A Study to identify the suitable locations for the adaptation of Underutilised Tropical Fruit Tree Species using G.I.S.

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January 2004

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Introduction

1.1 General

Some progress continues to be made in increasing food production in the developing world, however the issues of food and nutrition insecurity continue. An imbalance in world crop production has continued throughout the last two decades with fuel and food shortages in Africa, Asia, Central and South America. Diets lacking in vitamins and minerals has lead to some of the worlds most widespread and debilitating nutritional disorders. These include birth defects, mental and physical retardation, weakened immune system, blindness and even death.

The cause of this insecurity is due to a number of contributing factors; the uneven distribution of the wealth and high quality land, the contradiction between statutory and community tenure systems, civil wars and poor government policies all lead to a feeling of land insecurity and therefore lack of long term investment.

A large amount of farmland has become poorly managed, leaving crops unharvested and increasing land degradation due to a decrease in working rural population. This is due to the effects of aids in Africa (FAO 1995) and the increasing migration of men to urban areas to supplement household income, thus increasing the pressure on the already overworked female population.

The increase in global population has meant there is a greater demand on natural resources causing increased exploitation of forest resources and deforestation and increased demand on the land has meant a reduction in fallow time.

These factors have meant that a larger number of people now inhabit 'marginal' less favourable land. These people's livelihoods are based on small holdings of land with erratic rainfall and poor soil fertility, few crop species and yields that are highly dependant on climate and few management inputs. A large proportion of the developing world's food production is carried out by the smallholder farmers, this means the population's food and nutrition security is highly vulnerable to fluctuations in market price and climate (FAO 1997).

Merely increasing the yield per hectare with indiscriminate use of chemical fertilizers, pesticides or increased irrigation, and intensive farming methods will not alone improve food security and nutritional status. The possibilities of extending the area used for agriculture are limited and the yield capacity of some major staple crops is reaching a plateau. The ecological and economic consequences of increased use of agrochemicals and over irrigation are continuing to pose threats to the sustainability of agriculture (Menini 1999). The effects of climate change and pests and disease on mono-culture cropping systems has meant that farmers are unable to rely on small number of crop species they grow to provide sufficient nutrition or income to meet their needs.

Attention has now been focused on the need to develop enterprises to augment the crops currently grown. Emphasis is being placed on increasing food production and food security through diversification of the agricultural crop base. The number of plant species currently being exploited by man is few, and represents only a minute fraction of the botanical diversity on the planet (Smith 1995). Although 80,000 of the 350,000 species of plants have been found to be edible, today only 150 plant species are cultivated. Of these, only 30 species make up the list of so-called major crops, which are producing 95% of the world's calories and proteins (Menini 1999). The sustainable exploitation of the genetic diversity can be achieved through the introduction or increased production of "new", "unexploited" or "underutilised" crops (Menini 1999; Sanchez *et al* 1997) The outcome of this is increased crop diversity and improved food security.

1.2 Under-utilised crops

The International Centre for Underutilised Crops (ICUC) defines underutilised crops as wild species which make a contribution to food and nutritional security or partially domesticated species which are grown in traditional agricultural systems and cultivated on a small scale and for which there is potential for more extensive productive cultivation (Haq 2002).

Many of the underutilised species have huge potential and are currently widely used by indigenous people in traditional farming systems. They contribute to food security through agricultural diversification, reducing the risk caused by variations in climate and market prices. They provide income generation particularly in the increasing numbers of marginal and wasteland areas where cultivation of major crops is poor. The vast number of underutilised species provides an enormous resource which can help meet the increasing demand for food and nutrition, energy, medicines and industrial needs (Haq 2002).

They are often collected from the wild or grown as semi domesticated land races alongside staple crops. These agricultural systems include diverse cropping practices suitable to ecological, social and cultural conditions. They are tolerant of biotic and abiotic stresses and adapted to harsh environments (Haq 1995). They are often cultivated by small-scale farmers with little or no access to irrigation, fertilisers or other inputs, with little guidance on improved propagation methods or access to high quality planting materials (Azam–Ali *et al* 2001).

1.3 Underutilised tropical fruit tree species

As per Sanchez *et al* (1997) the largest opportunity for diversification comes from small holders planting trees alongside basic crops. Tropical fruit trees are important multipurpose species for smallholders (Haq 1999). Traditionally people throughout the tropics have depended on indigenous trees for fruits and everyday household products including fiber, timber and medicines.

Underutilised tropical fruit tree (UTFT) species fill specific niches on farms making the system ecologically stable and more rewarding economically, providing resilience against weather or price fluctuations. Being tree species they provide many environmental qualities; soil erosion is minimised, nutrient cycling is maximised and biodiversity is enhanced. This provides a productive and sustainable production system. UTFT species are particularly suitable for areas of marginal or waste land where cultivation of other tree species would be difficult, due to poor soil quality and lack of water (Hegde 2002).

These species have the potential for providing fruit throughout the year (Mateke *et al*) with different varieties or species ripening at different times including strategic periods when conventional staple crops and vegetables are scarce (Okafor and Lamb 1992; Sanchez 1997). UTFT's provide essential vitamins and minerals often deficient in diets, especially in urban areas, reducing the number of disorders caused by vitamins and mineral deficiencies (Verheij and Coronel 1991). The result of planting UTFT's is that farm income is increased, income source is diversified and food and nutritional security improved (Sanchez, 1997).

Underutilised tropical fruit tree (UTFT) species can produce quality fruit, often with high value and demand, many of which are more highly nutritious than many of the species widely cultivated, researched and marketed at present such as mango and guava. Results from ethno-botanical studies conducted in Malawi, Tanzania and eastern Zambia identified local level markets demonstrated the importance and popularity of indigenous fruits (Kwesiga and Mwanza 1997). They can be easily grown with little management and are often found along roadsides, in home gardens and in agroforestry schemes along side staple crops or livestock. A number of UTFT species have also shown some potential as high value commercial crops suitable for export; therefore increasing numbers of commercial orchards are now being established growing improved varieties.

The major constraints for the development of these species are low yield due to poor planting materials, non availability of recommended propagation material and in most of the locations in which they are grown there is little infrastructure for transport, processing or marketing (Haq 1997). However, with the new emphasis on improved food security through the diversification of the crop base, increased resources are now being invested into underutilised crops. This encompasses increasing awareness of the potential of these species and research into the improvement, production, processing and marketing of the underutilised crops.

Germplasm studies in which the collection, characterisation and evaluation of plant materials has lead to the production of gene banks and the selection and release of elite varieties. It provides farmers the access to planting material of high quality adapted to their region and allows for the conservation of genetic material, which may be lost due to the increasing deforestation, changes in traditional farming systems and changing diets.

Research into processing has lead to the development of both low and high technology procedures which can be used from the household to commercial level adding value to the crop and providing products with longer shelf lives. Market surveys have identified new markets and improved market chains increase the amount of income received by the producer.

Training programs run by extension organisations has brought about increased awareness of the benefits the species can provide and knowledge of improved propagation and management techniques.

The growth in demand for UTFT products due to increased marketing and processing, the increasing availability of high quality planting materials and the increased awareness of knowledge of the benefits these species provide has meant that and farmers are now seeing the potential of these crops when grown in conjunction with the major crops. Increasing numbers farmers now wish to increase the production of these crops in order to increase household income and/or nutritional benefit through home consumption.

1.4 Scope of Study

Organisations such as the FAO have developed models to match a land unit, based on its physical, social and economic information, with a crop or production system that is physiologically, socially and economically suitable.

Due to the increased interest in the potential of UTFT crops, it has become important to identify locations which are most suitable for their production. A model identifying such locations will provide farmers and extension workers with a useful tool to aid selecting which UTFT species will best suit their agro ecological, economic and social environment.

The aim of this investigation is to;

Develop a model which will identify suitable locations for the adaptation and production of a number of underutilised fruit tree species.

This model will;

Identifying locations with environmental conditions which match the biophysical/ecological requirements of the species

Identify locations with socioeconomic characteristics in which production of the species will provide social and economical value.

It is hoped that the model will be a useful tool for farmers and extension workers to suggest potential UTFT species that can be successfully grown and provide social and economic benefits to the farmers, thus further promoting the production of the UTFT species.

The model developed from this investigation will be transferable to many species, particularly those in which there is limited detailed information on their physical requirements and will be a useful tool for land resource management.

2

Literature review

This literature review provides information on the three UTFT species that the model will be developed for; tamarind (*Tamarindus indica*), ber (*Ziziphus mauritiana*) and jackfruit (*Artocarpus hetrophyllus*). It goes on to describe land evaluation and various modeling techniques used to match plants species to suitable localities. Particular attention is paid to methods used to identify plant-environment relationships for lesser known species. Previous studies which consider social and economic evaluations, as well as methods of model validation are noted and referenced.

2.1 Tamarind

Tamarind (*Tamarindus indica* L.) is a member of the dicotyledonous family Fabaceae (Gunasena and Hughes 2000). Tamarind is a slow growing, long-lived, leguminous, and evergreen or semi evergreen tree, which can grow up to 30m under favourable conditions (Morton, 1987; Gunasena and Hughes 2000).

The origin of tamarind is unknown, however there is evidence of it originating in Madagascar or Central Africa, it has been naturalised in Asia for a long time where it shows large amounts of variation. At present Tamarind is cultivated in 54 countries throughout the tropic and subtropics, 18 in its native range and 36 other countries where it has become naturalised. The major areas of production are in the Asian and American continents.

In most countries tamarind is a subsistence based tree crop mostly meeting local demands. Consequently although it is grown in many countries, production and export data are not readily available. In India, Thailand, Mexico and Brazil the crop is grown to some extent in orchards, in these countries and elsewhere production is found along road sides, in field borders and in home gardens.

Two major types of tamarind are recognised based on the sweetness of the fruit pulp. These are ‘sweet fruit’ and ‘sour flavoured ‘types, often a branch producing sweet fruit can be found on a predominantly sour tree. Variation has also been reported for tolerance to climatic and edaphic factors. Phenological diversity also exists in tamarind and tree to tree variations are common in flowering and maturing fruits, which may reflect either genetic variation or genotype by environmental interactions or both (Gunasena and Hughes 2000).

Tamarind is adapted to a wide range of ecological conditions reflecting its wide geographical distribution in the sub and semi arid tropics. It deep tap root makes it highly drought tolerant, it is very resistant to strong winds and can tolerate violent typhoons and cyclones and can grow in a range of soils (Sozolonki 1985 in Gunasena and Hughes, 2000; Salim *et al* 2001). It occurs in low-altitude woodland, savannah and bush and is often associated with termite mounds (Gunasena, and Hughes 2000; Salim *et al* 2001). It prefers semi-arid areas and wooded grassland, and can also be found growing along stream and riverbanks. It does not penetrate into the rainforest (Salim *et al* 2001). It withstands salt spray and can be planted fairly close to the seashore (Morton 1987).

Tamarinds main produce is fruit, which can be eaten raw or use to produce jams and jellies, however it is a multipurpose species, the fruit, leaves and bark have a range of uses. It also has been used in agroforestry schemes and field borders as well as acting as a wind break for other crops.

Most countries do not consider tamarind as a priority species for conservation. This may be due to its present modest utility value and its wide use in subsistence economics. Tamarind is not considered to be an endangered or vulnerable species. However several countries in Africa have prioritised it for conservation. On market surveys of non wood forest products carried out in Sudan by the FNC/FAO (1995) revelled that tamarind products used for home consumption ranked number one among species studied. In Burkina Faso, Cameroon, Chad, Cote d'Ivorie, Gambia, Guinea, Kenya, Mauritania, Nigeria and Senegal have prioritised it for conservation based on utilisation and value. In India despite heavy bearing and higher income, tamarind is not considered a commercial crop because of long gestation and poor availability of superior planting materials (Hedge 2002) Surveys in India have shown that although tamarind does not contribute substantially to the economy, it is of major importance to local population in rural areas and worthy of conservation (Gunasena and Hughes 2000).

Tamarind is highly suitable for growing in regions with adverse climate conditions. It provides an asset to the smallholder for the development of sustainable agroforestry systems to avoid risks and improve incomes; it could also provide benefit when grown on field boundaries in the development of agroforestry system in favourable areas. There is also potential for development of more organised commercial plantation provided improved germsplasm is made available and production and distribution pathways are developed. Gunasena and Hughes (2000) believed that Governments and policy makers should be encouraged to promote tamarind production in arid and semi arid areas for its economic and nutritional benefits.

2.2 Ber

Ber or Indian jujube (*Ziziphus mauritiana* Lam.) belongs to the family Rhamnaceae and Order Rhamnales. Ber is a spiny, evergreen shrub or small tree up to 15 m high, with trunk 40 cm or more in diameter; spreading crown; stipular spines and many drooping branches. Where climatic conditions are severe, it is commonly a compact shrub only 3-4 m tall (Pareek 2001).

Ber probably originates in the Middle East or Indian subcontinent (Verheij and Coronel 1991) and is said to be indigenous to North Africa, Afghanistan, North India, Southern China, Malaysia and naturalised in Tropical Africa, Iran, Syria, Sri Lanka, Burma, Barbados, Jamaica, Guadeloupe, Martinique and parts of the Mediterranean.

It is cultivated on a small scale throughout the tropics and subtropics, and is commercially important in India and China. Ber grows in both wild groves and regular plantation producing high quality fruit all over India. The estimated area in India under regular plantation of improved varieties in about 70,000 ha, the major production area is in the semi –arid and arid areas. It is widely distributed over the whole of the Sahelian zone and all over semi arid Africa (Vogt Kees 1995).

In countries such as Botswana, Burkina Faso, Ethiopia, Libya, Malawi, Mali, Mozambique, Niger, Nigeria, Senegal and Tanzania and Zimbabwe, fruits are harvested from natural seedling groves. Some recently introduced improved Indian varieties have shown tremendous potential for extensive cultivation (Pareek 2001) although regular plantations/orchards of identified varieties are rare.

Plantations have been recently been established in Israel and also in some Middle Eastern countries. In Australia ber occurs as relatively numerous populations in Queensland, the Northern Territories and Western Australia. The species was often associated with old mining villages during the early days of the gold rush. Later abandoned the trees are now considered a woody weed, forming an almost impenetrable ticket, preventing grazing by cattle and also shading out pasture (Grice 1998; Grice 1997)

Several Horticultural varieties of Ber are in cultivation in India. These varieties have developed as a result of selection in different eco-regions from progenies emanating from cross pollination between different varieties/types and have allowed the build up of a rich gene pool. Variation has been described in vegetative growth, flowering, fruiting and fruit characteristic. Characterisation of cultivars at different locations identified distinctive traits relating to resistance to diseases and pests, adaptation to various eco-regions, and productivity and quality of fruits. The fruit maturity period varies in different ber cultivars and varies according to location depending on the agroclimatic conditions, phenotypic variation occurs in fruit maturity with early mid or late season varieties (Pareek 2001).

Ber is found on open, poor, dry land, along rivers and wadis, in sandy depressions or on rocky ground; even on sandy mounds and termite mounds. In drier areas it performs best in ravine sites. It is a hardy tree which copes with extreme temperatures and thrives under dry conditions. Fairly light soil are preferred, but the tree can grow on marginal land, alkaline, saline of slight acid, light or heavy, drought susceptible or occasionally waterlogged soils.

Ber is a multipurpose species although fruit is it main produce, both fresh and dehydrated, its powder is used to make jam and in baking. On an industrial scale ber fruit is used to make preserves and candy. The leaves is a source of fodder, especially useful in arid regions as it is very stress tolerant and regenerates quickly. It also be used for Lac rearing, in sericulture, as fencing and its deep rooting system and extreme degrees of stress tolerance to drought, salinity and waterlogged soil means it is ideal for use in the improvement of degraded land, many parts of the ber tree have medicinal uses (Pareek 2001).

Ber provides nutritious fruit at low cost, grafted trees can provide a harvestable yield in the second year after planting, in arid regions in northwest India ber was found to have a higher annuity value per hectare than four other tree species over a felling cycle of 15 to 25 years. In certain area's cultivation has been found to be more profitable than annual crops especially in water scarce regions providing a regular yearly income giving a cost: benefit ratio of 3:1 after only 6 years (Pareek 2001). Ber also provides employment through it production and sale, at least 50% of which is carried out by women (Pareek 2001).

Ber is adapted to ecologically poor, drought prone areas, which encounter recurrent crop failures and thereby economic crisis. Ber trees yield even in years of severe drought when most other crops fail, producing nutritious fruits, and rich in vitamins and minerals, providing considerable subsistence and economic insurance for the grower. Its cultivation is highly cost effective owing to very low input requirements. Ber can have a sustained environmental and socioeconomic impact on degraded areas (Pareek 2001).

2.3 Jackfruit

Jackfruit, *Artocarpus heterophyllus* Lam. belongs to the family Moraceae. It is a medium sized, evergreen, monoecious tree up to 20 – 30m tall and 80 – 200cm in diameter, all living parts exude viscid white latex when injured. The bark is rough to some what scaly, dark grey to greyish brown (Verheij and Coronel 1991). Its canopy is dense, dome shaped or rarely pyramidal.

The jackfruit produces a multiple fruit consisting of several achenes (syncarp), each of which is indehiscent and 1-seeded, cauliflorus, 20-100 x 15-50 cm, the entire fruit weighing 4.5-50 kg; oval, oblong or ellipsoid, pale or dark green when young, greenish-yellow, yellow or brownish when mature; 2-10 cm long, 1-3.5 cm thick, covered by a rubbery rind and hard spines. Inside are the fruitlets, which are the true fruits, 4-11 x 2-4 cm, 6-53g, composed of a fleshy aril and the seed, fruits can contain more than 500 seeds (Salim *et al* 2002).

The jackfruit is probably indigenous to and in the past grew wild in the rainforest of the Western Ghats India (Verheij and Coronel 1991). The species then spread to neighbouring Sri Lanka, southern China, Southeast Asia, and further to tropical Africa, including Kenya, Uganda, Tanzania, Mauritius and Madagascar. It was probably introduced in the Philippines in the 12th century, and domestication of the crop started thereafter. It is commonly planted on smallholder Indian cane farms, in home gardens in Fiji, and occasionally in rural gardens and home gardens in other areas of the Pacific (Salim *et al* 2002).

Jackfruit is cultivated on a large scale in (as per 1987 records) Thailand (40700 ha), Philippines (13000 ha) and Malaysia (1500 ha). In Southeast Asia jackfruit is planted mainly in home gardens and mixed orchards. In the 1980,s several large commercial orchards were planted as an inter crop for durian. In Bangladesh, the tree is mostly grown on homestead farms and in small orchards (Azad and Haq 1999).
Although the large perishable fruit does not lend itself to export trade, canned products are exported to Australia, Europe etc. by canneries in Peninsular Malaysia (Verheij and Coronel 1991).

Jackfruit grows in tropical, near tropical and subtropical regions. The species extends into much drier and cooler climates than do other *Artocarpus* species, it bears fruit at latitudes up to 30 degrees north and south, with good crops at 25 degrees north and south. The tree will not tolerate drought or flooding (Verheij and Coronel 1991; Salim *et al* 2002) and has poor cold but moderate wind and salinity tolerance. For optimum production it requires a warm, humid climate and evenly distributed rainfall. It thrives in deep, alluvial, sandy-loam or clay loam soils of medium fertility, good drainage and a pH of 5-7.5. It grows even in the poorest soils, including gravely or lateritic soils, shallow limestone, shallow light soils, and sandy or stony soils (Salim *et al* 2002).

Jackfruit is highly cross-pollinated and propagated mostly by seed. As a result it exhibits a wide variation in size, shape fruit bearing and sensory quality of fruit (Azad and Haq 1999). No hybridisation of jackfruit has been undertaken and rootstock studies have yielded only preliminary results (Verheij and Coronel 1991). There are two main varieties, in one the fruits have small, fibrous, and mushy but has very sweet carpels with a texture somewhat akin to raw oysters. The other variety is crisp, though not quite as sweet. This form is more important commercially and is more palatable to western tastes (CRFG 2002).

Trees which have bee raised from seed start flowering at the age of 2 – 8 years, clonally propagated trees produce fruit within 2 – 4 years from planting under favourable conditions. In suitable environments jackfruit trees bear fruit throughout the year, but there is usually a major harvest period in April to August or September to December in Malaysia, January to May in Thailand and in the 'Summer' (March – June) in India (Verheij and Coronel 1991). In India a good yield is 150 large fruits per tree annually, though some probably of medium or small size (Morton 1987).

Jackfruit is a multipurpose species, it main product being fruit, the pulp of young fruit is cooked as a vegetable, pickled or canned in brine or curry. Pulp of ripe fruit is eaten fresh or made into various local delicacies (e.g., 'dodol' and 'kolak' in Java), chutney, jam, jelly and paste, or preserved as candy by drying or mixing with sugar, honey or syrup (Salim *et al* 2002). Leaves are cropped in India for fodder, and overripe, immature or fallen fruits are fed to hogs and cattle. Elephants eat the bark, leaves and fruits. The inner part of the bark or bast is occasionally made into cordage or cloth. The wood is also used as timber for furniture and construction and resin is used in varnishes. Leaves, roots and seeds are known to have medicinal purposes.

Jackfruit can be planted to control floods and soil erosion in farms.
Trees planted at a close spacing act as a windbreak and are sometimes used as shade for coffee. In Malaysia, trees have been used as an intercrop in durian orchards, and in India the trees are intercropped with mango and citrus, planted in coconut groves or used as shade trees in coffee plantations. Young jackfruit orchards may be intercropped with annual cash crops such as banana, sweet corn and groundnut (Salim *et al* 2002).

Jackfruit is one of the most popular species in Bangladesh, ranking third (after mango and banana) in total area of production. The production has been expanding because of popularity of the crop and the increased local, regional and international market. It is now designated national fruit of Bangladesh (Azad and Haq 1999). In many regions Jackfruit assumes an important role of a staple in periods of food scarcity (Azad and Haq 1999; Verheij and Coronel 1991).

2.4 Matching Plants and Land

By matching plants, crops or agricultural type and land it is possible to determine whether a crop will grow in a particular environment and how that crop will perform. When considering which species will be most suitable for a particular agro ecosystem in order to achieve a high yield and meet the cultural and social needs of the population, a good knowledge of the physical, biological and socio-economic parameters is required (Miézan 1998)

Physical parameters include all factors relating to production, both natural resources such as climatic (e.g. temperature, rainfall, photoperiod) soil characteristics (e.g. soil type, soil pH, salinity content, iron and Aluminium ions content, soil fertility, water dynamics) and topographic characteristics (slope, aspect), but also managements options (e.g. amount of fertiliser). When species are introduced to a site, many lack the appropriate physiological traits to adapt too or survive in the physical environment or produce a feasible yield. In many cases the species may survive but condition may limit growth or reproduction.

Biological parameters include diseases (e.g. fungi, viruses, and bacteria), insect pests, nematodes, weeds and other plant parasites. If a species is introduced to an area, which is inhabited by pests or disease it may grow and reproduce but the harvest may be destroyed or blighted.

Socio-economic parameters include government policies for agricultural food production (e.g. food security versus self-sufficiency, market-oriented versus self-consumption objectives), farming systems, cultural practices (including soil and pest management), food processing, consumers' preferences, market opportunities(Miézan 1998). Limitation is socio economic factors may be brought about by lack of infrastructure, transport, lack of work force, the crop may not fit with the present farming systems or they may be a more beneficial alternative crop, even lack of popularity due to cultural reasons or taste. If the plant is not popular with the local people they will not be willing to invest their time and resources in its production (Miézan 1998).

Cases of plant species being selected in locations where they are poorly adapted for large scale are apparent. In southern Spain the drought susceptible *Eucalyptus globulus* has been widely planted in dry areas where the stressed plants are attacked by the longicorn beetle (*Phoracantha semipunctata*), causing widespread growth retardation and even death (Boland 1997).

From the beginnings of agriculture farmers have been deciding the best use for the land that they possess or as settlers, where there is to be found land suitable for the crops they wish to grow (Dent and Young 1981).

Traditional techniques for selecting particular species for a location included a number of different methods:

- Local appraisal of species near planting site; native and local exotics should be assessed for performance and potential

- Climatic matching; this technique involves comparing the climate of the planting area with other equivalent climatic areas around the world. Species are then selected from these areas with adjustments for soil types or special features with adjustments for soil types or special features, e.g. salt tolerance.

- Selection of provinces for planting; this is based on the concept that provenance has a genetic and evolutionary basis. It implies that genetic variation is associated closely with ecological conditions in which species evolved. Application of the concept involves recognition of intraspecific variation in particular characteristics and classification of forest reproductive material according to its geographical origin (Boland 1997).

2.5 Land Evaluation

The broad term which has been given to the process of assessment of land performance when used for specified purposes, in order to identify and compare promising kinds of land use is land evaluation. As per Van Diepen *et al* (1991) in Rossiter (1995), land evaluation may be defined as all methods to explain or predict the potential of land. The term land refers not just to the soil but to all factors of the physical environment that can affect suitability for use including climate, landforms, pest and disease.

Land Evaluation involves a comparison between the identified kind of land use and the properties or characteristics possessed by the different areas of land (Young 1984). Early land evaluation includes examples such as the Storie Index (1933) which rates land on a scale of 1 to 100. It explicitly attempts to relate this rating to the lands inherit productive capacity and to the difficulty of removing or working around physical limitations. The UDSA land capability classification (Klingebeil and Montgomery 1961) rates land from class I (best) to class VIII (worst) according to the intensity of land use it could support and the degree of management that would be necessary to support that intensity (Rossiter 1995).

The Food and Agriculture Organisation of the United Nations (FAO) in 1976 published ‘A Framework for land evaluation’ in an attempt to produce a standard internationally acceptable methodology. This framework set forth the concepts, principles and methods that have been developed by consultation among many specialists of many nationalities (FAO 1980). The basic framework (FAO 1976) is still used in many recent land evaluation publications. The Framework is not specific to any form of land use, drawing its examples form agriculture, forestry and livestock production (Young 1984). The FAO framework was further developed in (FAO 1983) Guidelines for land evaluation for rain fed agriculture, (FAO 1984a) for forestry, (FAO 1985) for irrigated agriculture and (FAO 1991) for extensive grazing. The aim of the FAO framework was to identify the optimal land use for a piece of land, as per (FAO 1976) the types of land use considered are limited to those, which appear to be relevant under general physical, economic and social conditions prevailing in an area.

Different studies and methodologies in land evaluation have had a different emphasis, a number aim to identify the most suitable environment for a particular species (Site selection) others in selecting the optimal land use for a piece of land. The process is essentially the same, matching the characteristics of land and with the requirements of the land use. The degree of association between the land use requirements and the land area’s characteristics are assessed, and a suitability classification is assigned based on the lands ability to pertain to the requirements of a certain land use.

2.5.1 Physical land evaluation

Physical land evaluation identifies suitable locations for a land use type or plant species based on the degree of association between the land use/plants physical requirements and the land unit's physical characteristics. In order for this to be carried out two factors must be identified:

- Plant description: details of the plants environmental range and the plant - environmental response or relationship
- Land description: The lands environmental characteristics

2.5.2 Plant Description

Plants performance will vary, as will environments factors (e.g. rainfall). There is good reason to believe both observed and theoretical, that the plants performance has at least some of its underlying cause in the environmental factors. The plant description describes the relationship between the plant and the environment. A number of methods have been developed to model this relationship.

2.5.2.1 Explanatory and dynamic models

An explanatory model attempts to explain how a system works, from some first principles. A model which simulates effects of the environment on selected plant processes, which relate to growth, for example crop growth based on photosynthetic reactions as influenced by temperature light and vapour pressure.

In dynamic models time is included as an explicit element of the model, otherwise the model is static. In dynamic models, the state of the system at one time, plus the driving forces, follow definite transformation relations to reach the next state, and so on till the end of the simulation.

Important factors in such models are:

- Model parameters; constant during the execution of the model, but may be variable between executions. Analogous to the parameter of a regression equation, these parameterize the equations of the model e.g. the number of heat units that must accumulated before a plant will flower, or the parameters in regression of assimilation on temperature
- Data; are the time series inputs of input variable, which cause state changes in the model. They drive the behaviour of the model in particular execution e.g. temperature over time or rainfall over time.

However these sophisticated growth models require detailed experimental work to derive the model parameters (Rossiter 1994). The majority of species for which such models have been developed include those that are the most important per capita basis, such as the major food crops (Hackett 1988).

2.5.2.2 Statistical modelling of plant-environment relationships

The basic idea of statistical modelling is to quantify observed relationships and use these to predict future situations based on statistical inferences. Statistical methods can be used to quantify the relationship between the plants and the environment. The most common form of statistical modelling in land evaluation is yield prediction, the same method can be used to model other factors such as growth. Variations in yield have a least some of its underlying cause in environmental factors. Statistical methods have been used to quantify these relationships to determine how much of the observed variability can be explained by the environmental factors and how much remains to 'chance' i.e. unexplained. This unexplained variability may be brought about by other factors such as genotype.

The dependent variable y (yield) is predicted by one or more independent variables (environmental factor i.e. rainfall). From observations of performance i.e. yield and the supposed causes, the environmental factor i.e. amount of annual rainfall. A casual relationship can then be inferred between these by statistical inference.

These observations can come from two types of datasets:

- controlled (usually from a field experiments): the experimenter controls the levels of the independent variable

- observed (usually from surveys): the levels of the independent variable are not controlled, only observed.

Simple linear and nonlinear regression analysis can be used when considering the relationship between a single independent predictor (environmental factor) and the dependent variable (yield), and so a regression equation is fit to the observed data. However it is rare that a single predictor variable by itself is very successful for yield prediction. The multivariate considers when yield is predicted by several factors. In this case multiple regression analysis is used to quantify the relationship. Other than in controlled conditions or a very special situation in which only one factor is limiting, several factors normally limit plant growth and yield.

Many attempts have been made to quantify this relationship, using multiple regression. At its worst this exercise results in a meaningless monster equation, at its best it integrates the most important single environmental factors and their interactions in a single predictive equations.

Often in this sort of analysis there is a large amount of choice when selecting the predictor variables, one solution is to use lots of different variables and see which the better predictors are. Rossiter (1994) recommend use of the stepwise multiple regression method in order to show the importance of each factor and find the best combination of variables. Another approach is to use PCA (Principle component analysis) on these variables identifying which factors explain the greatest proportion of the total variance; the least significant variables can be discarded as insignificant noise. Better still is to have some theoretical basis for you decision, so as to produce a meaningful equation not just a statistically significant relationship.

Statistical Modelling will not work unless there is sufficient data, so is not appropriate for new land uses or areas with insufficient samples. For land evaluations of established crops with sufficient historical or experimental data it can be quite useful and often the preferred method (Rossiter 1994).

2.5.2.3 Plant-environment relationship modelling using informal data

Little work has been carried out on matching underutilised crops and land, however the few examples that exist include Azam–Ali *et al.* (2001) for the Bambara nut (*Vigna subterranea*) an underutilised grain legume crop and Bydekerke *et al* (1998) for cherimoya (*Annona cherimola* Mill.) an underutilised fruit tree species.

One of the main reasons for this is the lack quantitative information available on UTFT species environmental requirements and their relationship with the environment. Due to being under researched in comparison to the more major crops, little if any experimental work has been carried out to identify these UTFT species environmental requirements or responses. Most information tends to be descriptive and highly qualitative. There are a substantial number of literature resources, which give growth requirements of tree species. However most of these refer to timber species (FAO 1974; Web *et al* 1980; national Academy of Sciences, 1980; Baumer 1983; Pandey 1983) and, or suffer from broad generalisation and in some cases uncritical; copying from one to another. As described by Young (1984) much data in is in the form of “prefers deep soils” or “moderately drought tolerant”.

Database resources which give environmental requirement information on tree species include Ecocrop 1 and 2 (FAO 1999) a crop environmental requirement database. INSPIRE an environmental requirement database for forest tree species (Web *et al* 1984), Multipurpose Tree Species Computerised database (von Carlwitz *et al* 1991) TROPIS**,** Tree Growth and Permanent Plot Information System (CIFOR 1997). The TROPIS index contains details about the objectives of experiments and plot systems, the Agroforestree database (Salim *et al* 2001), Forestry Compendium - a silvicultural reference (CAB International), MIRA (CATIE) and TREDAT a database of growth data accumulated from trials utilising Australian species by the ASTC (Australian Seed Centre)(CIRSO 1996). For many of theses databases information on UTFT species is very limited however some give ranges in the species in known to grow for a number of environmental factors, however there is a large amount of inconsistency in information given by the different databases, and there is little on plant-environment relationships or responses.

A number of method have been developed to give some indication of the plant requirements and responses to the environment of traditional or lesser known species, often for the use in suitability prediction models.

2.5.2.3.1 Expert knowledge and Notational Relationships

Expert knowledge from researchers, extension workers and local farmers has also been relatively widely used; Young (1980) produced a questionnaire to be used for the collection of information of individual crops and produced the paper 'Proposals for collecting information necessary for the crop requirements and limitations'.

Hackett (1988) asked experts to prepare tabular description of plant requirements for a number of lesser-known species for a land suitability project in Papua New Guinea. Hackett developed this work through the development of PLANTGRO (Hackett 1991a; 1991b; Iris Media 1994; Hackett and Vanclay 1998).

PLANTGRO uses simple notational relationships to express the plants response to environmental factors. This system can use informal data and expert knowledge to identify these responses which can be used which can then be used along with experimental data (when available) to develop simple relationships for predictive purposes. The relationships are expressed as spline curves with characteristic plateau shape being defined by only four parameters representing the X values of 4 inflections. These points represent the values in the range at which the environmental conditions are at their optimal and lethal extremes (See figure 1).

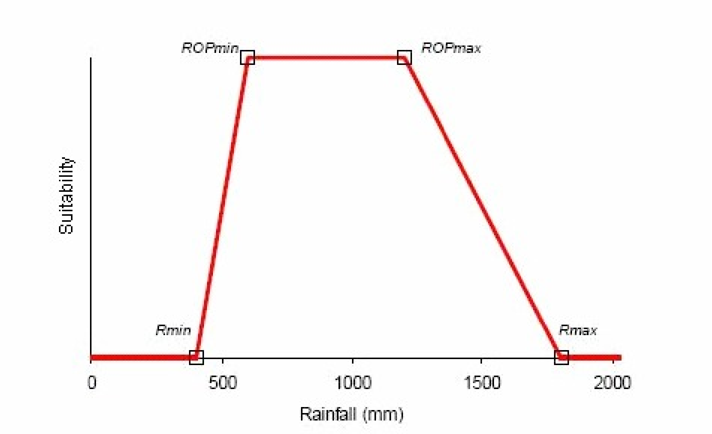


Figure 1 Notational relationship between rainfall and suitability

However due to problem large variations in the opinions of experts on crops responses believed to be due to the large amount of variation in the response to the environment having only undergone a small amount of human influence (Davidson 1996)

For this reason Hackett developed the system INFER (1996a), which estimates species environment relationships form observations on conditions tolerated by plant species. Entries in a table (ticks and blanks) suggest how a species experiences a particular soil or climate and can be concerted into functional relationship will simple rules (Hackett and Vanclay 1999). Hackett and Vanclay (1999) stated that although rarely will these preliminary relationships be adequate at first, they can be improved and retested until so, the initial step of turning raw data into a series of explicit and testable relationships has been achieved.

2.5.2.3.2 Site Distribution data and BIOCLIM

A number of programs have used site distribution data to identify species bioclimatic ranges. BIOCLIM uses site distribution location data of a species to generate climate profiles. The profile describes the statistical distribution for each of the bioclimatic parameters for that set of locations. The climatic estimate for each site is acquired based on their latitude, longitude location relating to values at the same location on climatic datasets. It computes the bioclimatic parameters for all distribution sites, summarises them parameter by parameter to describe the climate that the species is found in.

Predictions of suitability can then be made by comparing the bioclimatic parameter value at a particular location with the statistical distribution of that same parameter to see if it falls within one of the statistical spans, either percentile spans (eg. Between the 10^{th} and 90^{th} percentile) or on standard deviation multipliers (mean +/-1*SD), a suitability score is assigned to the location based on the narrowest percentile span class that contains the points parameters.

BIOCLIM uses 36 primary attribute datasets (12 monthly mean values for each of precipitation, maximum and minimum temperature). From these attributes parameter datasets are derived that are considered to have biological significance and that summarise annual and seasonal mean conditions, extreme values and intra-year seasonality. For example mean annual temperature and annual mean precipitation provide a gross approximation of total energy and water inputs at the site. Highest and lowest monthly mean values provide a measure of seasonal extremes and wettest and driest 3 months provides a measure of conditions prevailing during the potentially active and dormant seasons Nix (1986 in Busby 1991). BIOCLIM has been run with various numbers of climatic parameters,12 by Mackenzie and Nix (1984), 16 by Busby (1991) and 24 and 36 in to later unpublished versions (Booth 1996). Recent versions of BIOCLIM have included a calculation for moisture index values which uses precipitation and evaporation values in conjunction with soil type and maximum soil water availability values which is used to compute a further 7 parameters (Houlder *et al* 2000). A BIOCLIM model analysis was carried out for *Ecalyptbaus tetrodonta* by Stockwell *et al* (unpublished) included soil and topographical parameters such as soil reactivity and texture.

BIOCLIM (Booth 1996) has been applied to study the effects of climate change. Climatic mapping programs can be used to show how particular areas may change, becoming unsuitable or suitable for particular species under predicted climate change scenarios.

At the GIS unit at the Royal Botanical garden at Kew similar work has been carried out using site distribution records taken from herbaria information. These distribution points have been overlaid on to digital vegetation type, geology and altitude maps in a GIS. Based on their location statistical summaries and histograms are produced to indicate the species environmental preference. Further work will include the use of weather satellite imagery to provide a measure of seasonality and other climatic factors which are important in determining the distribution of plant species (DuPuy and Moat 1998).

One disadvantage of such methods is that some species perform well outside their current range, e.g. *E. robusta* grows well from tropical to near temperate parts of Brazil. Past events such as fire or climatic squeezes may have severely restricted the current range of the species, and thus the natural range may not indicate the potential range of the species (Boland 1997).

2.5.3 Land Description

The collection and mapping of data that refers to the physical, social and economic evaluation of land has been used for year in land use assessment. These are the products of surveys in which physical, social or economic data are recorded i.e. soil surveys and data from meteorological stations, geographical or anthology surveys. Land is classified by specific land characteristics such as soil type, annual temperature, population number etc.

This information is normally portrayed in the form of land classification maps in which areas of homogeneous land is defined as a land unit i.e. FAO/Unesco Soil map of the world (FAO 1978). Land classification maps, which identify agroecological zones, have been widely used in agricultural land resource management both for livestock (White *et al* 2001) and crop production. Agro-ecological zones are defined, as units of land which have similar combinations of climate and soil characteristics, and similar physical potentials for agricultural production (FAO 1996; Sivakumar and Valentin 1997; White *et al* 2001; Liu and Samal 2002).

Land classification data has been digitised and can be readily combined, queried and displayed with GIS. Digital data sets normally come in two formats vector and raster. These vary in detail/resolution, scale and the size of the area covered, from district, region to country. Examples include the CRU Global Climate Data set available through the International Panel for Climate Change Data Distribution centre (IPCC DDC) (New *et al* 2000), FAO (1999) Global Climate Maps, the International Water Management Institute (IWMI) World Water and Climate Atlas, Digital Soil Map of the World (FAO 1995c).

2.6 Socioeconomic evaluation

The FAO recognised that purely physical evaluation provides no objective method to compare different land uses as physical constraints have no inherent common scale of measure with respect to the monetary value of the land (Rossiter 1995).
From their first projects in land evaluation, FAO (1976) have been promoting two phase land evaluation in the form of both physical and economic evaluation either subsequent order or in parallel.

In qualitative studies, economic and social analysis is only in generalised terms. It may cover, for example, an inventory or analysis of government development objectives, available macro-economic tools and macro-economic data; general information on the present agricultural, including recent trends; an inventory of the technical and institutional infrastructure; available information on population and its present and probable future rates of change; and sociological information, such as land tenure systems, labour potential, educational levels, etc. In quantitative studies, economic analysis plays an important part, although the nature of the analysis varies according to the land utilisation type under consideration, and whether the study is at the semi-detailed or detailed level of intensity (FAO 1976).

The chief obstacle to economic evaluation is the difficulty in obtaining reliable data on the economics of production and how these are affected by land qualities (D.G. Rossiter 1995). Another factor which needs to be considered is that economic factor are stable for a short amount of time, market price, interest and exchange rates are often highly dynamic and project outputs have to be constantly updated and revised.

Kalogirou (2002) incorporated socio-economic evaluation into his land evaluation research. By taking into account social and economic characteristics, such as local labour force, product prices and market conditions the models became more realistic and useful in rural planning. The economic evaluation included income maximisation taking into account market restrictions; the expected yield is calculated based on the suitability classification of the land unit for a specific land use and the corresponding maximum yield. From a measurement of yield per hectare a monetary value per hectare was calculated based on information on market prices was acquired from FAO and World Bank data, the land use which produces the greatest income is deemed most suitable.

2.7 Validation

Due the nature of land evaluation, in which assumption of homogeneity and broad generalisation are often made on species requirements and land characteristics, combined with its predictive nature, it is import to carry out refinement and validation. Much of the validation work is carried out through field work or ground truthing. Bydekerke et al (1997) used field work to validate his evaluation method, he found that all sites were wild cherimoyas were found, were located within areas classified as suitable by the model, although growth conditions were marginal at 8 of 18 locations.

Hackett and Vanclay (1998) tested the PLANTGRO system at 9 sites in Australia for *P. radiate*. They found high correlation between predicted suitability indices and observed height growth. They concluded that PLANTGRO provides a framework to make predictions from a series of plant environment relationships and to investigate limiting factors. A Similar study was carried out by Fryer (1996) in Central America for *Eucalyptus camaldulenis*. Here predictions were found to correlate reasonably with actual field growth. He concluded that such predictive models for species performance on such sites could have a place in the methodologies for species introduction and testing.

3 Materials and Methods

3.1 Development of plant-environment relationship models

In order to develop a model to identify how the plant would respond to different environmental conditions, it is important to identify the plant-environment response for each environmental factor considered. This considers the maximum and minimum value tolerated by species for each environmental factor and the relationship between the plants performance (i.e. growth and yield) and the environmental factor. An extensive information search was carried out into the species physiological ecology of tamarind (*Tamarindus indica*), ber (*Ziziphus mauritiana*) and jackfruit (*Artocarpus hetrophyllus*) in which number of literature and database sources were searched. For each environmental characteristic the maximum and minimum values recorded throughout the literature were noted and used to derive a range. However due to lack of information on the plant response between each environmental factor and the species performance (growth and yield) specific relationships for each environmental factor could not be modelled individually. Therefore it was decided to assume a very basic ecological principle in order to derive the relationships between the environmental factors and performance. It was assumed that for most environmental factors the conditions become less suitable as you move away from the centre to the edge of the species niche or habitat range. Species have adapted to the condition found in the locations in which they inhabit, but as you move towards the edges of the range the species are less well adapted and performance is reduced.

