO, 1983, Martin and Sauerborn, 2013:7). The approach of agroecological zoning is very useful in the "identification of areas with specific climate, soil, and terrain conditions which control the cultivation of different crops and plants; estimation of the extent of rain-fed and irrigated land and crops, and potential for their expansion; estimation of crop production and yield; evaluation of land potential for crops cultivation and diversification; regional impact and geographical shifts of agricultural land and productivity; determining plant suitability for optimization of land use; study of potentials and implications for food security resulting from climate change and variability" (Fischer *et al.,* 2006, Gliessman, 2015:18).

There are different methods and schemes of determining agroecological zones for different crops, plants and regions. The FAO (1978) used mean growing period temperature and length of growing period determined by annual precipitation, potential evapotranspiration and the time required to evapotranspire 100 mm of water from the soil profile to demarcate world into different agroecological regions. The Consultative Group on International Agricultural Research-Technical Advisory Committee, CGIAR-TAC, has demarcated agroecological zones on the basis of mean annual temperature, growing period temperature and length of growing period determined as in the case of FAO zonation scheme (Sivakumar and Valentin, 1997). For the purpose of identifying different agroecological zones, the Global Agro-ecological Zones GAEZ uses temperature, precipitation, potential evapotranspiration and soil characteristics (Fischer *et al.,* 2012). The Harvest Choice Agro-ecological Zone, HCAEZ uses mean temperatures, elevation, and GAEZ-LGP to define thermal regimes and temperature seasonality. The agroecological zoning scheme of the Global Land Initiative, GLI includes harvested area of target crop, crop-specific GDD and soil moisture index calculated as actual evapotranspiration divided by potential evapotranspiration (Mueller *et al.,* 2012). The Global Environmental Stratification GEnS uses four variables (growing degree days GDD with base temperature of 0^0, an aridity index, evapotranspiration seasonality and temperature seasonality) and iso-cluster analysis to 'cluster' grid-cells into zones of similarity (Metzger *et al.,* 2013, Warta *et al.,* 2013).

This approach is also being increasingly adopted in India for demarcating areas on the basis of their suitability for different crops. Murthy and Pandey (1978) delineated eight agroecological regions of India. Subramaniyam and Rao (1984) have demarcated agroecological zones of Maharashtra. Chowdhary and Mandal (1989) divided West Bengal into different agroclimatic zones. Recently, use of remote sensing and GIS has greatly helped in the process of identifying agroecological zones and suitable areas for the cultivation of crops. The Indian Council of Agricultural Research (ICAR) and National Bureau of Soil Survey and Land Use Planning (NBSS and LUP) have divided the country into 20 agroecological regions (ICAR NBSS and LUP, 2015). Gajbhiye and Mandal (2000) studied agro-ecological zones of India in terms of their soil resource and cropping systems. Raina and Koul (2011) studied impact of climatic change on agro-ecological zones of the Suru-Zanskar valley, Ladakh, India. Zaidi (2011) studied agroecological suitability of cultivating select medicinal and aromatic plants in the state of Haryana, India.

Plants/crops yield and soil productivity in terms of the production of herbage, fruits, grains, roots and oils as the combined result of climate, soils, farm inputs and management practices in agricultural system has been the basis of identifying suitable agroecological zones of various levels (Shekara *et al.,* 2016: 2). In the present analysis also, expected yield (calculated for selected locations of the state) of *brahmi* has been taken as the sole criterion of determining agroecological zones of *brahmi* cultivation at different levels of suitability. It reflects not only environmental potential and constraints but also level of agricultural resources (irrigation) developed for the establishment and growth of this plant in the state (Zaidi, 2011: 193-199).