Three basic plant responses were used

1. The relationship would be similar to that of a normal distribution curve, a symmetrical two tailed distribution where the suitability would decrease as you moved further from the central value of the range (mean, median, mode in the case of a normal or symmetrical curve all very similar values).

2. As the environmental factor value increases there would be a proportional linear increase in suitability within the derived range.

3. As the environmental factor increases there would be a proportional linear decrease in suitability with in the derived range

Response 1 will be used to describe the response for factors such as temperature initially contributing to increased metabolic rate therefore increasing the rate of photosynthesis, once it has reached it optimum as the temperature continues to increase beyond a certain point it become limiting. High temperatures begin to denature proteins and cause increased water loss, low temperature reducing the metabolic processes or causing frost damage.

Response 2 and 3 accounts for those environmental factors which become limiting as you move towards either the maximum or minimum of the range (i.e. No. of frost days), for these factors it was not possible to assume a symmetrical relationship based around the mean value.

Environmental Characteristic	Plant responce
Annual rainfall	1
Mean Annual Temperature	1
Mean maxiumum temperature (hottest month)	3
Mean minimum temperature (coldest month)	2
Number of frost days	3
Altitude	3
Soil pH	1
Soil Depth	1
Soil Drainage	1
Soil Texture	1

Table 1 list of environmental factors and relationship used to describe the plant response.

To develop an index to describe the relationships, it was decided that the derived range for each environmental factor range should be broken up into 4 suitability classes' representative of percentage of maximum performance (table 2). The classification system is based on that classes developed by the FAO for land evaluation projects (FAO 1976).

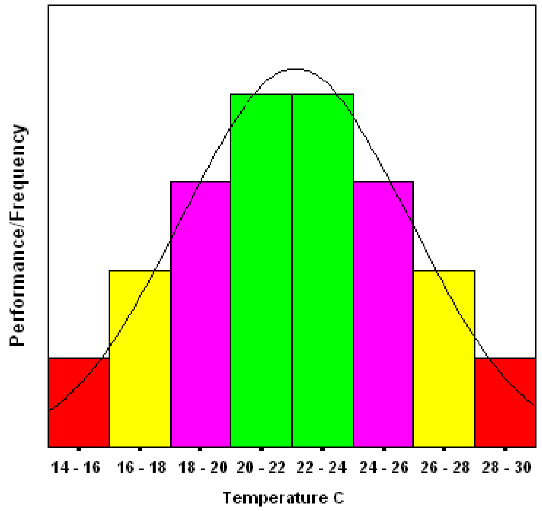
Suitability class	% Maximum performance
N1 (Not Suitable)	0
S4 (Marginally Suitable)	25
S3 (Moderately Suitable)	50
S2 (Suitable)	75
S1 (Highly Suitable)	100

Table 2 the suitability classes

In the case of response 1 those values outside the range are classified as N1 unsuitable and assigned a suitability score of zero. The range was split into 4 equal segments the most limiting 25% that furthest from the mean, that is the outer 12% on either side of the range was classified as S4 (Marginally Suitable), the suitability score increasing proportionally with each 25% portion of the range, so as the most suitable 25% that closest to the central value of the range would be classified as S1 (Highly suitable) and assigned a score of 4, this creates a suitability index as illustrated in table 3. An example is given for species X in table 4 and figures 2 and 3.

Percentage of Range		Suitability class	Suitability Score
Outside range		N1 (Not Suitable)	0
< 12.5	>87.5	S4 (Marginally Suitable)	1
12.5 - 25	75 - 87.5	S3 (Moderately Suitable)	2
25 - 37.5	62.5 - 75	S2 (Suitable)	3
37.5 - 50	50 - 62.5	S1 (Highly Suitable)	4

Table 3



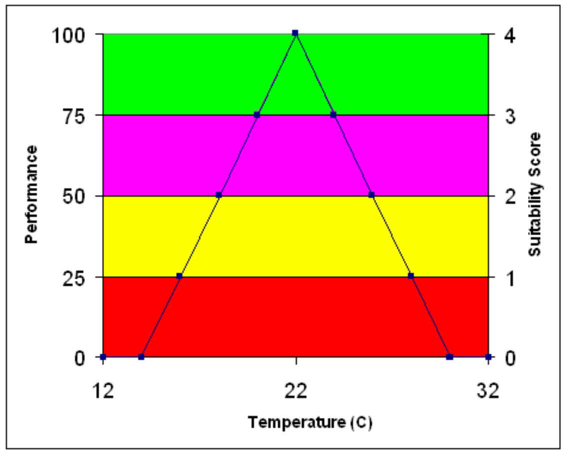


Figure. 2

Figure. 3

Mean annual Temperature Range (C)				14 - 30
Range (C)		Suitability Class	Score	
<14	>30	N1 (Not Suitable)	0	
14 - 15.9	28 - 30	S4 (Marginally Suitable)	1	
16 - 17.9	26 -27.9	S3 (Moderately Suitable)	2	
18 - 19.9	24 - 25.9	S2 (Suitable)	3	
20 - 23.9		S1 (Highly Suitable)	4	

Table 4

Table 2 and Figure 2 and 3 shows how the index was derived for mean annual temperature range of species X in which the mean annual temperature range had a minimum of 14 ºC and a maximum of 30 ºC.

In the case of the response 2 all values above the maximum of the range must be classed as N1 (Not suitable) and assigned a score of 0. Again the range is broken into 4 equal intervals and the same principle applied. The most limiting section classified as S4 (Marginally Suitable) in the case this will be the last quarter of the range (75 - 100%), the next section (50 – 100%) classed as S3 (Moderately Suitable) assigned a score of 2 etc as shown in table 5. The same principle is applied with response 3 in only the classifications are assigned in reverse as in table 6. An example is given for species X with ‘Number of frost days’ in table 7 and figure 4.

Percentage of Range Maximum	Suitability class	Suitability Score
Outside range	N1 (Not Suitable)	0
75 - 100	S4 (Marginally Suitable)	1
50 - 75	S3 (Moderately Suitable)	2
25 - 50	S2 (Suitable)	3
<25	S1 (Highly Suitable)	4

Table 5 Suitability index for response 2

Percentage of Range Maximum	Suitability class	Suitability Score
Outside range	N1 (Not Suitable)	0
<25	S4 (Marginally Suitable)	1
25 - 50	S3 (Moderately Suitable)	2
50 - 75	S2 (Suitable)	3
75 - 100	S1 (Highly Suitable)	4

Table 6 suitability index for response 3

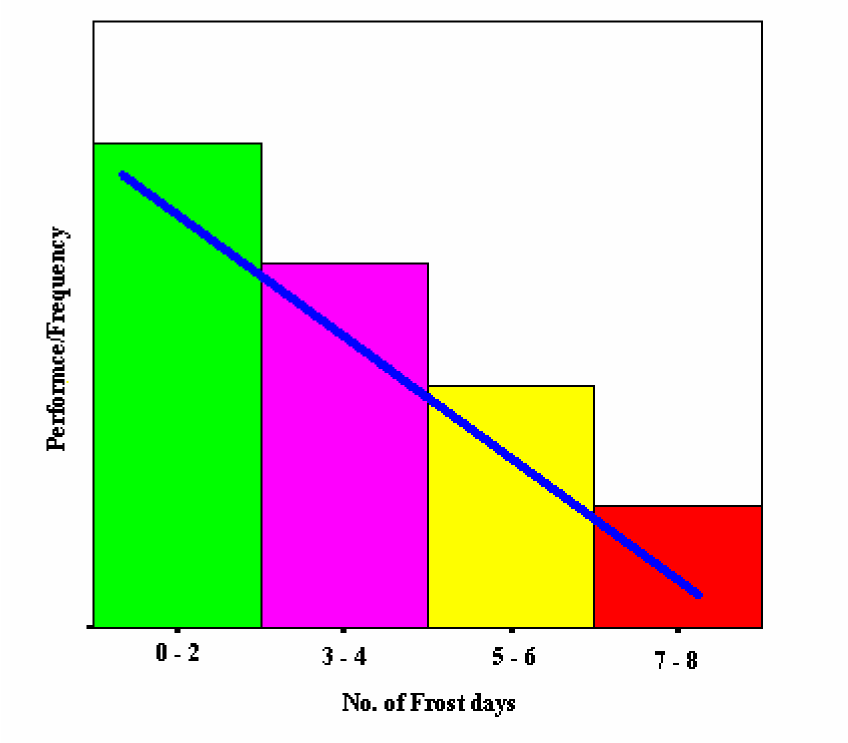


Figure 4

Number of Frost days		<=8
Percentage of Range Maximum	Suitability class	Suitability Score
>8	N1 (Not Suitable)	0
6 - 8	S4 (Marginally Suitable)	1
4 - 6	S3 (Moderately Suitable)	2
2 - 4	S2 (Suitable)	3
<2	S1 (Highly Suitable)	4

Table 7

Figure 4 and Table 6 give an example of how the index is derived for Number of frost day for species X

In the case of a number of environmental factors (particularly soil) were described using descriptive classes in the literature i.e. soil depth (shallow, medium, deep) and soil texture (loam, clay, sand). Although a plant response was assumed for these factors it was not possible to develop such relationships. For these environmental factors assigning the suitability classes and scores based on the plant response assumed and descriptions in the literature sources using a certain amount of subjectivity.

3.2 Production of Suitability Maps

Two environmental characteristic data sets were acquired, from the IPCC (International Panel for Climate Change) Data Distribution, University of East Anglia UK, 'A high resolution data set of surface climate over global land areas' (New *et al*. 2000) and from the software TERRSTAT (Nachtergaele *et al* 2002) part of the FAO Land and Water Digital Media Series.

The IPCC dataset had a resolution of 10* 10 minutes approx (18 by 18km at the equator). The TERRSATAT dataset has a resolution of 5 * 5 minutes (approx 9km by 9km at the equator).

The datasets were imported into the GIS (Geographical information system) ARC View and each data set was reclassified based on the corresponding suitability index.

However a number of problems were encountered with reclassifying the TERRSTAT data sets.

1. The data set values represented classes. The class intervals did not always fit with those class interval derived in the suitability and so a compromise had to be made to fit the reclassification with the class intervals available.

2. A number of the TERRSTAT environmental characteristics datasets, classification was based on both dominant and associated soils. Due to the simple method used to create the suitability classification index it was not possible to take into account of the effect on performance of associated soil. However due the classification system used by TERRSTAT the associated soil values could be ignored and classification based purely on dominant characteristics.

3. For a number of Environmental characteristic's TERRSTAT included datasets for both topsoil (0 – 30cm) and Subsoil (>30cm). Soil properties in both the top soil and subsoil are both important to tree performance, however there was however insufficient information available to derive different suitability ranges or relationships for each soil characteristic based on the differing effects of each soil layer. Therefore both were classified based on the same suitability index.

A further search revealed a number of other soil characteristic datasets;

- Global dataset of derived soil properties (ISRIC–WISE 2000) 0.5 Degree Grid
- Global gridded surfaces of selected soil characteristics (IGBP-DIS 2000) 0.5 Degree Grid.

However the above datasets were also found to have values representing class interval and were of lower resolution than the TERRSTAT dataset and so were not considered for use.

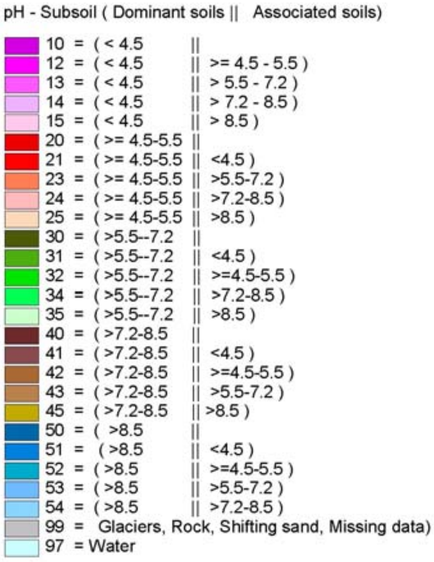


Figure 5 Legend from TERRSTAT dataset (pH-Subsoil) showing interval classes and dominant and associated soils class values.

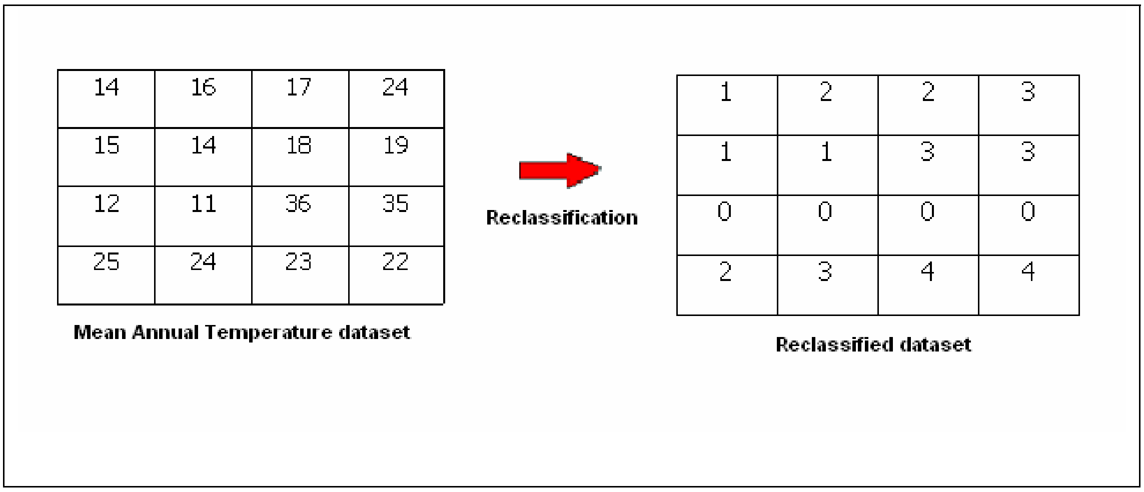


Figure 6 A example of the reclassification process, land units are reclassified based on mean annual temperature values to suitability score values.

The law of minimum approach was used in order to combine or overlay the reclassified datasets. This approach defines the overall suitability for each grid square/land unit by the score of the most limiting characteristics. This method was chosen above the additive and multiplicative methods as it avoids the effect of numerous favourable factors compensating for one vary unfavourable factor, which is hardly ever the case (Hackett 1988). Although the TERRSTAT and IPCC datasets were of different resolutions the output was set to produce the overall suitability map at that of the lowest resolution of input datasets (figure 7).

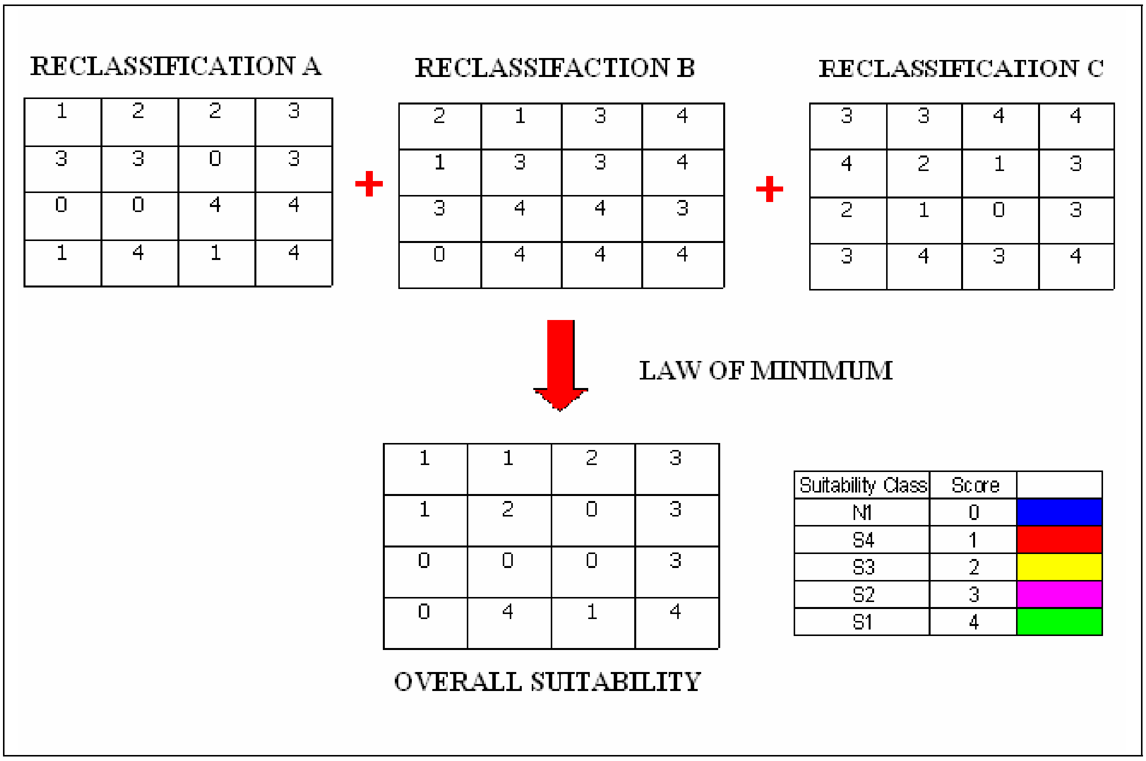


Figure 7 Example of combining or overlay of reclassified datasets, the overall suitability is given by the most limiting (lowest) value

3.3 Point Distribution Map

A point distribution map was produced on ARC View GIS, distribution data was collected from a number of different sources.

1. **Herbarium Passport data;** Location descriptions from herbarium records were recorded from Royal Botanical Gardens, Kew. Latitude, Longitude coordinates were identified for each location using a range of paper and digital gazetteers. In the case were more than one likely set of coordinates were identified for one location description all coordinate sets were recorded. All points were then plotted in ARC View, the 'GroProcessing wizard' 'Assign data by location' used to join the point distribution dataset to the DIVA – GIS 'gazetteer' dataset and the ESRI 'administrative units' dataset based on their spatial relationships. This helped in ensure the correct coordinates had been assigned to location description, the correct coordinates were identified when more than one likely option was available and the correct name for all administrative units had been assigned. In the case were coordinates could not be confidentially identified for a location description the location description was discarded.

2. **Germplasm Passport data;** the locations of mother tree which had been recorded during germplasm survey were gathered from grey literature such as thesis's collected from universities in India and the UTFANET project. Using digital gazetteers the coordinates for these locations were identified.

3. **Field location data;** The species distribution locations recorded using a GPS (Global positioning system) during a field survey in India (Section 3.4.3).

3.3.1 Creation of Environment Profile

The point distribution map dataset was overlaid onto the environmental datasets in ARC View using the 'Get Grid Value Extension 2' (Jeremery Davis 2000) the values from the underlying environmental dataset grids were written to the corresponding point in the point distribution dataset table, creating a dataset of the environmental conditions at each of the point distribution locations. Statistical distribution analysis was carried on this dataset for each environmental factor producing an environment profile identifying mean, minimum, maximum etc for each of the characteristic. This environment profile describes the statistical distribution for climatic and soil factors for the locations where the species is present and gives an indication of the species environmental preferences.

For those environmental factors on the TERRSTAT dataset, due to the data representing class data full statistical analysis was not possible, however it was possible to calculate the minimum, maximum and mode values and note the interval class of data they represent.

3.4 Validation

Validation was carried out on the tamarind suitability map to test the reliability of the model. Comparison was made between actual current distribution and the suitability map predicted distribution. Regression analysis was used to identify the strength of the relationship between grid cell/land unit suitability scores with height, girth and yield recorded at that location in the field.

3.4.1 Country Distribution list

The ESRI country administration data set was overlaid onto the tamarind suitability map in Arc View, the GIS queried to list the countries in which there was at least one grid cell which had been classified as suitable. A list of countries in which tamarind is known to be distributed was created using information from a literature search and from herbarium distribution records acquired from the Royal Botanic gardens Kew. The lists of actual and predicted distribution were compared.

3.4.2 Potential verses actual distribution

The point distribution maps was overlaid on to each of the reclassified environmental characteristic datasets and the overall suitability data map and the 'Get Grid Value Extension 2' ARC View extension (Jeremery Davis 2000) used to write the underlying suitability values to the corresponding points in point distribution dataset table. Frequency tables were produce to identify the number of tamarind distribution locations classified with each suitability class.

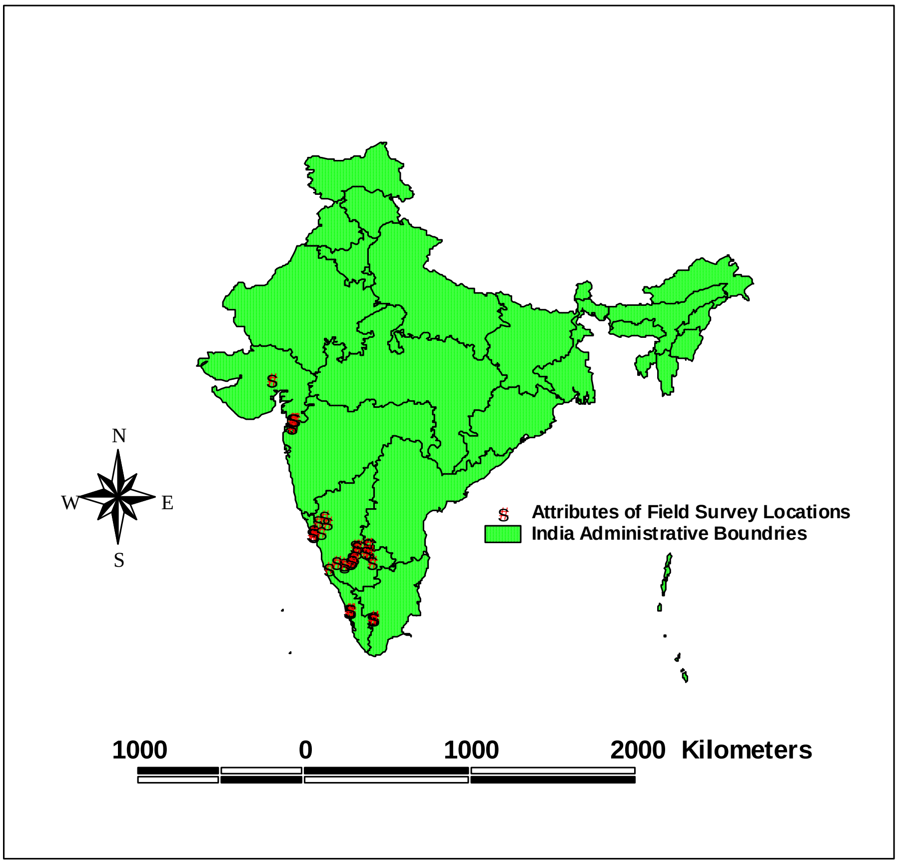
3.4.3 Comparison with environment profile

For those environmental factor in which had been used in the model, the minimum and maximum from the range derived from the literature was compared with the minimum and maximum from the climate profile. Histograms and frequency tables were analysed to investigate how the frequency distribution related to the relationship predicted by the model.

3.4.4 Field Survey

During July – September 2003 a field survey was conducted in India. Information on growth and yield was recorded in order to be used in validation of the model. A socioeconomic and agronomic survey was also conducted with heads of household to gain information on how such factors relate to the production of the species. 70 villages were visited across western India through four states, Gujarat, Karnataka, Kerela and Tamil Nadu.

Figure 8 Field Survey Locations



The selection criterion for survey locations was based on:

- the location being near by field base of the supporting organisation, so as local staff could be provided to act as guides and translators,

- logistical limitations

- In order to cover as much as much agro climatic variation as possible for each of the species

Selection of villages and farmers within each area was based on local staff knowledge or general inquiries into which farmers grew the tamarind, ber or jackfruit (See Appendix 3 for list of locations). At each location a physical survey was carried out in which growth characteristics of the tree were measured and the farmer questioned on yield and height. The socioeconomic and agronomic survey carried out through a questionnaire.

3.4.4.1 Physical survey

If numbers allowed between 5 and 10 trees were randomly selected at each farm/homestead and farmers/residents were asked to provide information phonological aspects, on the source and type of planting material, the age and yield of the tree. The height was recorded using an altimeter and girth using a tape measure. The trees were grouped by age and for each age group the height, girth, and yield were plotted against the suitability score assigned to the location in which they were survey. Linear regression was carried to find if there was a correlation between the tree growth parameters (height, girth and yield) and the suitability score assigned by the model.

3.4.4.2 Socioeconomic and agronomic survey

A survey was also conducted to acquire information on production system and management practices and a number of socioeconomic aspects involved with the production and use of the trees. At each homestead or farmstead visited the head of the household was asked questions on socioeconomic and agronomic factors relating to the production of the species (for questionnaire see Appendix 1).

3.5 Geographical Database

A relational database has been created in Microsoft access (2002), which to hold geographically related data on UTFT species. The database currently contains all distribution record used to produce the distribution map for tamarind. All other information is linked to this such as the accession characterisation details collected from germplasm studies and all information collect during the field visit, this includes data on phenology, growth characteristics, climate and soil conditions, economic factors (i.e. price per kg), production factors (productions system, irrigation method), social factors such as family size, type of land tenure.

4 **Results**

4.1 Suitability Classification

4.1.1 Suitability Index

Table 8 – 10 show the suitability index's used to produce the suitability maps for tamarind, ber and jackfruit, the environmental factors listed as those for which ranges could be derived from the literature and the interval classes shown for each suitability class (N1 – S4) those derived from the model. The pH interval classes shown here had to be modified in order to fit with the interval classes used by the TERRSTAT database.

Suitability Index Table; *Tamarindus indica*

Environmental Characteristic	**Range**	**N1**	**S4**	**S3**	**S2**	**S1**
Annual rainfall (mm)	250 - 4500	<250	250 - 781.25	781.25 - 1312.5	1312.5 - 1843.5	1843.5 - 2906
		>4500	3968.25 - 4500	3437.25 - 3968.25	2906 - 3437.25	
Mean Annual Temperature (ºC)	17 - 30	<17	17 - 18.65	18.625 - 20.25	20.25 - 21.85	21.875 - 25.125
		>30	28.35 - 30	26.75 - 28.375	25.125 - 26.75	
Mean maxiumum temperature (hottest month)	30 - 40	>40	37.5 - 40	35 - 37.5	32.5 - 35	<32.5
Mean Minimum temperature (coldest month)	12 - 25	12 - 15.25	12 - 15.25	15.25 - 18.5	18.5 - 21.75	>21.75
Number of frost days	<1	>1	-	-	-	0
Altitude	<2000	>2000	0 - 500	500 - 1000	1000 - 1500	1500 - 2000
Soil pH	4.5 - 8.5	<4.5	4.5 - 5.5	5 - 5.5	5.5 - 6	6 - 7
		>8.5	8 - 8.5	7.5 - 8	7 - 7.5	
Soil Depth	Very deep - Shallow	Very shallow	Shallow	Moderately Deep	Deep	Very Deep
Soil Drainage	Well Drained - Imperfectly drained	Poorly drained	Excessivily drained	Extremely Drained	Moderately well drained	Well drained
		Very Poorly drained	Imperfectly drained			
Soil Texture	Loam - Clay	Organic	-	-	Sand	Loam
					Clay	

Table 8 Suitability Index for tamarind (*Tamarindus indica*).

Table 9 Suitability Index for ber (*Ziziphus mauritiana*)

Suitability Index Table; *Ziziphus mauritiana*

Environmental Characteristic	Range	N1	S4	S3	S2	S1
Annual rainfall (mm)	125 - 4000	<124	125 - 609	609 - 1094	1094 - 1578	1578 - 2547
		>4000	3516 - 4000	3031 - 3516	2547 - 3031	
Mean Annual Temperature (ºC)	25 - 29	<25	25 - 25.5	25.5 - 26	26 - 26.5	26.5 - 27.5
		<29	28.5 - 29	28 - 28.5	27.5 - 28	
Mean maximum temperature (hottest month)	30 - 50	>50	45 - 50	40 - 45	35 - 40	<35
Mean minimum temperature (coldest month)	7 - 25	<7	7 - 11.5	11.5 - 16	16 - 20.5	>20.5
Number of frost days						
Altitude	<1800	>1800	1350 - 1800	900 - 1350	450 - 900	<450
Soil pH	5 - 9.2	<5	5 - 5.525	5 - 6.05	6.05 - 6.575	6.575 - 7.627
		>9.2	7.625 - 8.15	8.15 - 8.675	8.675 - 9.2	
Soil Depth	Shallow - Very Deep	Very Shallow		Shallow	Moderately Deep	Very Deep
Soil Drainage	Very Poorly drained - Excessivily Drained	-	Very Poorly Drained	Poorly Drained	Imperfectly Drained	Well Drained
			Excessivily Drained		Extremely Drained	Moderately Well Drained
Soil Texture	Clay - Sand	Organic	-	-	Clay	Sand
						Loam

Suitability Index Table; *Artocarpus heterophyllus*

Environmental Characteristic	Range	N1	S4	S3	S2	S1
Annual rainfall (mm)	700 - 4200	<700	700 - 1137.5	1137.5 - 1575	1575 - 2012	2012 - 2887.5
		>4200	3722.5 - 4200	3325 - 3762.5	2887.5 - 3325	
Mean Annual Temperature (°C)	16 - 28	<16	16 - 17.5	17.5 - 19	19 - 20.5	20.5 - 23.5
		>28	26.5 - 28	25 - 26.5	23.5 - 25	
Mean maxiumum temperature (hottest month)	30 - 35	>35	33.75 - 35	32.5 - 33.75	31.25 - 32.5	<31.25
Mean minimum temperature (coldest month)	16 - 20	<16	16 - 17	17 - 18	18 - 19	>19
Number of frost days	<1	-	-	-	-	0
Altitude	<1600	>1600	1200 - 1600	800 - 1200	400 - 800	<400
Soil pH	4.3 - 8	<4.3	4.3 - 4.76	4.76 - 5.22	5.22 - 5.68	5.68 - 6.6
		>8	7.2 - 8	7.06 - 7.52	6.6 - 7.06	
Soil Depth	Very Deep - Shallow	Very Shallow	Shallow	Moderately Deep	Deep	Very Deep
Soil Drainage	Well Drained - Excessivly Drained	Poorly Drained	Excessively Drained	Extremely Drained	Moderately Well drained	Well drained
		Very Poorly Drained	Imperfectly Drained			
Soil Texture	Sandy - Clay	Organic soils	-	-	Clay	Loam
					Sand	

Table 10 Suitability Index for jackfruit (*Artocarpus heterophyllus*)

4.1.2

Suitability maps

Figs 10 – 12 are the suitability maps were produced by combining the environmental dataset which had been reclassified based on the above suitability index (see Appendix 2 for individual environmental factors reclassification maps).

Figure 9 Suitability map for tamarind (*Tamarindus indica*) and histogram indicating number of grid cells/land units under each suitability classification

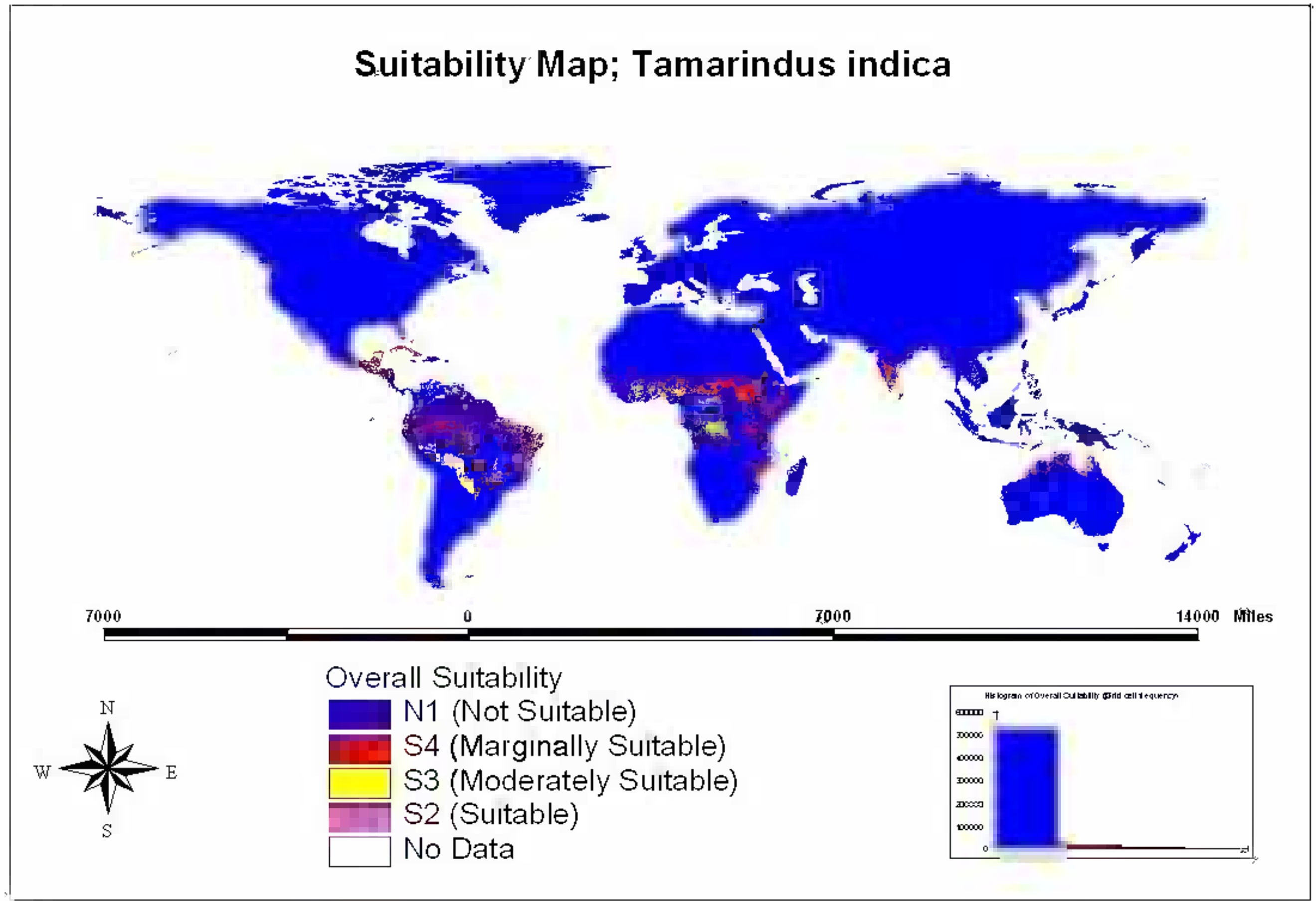


Figure 10 Suitability map for ber (*Ziziphus mauritiana*) and histogram indicating number of grid cells/land units under each suitability classification

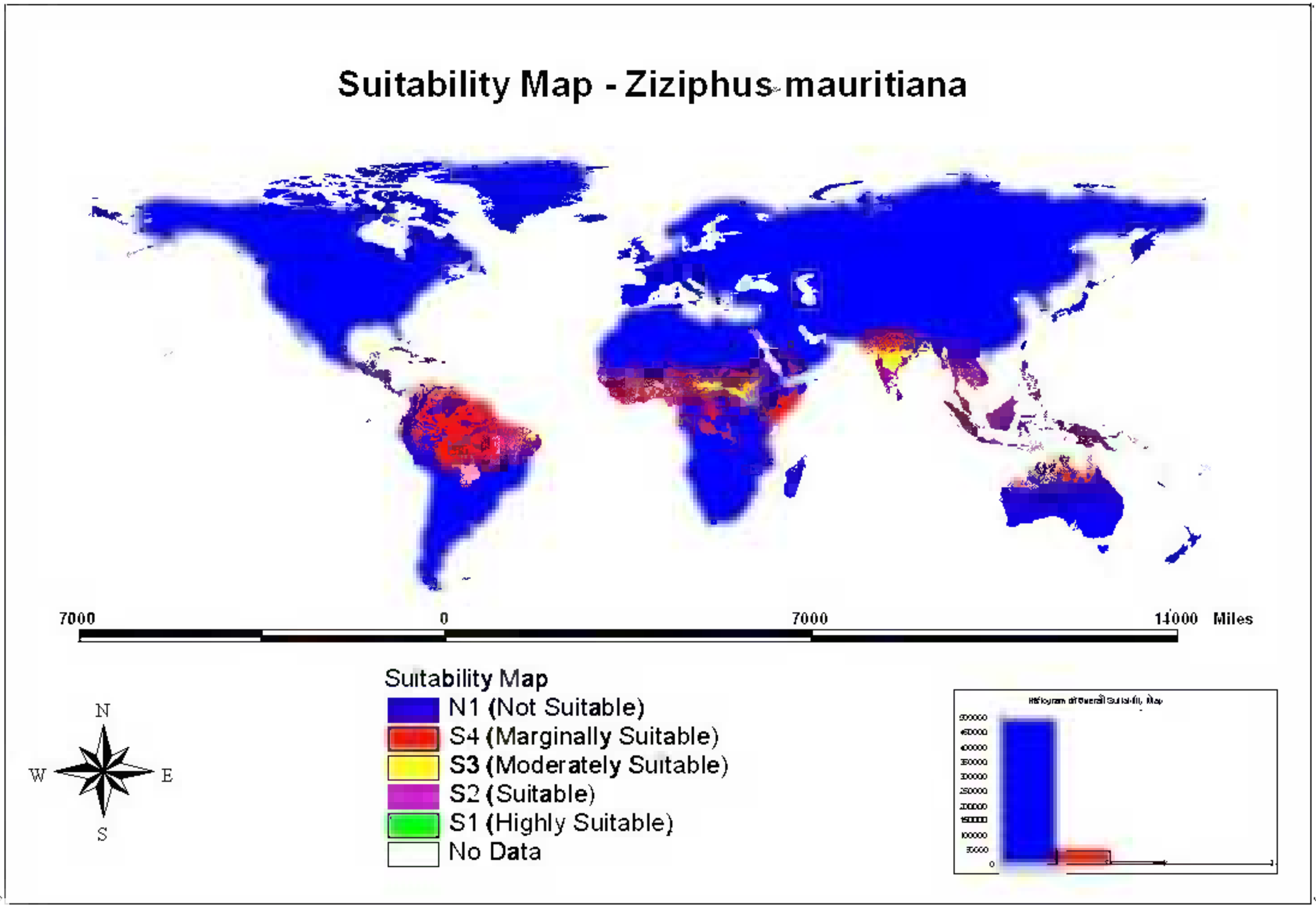
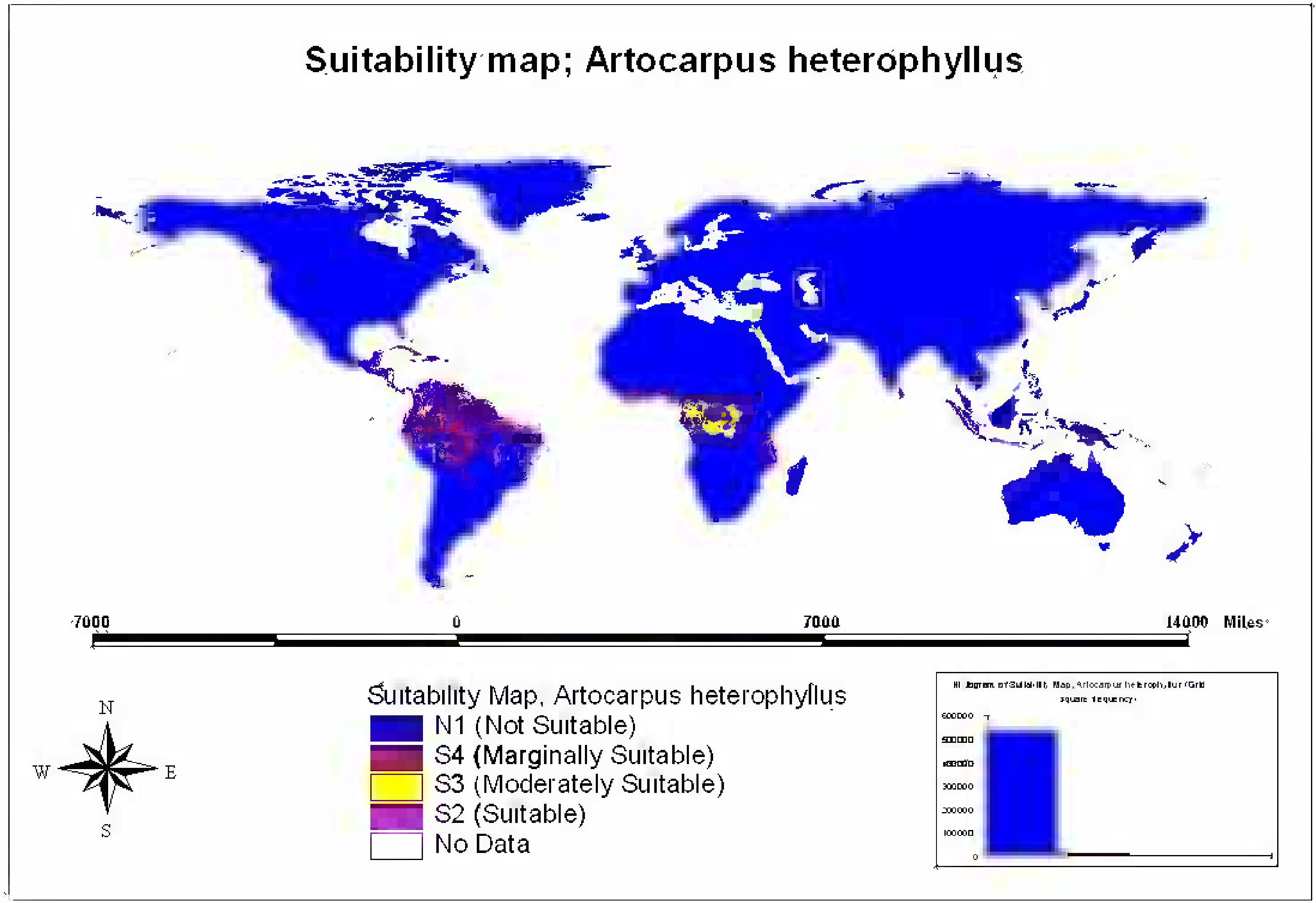


Figure 11 Suitability map for jackfruit (Artocarpus heterophyllus) and histogram indicating number of grid cells/land units under each suitability classification



4.1.2.1 Suitable country lists

Tamarind Suitability Map - Potential Distribution (countries)				
Angola	Congo	Guinea	Mozambique	Somalia
Antigua & Barbuda	Congo, DRC	Guinea-Bissau	Myanmar	South Africa
Argentina	Costa Rica	Guyana	New Caledonia	Sri Lanka
Australia	Cote d'Ivory	Haiti	Nicaragua	St. Lucia
Bangladesh	Cuba	Honduras	Niger	Sudan
Barbados	Djibouti	India	Nigeria	Suriname
Belize	Dominica	Indonesia	Panama	Taiwan
Benin	Dominican Republic	Jamaica	Papua New Guinea	Tanzania
Bolivia	Ecuador	Kenya	Paraguay	Thailand
Brazil	El Salvador	Laos	Peru	The Bahamas
Burkina Faso	Eritrea	Liberia	Philippines	The Gambia
Burundi	Ethiopia	Madagascar	Puerto Rico	Togo
Cambodia	Fiji	Malawi	Rwanda	Uganda
Cameroon	French Guiana	Malaysia	Senegal	Vanuatu
Central African Republic	Gabon	Mali	Sierra Leone	Venezuela
Chad	Ghana	Martinique	Singapore	Vietnam
China	Guadeloupe	Mauritania	Solomon Is.	Zambia
Colombia	Guatemala	Mexico		

Table 11 List of countries in which the tamarind suitability map classed at least one land unit with a suitability score of 1 (S4 marginally suitable) or above.