About study area :

The state of Haryana is located between 27º 39' N to 30º 55' N latitude, and 74º 27' E to 77º 36' E longitudes (Fig. 1). The state covers an area of 44,212 km^2 and accounts for about 1.35 per cent

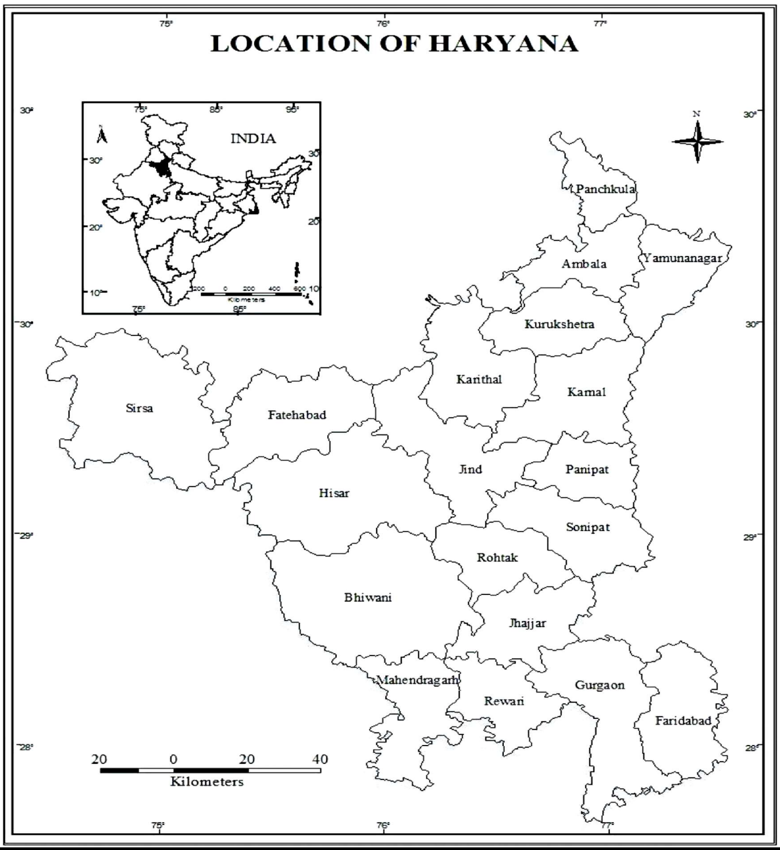


Fig. 1 : Location of Haryana

of the geographical area of the country. Almost 80 per cent land area of the state is under cultivation mostly under wheat and rice. As per the India State of Forest Report, FSI, 2017, the forest cover in the state is 1,588 km^2 or 3.59 per cent of the state's geographical area. Geology of the state is characterised by the Siwalik system, the Indo-Gangetic plain and the Aravali system. On the basis of physiographic features, the state may be divided into the structural hills of the Siwaliks, the piedmont plains, central plain and the structural hills in the Aravalis and the shallow pediments (Singh, 1971: 88, Duggal, 1975:3-5).

Average annual rainfall in the state varies from more than 100 cm in the northeast to 30 cm in the extreme western parts of the state. Average annual temperature varies between 24°C to 26°C. The average relative humidity in the state has been recorded to be around 65 per cent which varies from 45 to more than 80 per cent in different seasons of the year. Climate of the state is subtropical continental monsoon type. The state is characterised by tropical desert, hot and arid climate, tropical steppe and semi arid hot climatic conditions. These areas may be grouped into subtropical monsoon, mild and dry winter and hot summer climate regions (IMD, 1989, Singh, 1976: 44-45). Soils of the state are sandy and loamy sand (*bagar*), relatively sandy loam, sandy soft loam (*rohi*), coarse loam (*dahar, chaeknote*), light loam (*seoti*), loam (*bhangar and nardak*), silty loam (*khadar*), clayey silt (bet), silt clay (*naili* and *chhachhra, dakar*), Siwalik soils (*pahari*), piedmont (*ghar and kandi*), rocky surfaces. The pH value of these soils varies between less than 7.50 (in northeast) to more than 9.77 in the southeastern part of the state (Singh, 1976: 91, Zaidi, 2011:1-74).

About the plant :

Brahmi or Indian pennywort is a common perennial creeper succulent herb found in damp or marshy areas near streams or on the banks of ponds and lakes throughout India. There are two species of *brahmi*: (i) *Bacopa monniery* Linn. Pennel or *jalnim*; and (ii) *Centella asiatica* Linn. or *mandukparni*. In spite of many similarities in their chemical constituents and health effects, the *jalnim* is the true *brahmi* . It is found in the hills and plains of India, up to an altitude of 1,500 meters. The main producing areas of this plant are Uttar Pradesh, Punjab, Haryana, Bihar, Jharkhand, West Bengal, Tamil Nadu, Kerala, Karnataka, Madhya Pradesh, Assam and the foothills of Himachal Pradesh and Uttarakhand. The CIMAP, Lucknow has released two varieties 'pragyashakti' and 'subodhak' which have a high herbage yield and content of Bacoside-A. Other important varieties are Tirunelvelli, Panchkula, BMTV, BM-C, BM-C2 etc. (Uniyal, 2003:134, Zaidi, 2011: 193-199).

Temperature and rainfall :

The plant grows faster in hot and humid conditions with temperature 33ºC- 40ºC and relative humidity of 60-80 per cent. It should be cultivated in summer during rains. Ideally, the transplantation should be carried out from March to June and be allowed to grow and proliferate throughout hot and humid months of monsoon till the end of the month of September. Harvesting should be carried out after this period. The crop is also maintained in a perennial state with two harvests in a year, the first one in June and the another after monsoon during the month of October. It is cultivated as a summer crop during rains in sub-tropics. There should be sufficient soil moisture throughout its life cycle. It requires a higher water supply for its survival. Therefore, it should be cultivated where rainfall is at least 500 mm and well distributed. Low rainfall conditions do not favour its cultivation unless sufficient water supply is assured. Extremely dry conditions as *loo* and extreme cold or *pala* may be harmful to this plant (Zaidi, 2011: 193-199).

Soils and field preparation :

Though *brahmi* can be cultivated in any type of soil, but it proliferates well on sandy, sandy loam and light black cotton soils. This plant performs exceptionally well in poorly drained soils and water logged conditions of tropical and sub-tropical areas. It has also been noticed that it grows well in comparatively acidic soils. A pH value ranging 5.8-6.5 is thought to be ideal for the cultivation of this plant. It would be better if it is planted in wet lands suffering from advance eutrophication but have not completely died out. The field should be ploughed thoroughly before the arrival of monsoon. At least five tons of compost/FYM per hectare of land is applied before planting. It has also been noticed that a dose of 150 kg of lime per hectare is beneficial for its growth. The field should be irrigated a day before planting for successful establishment of plant cuttings (Chandra, 2004:248, Uniyal, 2003:136).

Propagation and irrigation :

Brahmi is a self propagating plant and, in a way, invasive with a high degree of resilience if ideal conditions prevail. The cuttings of its branches (4-5cm long) containing a few leaves, nodes and roots cut from the mother plants are transplanted in the wet soil of the field at a spacing of 40cm×40cm preferably during the months of June and July or on onset of monsoon in areas which depend on rains for moisture. Plantation should immediately be irrigated and allowed to grow and proliferate through hot and humid months of monsoon till the end of September. Harvesting is done in October. In areas where sufficient irrigation facilities are developed, it should preferably be transplanted during the months of February and March. This is why that it should be planted during the months of February and March in Haryana, where rainfall is low and erratic and irrigation facilities are available in most parts of the state. However, it thrives well in damp and particularly marshy lands as it requires lot of water for its growth and proliferation. The plantation may be irrigated by flooding as per requirement, usually at an interval of every 7-10 days. There is no need of irrigation during the monsoon period, if there is sufficient rainfall (Zaidi, 2011: 193-199).

Farm inputs and production :

Organic fertilizers like FYM, vermicompost, green manures etc. may be used as per the requirements of soils and plant species. In order to get good herbage, 100 kilogram per hectare of nitrogen may be applied in three split doses if necessary, but not in Haryana if irrigation is done using groundwater. A basal dose of 60 kilogram per hectare, each of phosphorus and potassium should also be given at the time of planting. The crop should be harvested between the months of October and November, as after this period there is loss of plant biomass and Bacoside yield. Average yield of fresh and dry herbage of *brahmi* is recorded to be 300 quintals per hectare, and 60 quintals per hectare, respectively. Harvest after September yields as much content of Bacoside-A as 85 kilogram per hectare. After the first post monsoon harvest, 40 quintals dry herb is obtained from the June harvest, thus, totalling to 100 quintals of dry herb per hectare per year. Thus, around 142 kilograms Bacoside-A may be produced from one hectare of land. Though, depending on agroecological conditions its yield may vary between 130 to 210 kilograms of Bacoside compound amount (Tiwari *et al.,* 2001:11).