Ber Suitability Map Potential Distribution (countries)				
Angola	Costa Rica	Guinea-Bissau	Mozambique	Sri Lanka
Antigua & Barbuda	Cote d'Ivory	Guyana	Myanmar	St. Lucia
Australia	Cuba	Haiti	Nepal	St. Vincent & the Grenadines
Bangladesh	Djibouti	Honduras	Nicaragua	Sudan
Barbados	Dominica	India	Niger	Suriname
Belize	Dominican Republic	Indonesia	Nigeria	Tanzania
Benin	East Timor	Iran	Pakistan	Thailand
Bolivia	Ecuador	Iraq	Panama	The Bahamas
Brazil	El Salvador	Jamaica	Papua New Guinea	The Gambia
Brunei	Equatorial Guinea	Kenya	Paraguay	Togo
Burkina Faso	Eritrea	Laos	Peru	Trinidad & Tobago
Cambodia	Ethiopia	Liberia	Philippines	Uganda
Cameroon	Fiji	Madagascar	Puerto Rico	United Arab Emirates
Central African Republic	French Guiana	Malawi	Saudi Arabia	Venezuela
Chad	Gabon	Malaysia	Senegal	Vietnam
China	Ghana	Mali	Sierra Leone	Yemen
Colombia	Guadeloupe	Martinique	Singapore	Zambia
Congo	Guatemala	Mauritania	Solomon Is.	Zimbabwe
Congo, DRC	Guinea	Mexico	Somalia	

Table 12 List of countries in which the ber suitability map classed at least one land unit with a suitability score of 1 (S4 marginally suitable) or above.

Jackfruit Suitability Map - Potentail Distribution (countries)				
Angola	Congo	Guadeloupe	Martinique	Sri Lanka
Antigua & Barbuda	Congo, DRC	Guatemala	Mexico	St. Lucia
Australia	Costa Rica	Guinea	Mozambique	Sudan
Barbados	Cote d'Ivory	Guinea-Bissau	Myanmar	Suriname
Belize	Cuba	Guyana	Nicaragua	Tanzania
Benin	Dominica	Haiti	Nigeria	Thailand
Bolivia	Dominican Republic	Honduras	Panama	The Bahamas
Brazil	Ecuador	India	Papua New Guinea	Togo
Brunei	El Salvador	Indonesia	Paraguay	Trinidad & Tobago
Burundi	Equatorial Guinea	Jamaica	Peru	Uganda
Cambodia	Ethiopia	Kenya	Philippines	Vanuatu
Cameroon	Fiji	Laos	Puerto Rico	Venezuela
Central African Republic	French Guiana	Liberia	Sierra Leone	Vietnam
China	Gabon	Madagascar	Singapore	
Colombia	Ghana	Malaysia	Solomon Is.	

Table 13 List of countries in which the jackfruit suitability map classed at least one land unit with a suitability score of 1 (S4 marginally suitable) or above.

The tamarind suitability map (figure 9) classifies 517912 (94.39%) pixels as N1 (not suitable) and 30774 pixels (5.61%) as being suitable for adaptation, 21569 (3.94%) of which as S4 (marginally suitable), 9134 (1.66%) as S3 (moderately suitable) and 71 (0.012%) as S2 (suitable), no pixels were identified as highly suitable. The predicted distribution appears to be broadly spread across the tropics reaching almost 29ºS and as far as 25ºN. Table 11 gives the names of the 88 countries containing land units classified as S4 (marginally suitable) or above.

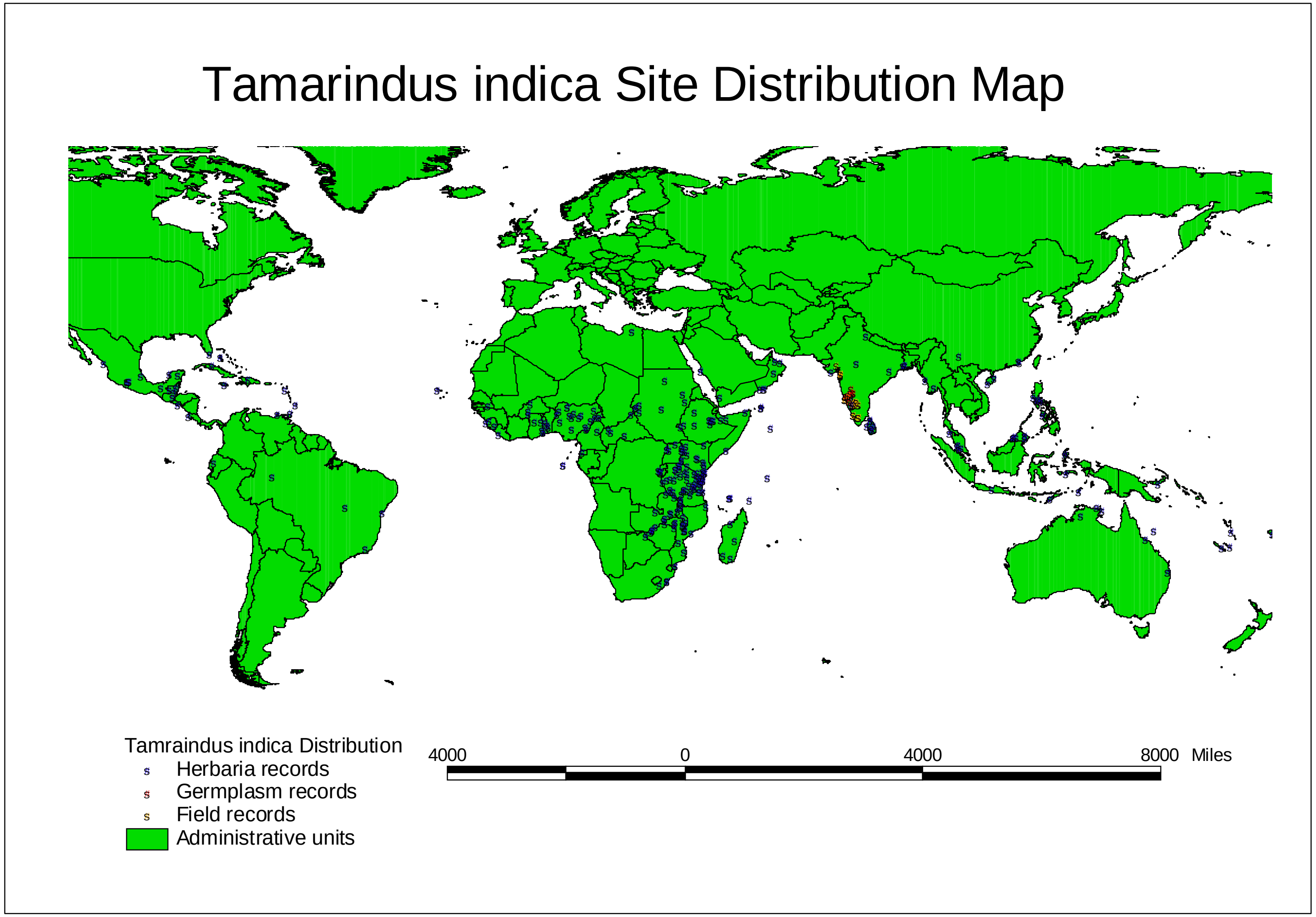
The ber suitability map (figure 10) classifies 486264 (88.623%) of pixels as N1 (Not Suitable), 62422 (11.377%) as suitable for adaptation of ber, of which 47327 (8.625%) are classified as S4 (marginally suitable), 11695 (2%) are classified as S3 (moderately suitable), 3232 (0.589%) as S2 (suitable) and 168 (0.031%) as S1 (highly suitable). Once again the predicted distribution is spread across the tropics reaching 24º S and almost 31ºN. Table 12 gives the names of the 94 countries containing land units classified as S4 (marginally suitable) or above

The jackfruit suitability map (figure 11) classifies 526737 (96%) of pixels as N1 (not suitable) and 21949 (4%) as suitable for adaptation of jackfruit of which 15470 (2.819%) are classified as S4 (marginally suitable), 6452 (1.176%) as S3 (moderately suitable), 27 (0.005%) as S2 (Suitable). The predicted distribution is spread across the tropics reaching 20ºS and 25ºN. Table 13 gives the names of the 73 countries containing classified as S4 (marginally suitable) or above.

4.1.2.2 Point Distribution Map

Fig 12 *Tamarindus indica* Site Distribution map

Figure 12 shows the point distribution map, tamarind is shown to be distributed in 331 locations across 59 countries for full location list see appendix



4.1.2.3 Environment profile

This environment profile describes the statistical distribution for climatic and soil factors for the locations where the tamarind is distributed and therefore gives an indication of the species environmental preferences. Tables 14 and 15 give the statistical summary of those environmental factors in which the IPCC datasets were used to extract values, the values in these datasets were continuous. The histograms in figures 14 - 20 show the frequency distribution for each of the environmental factors extracted from IPCC dataset.

Table 16 contains the statistical distribution summary (Environmental profile) derived using the point distribution dataset using the TERRSTAT dataset. As the values of the dataset were discrete and represented class intervals, it was not possible to carry out full statistical analysis. The minimum value did however represent the minimum class range, as the class number increased so did the values within the range class however most of the datasets the maximum value contained the values 97 and 99 which represented water glaciers and water bodies respectively, the value below this represented the maximum range and this is what is referred to in the table. The table therefore gives values for minimum, maximum and mode value and the corresponding class interval or descriptions it represents. The histograms is figures 21 – 26 give the frequency distribution for those factors used in the model, figures 26 – 40 give the frequency distribution for other environmental factors likely to have an effect on the performance (growth, yield) of tamarind.

Environmental Characteristics	Variance	Range	Minimum	Maximum	Percentiles			
					1	5	95	99
Altitude (km)	0.226221	2.057	0.001	2.058	0.00113	0.01	1.4488	1.85496
No. of Frost days	44.90541	58.6	0	58.6	0	0	14.085	40.154
Min Temp. coldest month (ºC)	14.31966	22.55	1.3	23.85	4.0865	8.8475	21.7025	23.237
Max temp. hottest month (ºC)	10.2226	19.9	23.4	43.3	25.3105	28.3825	39.3525	41.4285
Annual Rainfall (mm)	513906	4535.9999	13.4	4549.3999	57.727	416.41	2851.4	3533.5
Mean Annual Temperature (ºC)	6.108941	14.675	14.6167	29.2917	16.44075	20.12875	28.10291	28.77247
Mean Annual Relative Humidity (%)	102.1838	61.6083	24.775	86.3833	32.92411	48.1404	82.40915	85.3023

Table 14 Statistical distribution (Environment Profile) for environmental parameters derived from the IPCC dataset for the locations on the tamarind point distribution map.

Environmental Characteristics	No. of locations		Mean	Std. Error of Mean	Median	Mode	Std. Deviation
	Valid	Missing					
Altitude (km)	312	19	0.54024	0.026927099	0.468	0.073	0.475627401
No. of Frost days	312	19	2.832372	0.379377914	0.3	0	6.70115003
Min Temp. coldest month (ºC)	312	19	15.70609	0.214234305	15.6	13.8	3.784132309
Max temp. hottest month (ºC)	312	19	33.39119	0.181010331	33.05	33.05	3.197279924
Annual Rainfall (mm)	312	19	1243.225	40.58490481	1073.55	563.5	716.8723481
Mean Annual Temperature (ºC)	312	19	24.76771	0.139928338	25.1333	23.675	2.471627235
Mean Annual Relative Humidity (%)	312	19	68.06664	0.572286801	68.5	76.7167	10.10860034

Table 15 Statistical distribution (continued) for environmental parameters derived from the IPCC dataset for the locations on the point distribution map

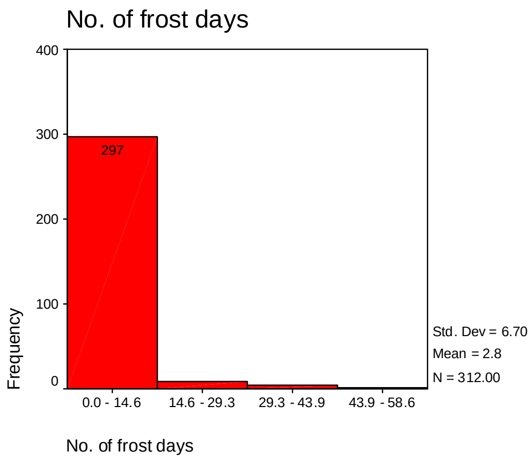


Figure 14

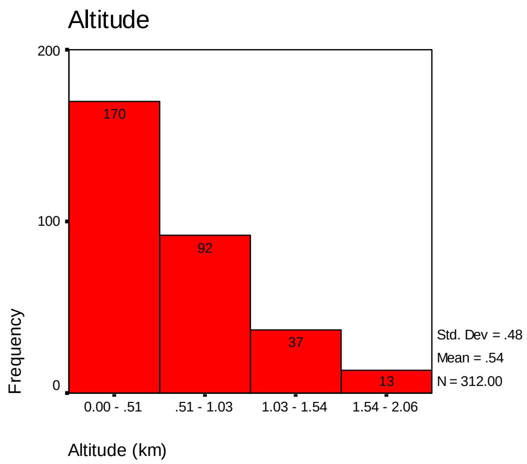


Figure 15

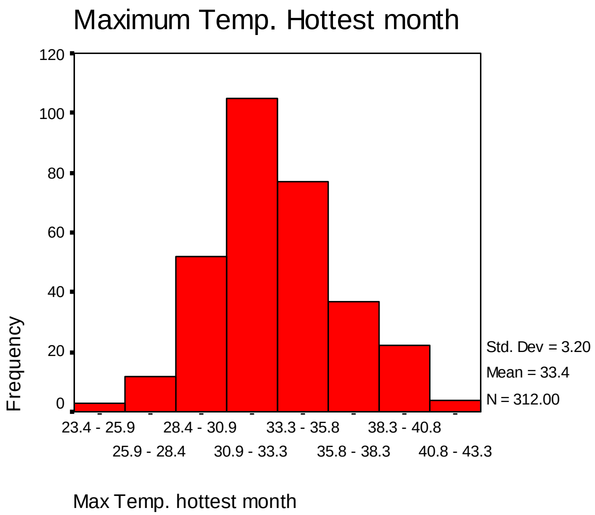


Figure 16

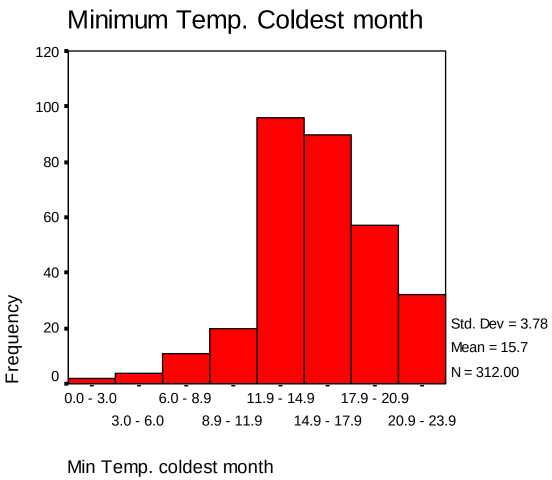


Figure 17

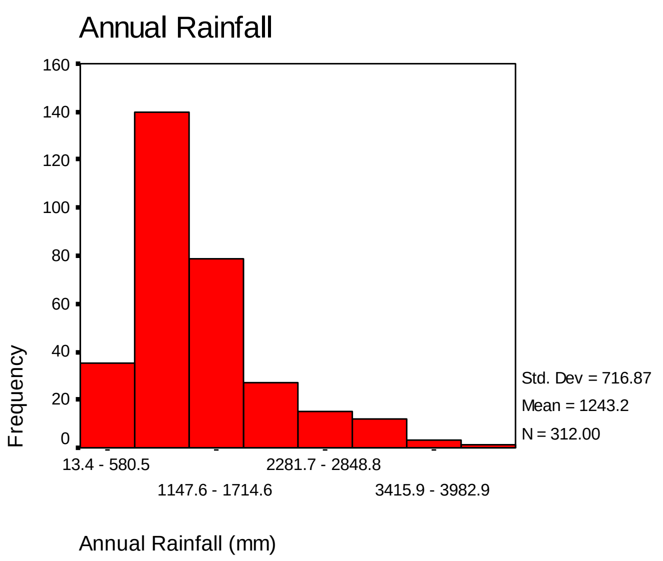


Figure 18

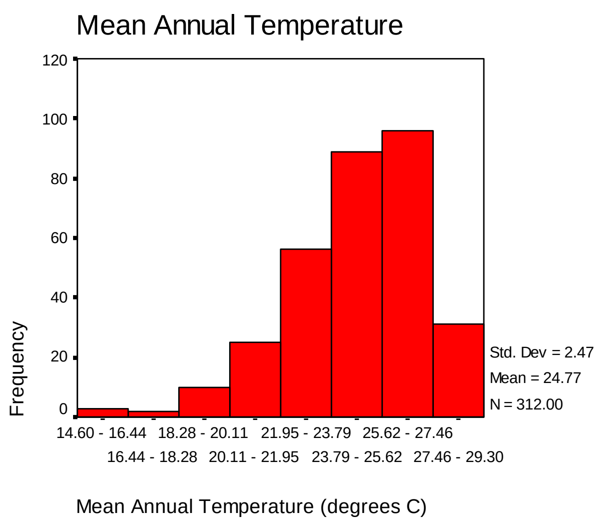
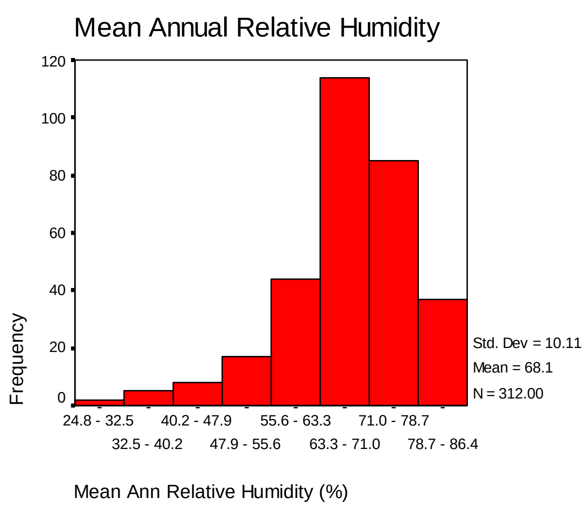


Figure 19

Figure 20



Point Distribution									
Environmental Charcateristic	Mode	Classification		Minimum	Classification		Maximum	Classification	
	TERRSTAT code	Dominat soil	Associated soils	TERRSTAT code	Dominat soil	Associated soils	TERRSTAT code	Dominat soil	Associated soils
(DEPTHW) Effective soil dept (cm)	40.00000	100 - 150 (Deep)		12.00000	10 - 50 (Very Shallow)	10 - 50 (Shallow)	54.00000	150 - 300 (Very Deep)	
(PHW_S) pH_subsoil	30.00000	>5.5 - 7.2		13.00000	<4.5	>5.5 - 7.2	54.00000	>8.5	>7.2 - 8.5
(PHW_T) pH_topsoil	30.00000	>5.5 - 7.2		13.00000	<4.5	>5.5 - 7.2	54.00000	>8.5	>7.2 - 8.5
(TXW_S) Textural class_subsoil	30.00000	Medium (loam)		20.00000	Course (sand)		43.00000	Fine (clay)	medium (loamy)
(TXW_T) Textural class_topsoil	30.00000	Medium (loam)		20.00000	Course (sand)		43.00000	Fine (clay)	medium (loamy)
DRAIN_CODE (Drainage Code	43.00000	Well drained	Soils extremely drained	23.00000	Excessively well drained	Soils extremely drained	87.00000	Very poorly drained	Poorly drained
(EAWW) Easily available water (mm/m)	50.00000	40 - 60		10.00000	Wetlands		75.00000	<20	40 - 60
(BSW_S) Base Saturation_subsoil (%)	40.00000	>80		10.00000	<20		43.00000	>80	>50 - 80
(BSW_T) Base Saturation_topsoil (%)	40.00000	>80		10.00000	<20		43.00000	>80	>50 - 80
(CCW_S) Cation Exchange capacity clay (meq/100g clay)	23.00000	20 - 50		10.00000	<20		34.00000	>50 - 100	>100
(CCW_T) Cation Exchange capacity clay (meq/100g clay)	20.00000	20 - 50		10.00000	<20		34.00000	>50 - 100	>100
(CEW_S) Cation Exchange capacity_subsoil (meq/100g)	30.00000	>10 - 20		10.00000	<4		54.00000	>40	>20 - 40
(CEW_T) Cation Exchange capacity_topsoil (meq/100g)	30.00000	>10 - 20		10.00000	<4		54.00000	>40	>20 - 40
(CNW_S) C/N ratio_subsoil	10.00000	<10		10.00000	<10		32.00000	>15 - 20	15 - 20
(CNW_T) C/N ratio_topsoil	20.00000	10 - 15		10.00000	<10		42.00000	>20	10 - 20
(NNW_S) Nitrogen_subsoil (%)	20.00000	>0.02 - 0.08		10.00000	0 - 0.02		40.00000	>0.2 - 0.5	
(NNW_T) Nitrogen_topsoil (%)	23.00000	>0.02 - 0.08	>0.08 - 0.2	10.00000	0 - 0.02		54.00000	>0.5	>0.2 - 0.5
(OCW_S) Organic Carbon_subsoil (%)	20.00000	0.2 - 0.6		10.00000	<0.2		53.00000	>2.0	>0.6 - 1.2
(OCW_T) Organic Carbon_topsoil (%)	30.00000	>0.6 - 1.2		20.00000	0.2 - 0.6		54.00000	>2.0	>1.2 - 2
(SMAXW) Soil Moisture storage capacity (mm/m)	30.00000	100 - 150		10.00000	Wetlands		74.00000	<20	150 - 200
(TERRSLOPE) Slope (%)	4	8 - 16		1.00000	0 - 2		7.00000	>45	
(LGP) Length of avialable growing period (days)	8	180 - 209		1.00000	0.00000		16.00000	365.00000	

Table 16 Statistical distribution (Environmental profile) derived from TERRSTAT dataset

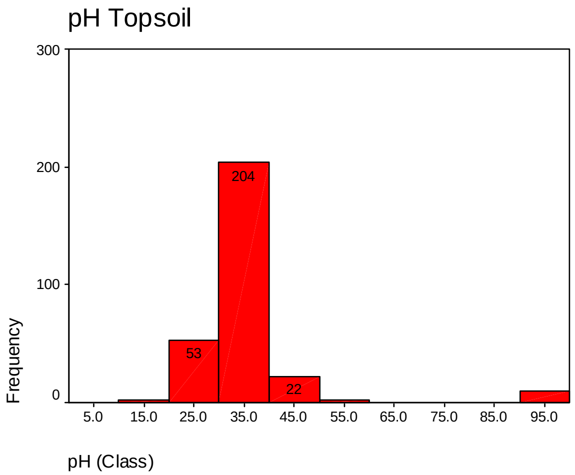
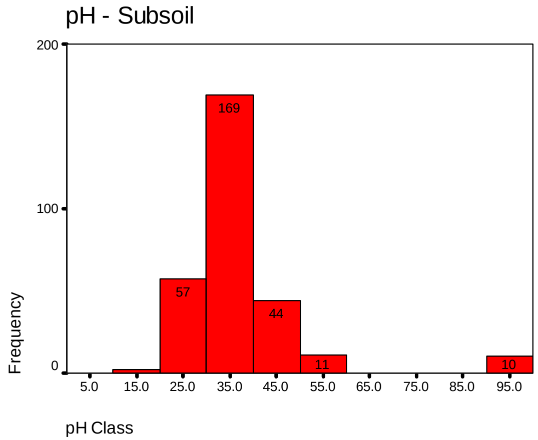


Figure 21



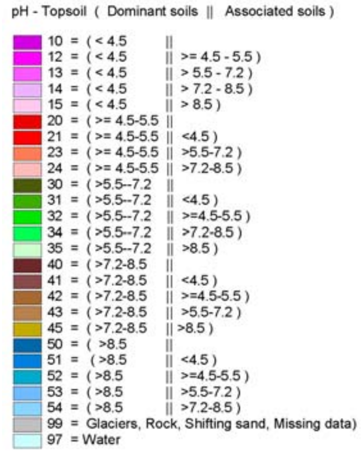


Figure 22

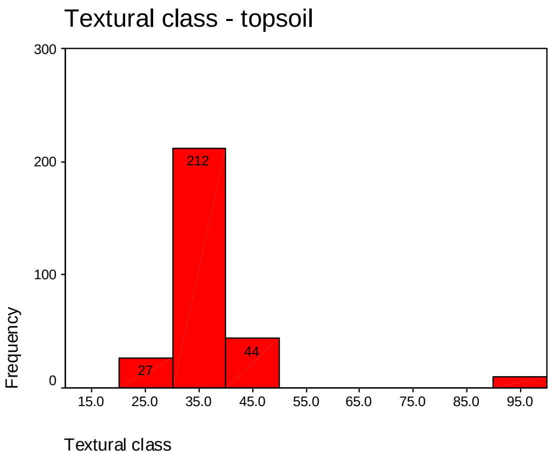


Figure 23

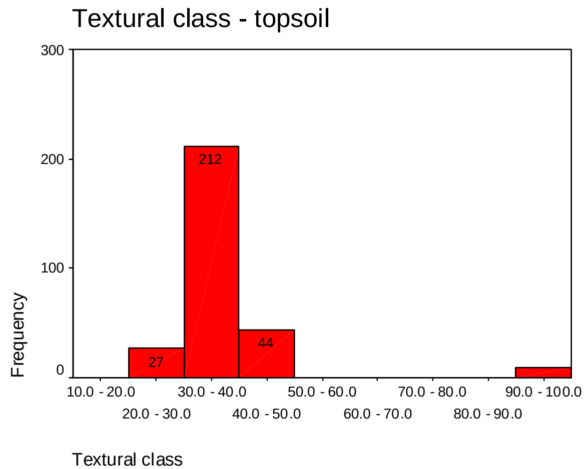


Figure 24

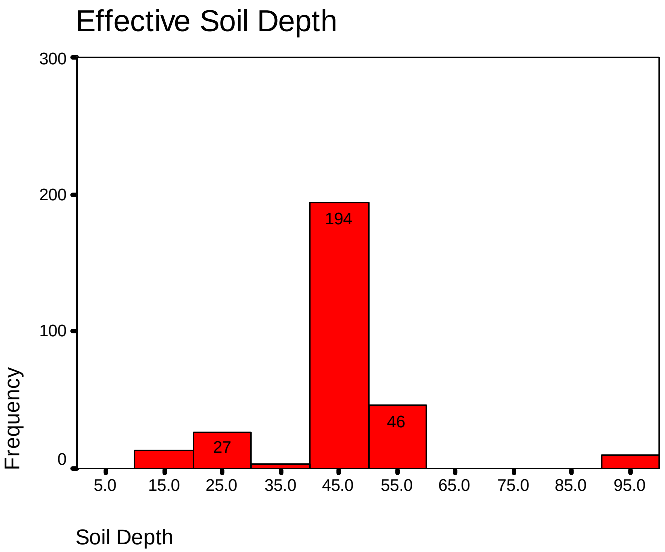


Figure 25

Depth soil (cm)

10 =	Very shallow (<10 cm)	||
12 =	Very shallow (<10 cm)	|| Shallow (10-50 cm)
13 =	Very shallow (<10 cm)	|| Moderately deep (50-100 cm)
14 =	Very shallow (<10 cm)	|| Deep (100-150 cm)
15 =	Very shallow (<10 cm)	|| Very deep (150-300 cm)
20 =	Shallow (10-50 cm)	||
21 =	Shallow (10-50 cm)	|| Very shallow (<10 cm)
23 =	Shallow (10-50 cm)	|| Moderately deep (50-100 cm)
24 =	Shallow (10-50 cm)	|| Deep (100-150 cm)
25 =	Shallow (10-50 cm)	|| Very deep (150-300 cm)
34 =	Moderately deep (50-100 cm)	|| Deep (100-150 cm)
40 =	Deep (100-150 cm)	||
41 =	Deep (100-150 cm)	|| Very shallow (<10 cm)
42 =	Deep (100-150 cm)	|| Shallow (10-50 cm)
43 =	Deep (100-150 cm)	|| Moderately deep (50-100 cm)
45 =	Deep (100-150 cm)	|| Very deep (150-300 cm)
50 =	Very deep (150-300 cm)	||
51 =	Very deep (150-300 cm)	|| Very shallow (<10 cm)
52 =	Very deep (150-300 cm)	|| Shallow (10-50 cm)
53 =	Very deep (150-300 cm)	|| Moderately deep (50-100 cm)
54 =	Very deep (150-300 cm)	|| Deep (100-150 cm)
97 =	Water	

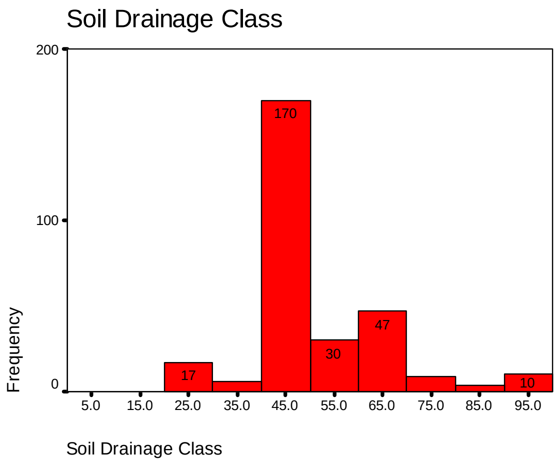


Figure 26

Soil Drainage Classes (Dominant Soils || Associated Soils)

20 = Excessively drained	||
23 = Excessively drained	|| Soils extremely drained
24 = Excessively drained	|| Well drained
25 = Excessively drained	|| Moderately well drained
26 = Excessively drained	|| Imperfectly drained
27 = Excessively drained	|| Poorly drained
28 = Excessively drained	|| Very poorly drained
32 = Soils extremely drained	|| Excessively drained
34 = Soils extremely drained	|| Well drained
35 = Soils extremely drained	|| Moderately well drained
36 = Soils extremely drained	|| Imperfectly drained
38 = Soils extremely drained	|| Very poorly drained
41 = Well drained	|| Not applicable
42 = Well drained	|| Excessively drained
43 = Well drained	|| Soils extremely drained
45 = Well drained	|| Moderately well drained
46 = Well drained	|| Imperfectly drained
47 = Well drained	|| Poorly drained
48 = Well drained	|| Very poorly drained
50 = Moderately well drained	||
52 = Moderately well drained	|| Excessively drained
53 = Moderately well drained	|| Soils Extremely drained
54 = Moderately well drained	|| Well drained
56 = Moderately well drained	|| Imperfectly drained
57 = Moderately well drained	|| Poorly drained
58 = Moderately well drained	|| Very poorly drained

60 = Imperfectly drained	||
62 = Imperfectly drained	|| Excessively drained
63 = Imperfectly drained	|| Soils extremely drained
64 = Imperfectly drained	|| Well drained
65 = Imperfectly drained	|| Moderately well drained
67 = Imperfectly drained	|| Poorly drained
68 = Imperfectly drained	|| Very poorly drained
72 = Poorly drained	|| Excessively drained
74 = Poorly drained	|| Well drained
75 = Poorly drained	|| Moderately well drained
76 = Poorly drained	|| Imperfectly drained
78 = Poorly drained	|| Very poorly drained
80 = Very poorly drained	||
82 = Very poorly drained	|| Excessively drained
83 = Very poorly drained	|| Soils extremely drained
84 = Very poorly drained	|| Well drained
85 = Very poorly drained	|| Moderately well drained
86 = Very poorly drained	|| Imperfectly drained
87 = Very poorly drained	|| Poorly drained
10 = Not applicable	||
12 = Not applicable	||
13 = Not applicable	||
14 = Not applicable	||
16 = Not applicable	||
97 = Water bodies	

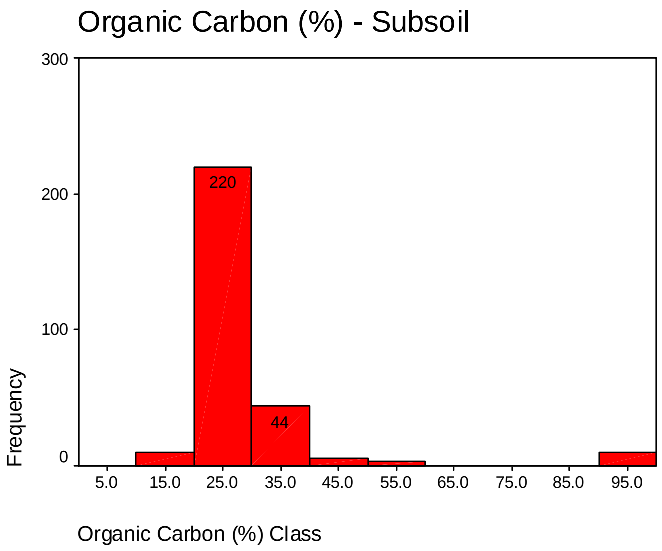


Figure 27

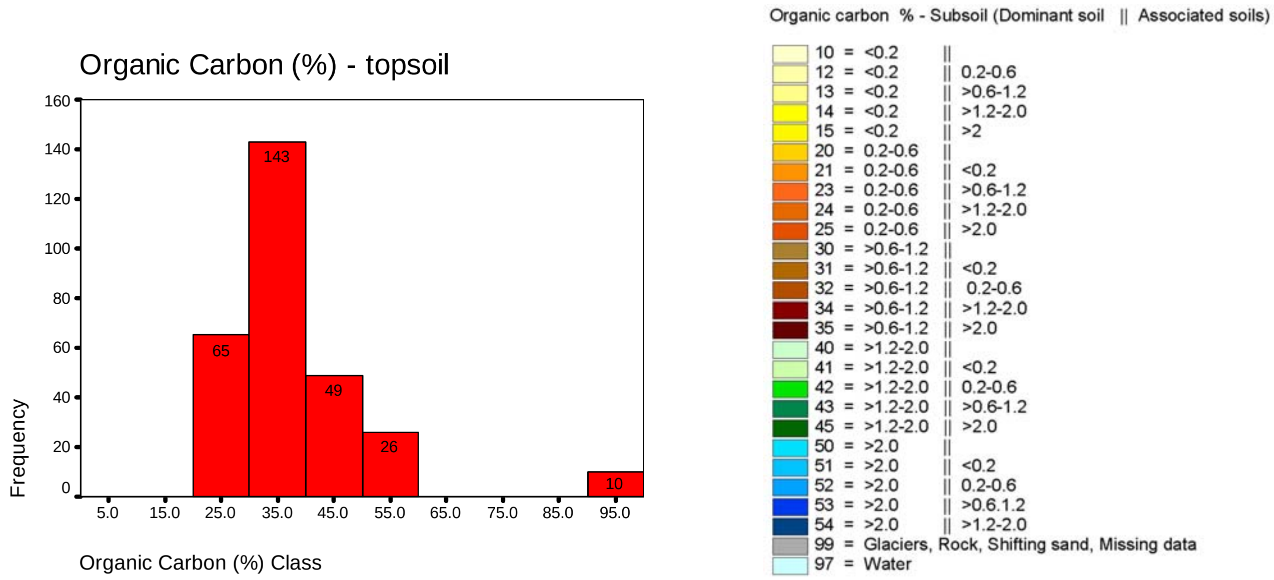


Figure 28

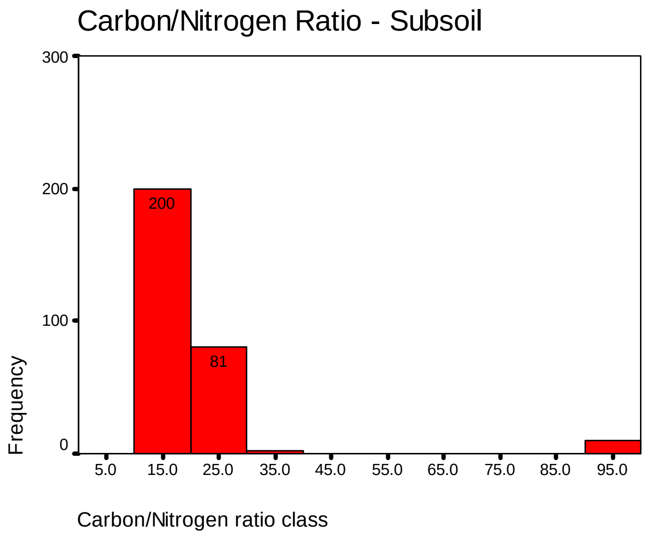


Figure 29

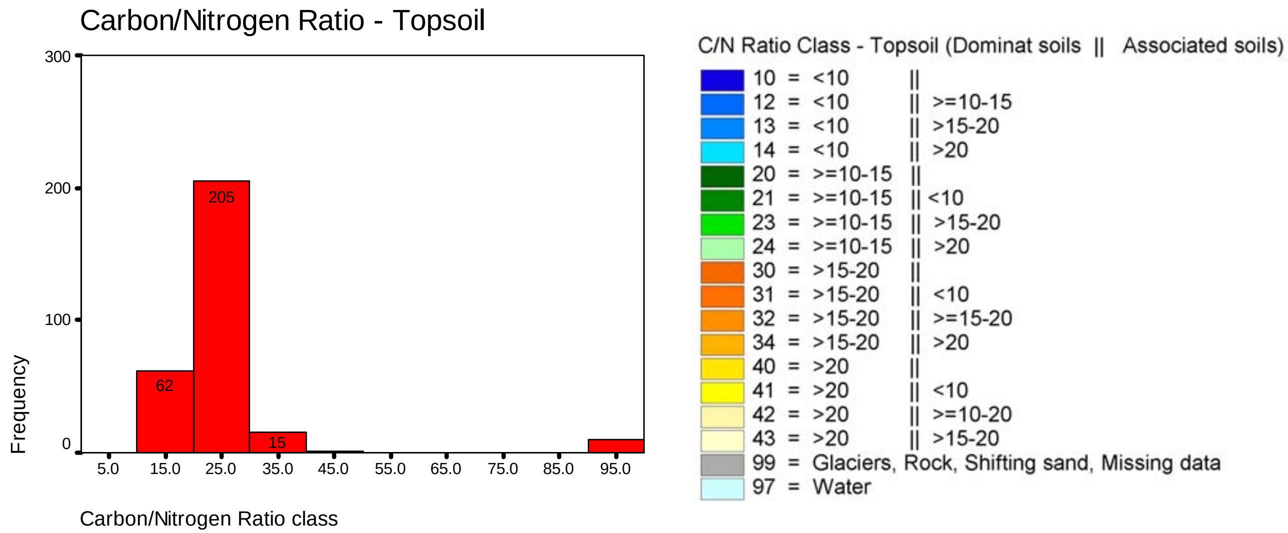


Figure 30

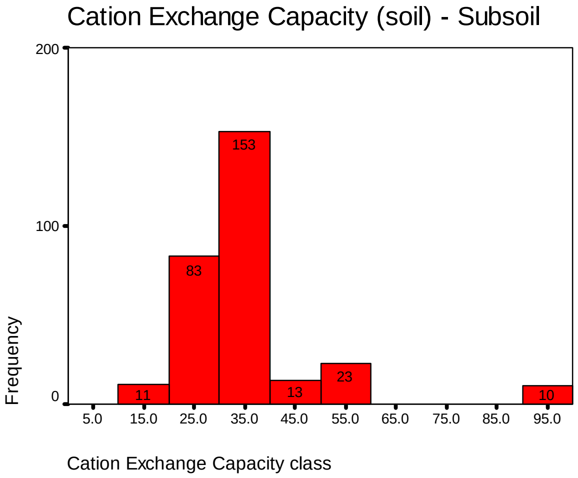


Figure 31

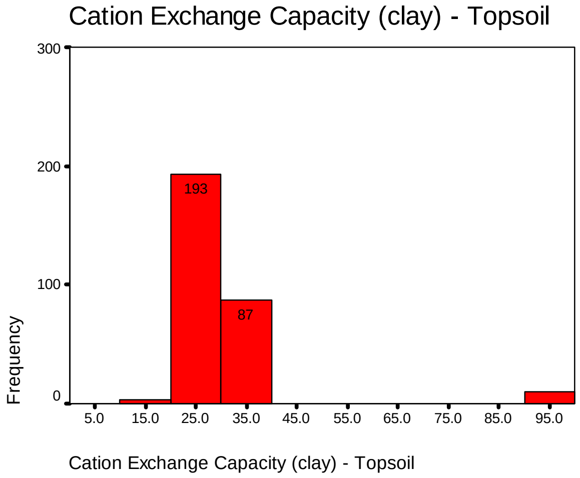


Figure 32

Cation Exchange Capacity (soil) - Topsoil (Dominant soils || Associated Soils)

10 = <4meq/100g ||
12 = <4meq/100g || 4-10meq/100g
13 = <4meq/100g || >10-20meq/100g
14 = <4meq/100g || >20-40meq/100g
15 = <4meq/100g || >40meq/100g
20 = 4-10meq/100g ||
21 = 4-10meq/100g || <4meq/100g
23 = 4-10meq/100g || >10-20meq/100g
24 = 4-10meq/100g || >20-40meq/100g
25 = 4-10meq/100g || >40meq/100g
30 = >10-20meq/100g ||
31 = >10-20meq/100g || <4meq/100g
32 = >10-20meq/100g || 4-10meq/100g
34 = >10-20meq/100g || >20-40meq/100g
35 = >10-20meq/100g || >40meq/100g
40 = >20-40meq/100g ||
41 = >20-40meq/100g || <4meq/100g
42 = >20-40meq/100g || 4-10meq/100g
43 = >20-40meq/100g || >10-20mq/100g
45 = >20-40meq/100g || >40meq/100g
50 = >40meq/100g ||
51 = >40meq/100g || <4meq/100g
52 = >40meq/100g || 4-10meq/100g
53 = >40meq/100g || >10-20meq/100g
54 = >40meq/100g || >20-40meq/100g
99 = Glaciers, Rock, Shifting sand, Missing data
97 = Water

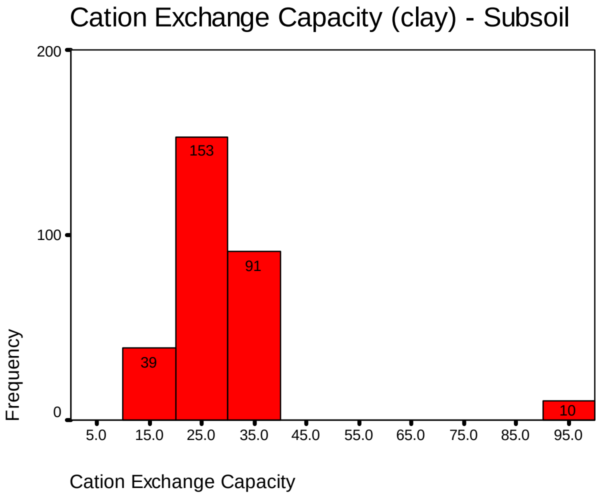


Figure 33

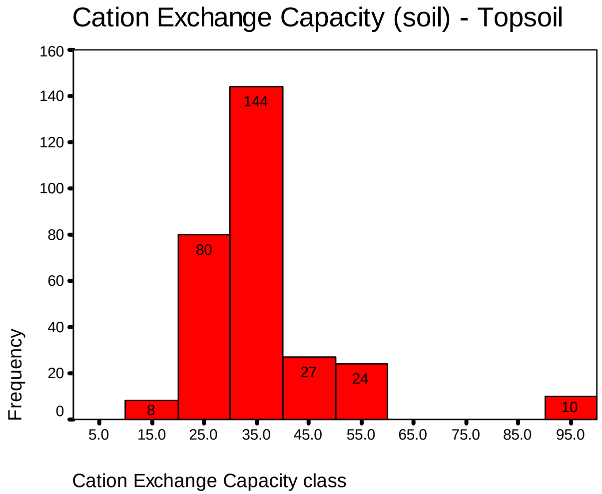


Figure 34

Cation Exchange Capacity (clay) - Topsoil (Dominat soils || Associated soils)

10 = <20meq/100g clay ||
12 = <20meq/100g clay || 20-50meq/100g clay
13 = <20meq/100g clay || >50-100meq/100g clay
14 = <20meq/100g clay || >100meq/100g clay
20 = 20-50meq/100g clay ||
21 = 20-50meq/100g clay || <20meq/100g clay
23 = 20-50meq/100g clay || >50-100meq/100g clay
24 = 20-50meq/100g clay || >100meq/100g clay
30 = >50-100meq/100g clay ||
31 = >50-100meq/100g clay || <20meq/100g clay
32 = >50-100meq/100g clay || 20-50meq/100g clay
34 = >50-100meq/100g clay || >100meq/100g clay
40 = >100meq/100g clay ||
41 = >100meq/100g clay || <20meq/100g clay
42 = >100meq/100g clay || 20-50meq/100g clay
43 = >100meq/100g clay || >50-100meq/100g clay
99 = Glaciers, Rock, Shifting sand, Missing data
97 = Water

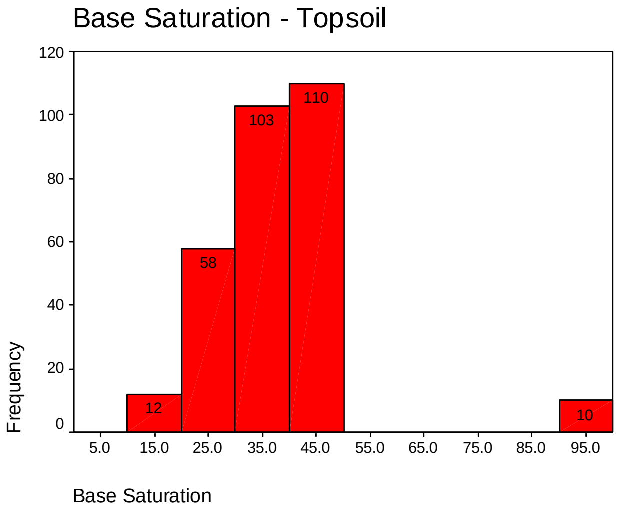


Figure 35

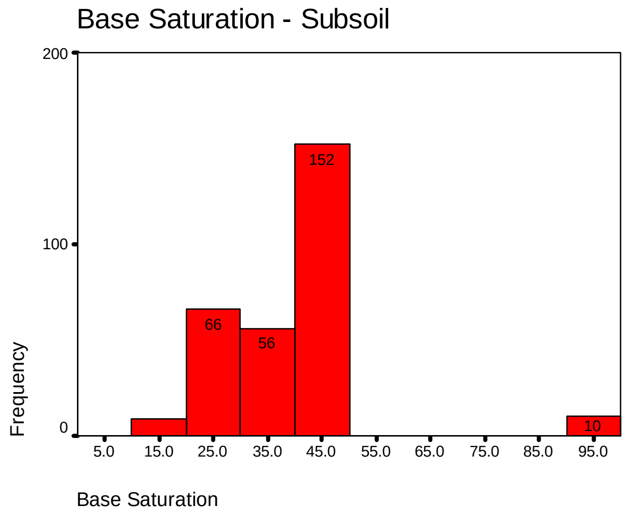
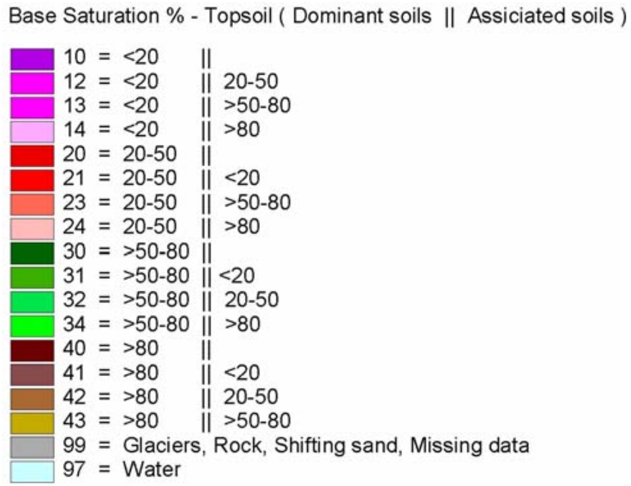


Figure 36



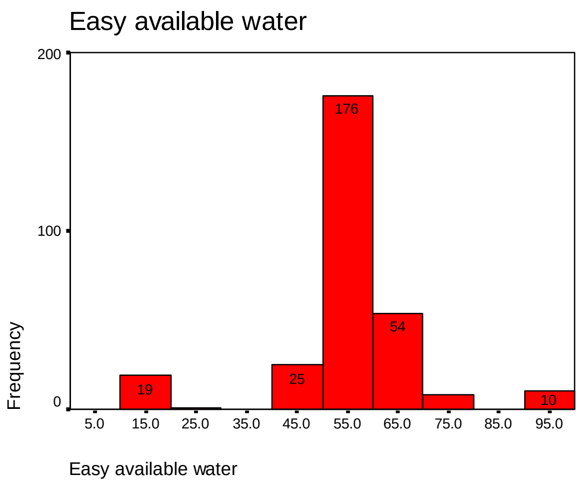
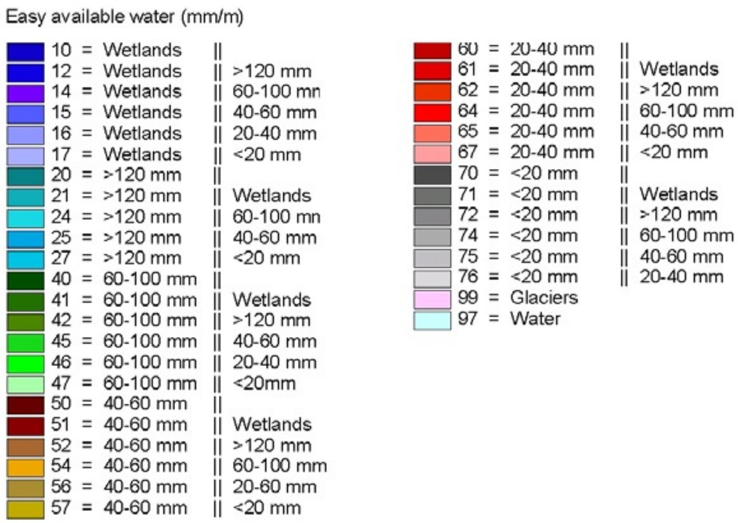


Figure 37



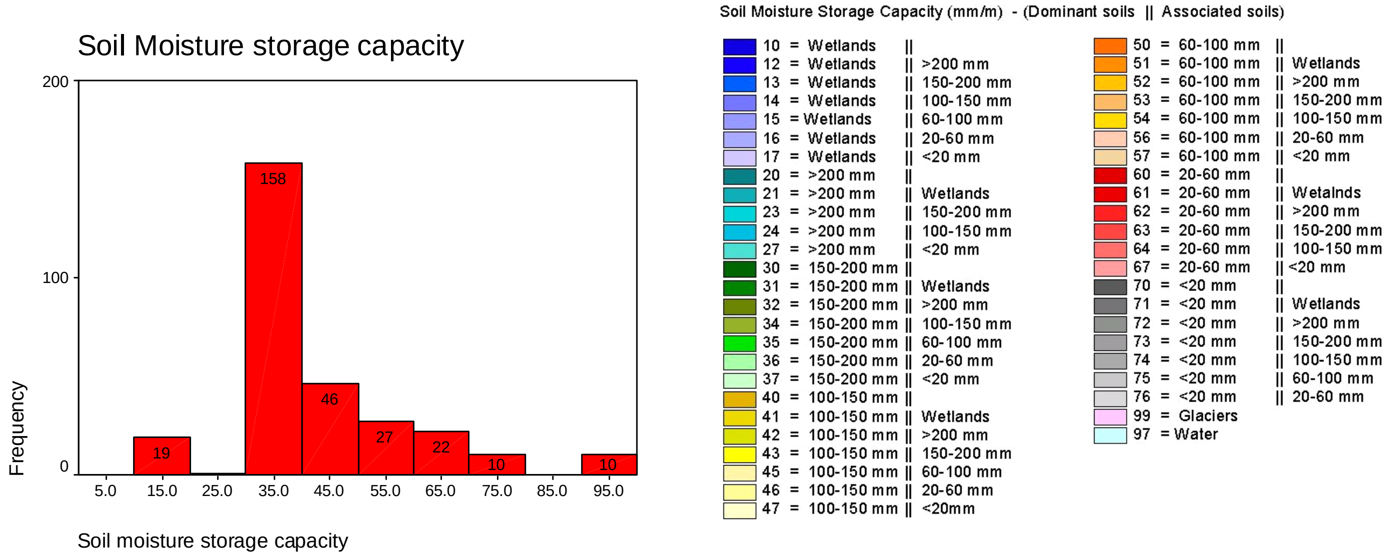


Figure 38

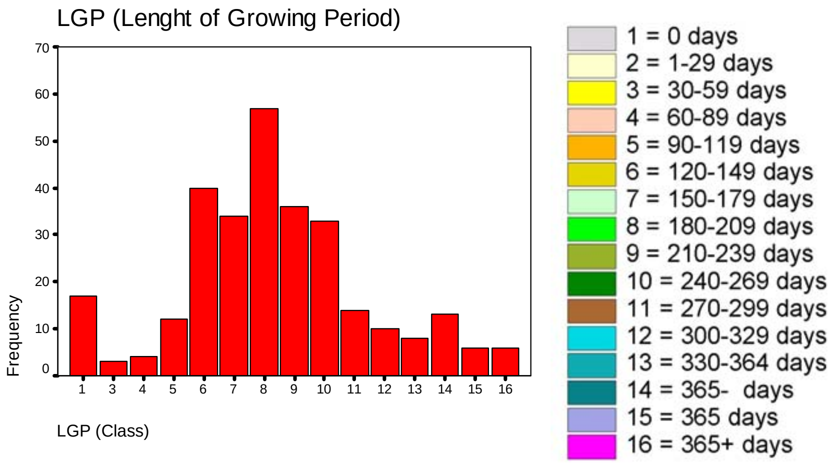


Figure 39

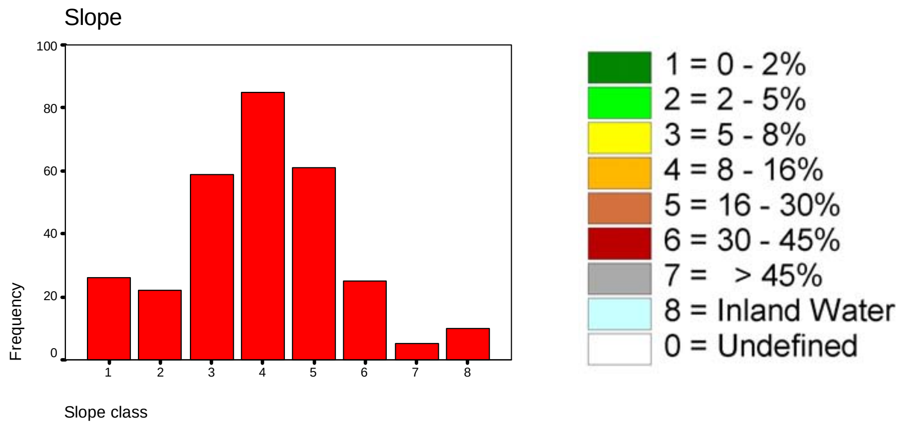


Figure 40

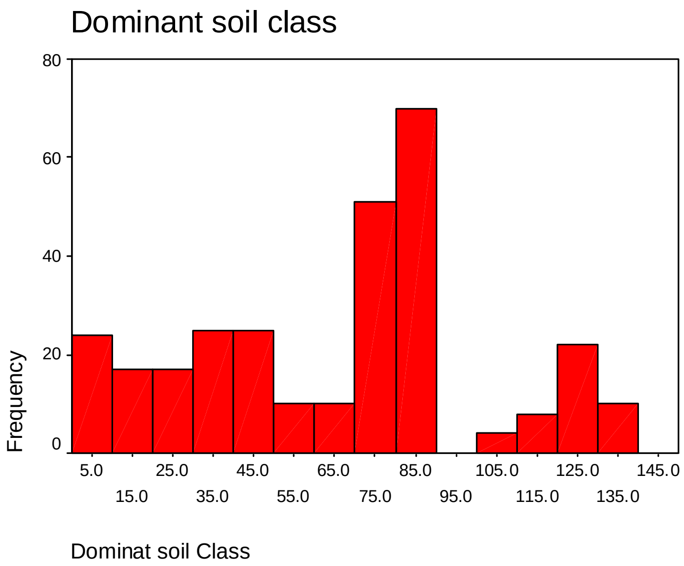
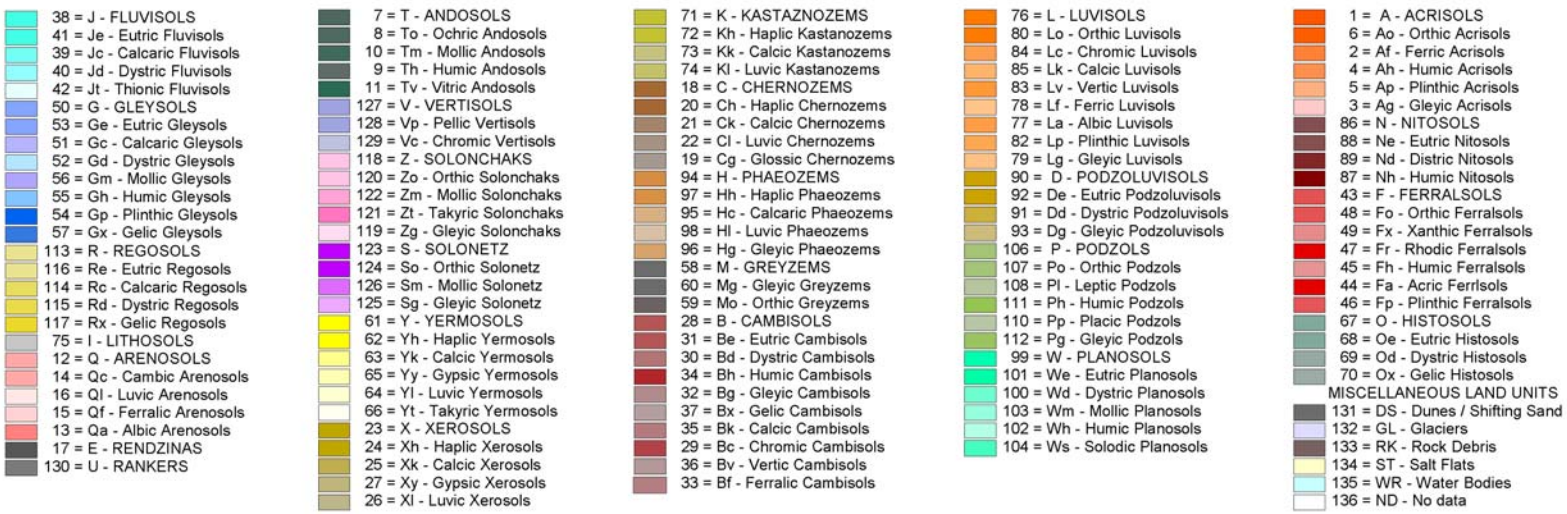

Dominant soil class
80
60
40
20
0
Frequency
5.0
25.0
45.0
65.0
85.0
105.0
125.0
145.0
15.0
35.0
55.0
75.0
95.0
115.0
135.0
Dominat soil Class

Figure 41


38 = J - FLUVISOLS
41 = Je - Eutric Fluvisols
39 = Jc - Calcaric Fluvisols
40 = Jd - Dystric Fluvisols
42 = Jt - Thionic Fluvisols
50 = G - GLEYSOLS
53 = Ge - Eutric Gleysols
51 = Gc - Calcaric Gleysols
52 = Gd - Dystric Gleysols
56 = Gm - Mollic Gleysols
55 = Gh - Humic Gleysols
54 = Gp - Plinthic Gleysols
57 = Gx - Gelic Gleysols
113 = R - REGOSOLS
116 = Re - Eutric Regosols
114 = Rc - Calcaric Regosols
115 = Rd - Dystric Regosols
117 = Rx - Gelic Regosols
75 = I - LITHOSOLS
12 = Q - ARENOSOLS
14 = Qc - Cambic Arenosols
16 = Ql - Luvic Arenosols
15 = Qf - Ferralic Arenosols
13 = Qa - Albic Arenosols
17 = E - RENDZINAS
130 = U - RANKERS
7 = T - ANDOSOLS
8 = To - Ochric Andosols
10 = Tm - Mollic Andosols
9 = Th - Humic Andosols
11 = Tv - Vitric Andosols
127 = V - VERTISOLS
128 = Vp - Pellic Vertisols
129 = Vc - Chromic Vertisols
118 = Z - SOLONCHAKS
120 = Zo - Orthic Solonchaks
122 = Zm - Mollic Solonchaks
121 = Zt - Takyric Solonchaks
119 = Zg - Gleyic Solonchaks
123 = S - SOLONETZ
124 = So - Orthic Solonetz
126 = Sm - Mollic Solonetz
125 = Sg - Gleyic Solonetz
61 = Y - YERMOSOLS
62 = Yh - Haplic Yermosols
63 = Yk - Calcic Yermosols
65 = Yy - Gypsic Yermosols
64 = Yl - Luvic Yermosols
66 = Yt - Takyric Yermosols
23 = X - XEROSOLS
24 = Xh - Haplic Xerosols
25 = Xk - Calcic Xerosols
27 = Xy - Gypsic Xerosols
26 = Xl - Luvic Xerosols
71 = K - KASTAZNOZEMS
72 = Kh - Haplic Kastanozems
73 = Kk - Calcic Kastanozems
74 = Kl - Luvic Kastanozems
18 = C - CHERNOZEMS
20 = Ch - Haplic Chernozems
21 = Ck - Calcic Chernozems
22 = Cl - Luvic Chernozems
19 = Cg - Glossic Chernozems
94 = H - PHAEOZEMS
97 = Hh - Haplic Phaeozems
95 = Hc - Calcaric Phaeozems
98 = Hl - Luvic Phaeozems
96 = Hg - Gleyic Phaeozems
58 = M - GREYZEMS
60 = Mg - Gleyic Greyzems
59 = Mo - Orthic Greyzems
28 = B - CAMBISOLS
31 = Be - Eutric Cambisols
30 = Bd - Dystric Cambisols
34 = Bh - Humic Cambisols
32 = Bg - Gleyic Cambisols
37 = Bx - Gelic Cambisols
35 = Bk - Calcic Cambisols
29 = Bc - Chromic Cambisols
36 = Bv - Vertic Cambisols
33 = Bf - Ferralic Cambisols
76 = L - LUVISOLS
80 = Lo - Orthic Luvisols
84 = Lc - Chromic Luvisols
85 = Lk - Calcic Luvisols
83 = Lv - Vertic Luvisols
78 = Lf - Ferric Luvisols
77 = La - Albic Luvisols
82 = Lp - Plinthic Luvisols
79 = Lg - Gleyic Luvisols
90 = D - PODZOLUVISOLS
92 = De - Eutric Podzoluvisols
91 = Dd - Dystric Podzoluvisols
93 = Dg - Gleyic Podzoluvisols
106 = P - PODZOLS
107 = Po - Orthic Podzols
108 = Pl - Leptic Podzols
111 = Ph - Humic Podzols
110 = Pp - Placic Podzols
112 = Pg - Gleyic Podzols
99 = W - PLANOSOLS
101 = We - Eutric Planosols
100 = Wd - Dystric Planosols
103 = Wm - Mollic Planosols
102 = Wh - Humic Planosols
104 = Ws - Solodic Planosols
1 = A - ACRISOLS
6 = Ao - Orthic Acrisols
2 = Af - Ferric Acrisols
4 = Ah - Humic Acrisols
5 = Ap - Plinthic Acrisols
3 = Ag - Gleyic Acrisols
86 = N - NITOSOLS
88 = Ne - Eutric Nitosols
89 = Nd - Distric Nitosols
87 = Nh - Humic Nitosols
43 = F - FERRALSOLS
48 = Fo - Orthic Ferralsols
49 = Fx - Xanthic Ferralsols
47 = Fr - Rhodic Ferralsols
45 = Fh - Humic Ferralsols
44 = Fa - Acric Ferrlsols
46 = Fp - Plinthic Ferralsols
67 = O - HISTOSOLS
68 = Oe - Eutric Histosols
69 = Od - Dystric Histosols
70 = Ox - Gelic Histosols
MISCELLANEOUS LAND UNITS
131 = DS - Dunes / Shifting Sand
132 = GL - Glaciers
133 = RK - Rock Debris
134 = ST - Salt Flats
135 = WR - Water Bodies
136 = ND - No data

4.1.3 Validation

4.1.3.1 Actual verses potential distribution

4.1.3.1.1 Country distribution lists

Table 17 gives a list of countries tamarind is recorded to be distributed as per literature sources. Table 18 gives a list of countries in which tamarind is recorded to distributed in as recorded in the herbaria records from the Royal Botanic garden, Kew. Tamarind is known to be distributed in 73 out of the 88 countries which were identified by the suitability map as having suitable locations. The remaining 15 countries in which the suitability map has classified as suitable but in which tamarind is known not to be distributed are listed in table 19. The 17 countries in which tamarind is known to be distributed but identified as not having suitable locations by the suitability map are listed in table 20. Only two countries identified by both the herbaria and literature distribution maps were not identified as suitable by the suitability map Trinidad and Tobago and the United States of America.

Tamarind distribution country data - Literature					
Country	Reference Source	Country	Reference Source	Country	Reference Source
Afghanistan	1	Ghana	1	Niger	1
Angola	5	Guatemala	1	Pakistan	1
Australia	1	Guinea Bissau	2	Papua New Guinea	1
Belize	4	Guniea	1	Philippines	1
Bangladesh	1	Haiti	1	Puerto Rico	1
Benin	3	Honduras	1	Senegal	1
Brazil	1	India	1	Sierra Leone	3
Brueni	1	Indonesia	1	Singapore	2
Burkina Faso	1	Iran	1	Somilia	6
Cambodia	1	Jamacia	1	Sri Lanka	1
Cameroon	1	Kenya	1	Sudan	1
Chad	1	Laos	1	Tanzania	1
China	1	Liberia	1	Thailand	2
Costa Rica	2	Madagascar	1	The Gambia	2
Cote d' Vorie	1	Malawi	6	Togo	1
Cuba	1	Malaysia	1	Trinidad and Tobago	1
Dominican Republic	1	Mali	1	Uganda	1
Egypt	1	Mauritania	1	USA	1
Ethiopia	1	Mexico	1	Venerzuela	2
Fiji	2	Myanmar	1	Vietnam	1
		Nicaragua	1	Zambia	1

Table 17 Tamarind distribution country list created from literature sources giving country name and reference

1	Salim et al 1998
2	Gunasena and Hughes 2000
3	Desmond 1988
4	El - Siddig
5	Shaw 1947
6	Mahony 1990

Tamarind distribution country data - herbarium records			
Australia	El Salvador	Montserrat	Sri Lanka
Bangladesh	Equatorial Guinea	Mozambique	Sudan
Barbados	Ethiopia	Myanmar (Burma)	Tahiti
Belize	Fiji	New Caledonia	Tanzania
Benin	Ghana	Nigeria	The Bahamas
BRASIL	Guatemala	Northern	Togo
Burkina Faso	India	Oman	Trinidad and Tobago
Burundi	Indonesia	Papua New Guinea	Uganda
Cameroon	Jamaica	Philippines	United States
Cape Verde	Kenya	Saudi Arabia	Vanuata
Central African Republic	Liberia	Senegal	Venezuela
China	Libya	Seychelles	Yemen
Costa Rica	Madagascar	Sierra Leone	Zaire
Cuba	Malawi	Somalia	Zambia
Dominican Republi	Malaysia	South Africa	Zimbabwe
Ecuador	Mexico	Sri Lanka	

Table 18 Tamarind distribution country list, source - herbarium passport data

Country Name	**Presence 1/Absence 0**		
	Suitability Map	**Herbaria distribution data**	**Literature distribution data**
Taiwan	1	0	0
Antigua & Barmuda	1	0	0
Bolivia	1	0	0
Congo	1	0	0
Congo, DRC	1	0	0
Gabon	1	0	0
Guadeloupe	1	0	0
Guyana	1	0	0
Martinique	1	0	0
Panama	1	0	0
Paraguary	1	0	0
Peru	1	0	0
St. Lucia	1	0	0
Colombia	1	0	0
Solomon Is.	1	0	0

Table 19 Countries identified by the tamarind suitability map to have suitable locations but not documented as being within the geographical distribution of tamarind.

Country Name	Presence 1/Absence 0		
	Suitability Map	Herbaria distribution data	Literature distribution data
Afghanistan	0	0	1
Brunei	0	0	1
Cape Verde	0	1	0
Egypt	0	0	1
Iran	0	0	1
Libya	0	1	0
Montserrat	0	1	0
Oman	0	1	0
Saudi Arabia	0	1	0
Seychelles	0	1	0
Tahati	0	1	0
Yemen	0	1	0
Zaire	0	1	0
Zimbabwe	0	1	0
Pakistan	0	0	1
Trinidad and Tabago	0	1	1
USA	0	1	1

Table 20 Countries in which tamarind is known to be distributed but have been identified as not suitable by the suitability map.

4.1.3.1.2 Point distribution map

Figure 13 shows the comparison between current distribution shown by the point distribution map and the predicted distribution of the suitability map. On initial observation it would appear that tamarind is distributed in the same general regions which the suitability map has indicated as suitable. However if we study the frequency table for this ‘overlay’ (Table 21), which shows the number of distribution points at locations assigned with each suitability class, we can clearly see that over 59% of the distribution point locations have been assigned a suitability score of 0 (N1 Not suitable), 31% with a score of 1(S4 marginally suitable) and only 9% with a score of 2 (S3 marginally suitable) indicating a poor match between predicted distribution and actual distribution of tamarind.

The high number of distribution points at locations in which land units had been assigned a score of zero indicates that the species is found growing in a large number of land units for which at least one environmental factor has a value outside the range derived for the model. By studying the frequency table for the ‘overlay’ between each reclassified environmental factor map and the point distribution map (tables 21 – 32) it will be possible to identify for which factor(s) this may be the case.

A number of the environmental factors have a low number of distribution locations assigned a suitability score of 0 (N1 (Not suitable) altitude, annual temperature, maximum temperature hottest month, soil texture topsoil, soil texture subsoil and annual rainfall (tables 17, 19, 20, 25, 26 and 18 respectively) 0.32, 0.96, 2.88, 3.41, 3.41 and 4.16% respectively. This indicates that for these environmental factors few land units in which tamarind is identified as being distributed have values outside that derived for the model.

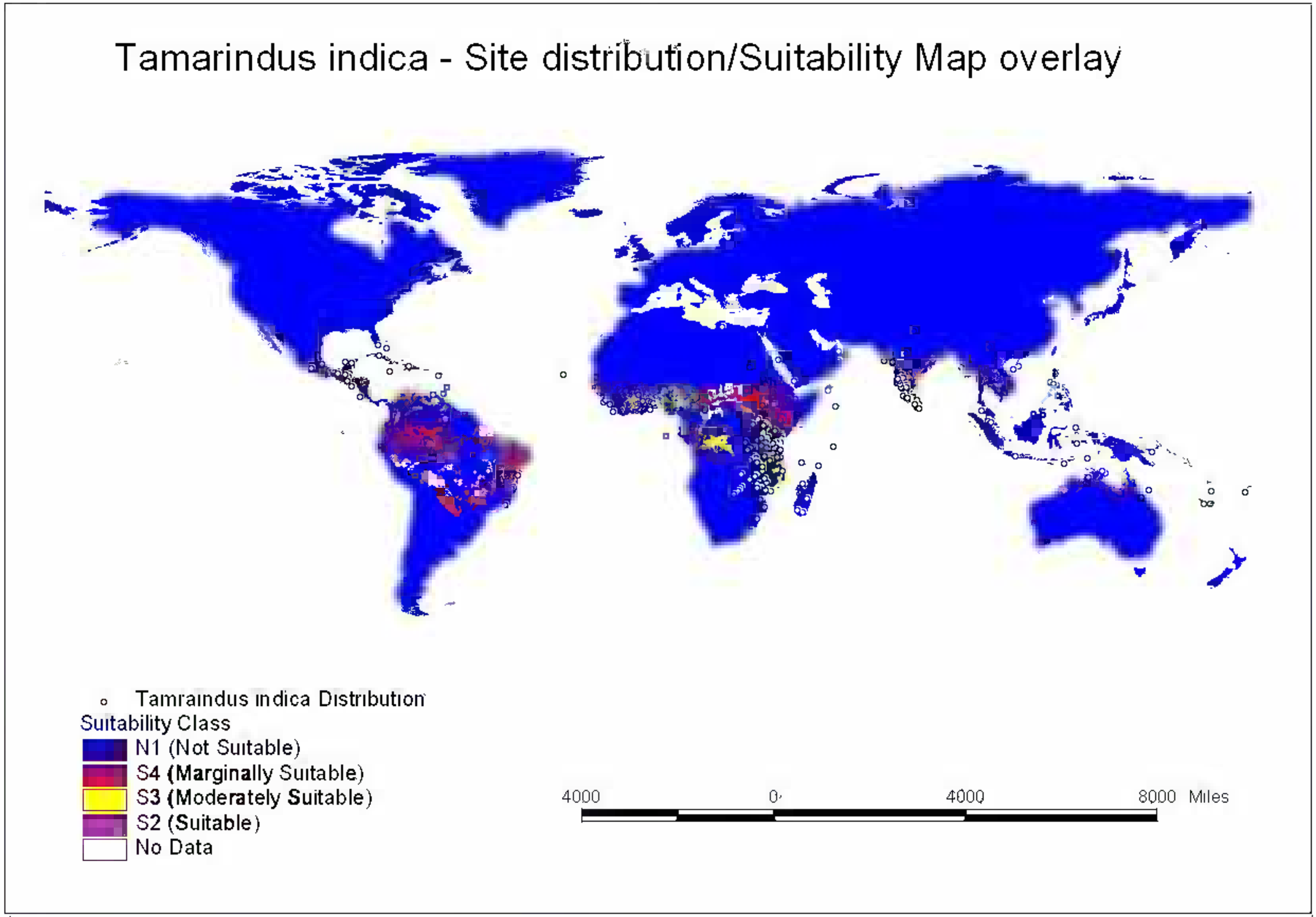
The frequency tables for No. of frost days (table 22) and Soil pH topsoil (table 23) both show a high number of point distribution locations in which tamarind have been assigned as suitability score of 0, 37.5 and 13.897 %respectively. This indicates that it is for these environmental factors that a large number of land units in which tamarind is distributed have values outside that of the range derived for the model. This would suggest that the range for these environmental factors derived from the literature and used in the model does not cover the full range experienced by the species.

It can be assumed that tamarind would be more likely to be distributed at locations which in which conditions are more suitable. It would therefore be expected that if the relationship used to describe the plant-environment response and so assign the suitability score were accurate, the majority of the distribution point locations would be assigned with the highest suitability score, the frequency of locations reducing with the decreasing suitability score.

For the environmental factors; altitude, annual temperature, maximum temperature hottest month, Soil pH subsoil, soil texture topsoil and soil texture topsoil (tables 21, 23, 24, 28, 29, 30 and 31 respectively)this is the case. The highest frequency of distribution locations has been classified with a score of 4 (S1 highly suitable). However for annual rainfall, minimum temperature coldest month, No. of frost days and soil pH topsoil this is not the case. For annual rainfall and soil pH subsoil (tables 22 and 27 respectively) the greatest number of distribution locations 39.1 and 56.3 % respectively have been classified with a score of 2 (S3 marginally suitable). This suggests that the relationship does not accurately describe the plant environment response for these factors.

For a number of the distribution point no classification value could be assigned for that location, this is because the distribution point occurred on a land unit/pixels classed as ‘No Data`. These points could not be assigned a suitability value and are represented by the frequency in the ‘missing’ row. This is due to the gridded nature of the raster datasets being unable to accurately simulate the details of the coastline. For this reason the tables give two percentage values, one to include the missing points and one only including the valid points (those points which have been assigned a value).The values given in the text are that of the valid percentage.

Figure 42 Point distribution map overlaid on to the tamarind suitability map



Overall suitability map					
	Suitability Score	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	173	52.26586103	59.45017182	59.45017182
	1	91	27.49244713	31.27147766	90.72164948
	2	27	8.157099698	9.278350515	100
	Total	291	87.91540785	100	
Missing		40	12.08459215		
Total		331	100		

Table 20

Altitude					
	Suitability score	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	1	0.302114804	0.320512821	0.320512821
	1	14	4.229607251	4.487179487	4.807692308
	2	38	11.48036254	12.17948718	16.98717949
	3	96	29.00302115	30.76923077	47.75641026
	4	163	49.24471299	52.24358974	100
	Total	312	94.25981873	100	
Missing		19	5.740181269		
Total		331	100		

Table 21

Annual Rainfall					
	Suitability Score	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	13	3.927492447	4.166666667	4.166666667
	1	70	21.14803625	22.43589744	26.6025641
	2	122	36.85800604	39.1025641	65.70512821
	3	65	19.63746224	20.83333333	86.53846154
	4	42	12.68882175	13.46153846	100
	Total	312	94.25981873	100	
Missing		19	5.740181269		
Total		331	100		

Table 22

Annual Temperature					
	Suitability Score	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	3	0.906344411	0.961538462	0.961538462
	1	10	3.021148036	3.205128205	4.166666667
	2	74	22.35649547	23.71794872	27.88461538
	3	107	32.32628399	34.29487179	62.17948718
	4	118	35.64954683	37.82051282	100
	Total	312	94.25981873	100	
Missing		19	5.740181269		
Total		331	100		

Table 23

Maximum Temp. hottest month					
	Suitability Score	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	9	2.719033233	2.884615385	2.884615385
	1	30	9.063444109	9.615384615	12.5
	2	45	13.59516616	14.42307692	26.92307692
	3	95	28.70090634	30.44871795	57.37179487
	4	133	40.18126888	42.62820513	100
	Total	312	94.25981873	100	
Missing	System	19	5.740181269		
Total		331	100		

Table 24

Minimum Temp. coldest month					
	Suitability Score	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	38	11.48036254	12.17948718	12.17948718
	1	105	31.72205438	33.65384615	45.83333333
	2	93	28.09667674	29.80769231	75.64102564
	3	61	18.42900302	19.55128205	95.19230769
	4	15	4.531722054	4.807692308	100
	Total	312	94.25981873	100	
Missing		19	5.740181269		
Total		331	100		

Table 25

No. of Frost Days					
	Suitability Score	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	117	35.34743202	37.5	37.5
	4	195	58.91238671	62.5	100
	Total	312	94.25981873	100	
Missing		19	5.740181269		
Total		331	100		

Table 26

Soil pH - topsoil					
	Suitability Score	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	46	13.89728097	15.6996587	15.6996587
	2	165	49.8489426	56.31399317	72.01365188
	4	82	24.7734139	27.98634812	100
	Total	293	88.51963746	100	
Missing		38	11.48036254		
Total		331	100		

Table 27

Soil pH subsoil					
	Suitability Score	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	23	6.948640483	7.849829352	7.849829352
	2	101	30.51359517	34.47098976	42.32081911
	4	169	51.05740181	57.67918089	100
	Total	293	88.51963746	100	
Missing		38	11.48036254		
Total		331	100		

Table 28

Soil Texture - topsoil					
	Suitability Score	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	10	3.021148036	3.412969283	3.412969283
	3	71	21.45015106	24.23208191	27.64505119
	4	212	64.04833837	72.35494881	100
	Total	293	88.51963746	100	
Missing		38	11.48036254		
Total		331	100		

Table 29

Soil Texture - subsoil					
	Suitability Score	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	10	3.021148036	3.412969283	3.412969283
	3	133	40.18126888	45.39249147	48.80546075
	4	150	45.31722054	51.19453925	100
	Total	293	88.51963746	100	
Missing		38	11.48036254		
Total		331	100		

Table 30

Soil Drainage					
	Suitability Score	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	23	6.948640483	7.849829352	7.849829352
	1	64	19.33534743	21.84300341	29.69283276
	2	6	1.812688822	2.04778157	31.74061433
	3	30	9.063444109	10.23890785	41.97952218
	4	170	51.35951662	58.02047782	100
	Total	293	88.51963746	100	
Missing		38	11.48036254		
Total		331	100		

Table 31

Soil Depth					
	Suitability Score	Frequency	Percent	Valid Percent	Cumulative Percent
Valid	0	23	6.948640483	7.849829352	7.849829352
	1	27	8.157099698	9.215017065	17.06484642
	2	144	43.50453172	49.14675768	66.2116041
	3	53	16.01208459	18.0887372	84.3003413
	4	46	13.89728097	15.6996587	100
	Total	293	88.51963746	100	
Missing		38	11.48036254		
Total		331	100		

Table 32

4.1.3.2 Comparison with Environmental profile

Table 33 shows the comparison between the maximum and minimum values used in the model (derived from the literature) with the maximum and minimum from the statistical distribution summary (Environment profile) for those environmental factors derived from IPCC datasets The range interval derived for the model for S1 (highly suitable is also compared with the mean and mode range from the environment profile. Table 34 – 36 show the minimum, maximum and optimum values used in the model compared with the minimum, maximum and mode values for environmental factors derived from the TERRSTAT dataset (tables 34 – 36). As the statistical summary was derived from the distribution map, this analysis supports many of the conclusions made from the previous analysis between the point distribution map and the suitability map (Section 4.1.3.2).

For many of the environmental factors which showed a low number of distribution point locations assigned with a suitability score of 0, the difference between maximum and minimum value used to define the range derive the model and those derived from the statistical distribution is small, i.e. altitude, mean annual temperature, mean annual rainfall, soil texture topsoil and soil texture subsoil. For these environmental factors most of the variation in the conditions experienced by the species is encompassed by the range used in the model.

For No. of frost days and Soil pH topsoil a large number of distribution points location were assigned with a suitability score of 0, The minimum and maximum value used to define the range derive the model were different to those derived from the statistical distribution. This is particularly the case for No. of frost days, locations on the point distribution map are found in locations having up to 58 days of frost as opposed to the maximum of 0 days derived from the literature, however it can be seen from the frequency of the points is such that 62.9 % of distribution locations are found with less that one days frost, 76% of distribution points found at locations with 3 or less days frost and 93% with less than 10 days. For these environmental factors the variation in the conditions experienced by the species was not encompassed by the range used in the model.

Analysis of statistical distribution and comparisons between the S1 interval and the mean and mode range can be used to support the argument that the relationships used by the model do not accurately describe the plant – environment responses for all environmental factors. As it was assumed that tamarind would be more likely to be distributed at locations which are more suitable, the highest frequency of locations should be found at an interval of the range similar to that derived as highly suitable for the model. The distribution should also follow the curve assumed by the relationship used to describe the plant response for that factor, with smaller frequencies of points at intervals which are less suitable. The frequency distribution is illustrated by the figures (14 – 20)

Only the histogram for altitude (figure 15) show a distribution relationship expected if it followed the model. With a one tailed with a proportional decrease in frequency with increasing altitude, the mode range being very similar to the S1 (highly suitable) interval class described by the model. If the model accurately described the plant response for number of frost days, the histogram (figure 14) would show a similar frequency distribution to that shown by altitude; however this was not the case. The number of frost day shows a shape decrease in frequency over a small percentage of the total range. The annual rainfall and mean annual temperature distribution (figure 18 and figure 19 respectively) are not symmetrical do not increase or decrease proportionally, as assumed by the model. For mean annual rainfall, although the range is similar to that used in the model, the highest frequency of distribution points comes at a much lower rainfall than that predicted by model.