METHODOLOGY

For the purpose of agroecological zoning; climatic, pedological and agricultural conditions for the cultivation of *brahmi* are compared and matched with the same conditions prevailing in the state. Finally those areas exhibiting suitability for the cultivation of this plant have been marked. For systematizing this process, a comprehensive study of the agroecological conditions where *brahmi* is naturally found or is being cultivated has been done to collect data and information about the cultivation and yield of this plant. Related data on variables like rainfall, temperature, humidity, soils, altitude, irrigation and yield have been collected from many places in India and abroad. A spatial framework of 95 villages/sites has been developed to study similar agroecological conditions prevailing in the state and calculating expected yield (Fig. 3). The agroecological data collected from these sites and some secondary sources reveals sufficient spatial variations. A comparative analysis of this data by employing the concept of geographic equivalence, locales (zones) has led to the evaluation of agroecological potentials and constraints of different areas in the state and the demarcation of different zones for the cultivation of *brahmi* (Fig. 2 and 4).

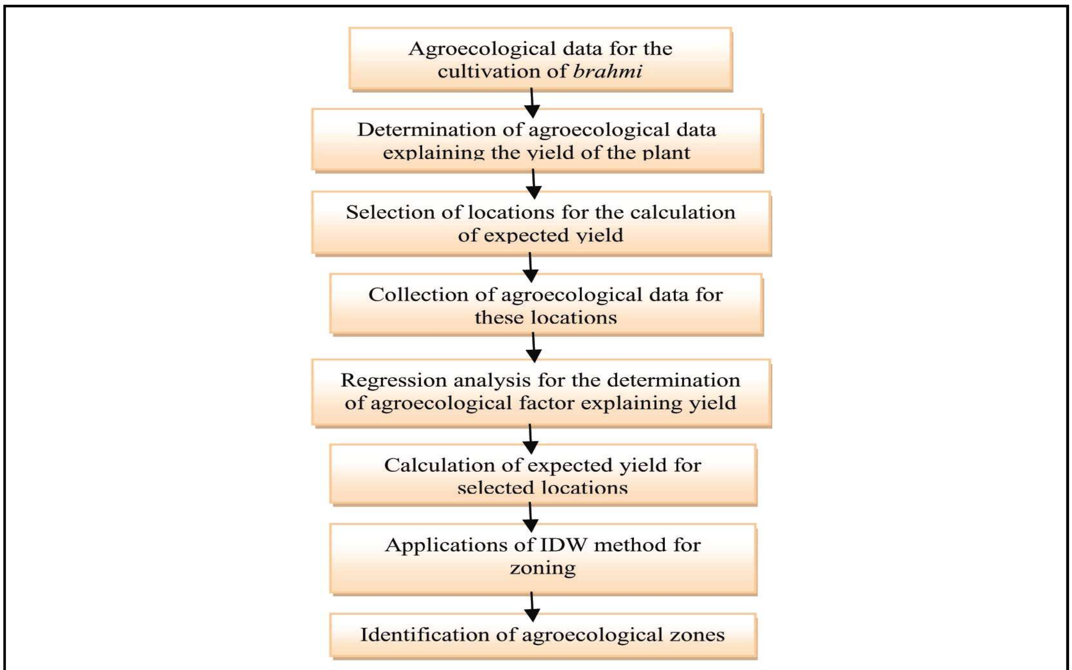


Fig. 2 : Methodological steps of agroecological zoning

The first step in this process has been the identification of key climatic, edaphic and agricultural variables which are scientifically proved most important for the cultivation of *brahmi* in India and around the globe. On the basis of these determinants and observed yields (per hectare production of Bacoside-A) of this plant in varying environmental conditions, explanatory functions have been derived by regression analysis. These explanatory functions or coefficients have been used for calculating expected or predicted yields of this plant for 95 selected sites/villages (Fig. 3). A review of expert literature on *brahmi* revealed that mean annual temperature, mean minimum and maximum temperature, annual mean temperature, soil chemical properties and altitude are the main predictors of yield of this plant.