The ranges derived from the point distribution data are much greater than that derived from the literature for maximum temperature hottest month and minimum temperature coldest month, the model only considered maximum temperature to be limiting at high temperature and minimum temperature at low temperature extremes and so used a one tailed relationship model, however the data derived from the point distribution map shows them to have a two tailed distribution and to be limiting at both the high and low extremes of their range.

As many of soil factors the suitability index was derived from descriptive terms in the literature, it is not possible to relate these factors to the discussion in terms of the accuracy of the model to describe the plant environment relationships.

Environmental Characteristic	Model data			Site Distribution derived Data			
	Minimum	Maximum	S1-range	Minimum	Maximum	Mode range	Mean
Altitude (kmsl)	-	2	<0.5	0.001	2.058	0 -0.51	0.54
Number of Frost Days	0	0	0	0	58.6	0 - 14.6	2.8
Minimum Temperature Coldest Month	12	25	>21.5	1.3	23.85	12.9 - 17.9	15.7
Maximum Temperature Hottest month	30	40	<32.5	23.4	43.3	28.4 - 33.3	33.4
Annual Rainfall	250	4500	1843.5 - 2906	13.4	4549.3999	508.4 - 1147.6	1243.2
Mean Annual Temperature	17	30	21.875 - 25.12	14.6167	29.2917	24 - 26	24.77

Table 33 Comparison of literature derived data and site distribution derived data for suitability ranges for environmental ranges

Environmental factor	Literature derived		Point Distribution derived	
	Optimum (S1)		Mode range	
	Terrsatat code	Classification	Terrsatat code	Classification
(DEPTHW) Effective soil dept cm	50 - 54	150 - 300(Very Deep)	40 - 45	100 - 150 (Deep)
(PHW_S) pH_subsoil	30 - 35	>5.5 - 7.2	30 - 35	>5.5 - 7.2
(PHW_T) pH_topsoil	30 - 35	>5.5 - 7.2	30 - 35	>5.5 - 7.2
(TXW_S) Textural class_subsoil	30 - 34	Medium (loam)	30 - 35	Medium (loam)
(TXW_T) Textural class_topsoil	30 - 34	Medium (loam)	30 - 35	Medium (loam)
DRAIN_CODE (Drainage Code	41 - 48	Well drained	41 - 48	Well drained

Table 34 shows the optimum values used in the model compare with the mode value in the environmental profile (TERRSTAT database)

Environmental factor	Literature derived		Point Distribution derived	
	Minimum		Minimum range	
	Terrsatat code	Classification	Terrsatat code	Classification
(DEPTHW) Effective soil dept cm	15 - 25	10 - 50 (shallow)	10 -15	<10 (Very Shallow)
(PHW_S) pH_subsoil	20 - 25	4.5 - 5.5	10 -15	<4.5
(PHW_T) pH_topsoil	20 - 25	4.5 - 5.5	10 - 15	<4.5
(TXW_S) Textural class_subsoil	20 - 24	Coarse (sand)	20 - 24	Course (sand)
(TXW_T) Textural class_topsoil	20 - 24	Coarse (sand)	20 - 24	Course (sand)
DRAIN_CODE (Drainage Code	20 - 28	Excessivily drained	20 - 28	Excessively drained

Table 35 shows the minimum values used in the model compared with that in the environmental profile (TERRSTAT database)

Environmental factor	Literature derived		Point Distribution derived	
	Maximum		Maximum range	
	Terrsatat code	Classification	Terrsatat code	Classification
(DEPTHW) Effective soil dept cm	50 - 54	150 - 300mm(Very deep)	50 - 54	150 - 300 (Very Deep)
(PHW_S) pH_subsoil	40 - 45	7.2 - 8.5	50 - 54	>8.5
(PHW_T) pH_topsoil	40 - 45	7.2 - 8.5	50 - 54	>8.5
(TXW_S) Textural class_subsoil	40 - 43	Fine (Clay)	40 - 43	Fine (clay)
(TXW_T) Textural class_topsoil	40 - 43	Fine (Clay)	40 - 43	Fine (clay)
DRAIN_CODE (Drainage Code	60 - 68	Imperfectly drained	80 - 87	Very poorly drained

Table 36 shows the maximum values used in the model compared with that in the environmental profile (TERRSTAT database)

4.1.4 Field data analysis

4.1.4.1 Regression Analysis

The trees were grouped by age group as shown in the table below.

Age	Age Group
1 - 5	1
6 - 10	2
11 - 15	3
16 - 20	2
21 - 30	5
31 - 50	6
51 - 70	7
>70	8

Table 37

For each age group the girth, height and yield was plotted against suitability score linear regression analysis was carried out to identify linear correlation between the growth parameter, yield and the suitability score.

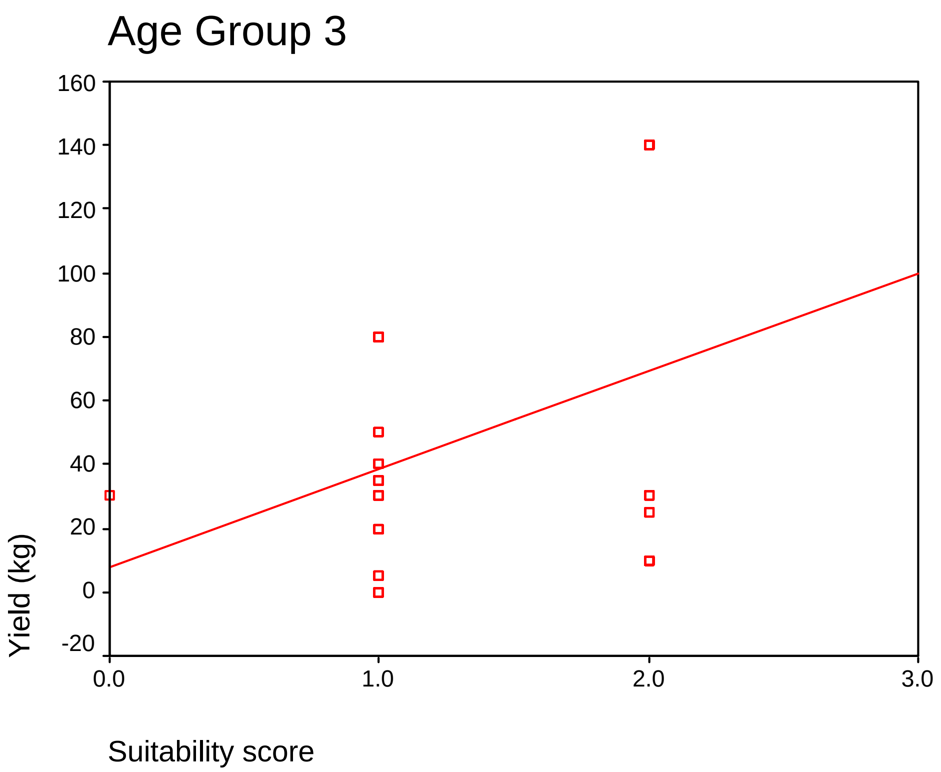


Figure 42

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.353[a]	.124	.113	40.95797686

a. Predictors: (Constant), Suitability score

b. Dependent Variable: Yeild (kg)

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	18808.889	1	18808.889	11.212	.001[a]
	Residual	132526.9	79	1677.556		
	Total	151335.8	80			

a. Predictors: (Constant), Suitability score

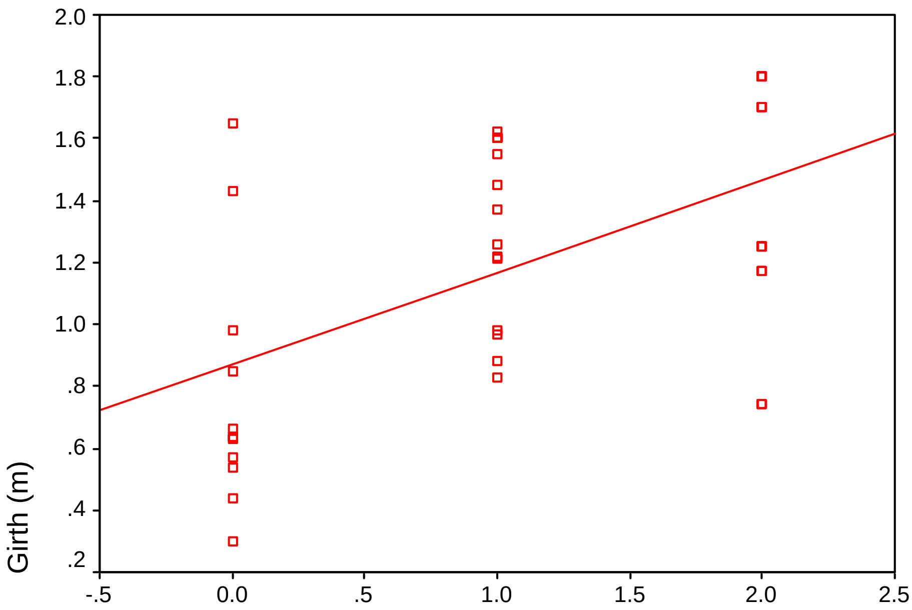
b. Dependent Variable: Yeild (kg)

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	8.062	13.032		.619	.538	-17.877	34.001
	Suitability score	30.667	9.158	.353	3.348	.001	12.437	48.896

a. Dependent Variable: Yeild (kg)

Age Group 5



Suitability score

Figure 43

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.544[a]	.296	.276	.37409038

a. Predictors: (Constant), Suitability score

b. Dependent Variable: Girth (m)

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	2.117	1	2.117	15.124	.000[a]
	Residual	5.038	36	.140		
	Total	7.155	37			

a. Predictors: (Constant), Suitability score

b. Dependent Variable: Girth (m)

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	.871	.101		8.635	.000	.666	1.075
	Suitability score	.298	.077	.544	3.889	.000	.142	.453

a. Dependent Variable: Girth (m)

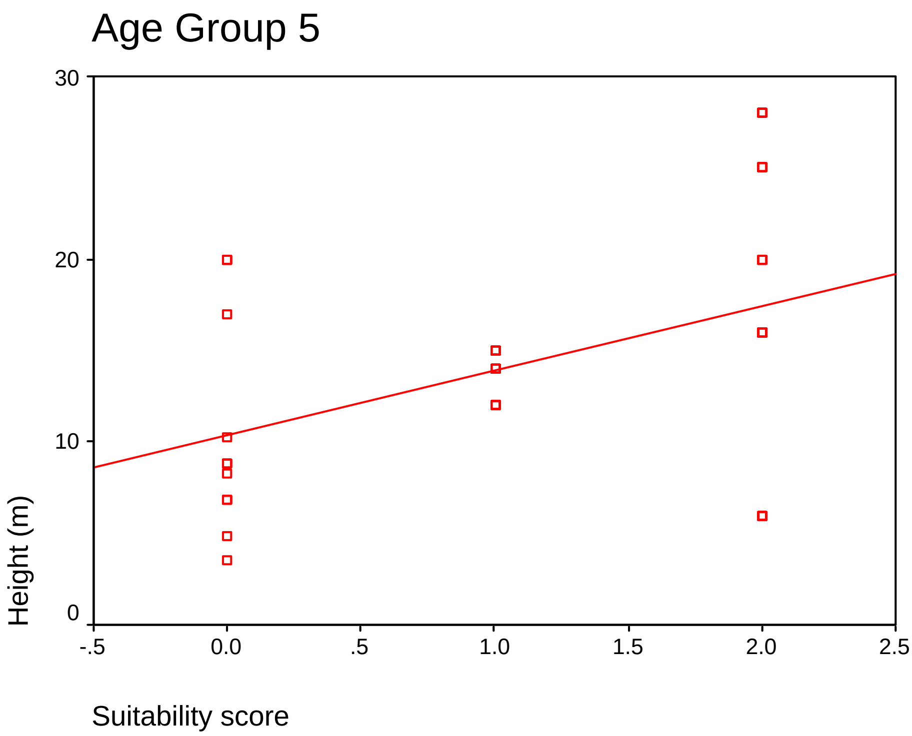


Figure44

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.461[a]	.212	.190	5.56342798

a. Predictors: (Constant), Suitability score

b. Dependent Variable: Height (m)

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	300.125	1	300.125	9.697	.004[a]
	Residual	1114.262	36	30.952		
	Total	1414.388	37			

a. Predictors: (Constant), Suitability score

b. Dependent Variable: Height (m)

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients			95% Confidence Interval for B	
		B	Std. Error	Beta	t	Sig.	Lower Bound	Upper Bound
1	(Constant)	10.377	1.500		6.919	.000	7.335	13.419
	Suitability score	3.544	1.138	.461	3.114	.004	1.236	5.852

a. Dependent Variable: Height (m)

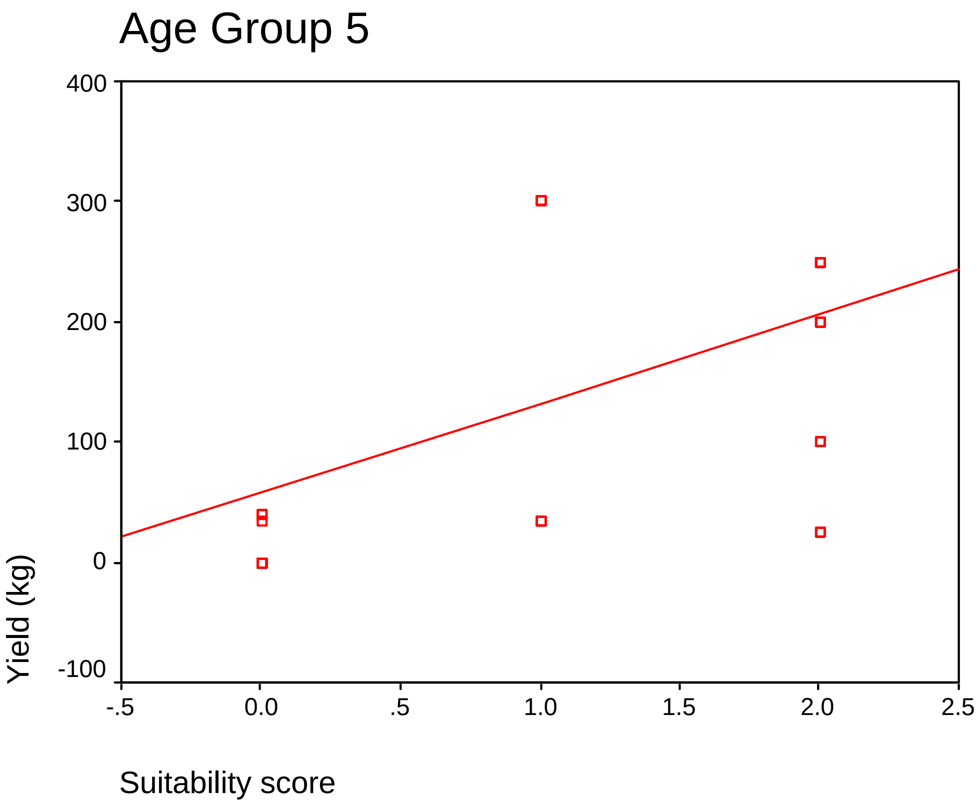


Figure 45

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.512[a]	.263	.243	105.867591

a. Predictors: (Constant), Suitability score

b. Dependent Variable: Yield (kg)

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	147613.7	1	147613.658	13.170	.001[a]
	Residual	414694.0	37	11207.947		
	Total	562307.7	38			

a. Predictors: (Constant), Suitability score

b. Dependent Variable: Yield (kg)

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	58.267	28.956		2.012	.052	-.404	116.938
	Suitability score	73.835	20.345	.512	3.629	.001	32.612	115.059

a. Dependent Variable: Yield (kg)

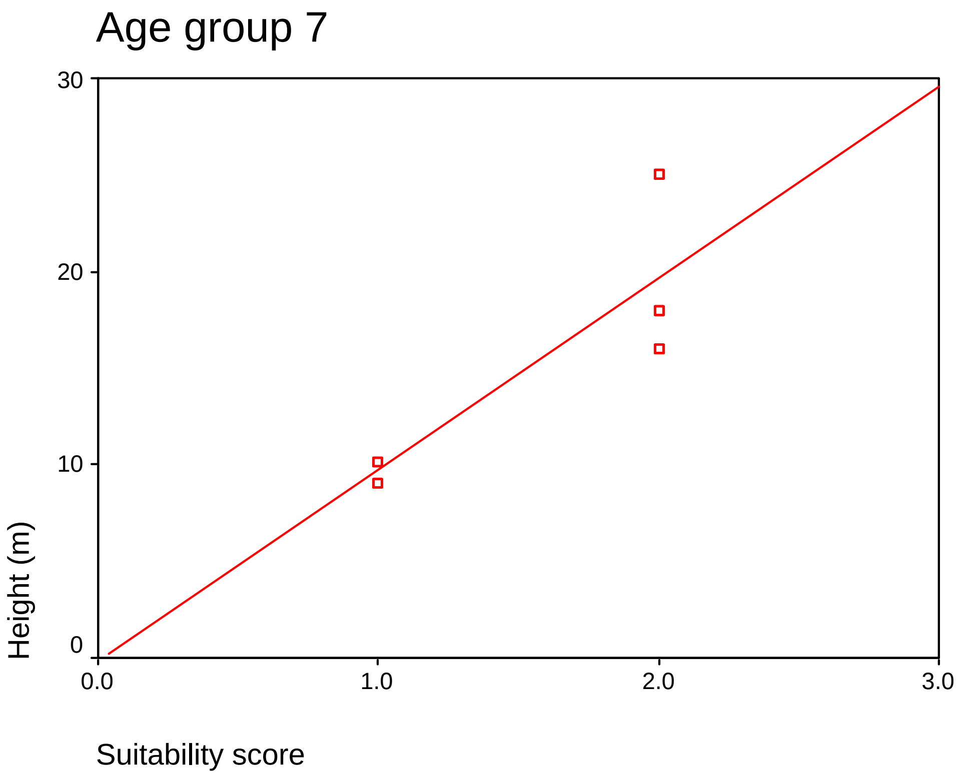


Figure 46

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.829[a]	.686	.667	3.35670970

a. Predictors: (Constant), Suitability score

b. Dependent Variable: Height (m)

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	394.684	1	394.684	35.029	.000[a]
	Residual	180.280	16	11.268		
	Total	574.964	17			

a. Predictors: (Constant), Suitability score

b. Dependent Variable: Height (m)

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	-.200	2.907		-.069	.946	-6.363	5.963
	Suitability score	9.933	1.678	.829	5.918	.000	6.375	13.491

a. Dependent Variable: Height (m)

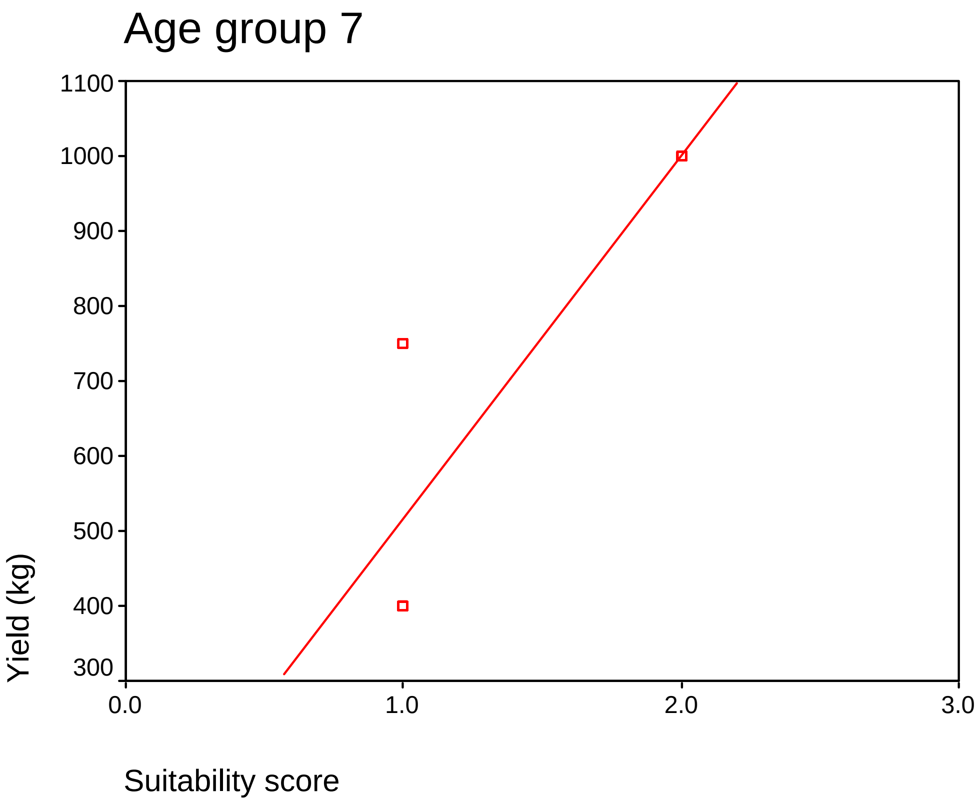


Figure 47

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.880[a]	.774	.746	142.886902

a. Predictors: (Constant), Suitability score

b. Dependent Variable: Yield (kg)

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	560666.7	1	560666.667	27.461	.001[a]
	Residual	163333.3	8	20416.667		
	Total	724000.0	9			

a. Predictors: (Constant), Suitability score

b. Dependent Variable: Yield (kg)

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	33.333	136.804		.244	.814	-282.137	348.803
	Suitability score	483.333	92.233	.880	5.240	.001	270.643	696.023

a. Dependent Variable: Yield (kg)

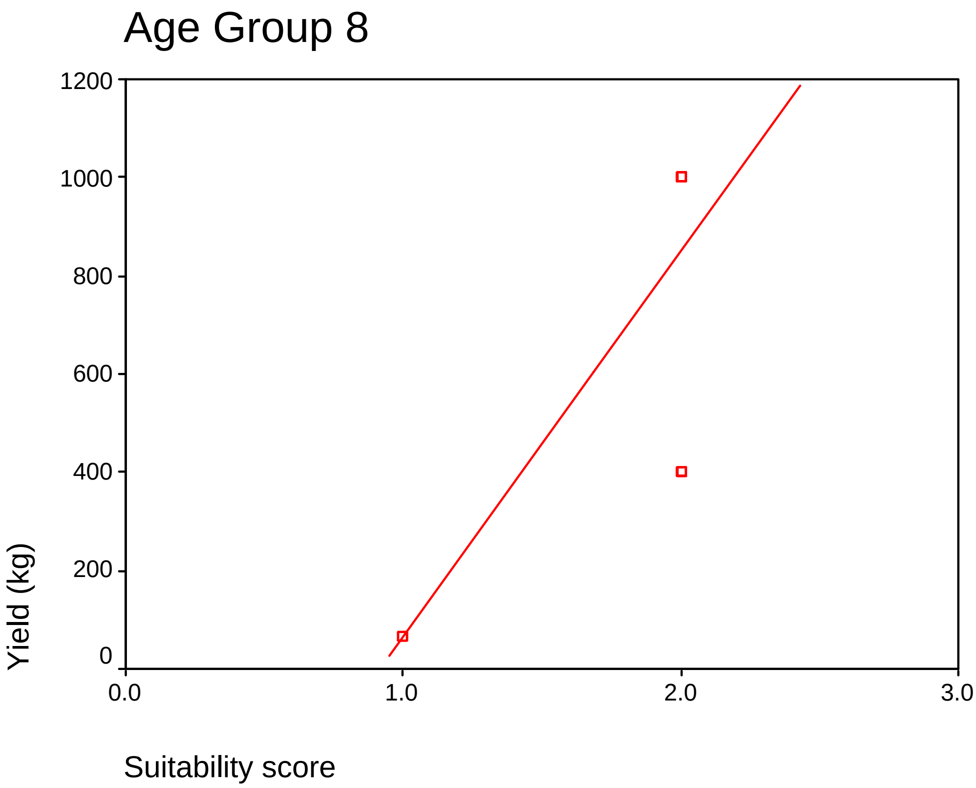


Figure 48

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.591[a]	.349	.329	259.807621

a. Predictors: (Constant), Suitability score

b. Dependent Variable: Yield (kg)

ANOVA[b]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1159953	1	1159952.941	17.184	.000[a]
	Residual	2160000	32	67500.000		
	Total	3319953	33			

a. Predictors: (Constant), Suitability score

b. Dependent Variable: Yield (kg)

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	-720.000	370.283		-1.944	.061	-1474.241	34.241
	Suitability score	785.000	189.366	.591	4.145	.000	399.275	1170.725

a. Dependent Variable: Yield (kg)

Figure 42 – 48 show the scatter diagram and results of the linear regression analysis for those growth parameters which showed a significant correlation with the suitability score. A number of age groups did not show significant correlation for any of the growth parameters. Only age group 5 showed a significant positive correlation for all growth parameter (yield, height and girth).

Yield showed significant positive linear correlation with suitability score in age groups 3, 5, 6, 7, 8 the highest correlation coefficient found for age group 7 (r^2 = 0.774) the lowest found in age group 3 (r^2 =0.124). Height showed significant positive linear correlation with suitability score for age groups 7 (r^2= 0.687) and 5 (r^2= 0.212). Girth showed significant positive linear correlation with suitability score for age group 5 (r^2 = 0.295).

Significant linear correlation was found between suitability score and all three parameters, girth, height and yield with maximum correlation coefficient values of 0.544, 0.829 and 0.880 respectively indicating a reasonable correlation between both vegetative and reproductive growth and suitability score. However for measure of girth only age group 5 showed significant correlation, for height only age group 5 and 7 and for yield only groups 3, 5, 6, 7 and 8.

The trees in age group 1 were not yet bearing and so it was not possible to find any relationship between suitability and yield for this age group. Other than this why some age groups have shown significant correlation for the growth parameters and other haven't and why yield shows correlation with suitable conditions for more groups than girth and height is more difficult to explain.

There is variation in the number of samples between age groups, also an equal sample of each age group has not been taken from all areas and this may explain in part why variation is seen between them. It may be the case that there is no relationship between suitability score and the growth parameters and the relationship although significant is purely due to chance.

5 Discussion and Conclusions

5.1 Validation

At a country level the model performed reasonably well with 73 out of the 88 countries in which tamarind is recorded as distributed listed as suitable. This validation was at a very broad scale and as only considered weather areas were suitable or not suitable, it did not consider the class of suitability assigned and therefore did not test the plant environment relationships used in the model

A number of factors showed differences seen between the ranges derived from the environment profiles and those used in the model, and a large number of distribution locations being classified as zero when overlaid onto the reclassification map was overlaid with the point distribution map. Some of the small differences seen between the ranges, and the reasons for a number of distribution locations being classified as zero when overlaid onto the reclassification maps could be explained due to the fact that the current distribution is effected by circumstances at particular tamarind distribution locations that are not considered by the model. For example in the case of mean annual rainfall the minimum value given in the literature is 250 mm (Gunasena and Hughes 2000), however the minimum annual rainfall identified by the environmental profile is given as 13.4 mm (location; Dongola, Northern Province, Sudan lat. 19.1667 long. 30.4833). However the fact it is able to survive with such low rain may be due to the fact that it is growing near an underground water course or seasonal stream. Gunasena and Hughes (2000) do state that where water is low the trees are normally located near the water table or along water courses; however they give the example of the Sahel, where annual rainfall is 300 – 400mm. Factors such as ground water cannot be easily accounted for by the model, partly because it does not consider interaction between different environmental factors and partly due to lack of information and dataset. However this cannot explain large difference in the range for factors such as ‘Number of Frost days’.

For many environmental factors the highest frequency of distribution locations were not classified with S4 when the distribution map was overlaid on to the reclassification map. The statistical distribution derived from the distribution map did was not that expected if it followed the relationship used in the model. Mean annual rainfall for example did not show a symmetrical distribution. The mean value (1243.2) and mode range (508 – 1147mm) were much lower than the central value or median of the range and so lower than the S1 interval derived by the model (1843 – 2906mm). This indicates that the relationships for these environmental factors do not accurately model the plant response. Many of the literature sources also give tamarind’s optimum annual rainfall value as lower than the range interval derived by the model. Gunasena and Hughes (2000) state although tamarind can be found in areas with between 250 and 4000 mm it will grow well between 500 – 1500mm. Indiaagronet (1990) gives the optimum rainfall requirement as 750 – 1900. Ecocrop (FAO 1994) however states that on the states that although rainfall becomes optimum at 800mm and does not become limiting until 3000mm.

The suitability map defining the over all suitability score compared very poorly with the point distribution map, 59% of distribution locations were classified as unsuitable for the adaptation of tamarind. This is most likely due to inaccuracies in the ranges and the plant environment relationship assumed by the mode as discussed above. This will be enhanced by the fact the ‘law of minimum’ method which does not allow favourable factors to compensate for unfavourable ones, is used to combine the reclassification maps to produce the suitability map. Meaning that environmental factors being classified with low suitability factors due to error in the range or plant environment relationships can have a great affect on the over all suitability.

Although the regression analysis did show significant correlation, in at least one age group between the suitability score with height, girth and yield. Most age groups do however show a significant relationship between suitability score and yield, The poor consistency within results between age groups and between the performance factors means that these results must be viewed with caution. The poor match between locations described as suitable by the model and the point distribution map locations indicate that the relationships used in the model do not accurately represent all the plant responses. This may be improved by modifying a number of the environmental factor ranges, however the major limiting aspects of the model is it uses 3 very simple relationships to describe the plant response to the environment. These were created based on a very simple yet reasonably sound ecological principle, as there was insufficient information available to develop individual plant response relationship for each environmental factor for each species. It is clear however from the validation analysis that this method is over simplistic and the relationships do not accurately simulate the plants responses to the various environmental factors.

Plant species differ in their phenotypic adaptations they have developed to deal with environmental conditions. It is therefore unlikely that they will respond to variations in the environment in the same way. In this model the relationships describing the plants responses have been assumed, other than extreme values of the range derived from the literature, it is not based on any experimental or observational data, which could be used to accurately model the plant response. By using the same relationships for each species the model has not attempted to describe the variation in plant responses shown by different species. It has used relationships based on assumption and not real data and by using only 3 relationships to describe the variation response to different environmental factors it has oversimplified the situation. In order to improve the accuracy of predicting suitable locations, the plant responses to all environmental factors for each species should be individually modelled.

5.2 Proposal for future work

5.2.1 Development of environment-plant relationship model

One of major limitations identified for the method is that only 3 relationships were used to describe the plant environment responses for of all environmental factors for all species modelled. It is important therefore to identify some methodology to derive individual relationships that accurately model the species response to each environmental characteristic, as discussed above the information available for the plant environment responses is not available for such unknown crops due to lack of experimental research.

5.2.1.1 Statistical modelling

Statistical modelling can be used to quantify the relationship between the plant and the environmental factors. The tree performance measurement recorded during the field survey (height, girth and yield) will be plotted against the environmental characteristics values derived from the datasets to identify any correlation. Statistical modelling can be used to quantify observed relationships and use these to predict future situations based on statistical inferences. Using regression analysis algebraic equation can be derived describing the plant response.

Simple regression can be used to produce a regression equation for each environmental factor individually for each of the plant response indicators (height, girth and yield). A single predictor variable may be enough to explain the observed plant response however other than in a controlled environment several factors usually limit plant growth and yield (Rossiter 1994). The relationship between a single independent variable (an environmental factor) with the dependent variable (height, girth, or yield) may be due to the effect of covariance with another independent variable.

Multiple regression can be carried out using all environmental factors; this will produce a multivariate regression equation which will include all independent variables. In multiple regression an independent variable is correlated to the dependent variable, after controlling for all other independent variables. By calculating the part correlation it will be possible to identify which independent variables account for most of the variance in each of the dependent variables (height, girth and yield). Those factors which account for little of the variation or show a high level of covariance with other variables can be discarded from the model. As well as producing a valid model this will give an indication as to which environmental factors significantly effect the performance indicators and if different environmental factors are responsible for variation in the different performance indicators.

Regression analysis also gives the strength of the relationship; this is measured by the coefficient of determination, which the correlation coefficient squared. This gives an indication on how much of the relationship is based on the environmental factor(s) and how much is due to chance, this could give an indication on how much of the variation in growth and yield maybe due to other factors such as genotype.

It must be considered that the data was collected only from eastern India (for field survey locations see figure 8). This means the model for the environmental factors will only give the relationship for the range found with this area. It is not possible to extrapolate the model to include higher or lower values found outside this region. Although a wide amount of climatic and soil variation was covered during the field work it may not have covered the full range for all environmental factors encountered by the species.

One solution is to assume the model is only valid for this area of India, although it would be preferable to acquire observational values for other regions or even countries. This data can be used to validate the model, if the original observations was truly representative of the desired sample space, we would expect to obtain the same parameters from the regression equation derived from the new sample (new observations) Proving the model to be valid over a larger area, even a global scale.

Rossiter (1994) stated that statistical analysis will not work unless there is sufficient data on which to base statistical inference and so is not appropriate for new land uses or areas with insufficient samples. The data collected during the field study is limited in geographic areas as discussed above as well as by the number of samples. The problem of lack of number of samples is amplified due to the tree sampled ranging in ages from 3 – 80 years, an assumption can be made that age will be positively related with all growth indicators. Therefore tree will have to be grouped by age before regression analysis can be conducted. It may however be possible to overcome this problem if the relationship between age and yield can be derived an index developed.

5.2.1.2 Developing models from informal data

Hackett (1988) developed a method which used informal data to develop plant notational relationships to express the plants response to environmental factors. Methods are suggested below to derive such simple relationships for underutilised species.

The Ecocrop database (FAO 1984) gives information on environmental requirements in terms of four factors

- Minimum: the minimum conditions for practical production.
- Optimum minimum: minimum conditions required for optimal growth and yield
- Optimum maximum: maximum conditions required for optimal growth and yield
- Maximum: the maximum conditions for practical production.

These four values can be used to produce a the relationships are expressed as spline curves with characteristic plateau shape as shown in figure 1 (Chapter 1)

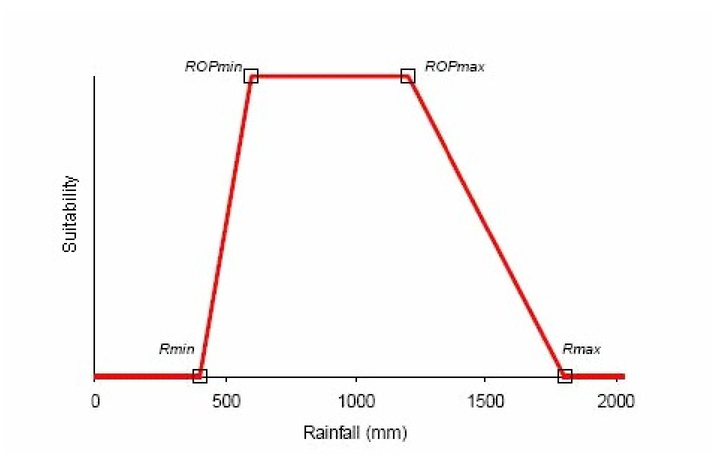


Figure 49

However Ecocrop includes data for a limited number of characteristic and has information for a limited number of species. For those factors not included for species which are not included INFER (see chapter 2) can be used to develop further relationships, data can be collected from expert knowledge names can be acquired from the ICUC database (unpublished) and from the environment profile to identify minimum and maximum values. However as stated by Hackett and Vanclay (1997) these relations are rarely adequate and require further testing and modification

So an alternative method was sought which would initially provide a more accurate and complex relationship. The use statistical distribution from the environment profile can be used to develop a relationship for the plant environment response as shown below.

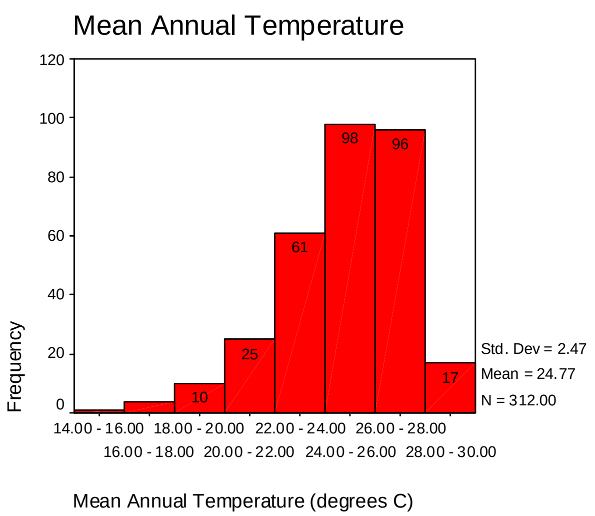


Figure 50

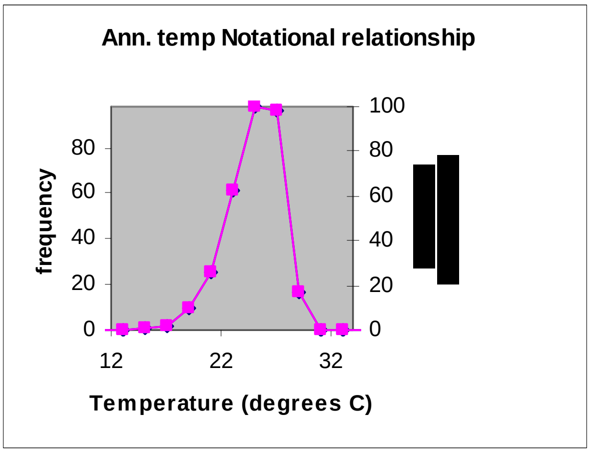


Figure 51

Interval class	Plotted value	Frequency	% of mode	% of max performance
-	13	0	0	0
14 - 16	15	1	1.02	1.02
16 - 18	17	2	2.04	2.04
18 - 20	19	10	10.2	10.2
20 - 22	21	25	25.51	25.51
22 - 24	23	61	62.24	62.24
24 - 26	25	98	100	100
26 - 28	27	96	97.95	97.95
28 - 30	29	17	17.34	17.34
-	31	0	0	0

Table 38

The Histogram in figure 50 shows the statistical distribution of mean annual rainfall at locations in which tamarind is known to be distributed. The total rainfall range is broken into a number of equal interval classes and the frequency recorded from the environment profile as shown in table 38. The mode range is assumed to be the optimum condition that is 100% of the maximum performance and the other interval classes as a percentage ratio of the mode range. The middle value of the interval is plotted. Suitability scores can be assigned based on % of the maximum performance. The result is a relationship as appears in figure 51.

Such model can be developed for all environmental factors for which digital datasets are available and for all species in which point distribution information is available. Digital environmental datasets can be reclassified and suitability maps can be produced based on these models. These will then be tested and results compared to validation results from the original model to see if the method has increased the accuracy of the model.

5.2.2 Water balance model

The model contains no measure of water stress; this was due to the fact that there was very little information in the literature on the plants response to water availability. Using the WATBAL model described in Hackett (1988) it should be possible to develop a dataset of AET/PET and using the species point distribution map to extract information to create an environment profile from which a simple notational relationship between suitability and water availability can be developed for each species (see below).

5.2.3 Dynamic aspect

Many factors which affect plant growth or yield are by nature dynamic (time – dependent), all climatic factors vary with time. The present model is static; it uses land characteristics which summarise the seasonal variation throughout the year. This is a limitation as when considering factors such as the water balance model above, simply calculating the annual water deficit often is not as important as the deficit during different parts of the year. This can be taken into account by carrying out the suitability analysis on a monthly basis. This could be related to the time required to complete its growth cycle and the overall suitability for the year calculated based on the optimum score within a continuous period of this duration. One consideration however is if conditions are favourable all year round the plant may continue to grow all year round and and may even produce 2 crops with a year.

5.2.4 Distribution maps and Environment Profiles

Completion of point distribution maps for the jackfruit and ber will allow the production of environment profiles for these species. Distribution Information has already been collected for ber and jackfruit from herbarium records, field data, germplasm records and literature sources. Germplasm accession data from Asia for jackfruit and Pakistan for ber was made available through the UTFANET project. This data must be organised and coordinate data must be assigned to these locations.

5.3 Populations structure

A statistical summary of variation or height, dbh and yield with the population will be produced. The data will be grouped by agro climatic zones and subpopulations compared using ANOVA, indicating if variation in the population might be related to climate and soil factors. The use of cluster analysis will group the population based on the morphological variation, whether these groups show geographical separation which relates to the agro climatic variation may give a further indication of how much of the variation in the population can be described by climate and soil factors and how much might be described by other environmental factors or genetic variation.

5.4 Phenology data

Flowering and fruiting time varies with location for both tamarind (Gunasena and Hughes 2000) and ber (Pareek 2001). Phonological variation in many UTFT species is thought to be related to climatic factors as well as genotype. Flowering and fruiting time in recorded for each species during the field work will be plotted against climatic factors. Regression analysis will be carried out to find the relationship between these factors and the plant phenology. The strength of the relationship may give an indication as to how much of the phonological variation relates to climate of how much may be related to other factors.

5.5 Socioeconomic and agronomic analysis

Analysis of the socioeconomic data collected in the will be carried out. This should result in a number of case studies on the various productions systems and uses and importance place on the crop based on the type of environment in which they are grown.

5.6 Database

The rest of the field survey data will be entered into the database, along with all data germplasm characteristic data collected from the UTFANET project. The database will be combined with a larger database produced by ICUC on other aspects relating UTFT’s which will available as a public information source.

5.7 Socio – economic Evaluation

It is important to consider socioeconomic and cultural aspects when consider which locations are suitable location to grow a crop. Indexes will also be developed in order to rate land for suitability based on such factors. Little work has been carried out on investigating on which factors it is possible to consider, based on what data is available etc, listed below are some initial ideas;

- Distance to Natural forest –land will be assigned a suitability classification based on distance to natural forest, to prevent possible encroachment or damage to natural stands.

- Distance/time to market –land will be assigned a suitability classification based on distance to too the nearest city, this will depend on the storage time of harvested products and the ability to process the product before travel.

- Distance to major road - land will be assigned a suitability classification based on distance to the nearest main road; this will depend on the storage time of harvested products and the ability to process the product before travel.

- Distance to export – land will be assigned a suitability classification based on distance to too nearest sea or air port.

- Land type – A land type datasets will be used and suitability classifications can be assigned depending on the land type, for example marginally land will be classified as highly suitable while land of high quality rating suitable for monoculture crops will be assigned as a lower suitability score.

- Major land use - This may effect the suitability of the crop as well as it main use, In part of the Western Ghats, India the main purpose for growing jackfruit is not for it fruit but as shade for coffee the main cash crop in the region

- Protected land and national parks – fruit tree production cannot take place in these areas and so they must be deemed unsuitable in spite of other classifications

5.8 Biotic Evaluation

Pests and disease can have a major impact on both the level economic and nutritional benefits provided by UTFT species. In India alone 40 insects pest are have been recorded as attacking tamarind causing severe economic losses. Several diseases have been reported to infect tamarind, in Karnataka, India stony fruit disease caused by the fungal pathogen (*Pestalotia macrotricha* Syd.) (Gunasena and Hughes 2000)
For each species a literature survey needs to be conducted to investigate the main pests and disease which attack and their effect on growth and yield. Information on the pest's life cycle and distribution can be acquired. Temporal distribution maps produced could be produced and suitability classes can be assigned based the presence or absence (if possible density) of the insect or pest during particular stages of the plants growth cycle, and the potential degree of damage or loss of yield it may cause to the plant. A similar process can be carried out for diseases which infect the species, this may relate to period of the year in which environmental condition promote the infection such as increased moisture effecting the level of tree rots.

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7

Appendices

7.1 Appendix 1

7.1.1 Field Work Questionnaire

Location: Long: Lat:
State:
District:
Village:
Name of nearest town:

Personal details

Name:
Age:
Sex:
Ethnic group:
Religion:
Education:
Status:

General information

General Farm information

What crops do you grow?

How large is your holding?

What form of land tenure do you have over the land you farm?

Activities

What other fruit species do you grow

Other off farm activities

Contribution to income

Income from crops?

Do you carry out any off farm work?

Other sources of income?

What is your total annual income?

Education

What education standard to you have?

Do the children of the household attend school?

Culture

What is your religion?

What Community/Ethnic/Caste group do you belong to?

Species Information

	Species 1	Species 2
Species:		
Variety/Cultivar:		
Number of trees:		
Age of tree(s)		
Yield (approx no. of fruit/weight)		
Age of bearing:		

Phenology:

Time of leaf drop

New leaves

Flowering

Fruit development

Fruit maturity

Harvest (How many in a year)

Production system

How much of your land is under the fruit tree production

Cropping System

Home garden
Field Borders

Groves
Orchards
Plantations – Small scale (up to 5 hectares)
Large scale (above 5 hectares)

Water management

Water Catchment; Yes/No

Mulching; Yes/No

Mulching material:

Irrigation; Yes/No

If Yes – Amount, frequency, time of year, method of application

Source of irrigation water

Nutrition

What fertiliser do you add to the soil;

Natural (Manure)
Chemical (if so which one)
Bone meal
Other

How often?

What is the source of the fertiliser?

Propagation

Method of propagation

Seeds
Do you grow seedlings in nursery
At what time are they planted

Vegetative
What method of vegetative propagation do you use?

What is the source of the ber/tamarind/jackfruit seed/planting material?

Do you add fertiliser seedlings/grafted plant (if so how and when)
Do you irrigate seedlings/grafted plant (if so how and when)

Labour

Who plants the trees?

Who tends to the trees?

Who harvests the crop?

Intercropping (if cropping system)

What intercrops do you grow?

For how many years after planting do you grow intercrops?

Pest and Disease

Which pests and disease affect the crop?

What control method do you use?

What is the approximate annual loss to pest and disease?

Yield

What is the annual yield?

Does this vary from year to year?

If so by how much

Socioeconomic

Main purpose/market for tree production

Fruit
Wood
Fodder
Other

What percentage is

Used in home Consumption

Sold

If sold what is the produce

Pulp
Fresh fruit
Wood
Other

Do you carry out any post harvest processes

Where/to whom are the goods sold

Local market
Trades person

What income per/weight/fruit do you receive for the crop?

How much does this vary and why?

What is the annual income per weight/area provided by the crop?

What is the market value of the crop?

What is the annual total from sale of the crop?

Costs

What are the costs of inputs
Fertilisers
Pesticides
Water harvesting - Irrigation,
Planting material
Labour

Access to market

How are goods transported to market

Which market(s) do you sell your goods at

How far away is the local market(s)

How long does it take to transport goods to market?

Contribution to subsistence

What other fruit products are available during time the fruit is available?

What other food crops are available at this time?

Is the fruit ever eaten as a staple?

Species	Tree No.	Cultivar/ Variety	Source	Height	Girth

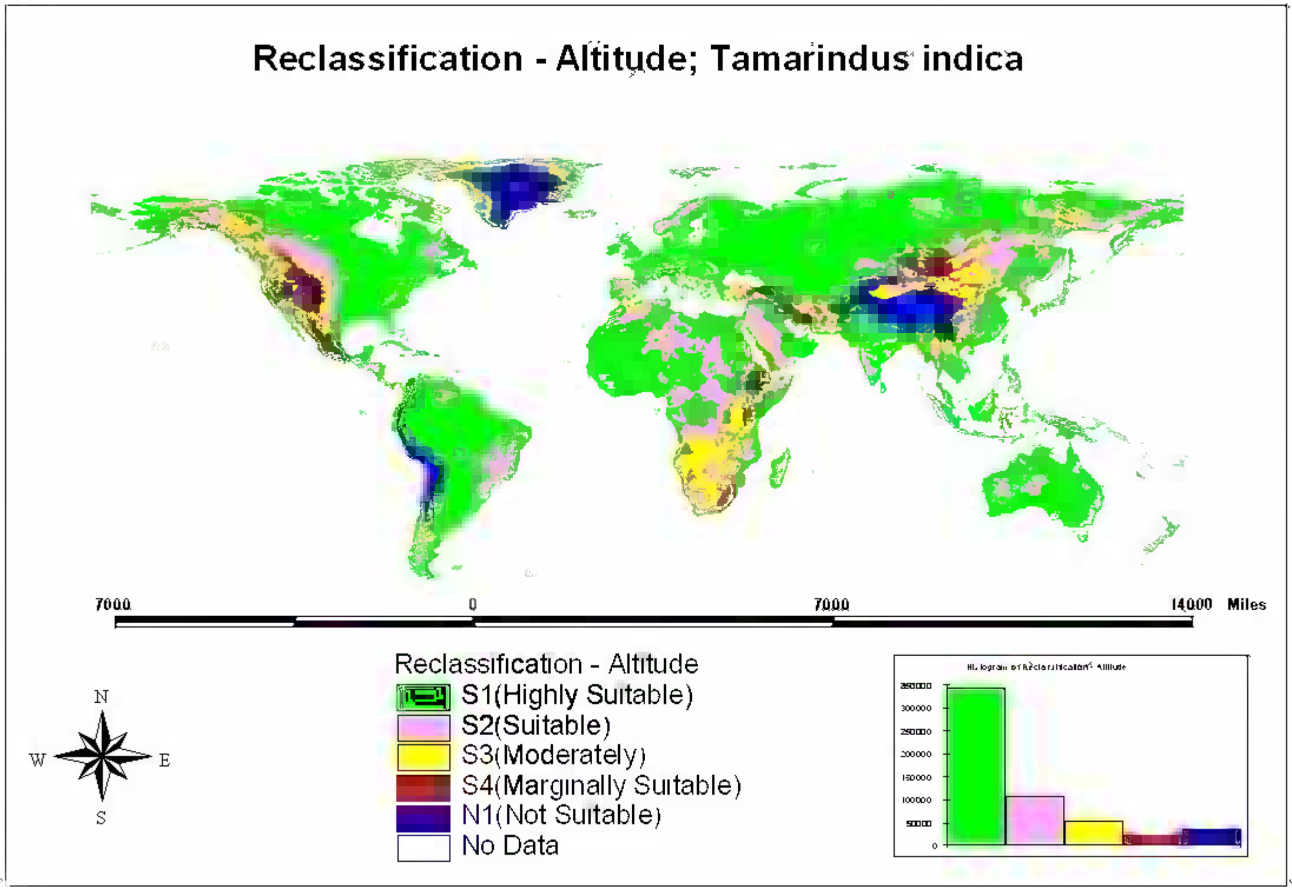
Tree No.	Yield	Yield Variation

Phenology						
Tree No.	Leaf drop	New flush (vegetative)	Flowering	Fruit set	Fruit maturity	Harvest

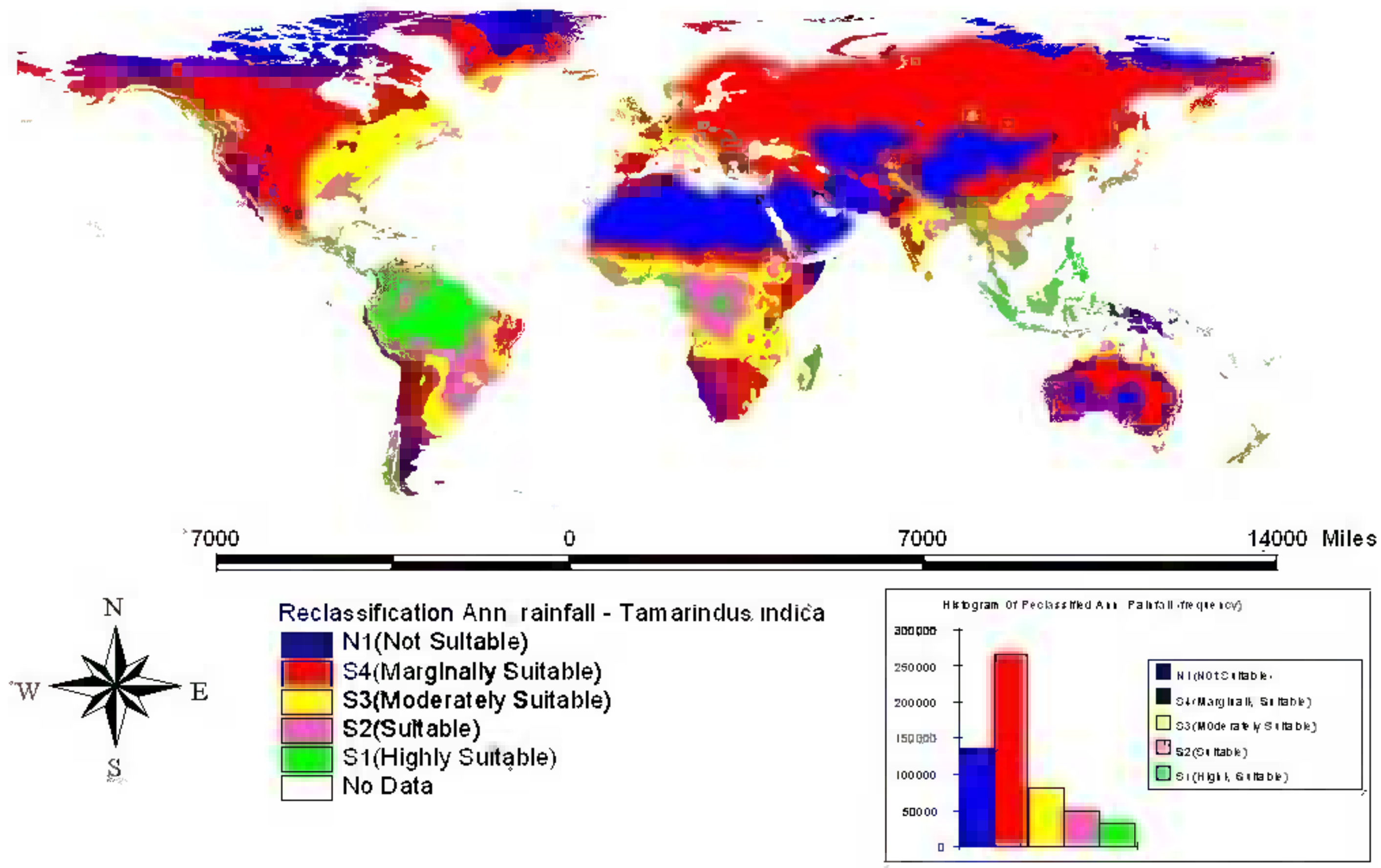
7.2 Appendix 2

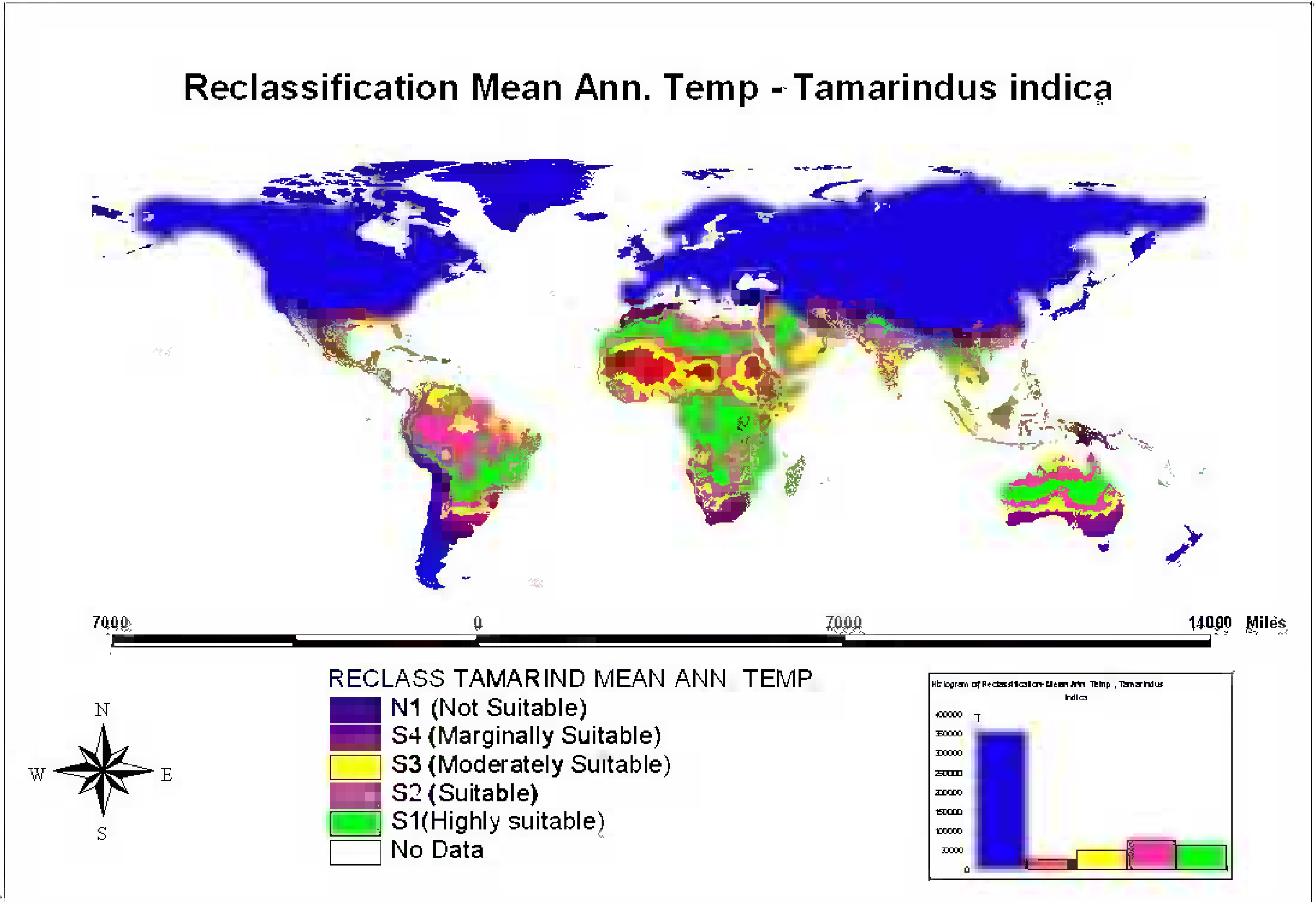
7.2.1 Reclassification Maps

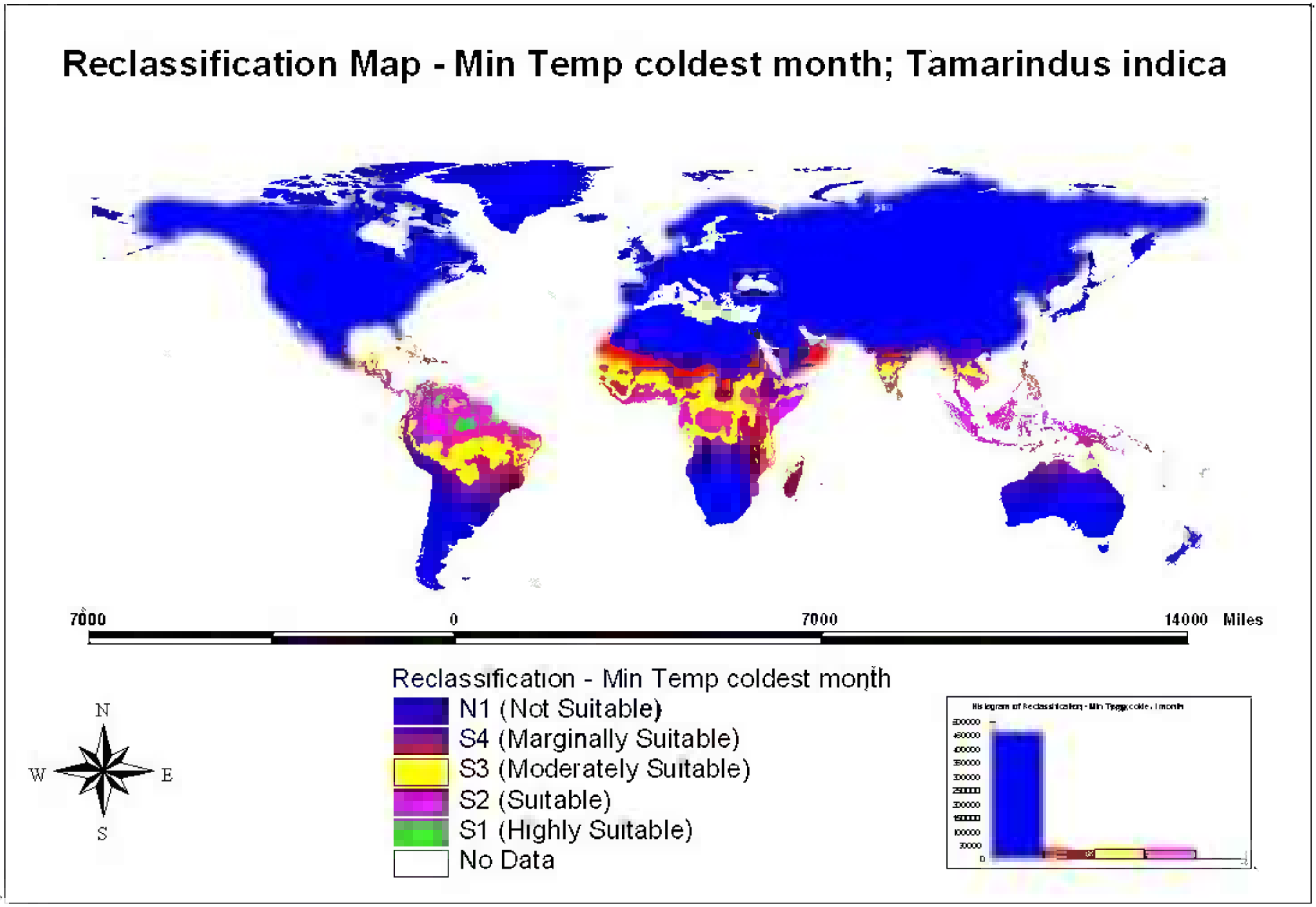
Tamarindus indica

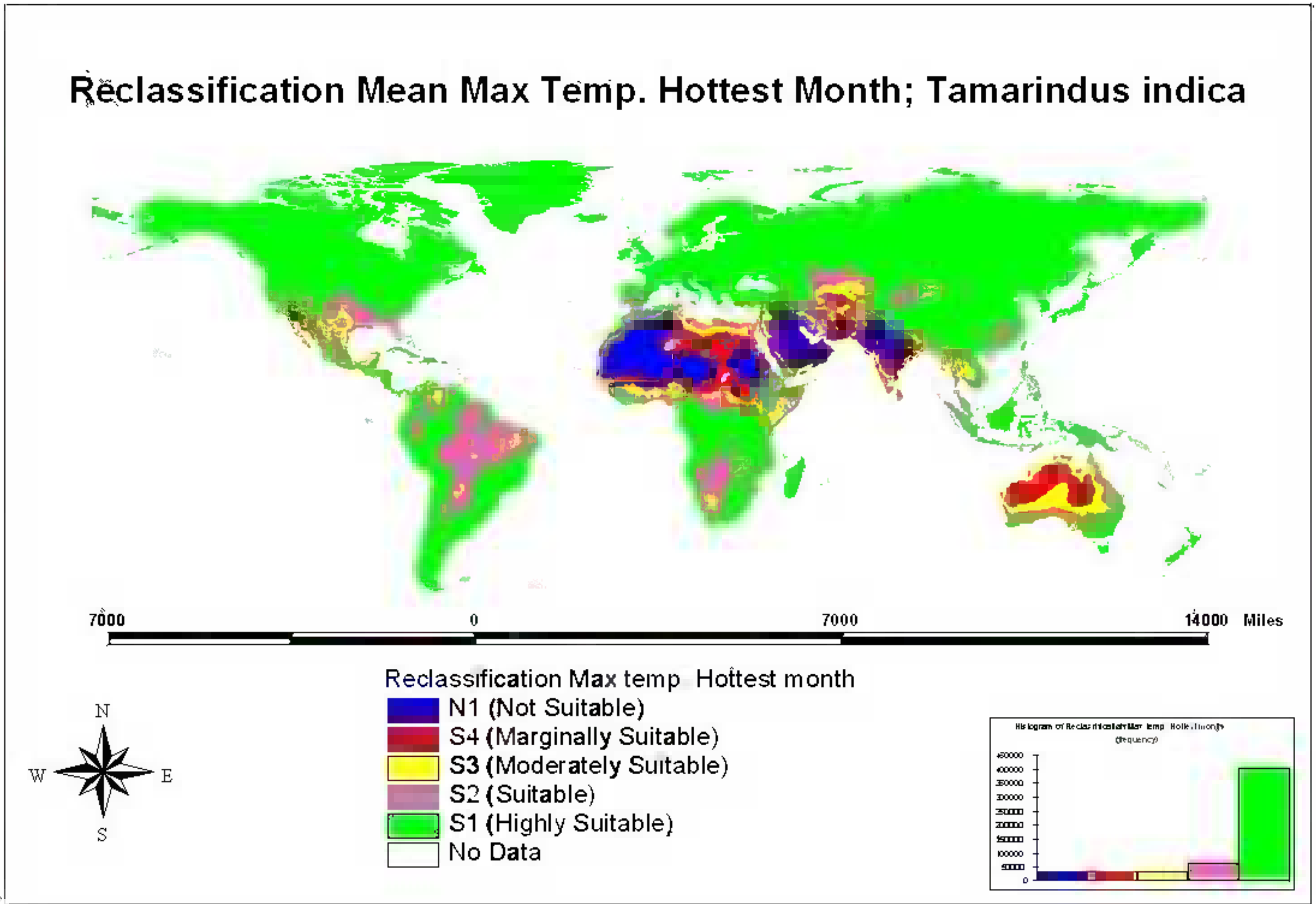


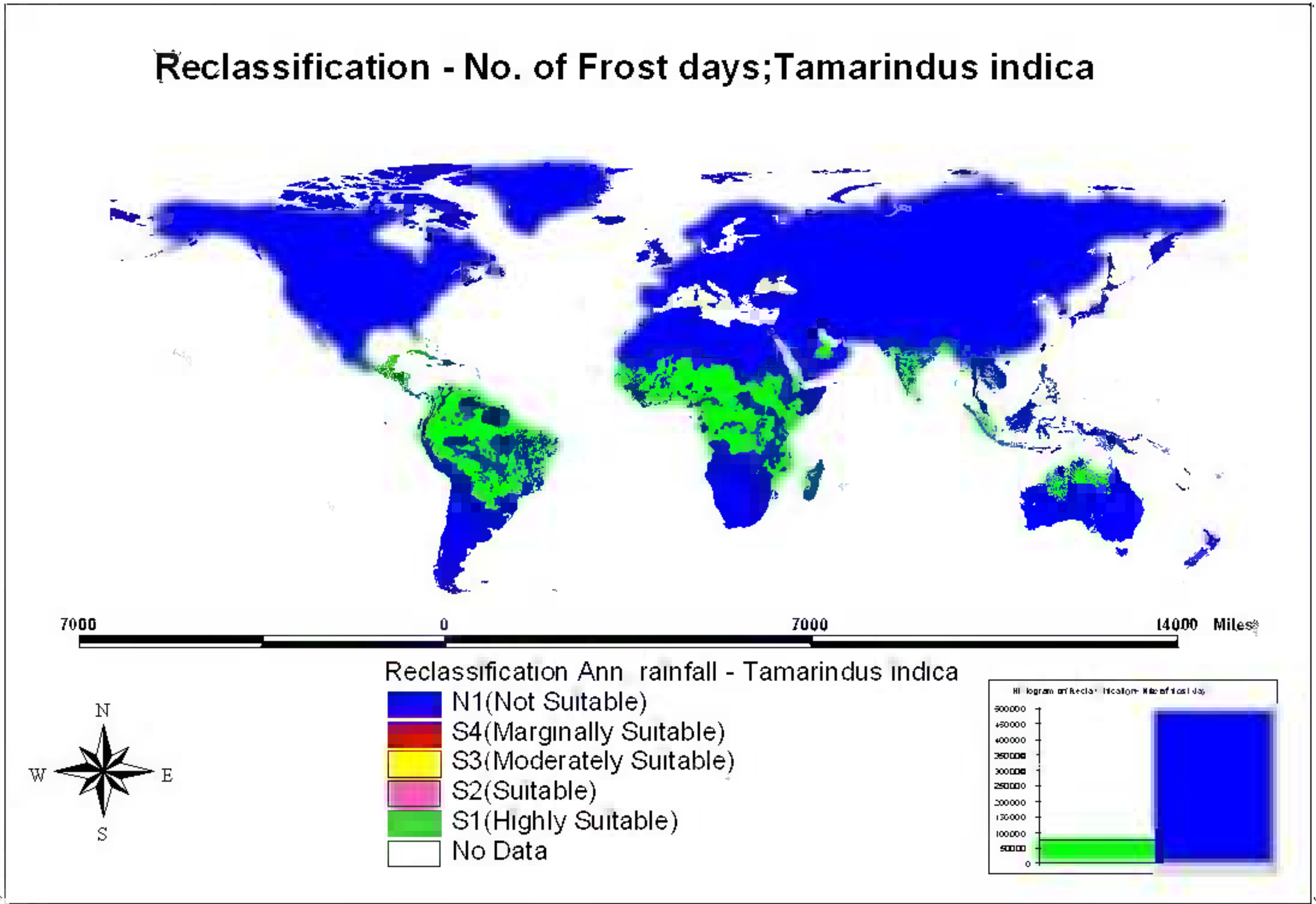
Reclassification Mean Ann. Rainfall, Tamarindus indica

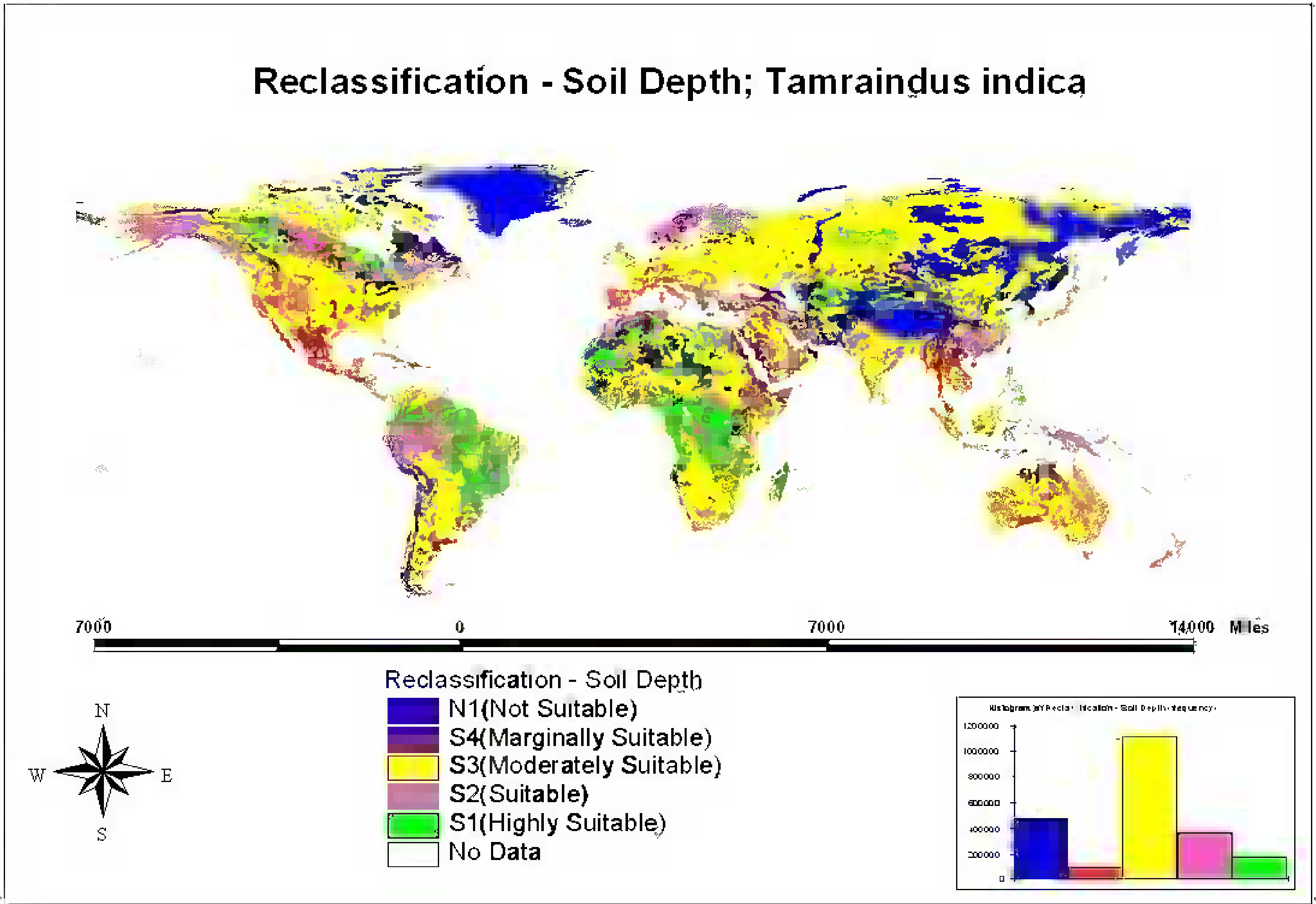


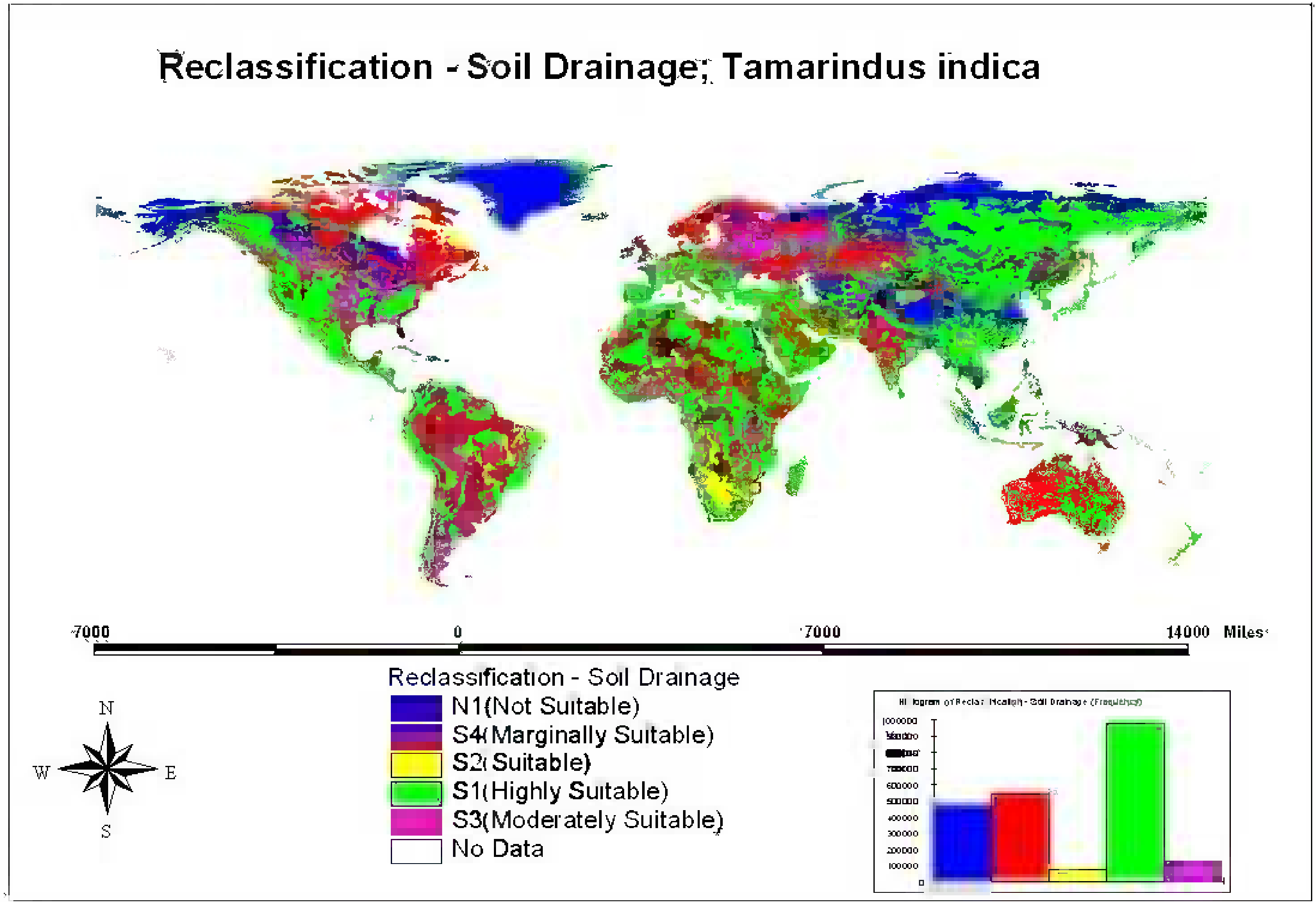

Reclassification Mean Ann. Temp - Tamarindus indica
7000
0
7000
14000 Miles
N
W
E
S
RECLASS TAMARIND MEAN ANN TEMP
N1 (Not Suitable)
S4 (Marginally Suitable)
S3 (Moderately Suitable)
S2 (Suitable)
S1(Highly suitable)
No Data

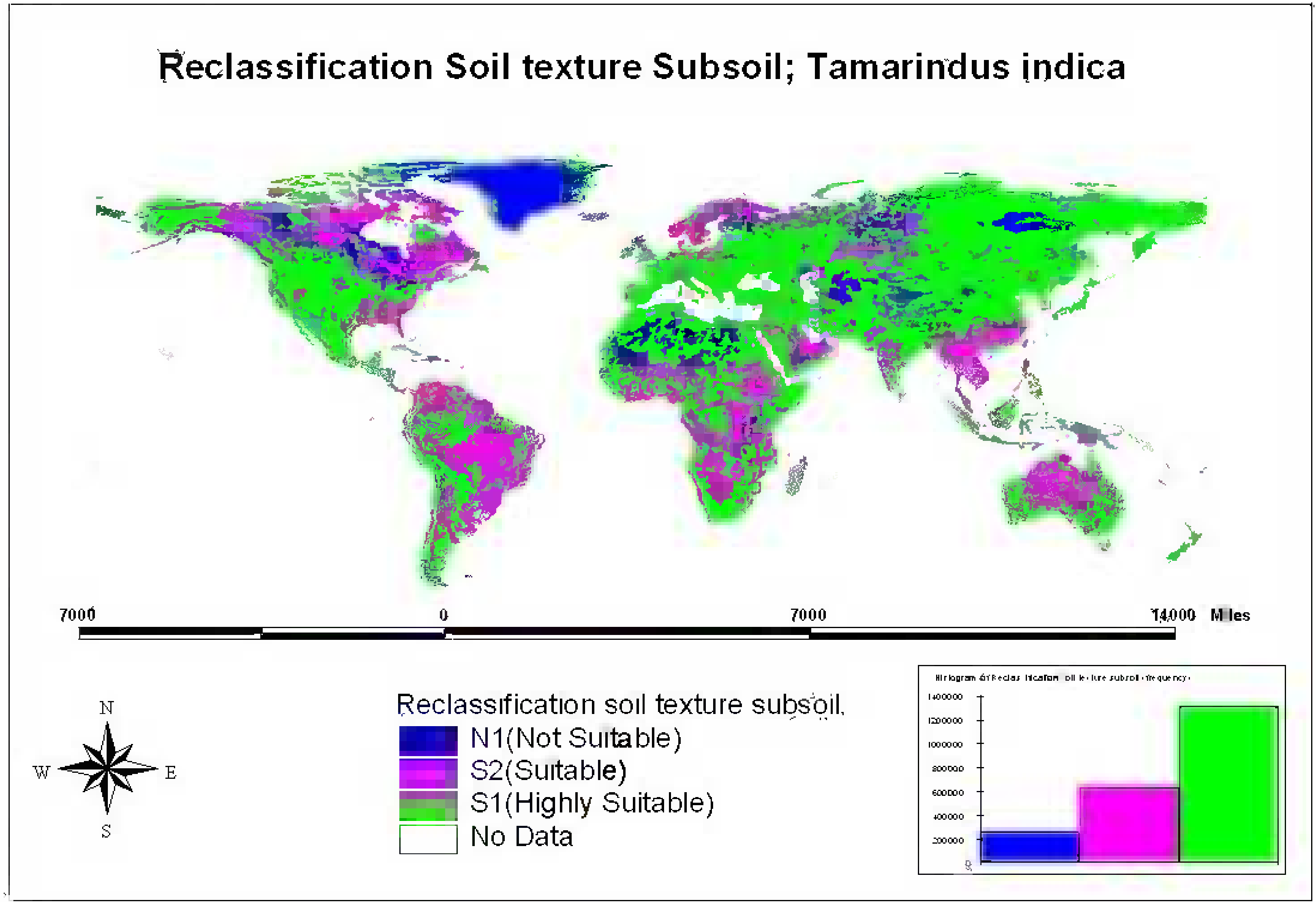

Reclassification Map - Min Temp coldest month; Tamarindus indica
7000
0
7000
14000 Miles
Reclassification - Min Temp coldest month
N1 (Not Suitable)
S4 (Marginally Suitable)
S3 (Moderately Suitable)
S2 (Suitable)
S1 (Highly Suitable)
No Data
N
W
E
S

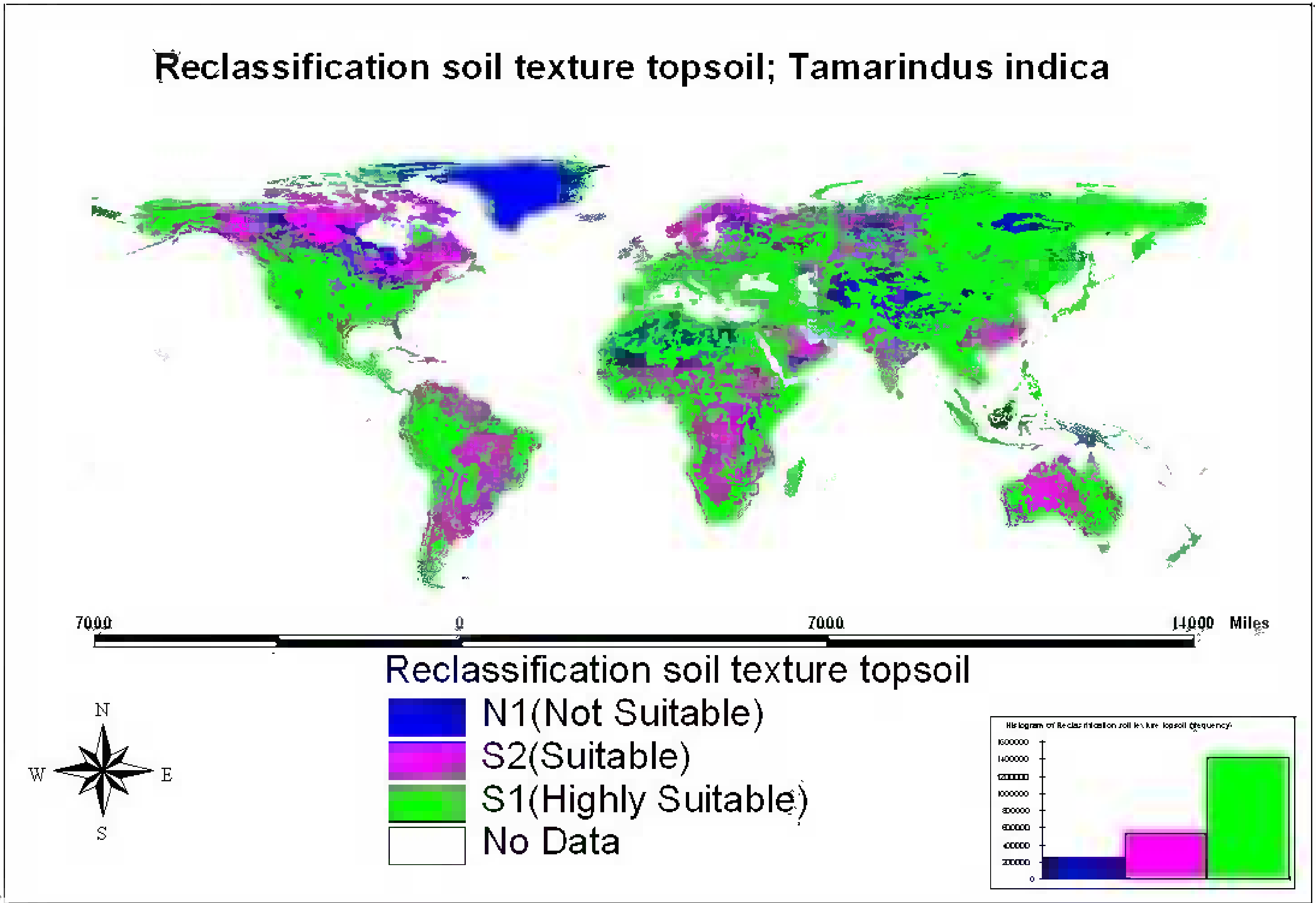

Reclassification Mean Max Temp. Hottest Month; Tamarindus indica
7000
0
7000
14000 Miles
N
W
E
S
Reclassification Max temp Hottest month
N1 (Not Suitable)
S4 (Marginally Suitable)
S3 (Moderately Suitable)
S2 (Suitable)
S1 (Highly Suitable)
No Data