For the purpose of calculating expected yield, collected data has been processed in the statistical package IBM SPSS 20, and all given curvilinear multivariate functions, Cobb Douglas production function and stepwise linear regression have been experimented with. An inspection of the explained variance in the average yield of *brahmi* has revealed that the stepwise regression analysis explains most of it with a high significance of regression coefficients and an F statistics at a very high level of significance pointing out a very reliable fit of the model:

$YL = 153.419 + 0.019*RF + 1.231*MN$ $\quad R^2 = 0.771$, Adjusted $R^2 = 0.770$, $F = 37.070$

(0.000) (0.000) (0.000) (0.000)[1]

Where,

YL = yield of *brahmi*, RF= annual rainfall, MN = mean annual minimum temperature

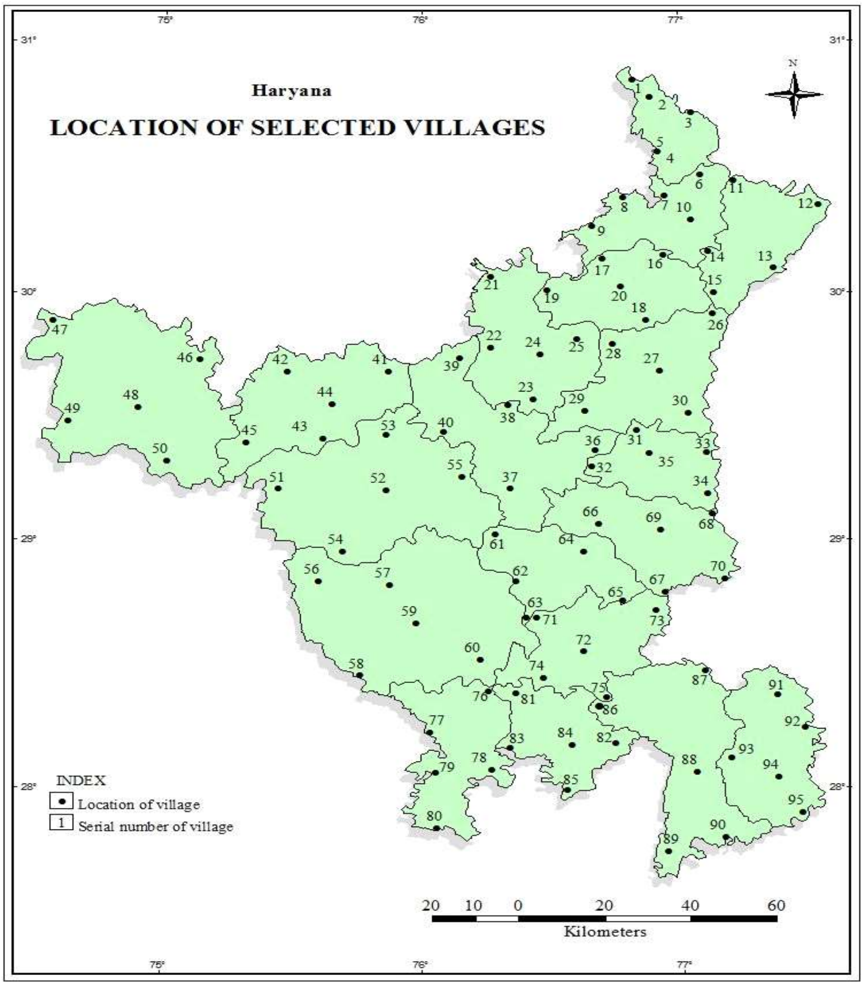


Fig. 3 : Location of selected villages in Haryana

An inspection of regression values show that only annual rainfall and minimum temperature are retained in the equation whose regression coefficients are very significantly different from zero (0.000) meaning thereby that these regression coefficients may be relied upon for prediction of yield and so is case with the constant (153.419). The Value of R^2 is 0.771 which after adjustment turns out 0.770 signifying that at least 77 per cent variation in the observed yield of *brahmi* is

1. Figures in parentheses are significance levels of parameters.

explained by these two predictors. Significance level of F statistics validates the fitted model with a high degree of confidence. In the second instance, annual mean temperature and annual rainfall plus volume of irrigation water in mm over the geographical area of sample villages and soil chemical properties and altitude are used to predict the yield of *brahmi* for these 95 sites. The predicted yields are taken merely as indicator of suitability and form a reasonable basis of agroecological zoning for this plant.