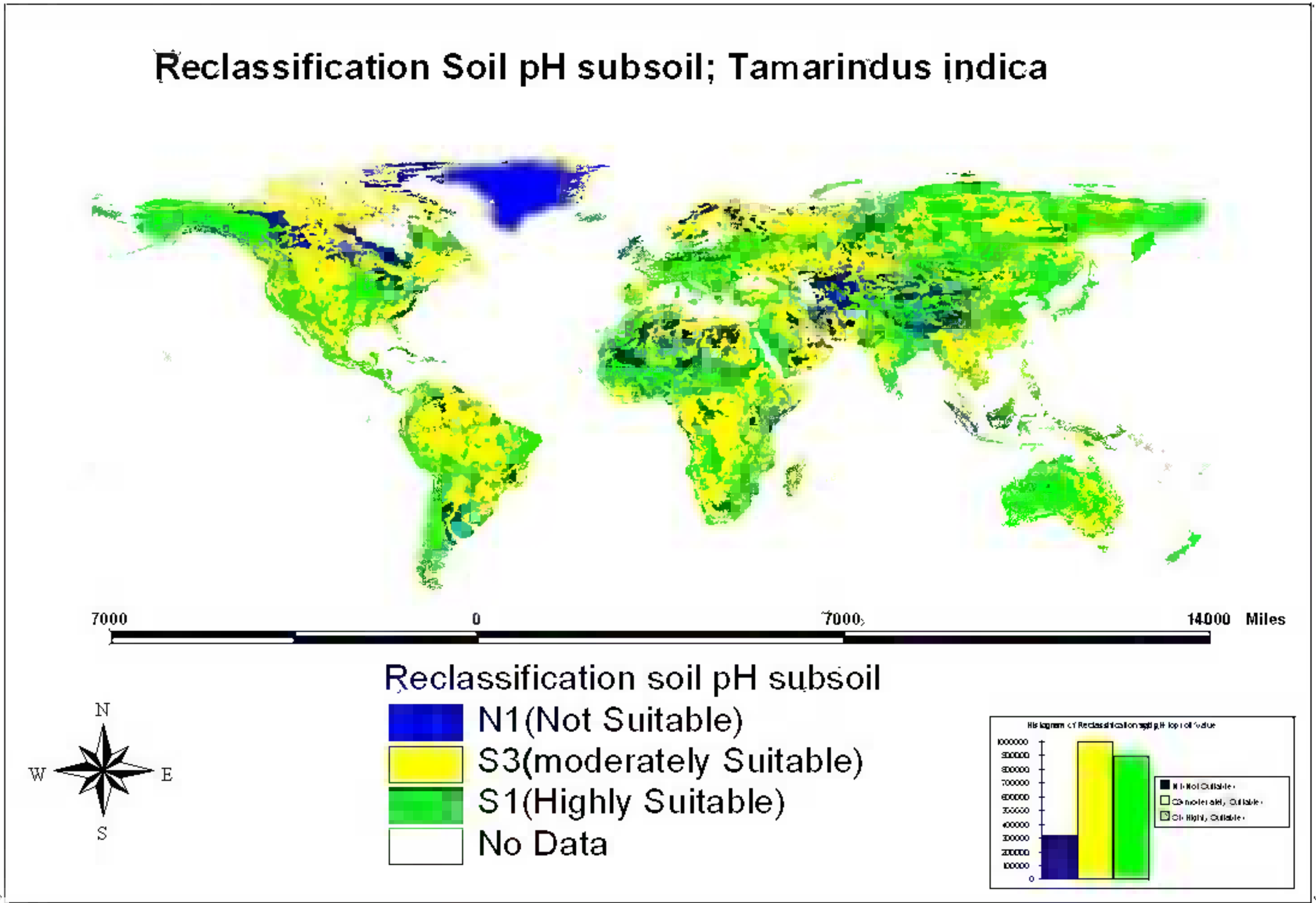

Reclassification - No. of Frost days;Tamarindus indica
7000
0
7000
14000 Miles
Reclassification Ann rainfall - Tamarindus indica
N1(Not Suitable)
S4(Marginally Suitable)
S3(Moderately Suitable)
S2(Suitable)
S1(Highly Suitable)
No Data
N
W
E
S

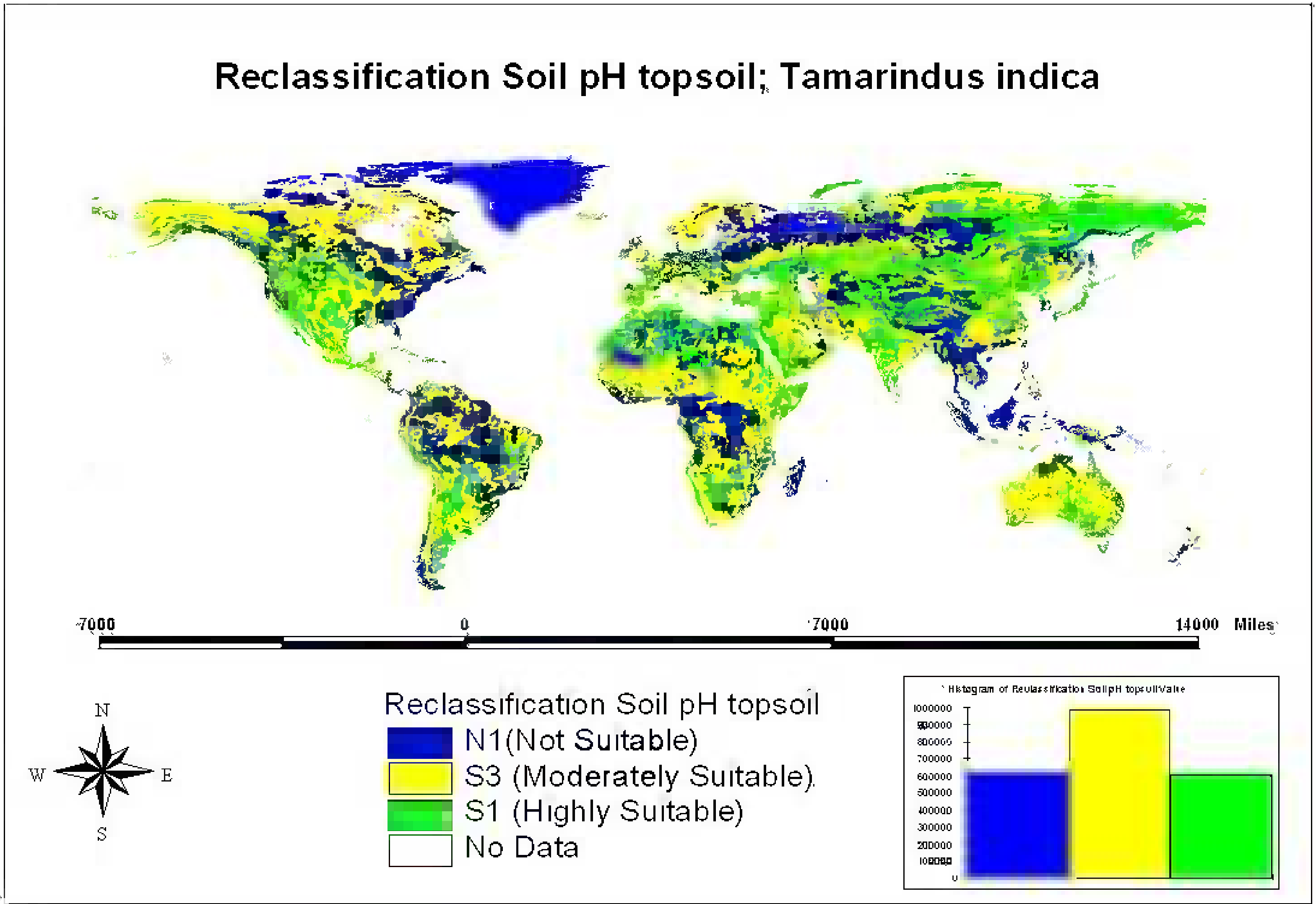

Reclassification - Soil Depth; Tamraindus indica
7000
0
7000
14000 Miles
Reclassification - Soil Depth
N1(Not Suitable)
S4(Marginally Suitable)
S3(Moderately Suitable)
S2(Suitable)
S1(Highly Suitable)
No Data
N
W
E
S


Reclassification - Soil Drainage; Tamarindus indica
7000
0
7000
14000 Miles
Reclassification - Soil Drainage
N1(Not Suitable)
S4(Marginally Suitable)
S2(Suitable)
S1(Highly Suitable)
S3(Moderately Suitable)
No Data
N
W
E
S

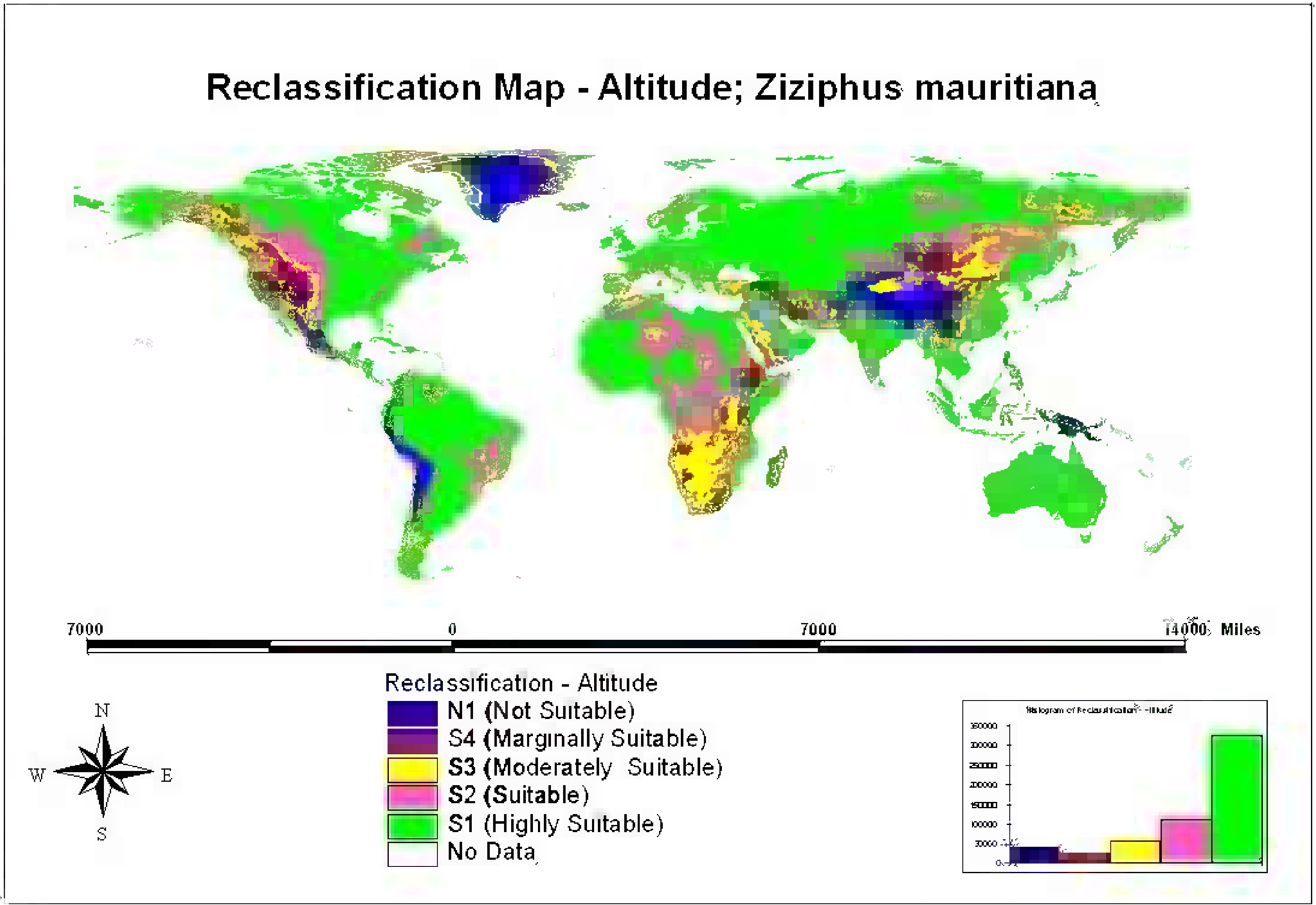

Reclassification Soil texture Subsoil; Tamarindus indica
7000
0
7000
14000 Miles
N
W
E
S
Reclassification soil texture subsoil
N1(Not Suitable)
S2(Suitable)
S1(Highly Suitable)
No Data
1400000
1200000
1000000
800000
600000
400000
200000
0

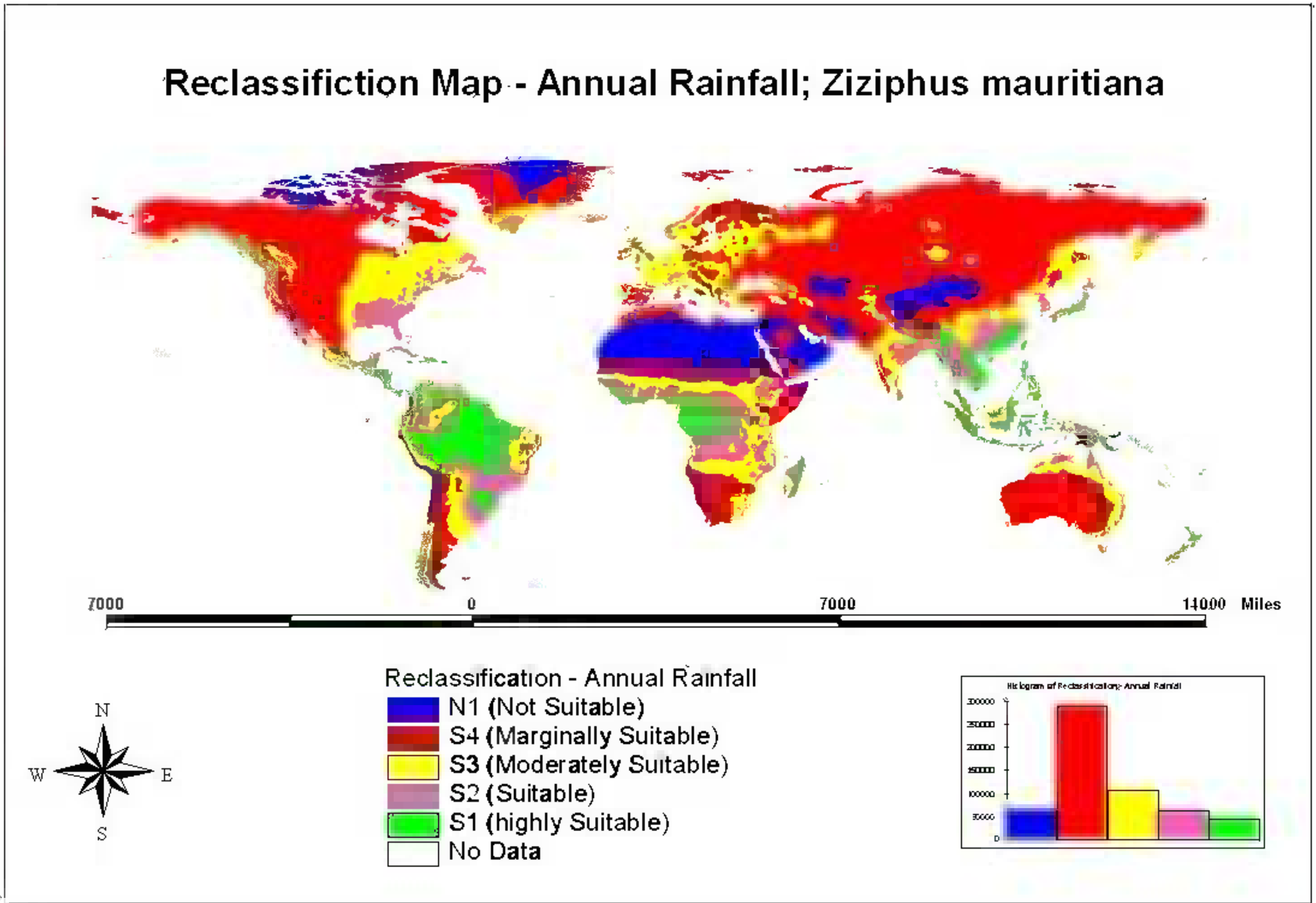

Reclassification soil texture topsoil; Tamarindus indica
7000
0
7000
14000 Miles
Reclassification soil texture topsoil
N1(Not Suitable)
S2(Suitable)
S1(Highly Suitable)
No Data
N
W
E
S


Reclassification Soil pH subsoil; Tamarindus indica
7000
0
7000
14000 Miles
Reclassification soil pH subsoil
N1(Not Suitable)
S3(moderately Suitable)
S1(Highly Suitable)
No Data
N
W
E
S

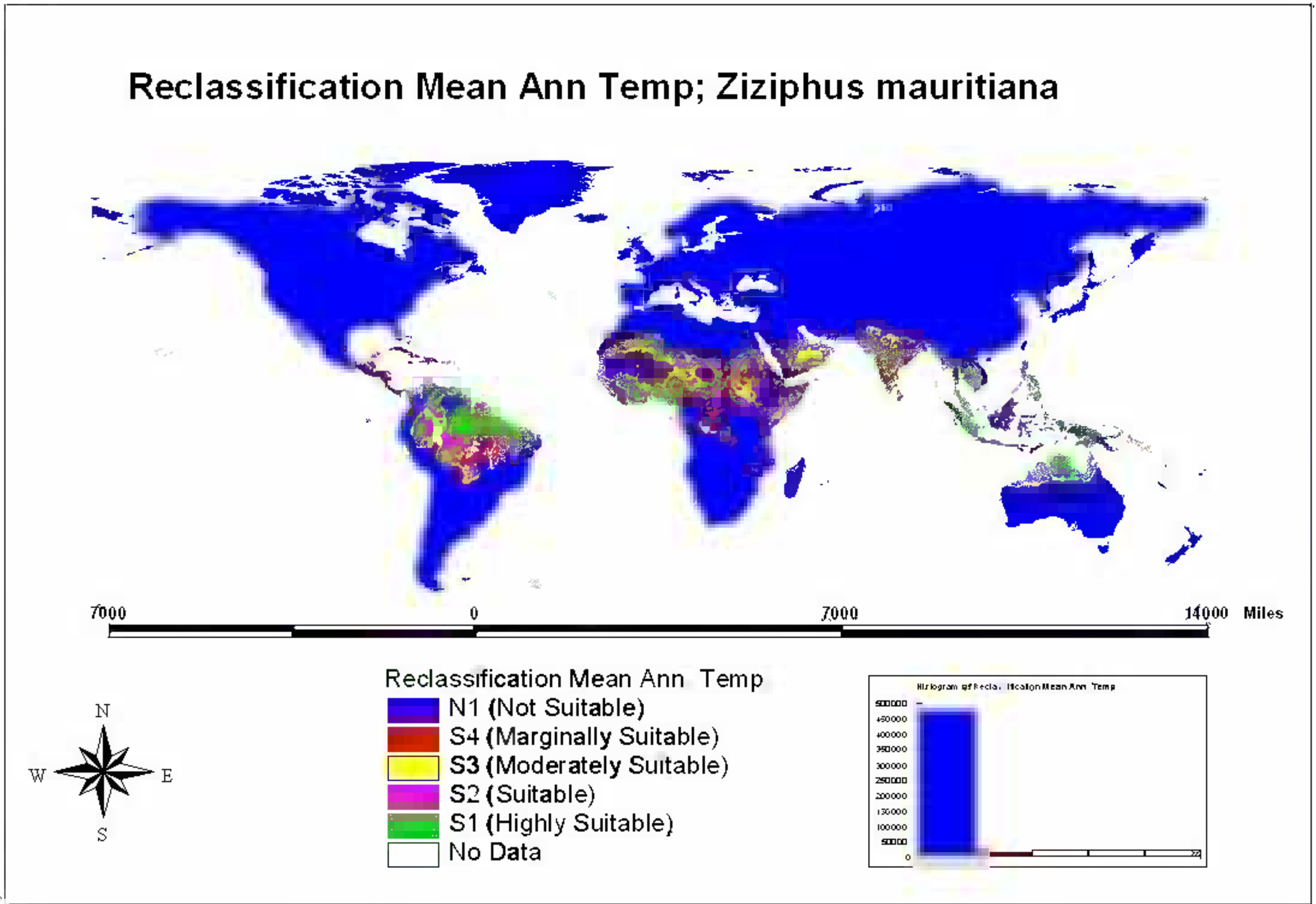

Reclassification Soil pH topsoil; Tamarindus indica
7000
0
7000
14000 Miles
N
W
E
S
Reclassification Soil pH topsoil
N1(Not Suitable)
S3 (Moderately Suitable)
S1 (Highly Suitable)
No Data
1000000
700000
600000
500000
400000
300000
200000

Ziziphus mauritana

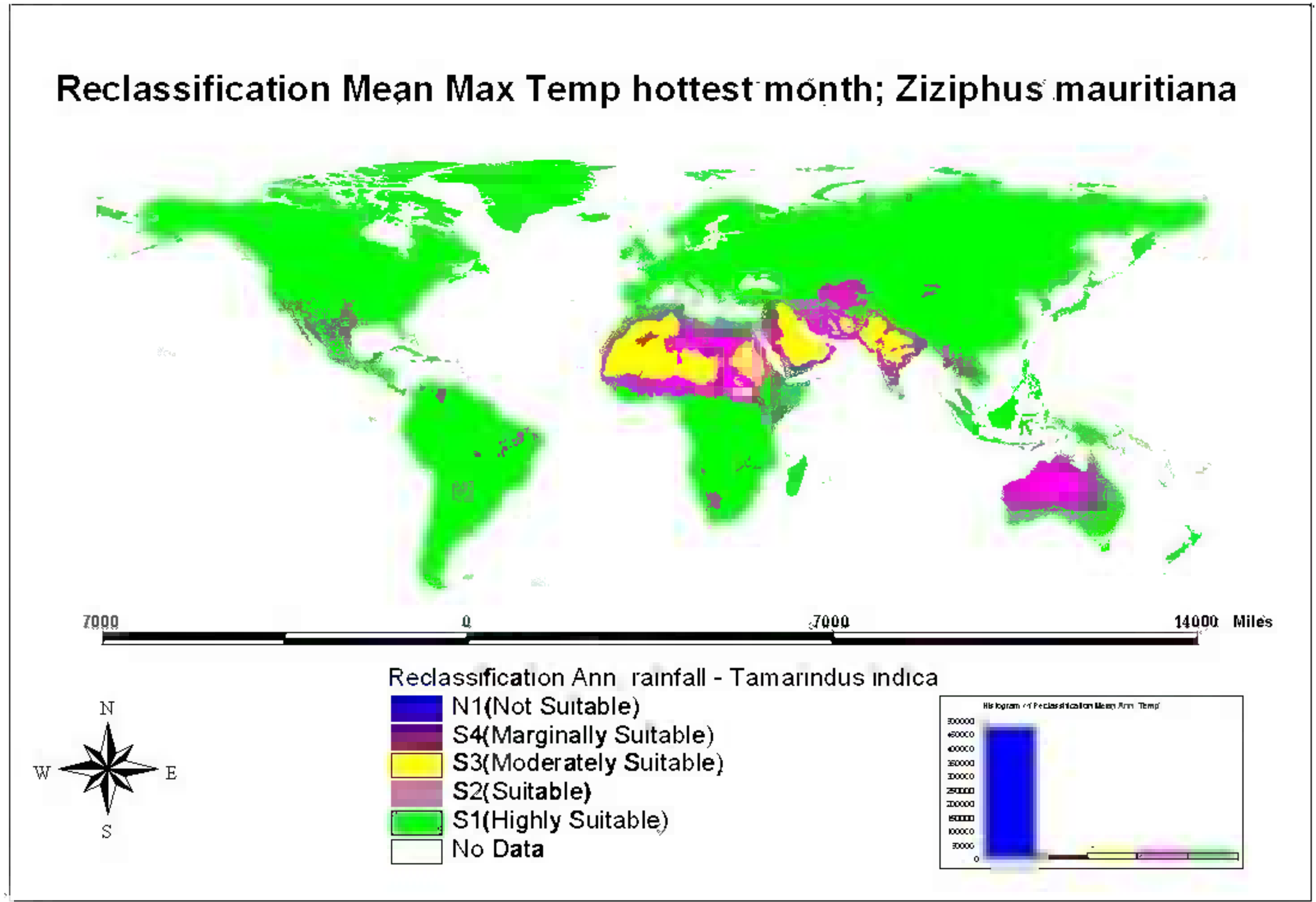


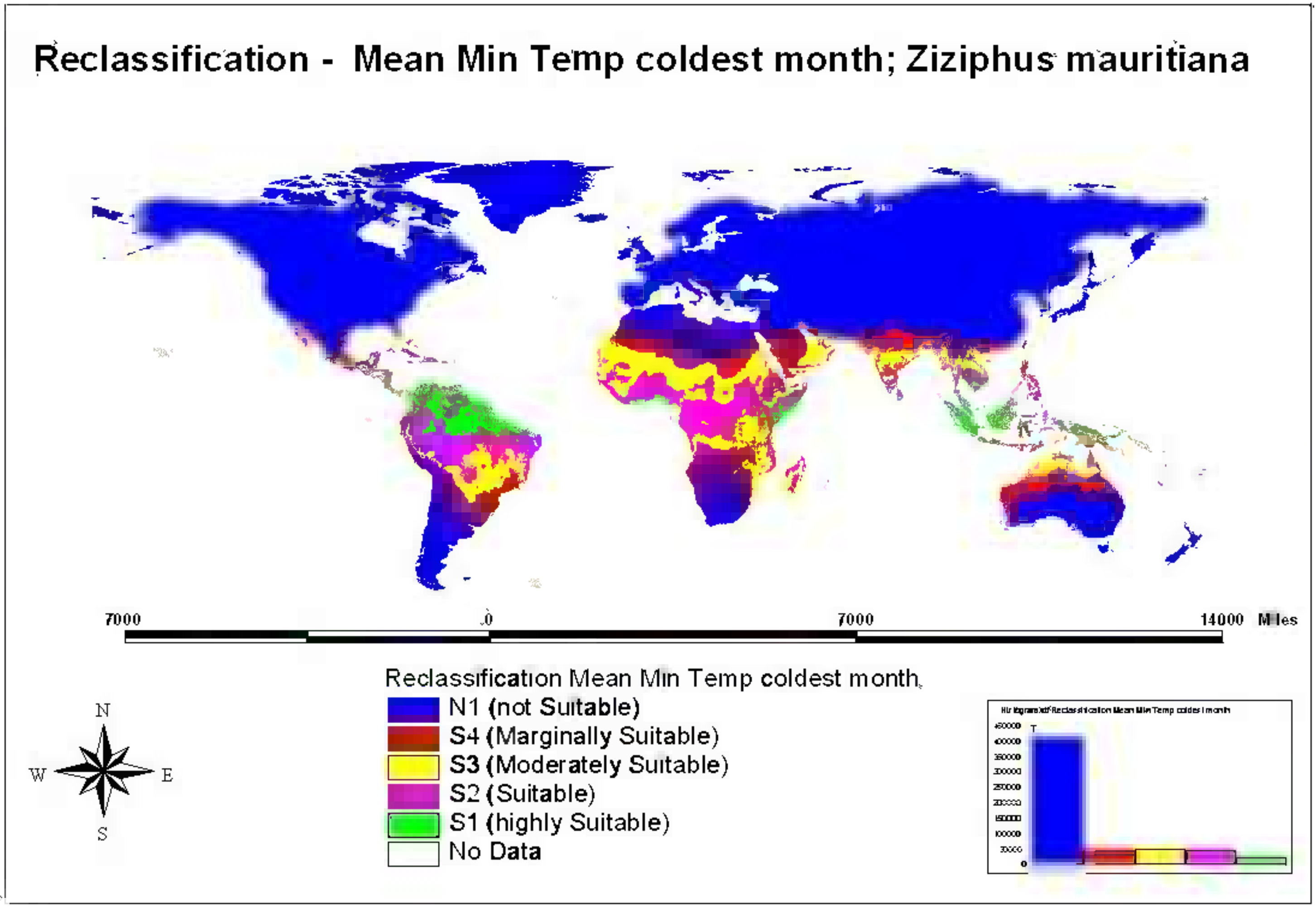


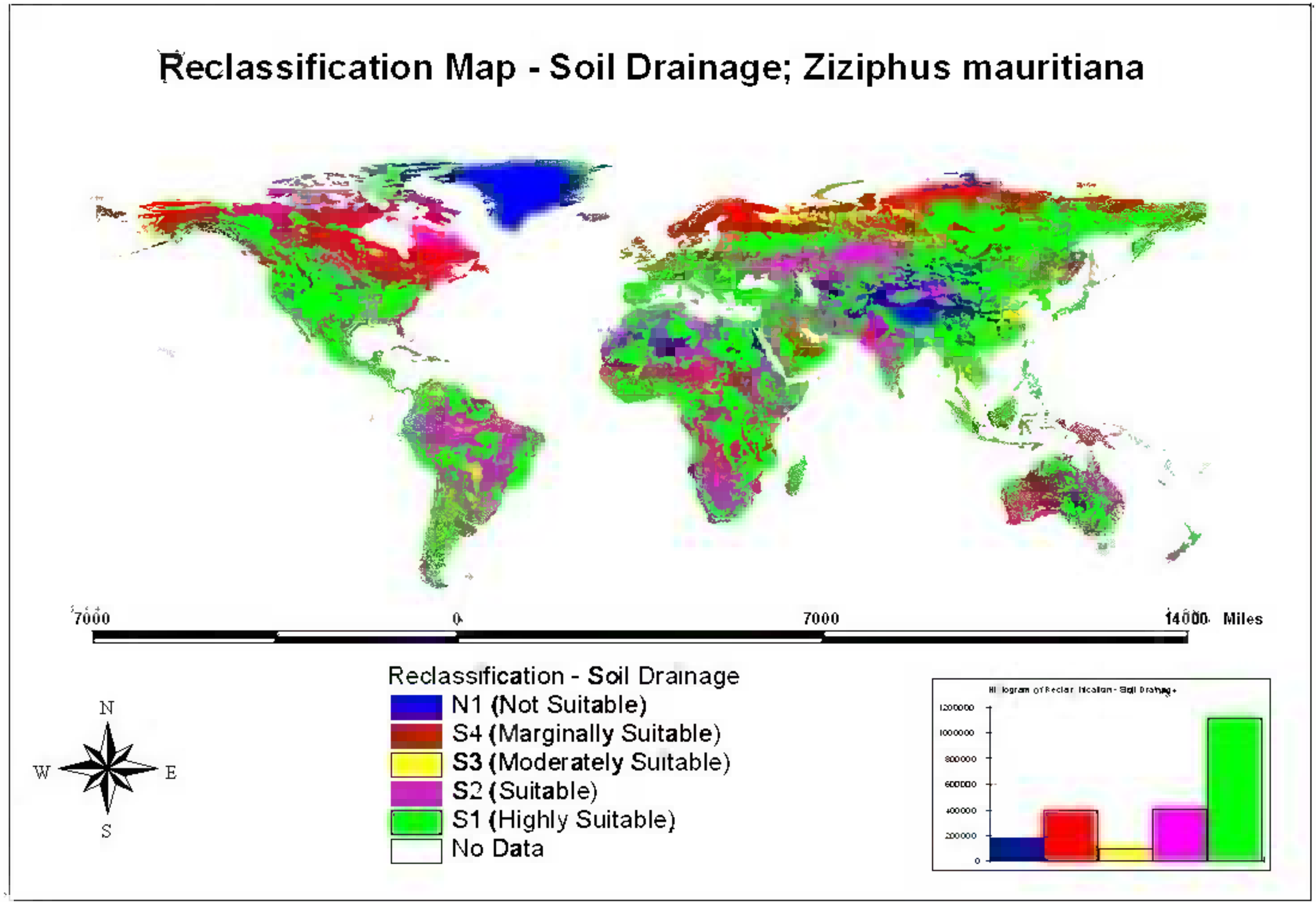
Reclassifiction Map - Annual Rainfall; Ziziphus mauritiana
7000
0
7000
14000 Miles
N
W
E
S
Reclassification - Annual Rainfall
N1 (Not Suitable)
S4 (Marginally Suitable)
S3 (Moderately Suitable)
S2 (Suitable)
S1 (highly Suitable)
No Data

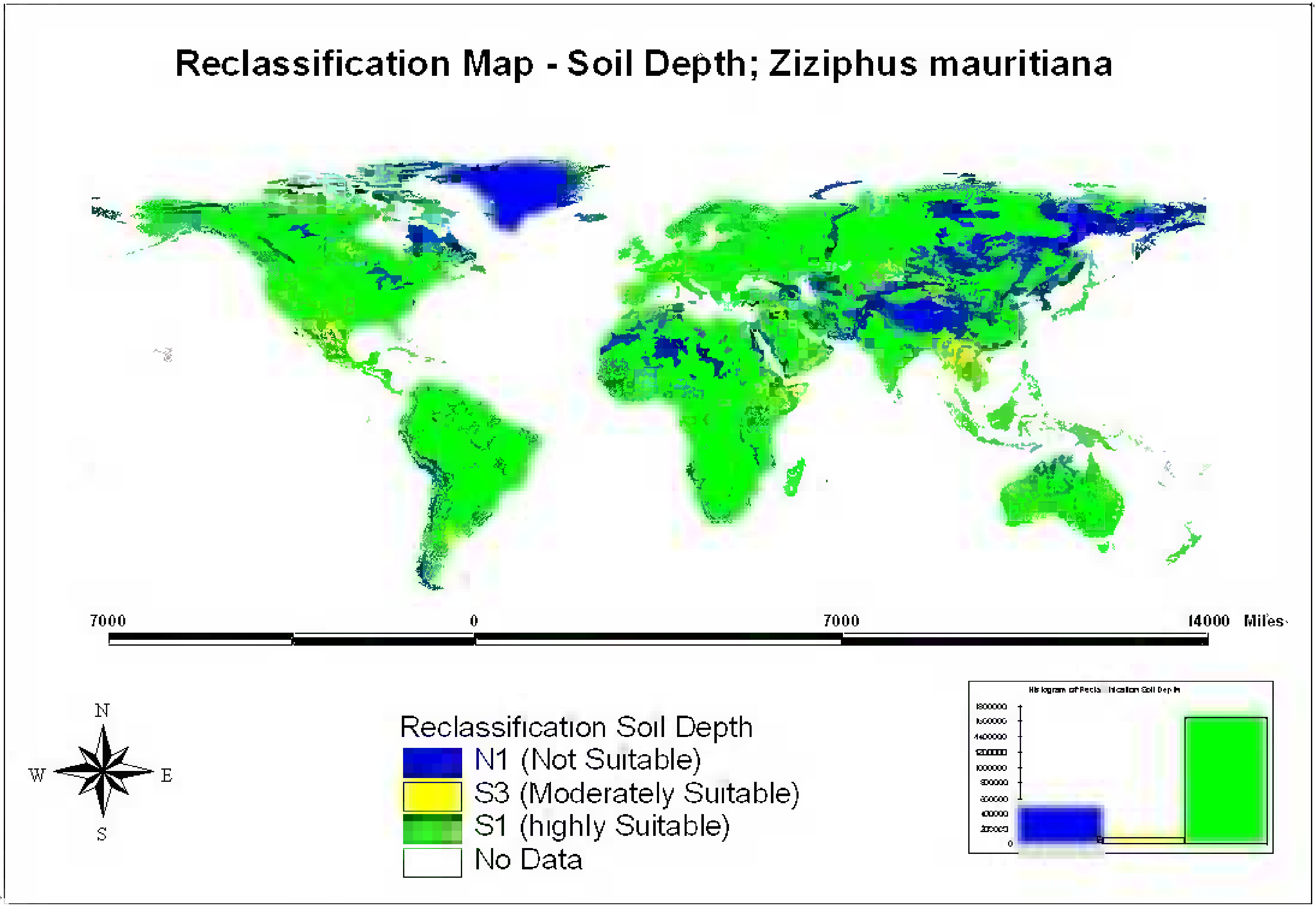


Reclassification Mean Ann Temp; Ziziphus mauritiana
7000
0
7000
14000 Miles
N
W
E
S
Reclassification Mean Ann Temp
N1 (Not Suitable)
S4 (Marginally Suitable)
S3 (Moderately Suitable)
S2 (Suitable)
S1 (Highly Suitable)
No Data

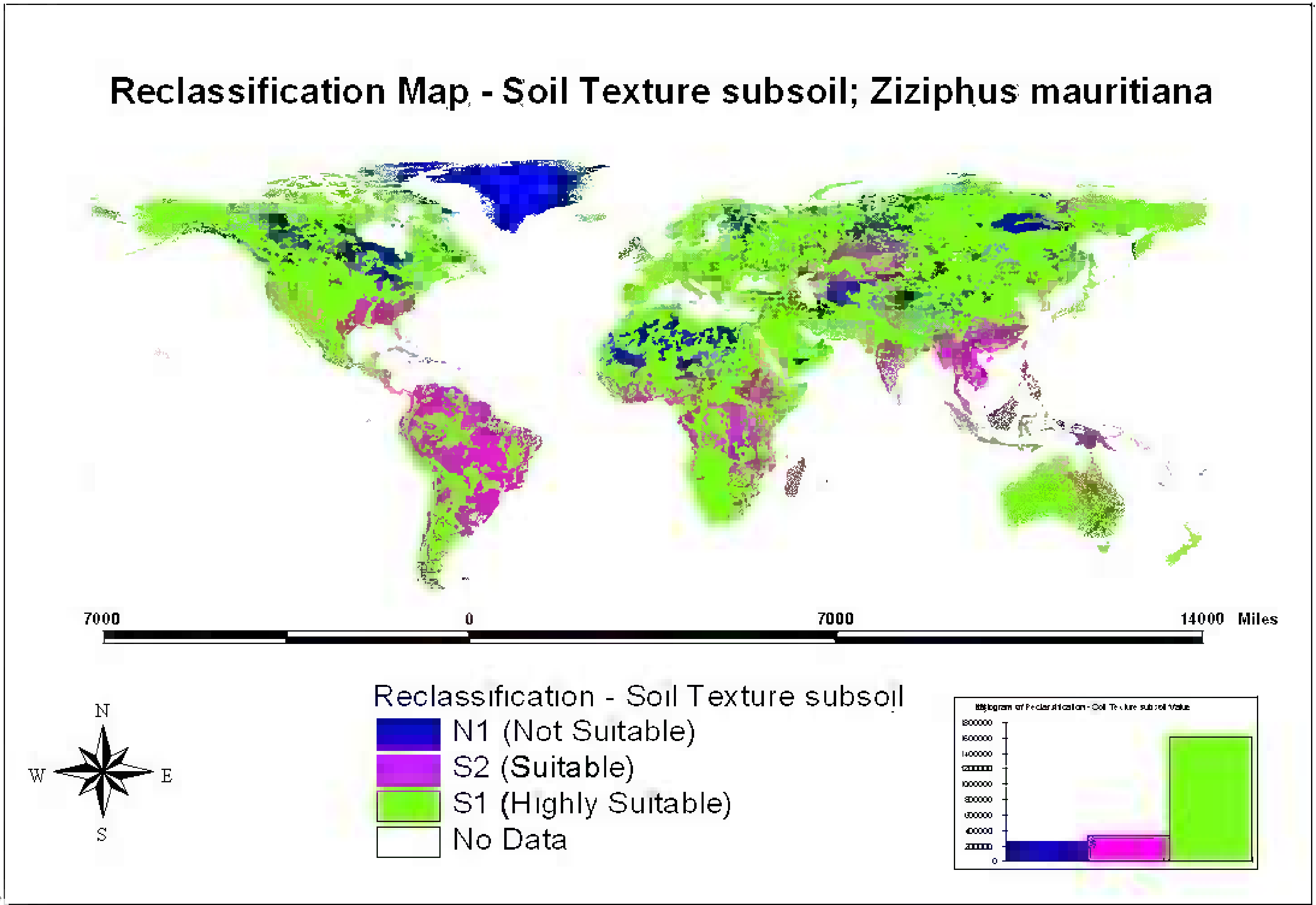

Reclassification Mean Max Temp hottest month; Ziziphus mauritiana
7000
0
7000
14000 Miles
Reclassification Ann rainfall - Tamarindus indica
N1(Not Suitable)
S4(Marginally Suitable)
S3(Moderately Suitable)
S2(Suitable)
S1(Highly Suitable)
No Data
N
W
E
S