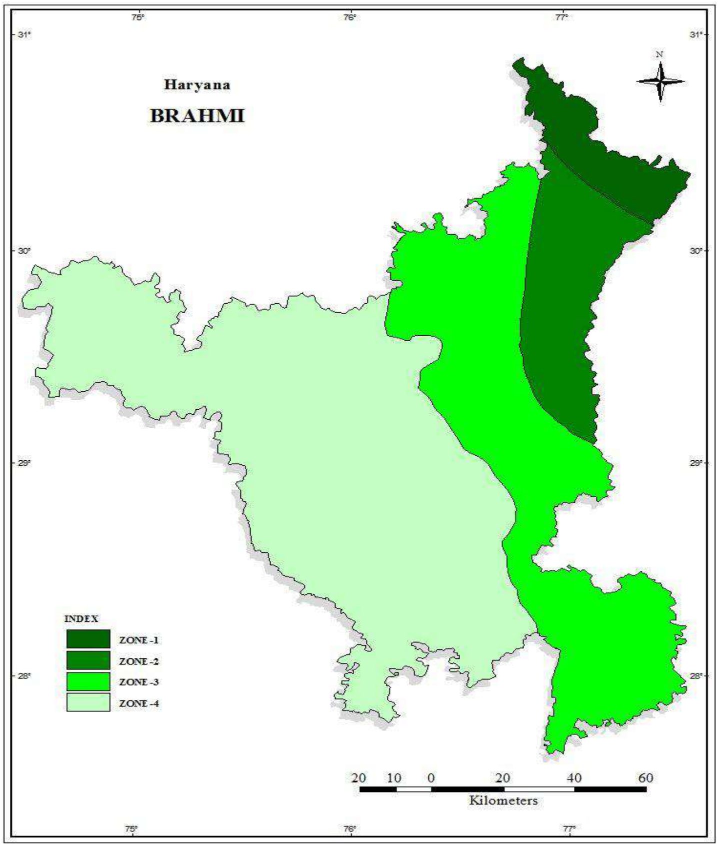


Fig. 4 : Agroecological zones for *brahmi* cultivation

In the third instance, the file of expected/predicted yield of *brahmi* has been attached with the location code file of the sample villages in ArcGIS 10.3 environment. Using the IDW method of interpolation, surfaces of yield distribution are interpolated. In this method, a value at an unknown point is calculated as weighted sum of the values of N known points. The inverse distance weighting (IDW) method has advantage over the other methods of interpolation as this method is best suited for randomly distributed point data. In the present analysis a variable search radius of minimum of 10 map units and a minimum of 5 points are used with the calculation of weights of distances by squaring distances in order to minimise bias due to higher values at farther distances. This interpolation has given a number of zones. Therefore, a resampling has been carried out by assigning three natural breaks on the basis of the yield and which has classified all the interpolated area into four zones (Fig. 4). After resampling, the vectorisation is carried out to draw clear boundaries between different zones.

RESULTS AND DISCUSSION

On the basis of analysis of the expected yield of *brahmi* in each of these four zones, it is found out that the darkest green polygon (zone) represents the most suitable area for the commercial cultivation of this plant, the green zone represents a suitable zone for raising *brahmi* with appreciable profits, the area represented in dull or faded green is less suitable for its cultivation as profit earned from the cultivation of this plant though will be higher from that of conventional cropping but not significantly higher to recommend allocation of large area under this plant in this zone. The lightest green area represents a zone where cultivation of *brahmi* will be a loss incurring enterprise in comparison to conventional farming. Therefore, this zone is designated least or not suitable for cultivation of *brahmi*.

Agroecological zones for *brahmi* cultivation :

A brief description of the agroecological characteristics of each of four zones where *brahmi* can or cannot be commercially produced is given below (Table 1). Besides these zones, wetlands and waterlogged areas also form special areas of cultivating *brahmi* in the state (Fig. 5).

Table 1: Zones for *brahmi* cultivation in Haryana

Sr. No.	Zone	Level of suitability	Area in km^2	Area in per cent
1.	Zone 1	Most suitable	2,229.66	5.04
2.	Zone 2	Suitable	4,564.63	10.33
3.	Zone 3	Less suitable	13,489.27	30.51
4.	Zone 4	Least or not suitable	23,928.44	54.12

Zone 1 (Most suitable) :

This zone is located in northern Haryana along the Siwaliks. It covers 2,229.66 km^2 or 5.04 per cent of total area of the state. Geographically this zone is very important for the cultivation of *brahmi*, as it satisfies most of the natural requirements for this herb. Average altitude of this zone ranges between 300 and 500 meters from west to east. A long growing period of 180-210 days favours growth of most plants and herbs in this zone. Average annual temperature in this zone has been recorded varying between 23°C in south to 24°C in north. But, average monthly temperature during the month of May has been recorded to be less than 37°C which is most suitable for the faster growth of this plant. Average rainfall is more than 950 mm and soils are silty loam, piedmont (sandy), loam and light loam in this zone. Average pH value of these soils is less than 7.0 which is also favourable for commercial cultivation of this herb (Sachdev *et al.,* 1995, Zaidi, 2011: 309-314).

Zone 2 (Suitable) :

This zone extends over an area of 4,564.63 km^2 in the north and eastern part of Haryana. Area of this zone makes up 10.33 per cent of total area of the state. This zone roughly falls between the isohyets of 600 mm in the south and west and that of 950 mm in the north. Temperature and altitudinal conditions are same as those of the first zone, which are considered to be most suitable for the cultivation of *brahmi*. Soils are silty loam, silty clay and light loam with their average pH value measuring less than 8.0. The growing period is sufficiently long extending over 100-120 days. As average rainfall and soils are main determinants of *brahmi* cultivation, therefore, commercial cultivation of *brahmi* may be profitably carried out in this zone if irrigation is provided in time. However, the margin of profit may be lower in comparison to that of the most suitable zone (Sachdev *et al.,* 1995, Zaidi, 2011: 309-314).

Zone 3 (Less suitable) :

This zone extends in the central and south eastern part of the state. Total area of this zone is 13,489.27 km² or 30.51 per cent of total area of the state. As far as the agroecological conditions of this zone are concerned, its mean monthly temperature during the month of May exceeds 40ºC, and annual average rainfall varies between 500 and 600 mm from east to west. Soils are silty clay, clayey silt, coarse loam and light loam. The pH value of the soils in this zone ranges between 7.5 and 8.5 points. The growing period is as long as 90-120 days. Though, some ecological conditions of this zone are not very favourable for commercial cultivation of this plant. However, well developed irrigation facilities may support its profitable cultivation compared to conventional cropping (Sachdev *et al.,* 1995).

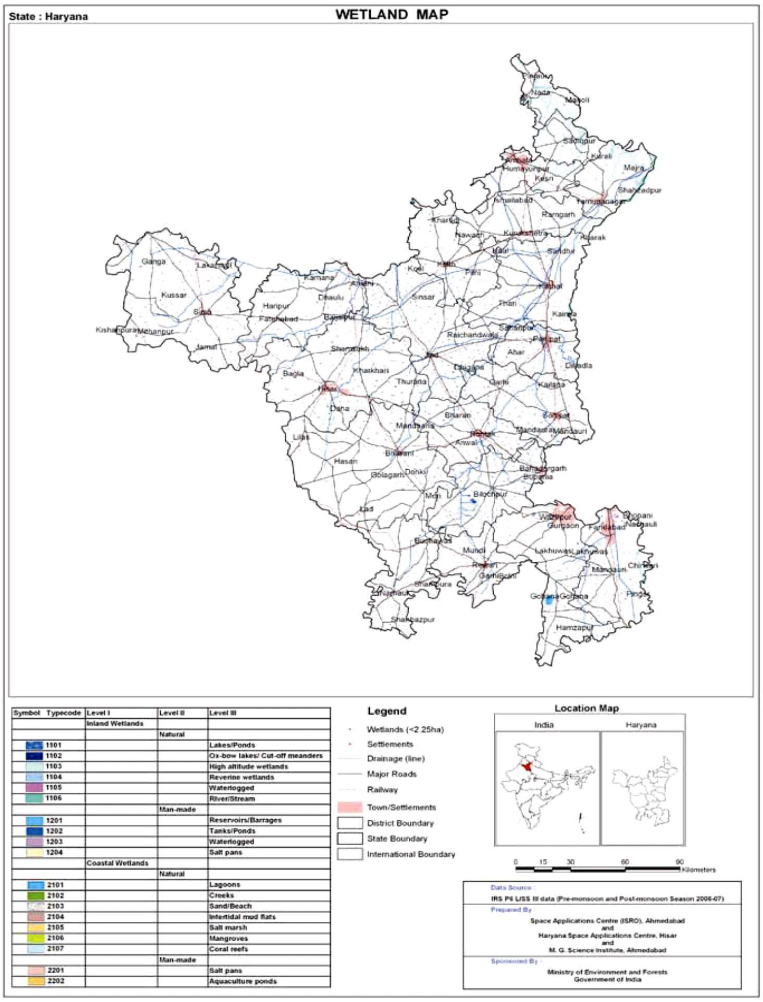
Zone 4 (Not suitable) :

Total area covered by this zone is 23,928.44 km² which is more than a half (54.12 %) of total area of the state. This zone is characterized by less than 500 mm of average annual rainfall. Soils are generally sandy, which do not retain water and their pH value is recorded to be more than 8.0 points. Therefore, this zone is least suitable for the commercial cultivation of this herb. Considering all these facts about this zone, it may be concluded that it is unfit for the cultivation of *brahmi*. Though, wetlands and waterlogged areas may be considered for its cultivation in this zone (Zaidi, 2011: 309-314).

Special areas of *brahmi* cultivation in Haryana :

Brahmi plant is known to grow under varying soil and climatic conditions. It is a common perennial creeper found in damp or marshy areas near streams or on the banks of ponds and lakes throughout India. It grows exceptionally well in poorly drained soils and waterlogged areas under sub-tropical conditions. The plants grow faster in the conditions of high temperatures (33-40°C) and high humidity (65-80 %). Therefore, special areas where this herb may be raised also include wetlands of Haryana which are spread all over the state. River banks and areas surrounding other wetlands may be utilised to raise this herb in the state. According to the estimates of the Ministry of Environment and Forests, Government of India, total area under wetlands in Haryana is 424.78 km2 which constitutes 0.86 per cent of total area of the state. District-wise distribution of wetlands shows that three districts could be called as wetland rich. Panchkula has highest concentration accounting for 3.53 per cent of its geographic area under wetlands. The other two districts are Yamunanagar and Karnal which have 2.79 and 1.65 per cent of their area under wetlands, respectively. Five districts of the state *i.e.* Mahendragarh, Rewari, Bhiwani, Sirsa, and Hisar have least share of wetland area in comparison to their total area (SAC ISRO *et al.*, 2010, Zaidi, 2011: 309-314).

Fig. 5 shows the spatial distribution of wetlands in Haryana. In the case of Haryana, wetlands include lakes, ponds, oxbow lakes/cut off meanders, high altitude wetlands, riverine wetlands, waterlogged areas and river/streams. These areas provide natural niche for *brahmi* cultivation.



Source : Space Applications Centre (ISRO) *et al*. (2010)

Fig. 5 : Wetlands representing special areas of *brahmi* cultivation of Haryana

Conclusion :

Brahmi is a water loving plant and semi arid and arid conditions covering most part of the state do not support its commercial cultivation. Therefore, only a small area in the extreme northeast consisting only five per cent area of the state has been identified as most suitable for the cultivation of this plant. Areas which may be termed as suitable for raising this plant constitute around 10 per cent area of the state. In this zone this plant can be cultivated with timely irrigation given to the crop at different stages of its growth. Western part of the state constituting more than 54 per cent area of the state is not suitable for the cultivation of this plant. But, there are special areas which are scattered throughout the state in different agroecological condition. These are wetland and damp areas and provide perfect ecology for the growth of this plant in the state. Thus, adoption of agroecological approach/method has made is easier to locate suitable areas for the cultivation of this plant. Agroecological zoning method opens enormous opportunities for the adoption and cultivation of new crops and rationalization of existing cropping pattern of an area by making it more suitable and sustainable. Actual cultivation of this plant in the different parts of the state will further reveal its suitability and present work is just an exploratory research.

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