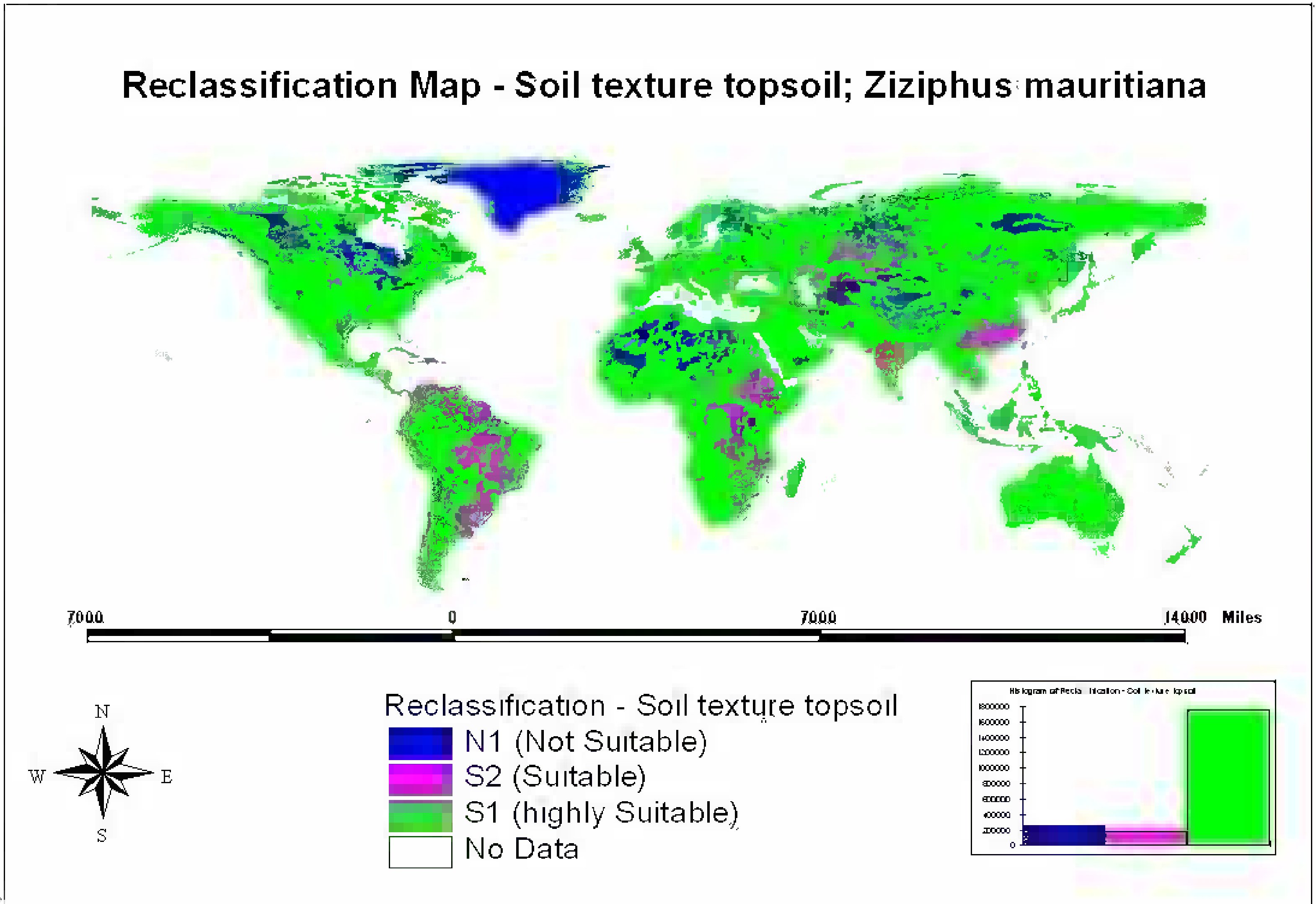

Reclassification - Mean Min Temp coldest month; Ziziphus mauritiana
7000
0
7000
14000 Miles
Reclassification Mean Min Temp coldest month
N1 (not Suitable)
S4 (Marginally Suitable)
S3 (Moderately Suitable)
S2 (Suitable)
S1 (highly Suitable)
No Data
N
W
E
S

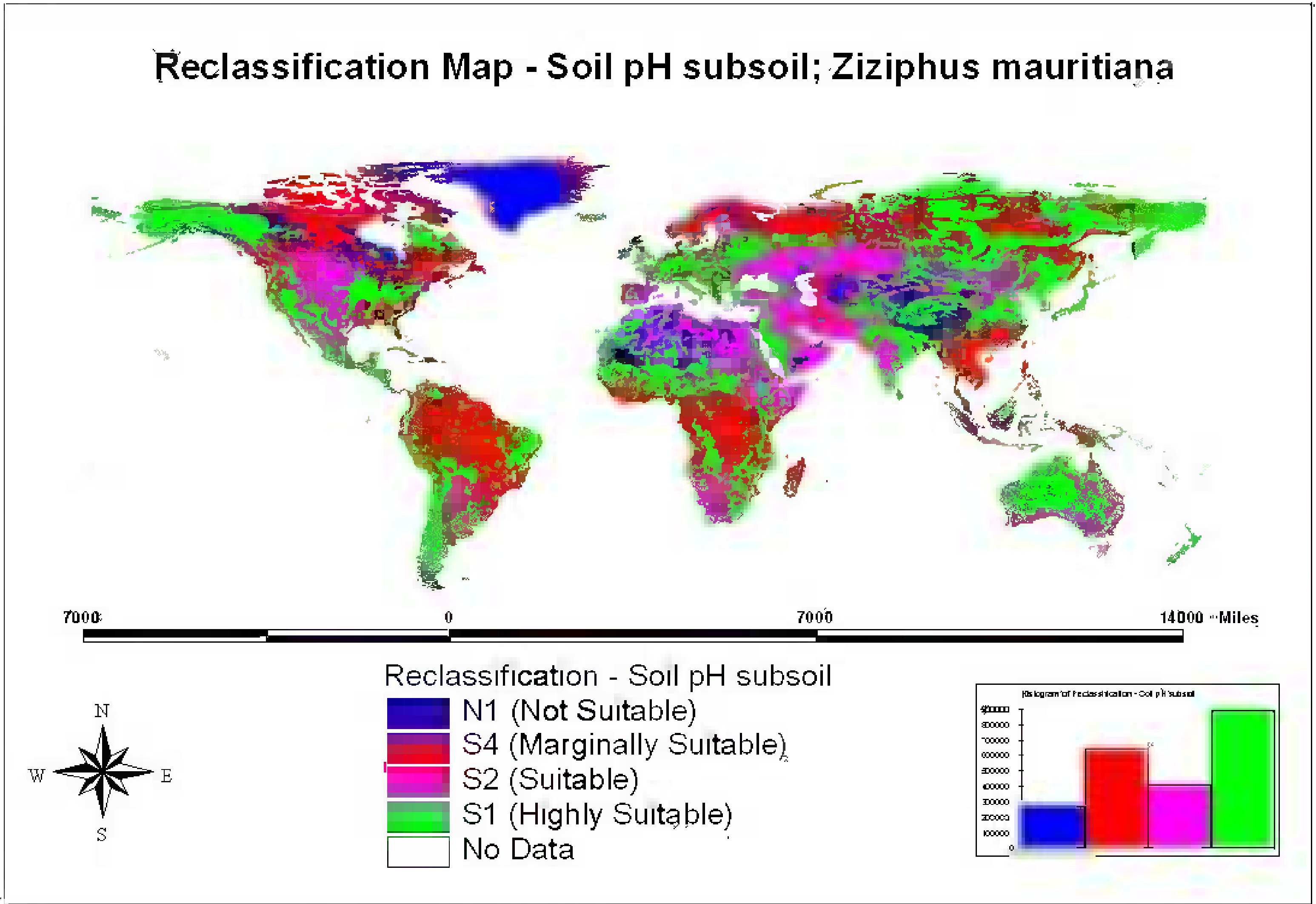

Reclassification Map - Soil Drainage; Ziziphus mauritiana
7000
0
7000
14000 Miles
Reclassification - Soil Drainage
N1 (Not Suitable)
S4 (Marginally Suitable)
S3 (Moderately Suitable)
S2 (Suitable)
S1 (Highly Suitable)
No Data
N
W
E
S
1200000
1000000
800000
600000
400000
200000
0

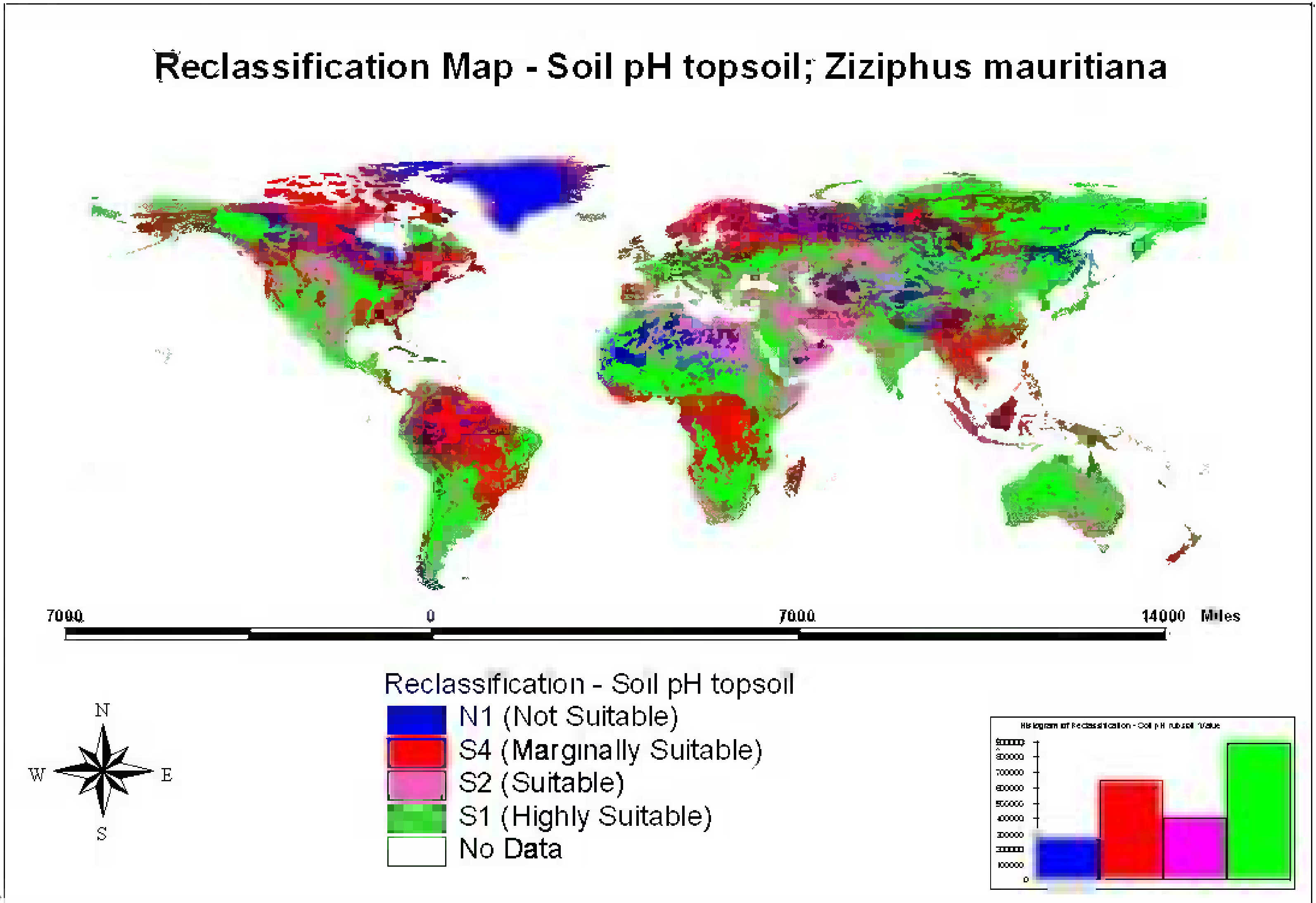


Reclassification Map - Soil Depth; Ziziphus mauritiana
7000
0
7000
14000 Miles
N
W
E
S
Reclassification Soil Depth
N1 (Not Suitable)
S3 (Moderately Suitable)
S1 (highly Suitable)
No Data

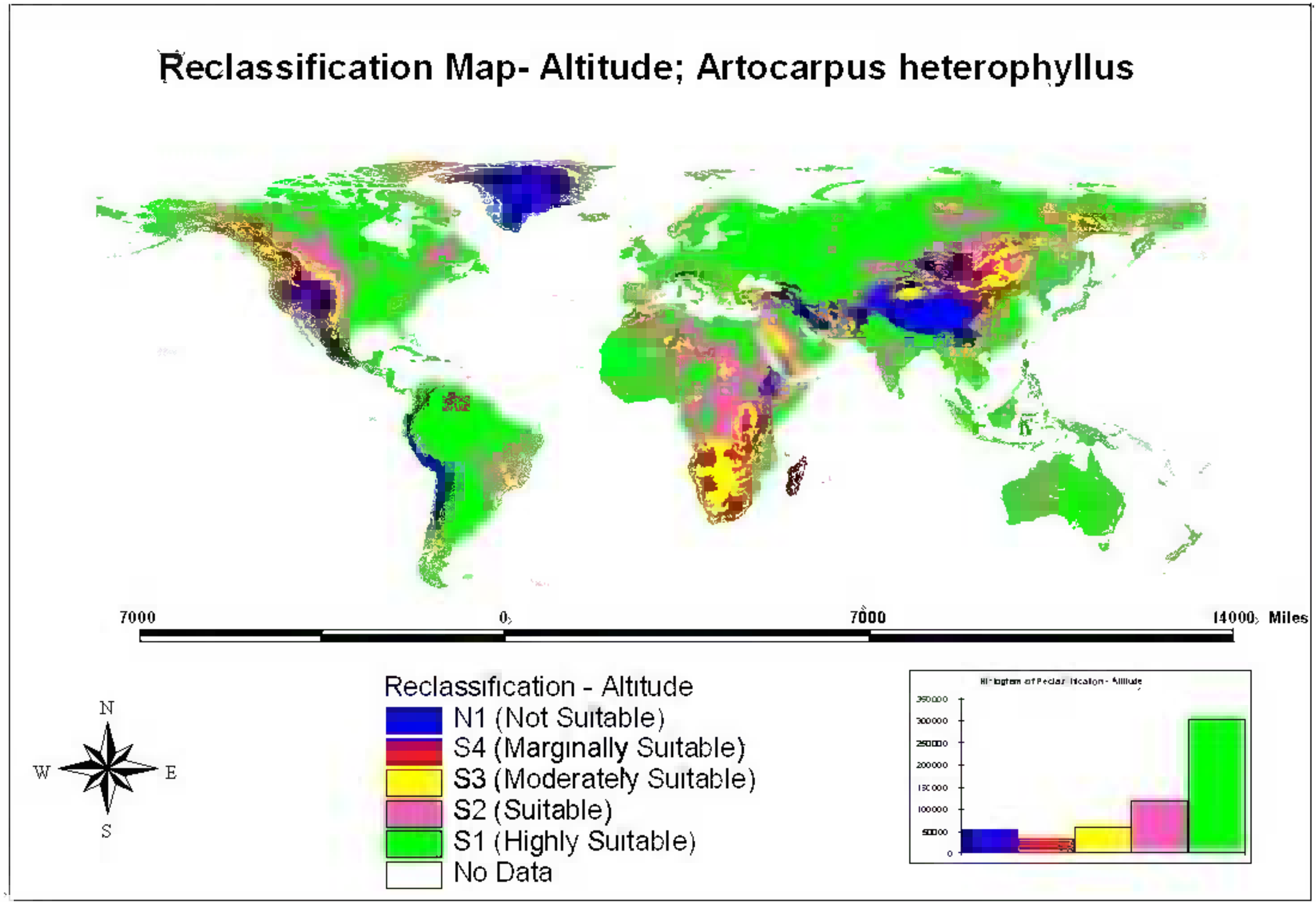

Reclassification Map - Soil Texture subsoil; Ziziphus mauritiana
7000
0
7000
14000 Miles
N
W
E
S
Reclassification - Soil Texture subsoil
N1 (Not Suitable)
S2 (Suitable)
S1 (Highly Suitable)
No Data

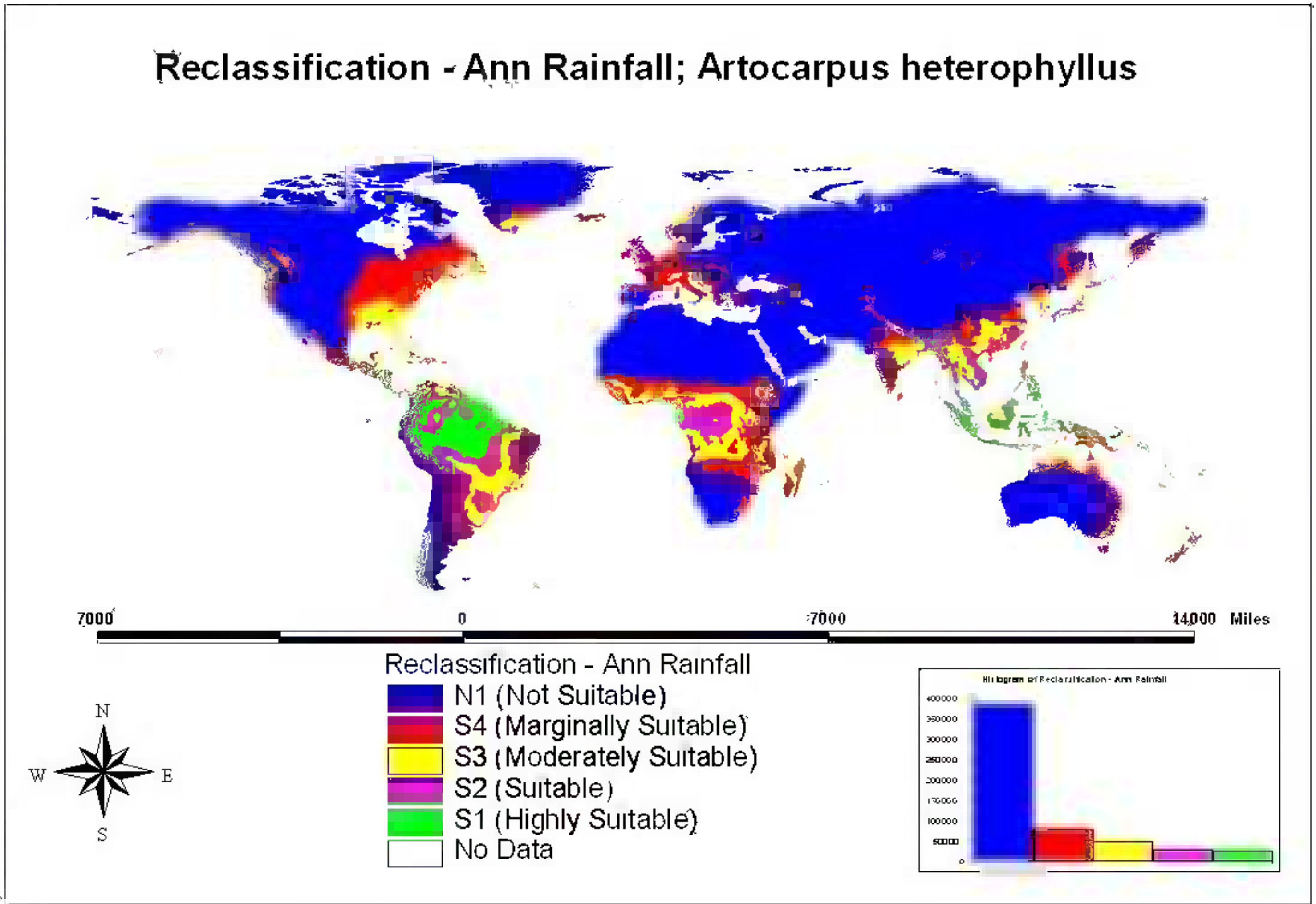

Reclassification Map - Soil texture topsoil; Ziziphus mauritiana
7000
0
7000
14000
Miles
N
W
E
S
Reclassification - Soil texture topsoil
N1 (Not Suitable)
S2 (Suitable)
S1 (highly Suitable)
No Data

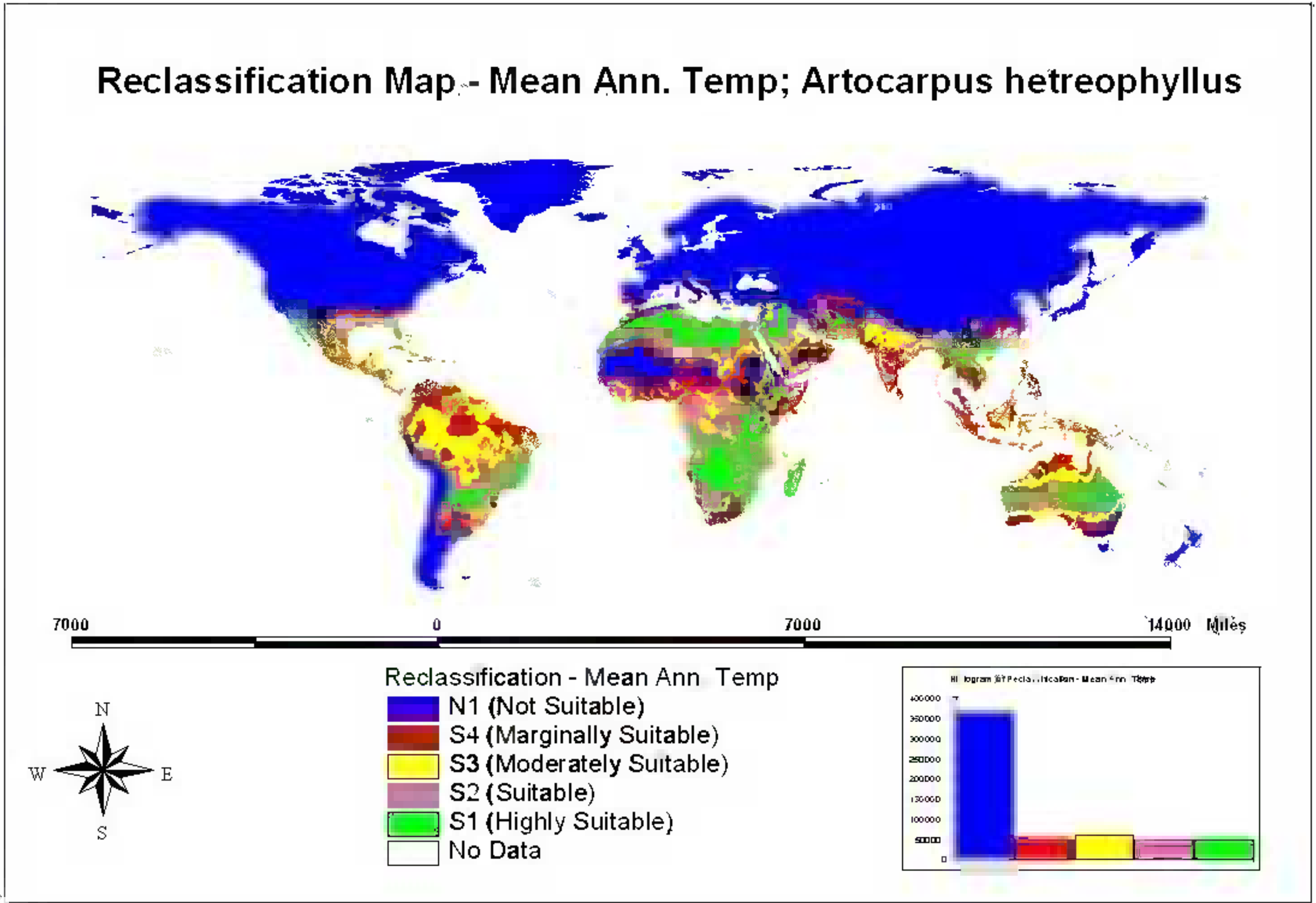

Reclassification Map - Soil pH subsoil; Ziziphus mauritiana
7000
0
7000
14000 Miles
Reclassification - Soil pH subsoil
N1 (Not Suitable)
S4 (Marginally Suitable)
S2 (Suitable)
S1 (Highly Suitable)
No Data
N
W
E
S


Reclassification Map - Soil pH topsoil; Ziziphus mauritiana
7000
0
7000
14000 Miles
N
W
E
S
Reclassification - Soil pH topsoil
N1 (Not Suitable)
S4 (Marginally Suitable)
S2 (Suitable)
S1 (Highly Suitable)
No Data

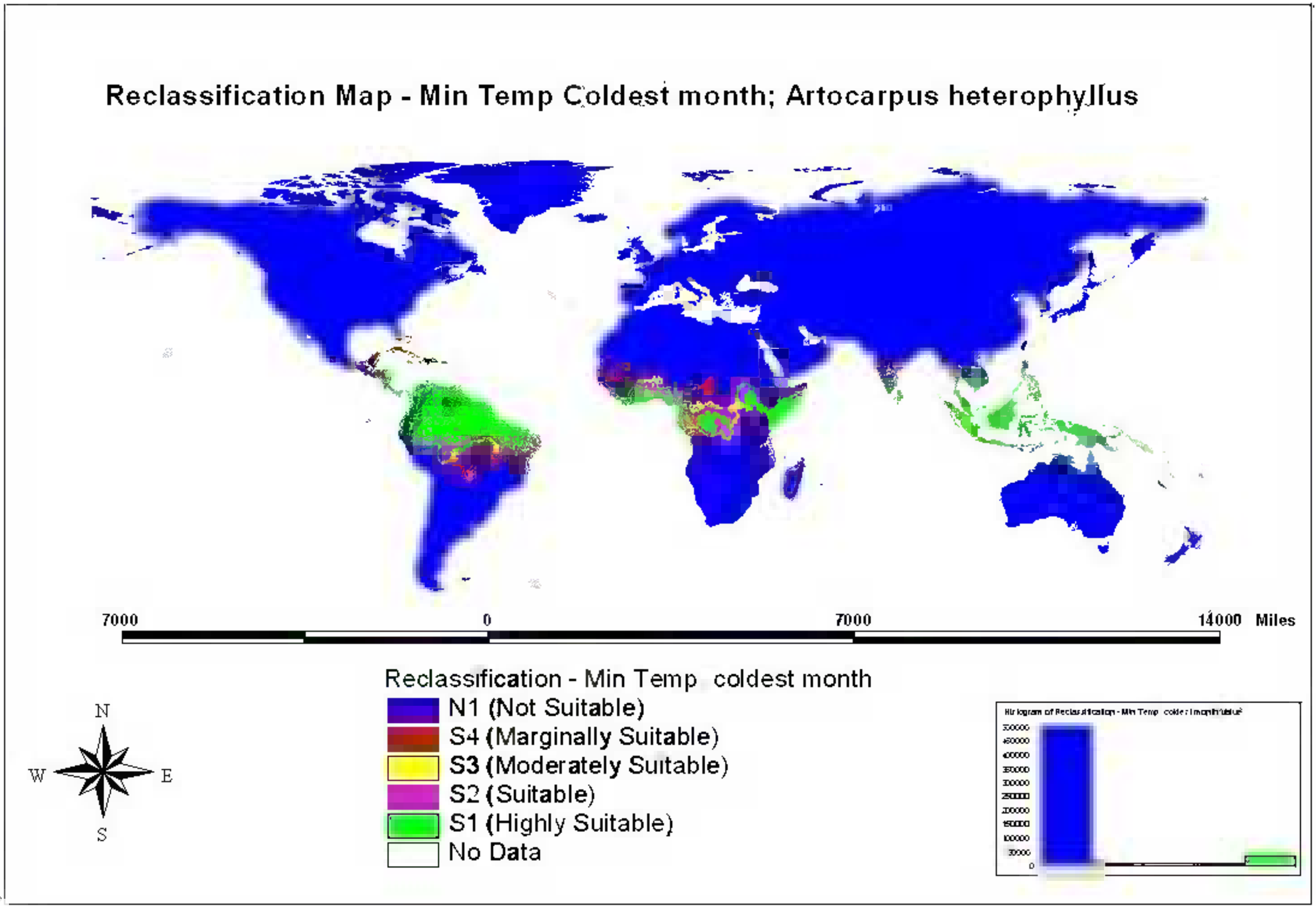
Artocarpus hetrophyllus

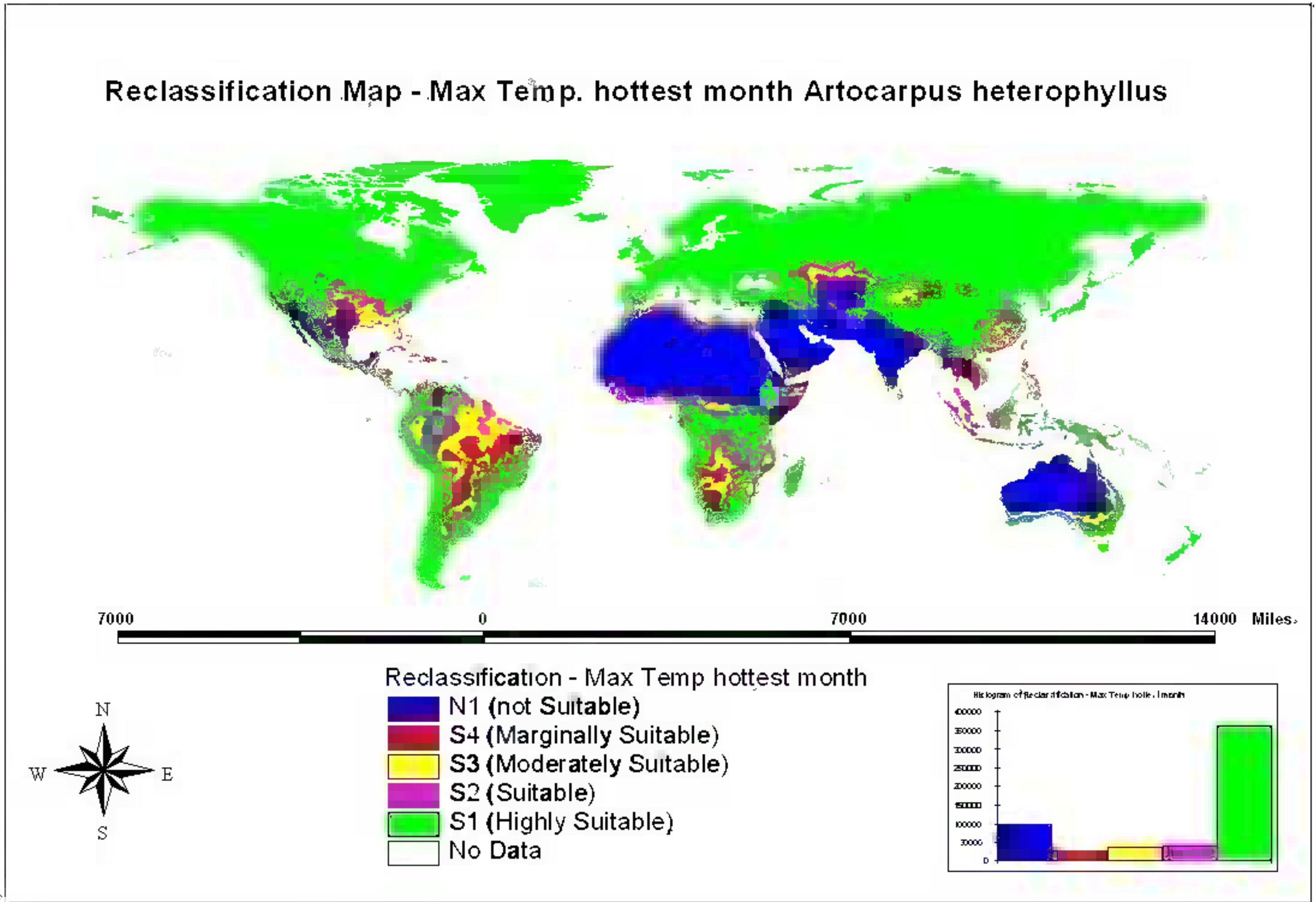


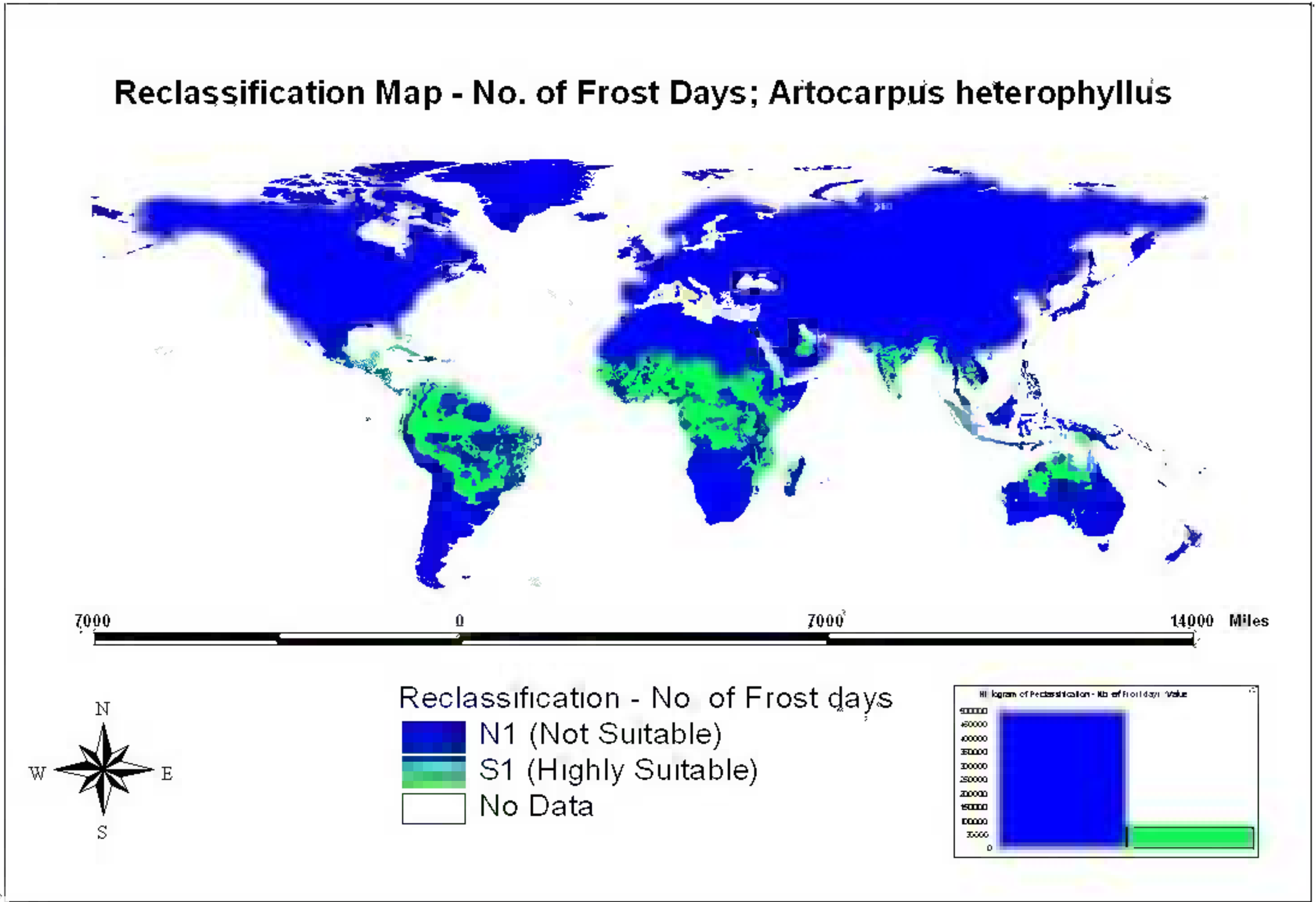

Reclassification - Ann Rainfall; Artocarpus heterophyllus
7000
0
7000
14000 Miles
Reclassification - Ann Rainfall
N1 (Not Suitable)
S4 (Marginally Suitable)
S3 (Moderately Suitable)
S2 (Suitable)
S1 (Highly Suitable)
No Data
N
W
E
S

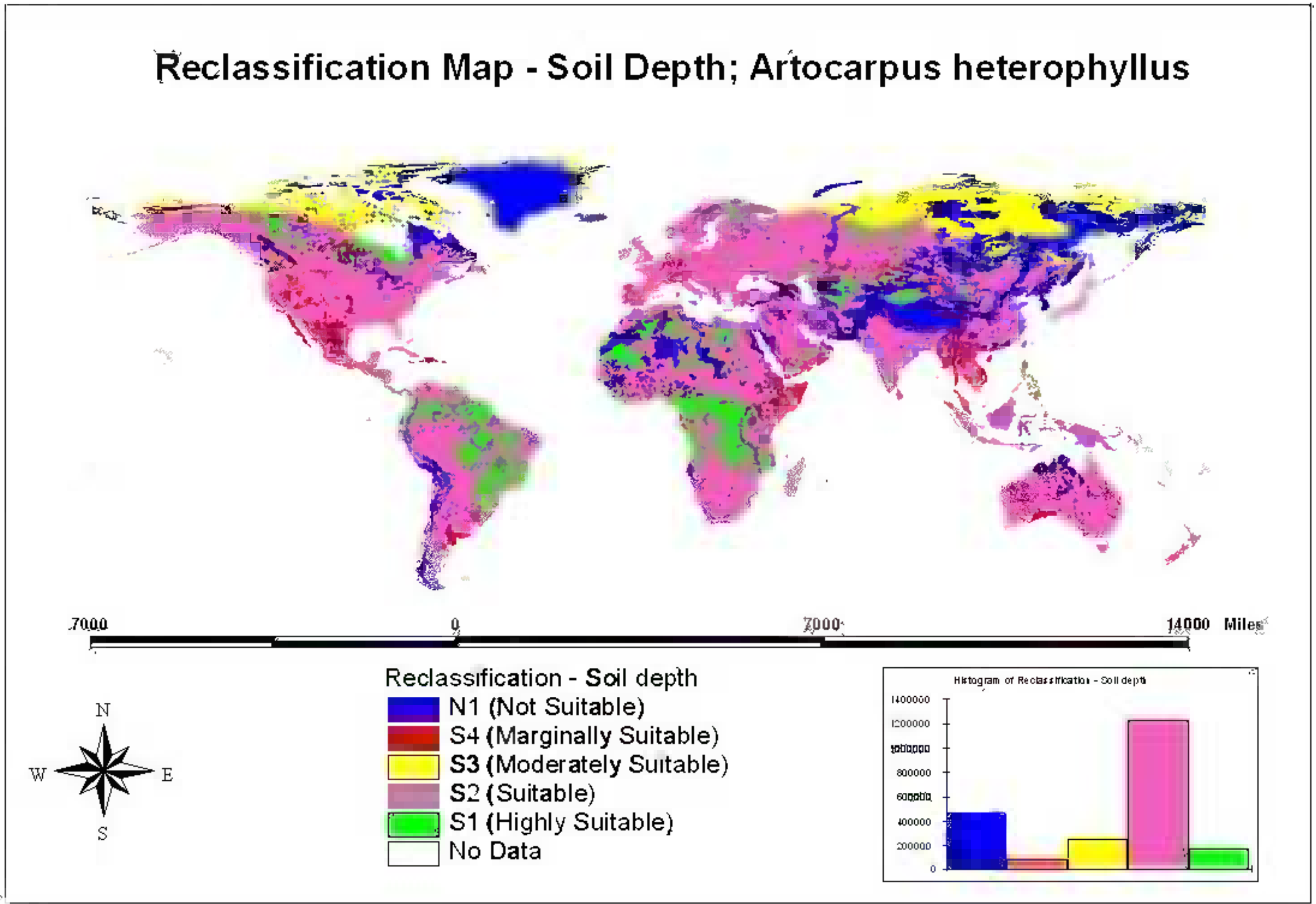


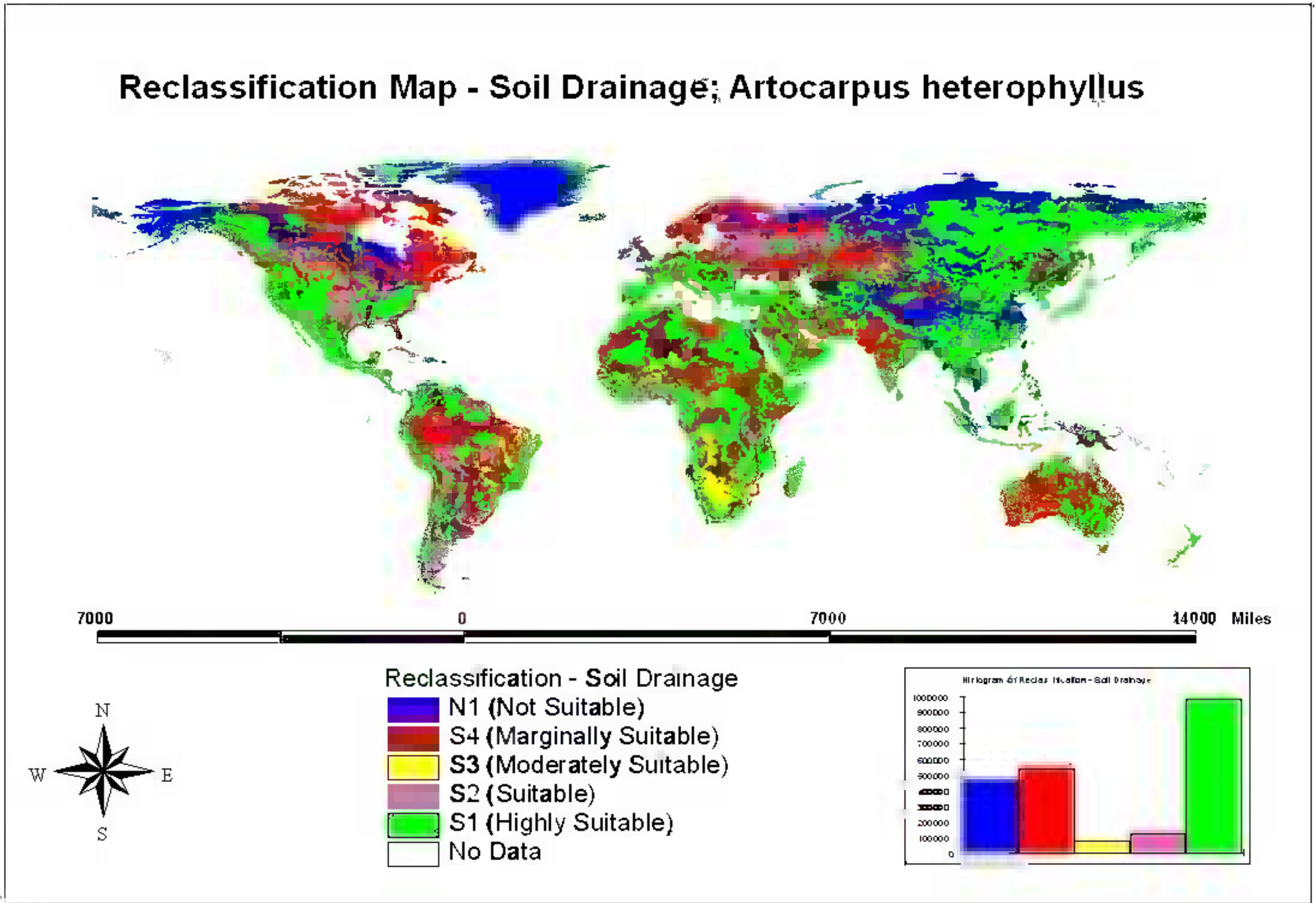
Reclassification Map - Mean Ann. Temp; Artocarpus hetreophyllus
7000
0
7000
14000 Miles
N
W
E
S
Reclassification - Mean Ann Temp
N1 (Not Suitable)
S4 (Marginally Suitable)
S3 (Moderately Suitable)
S2 (Suitable)
S1 (Highly Suitable)
No Data

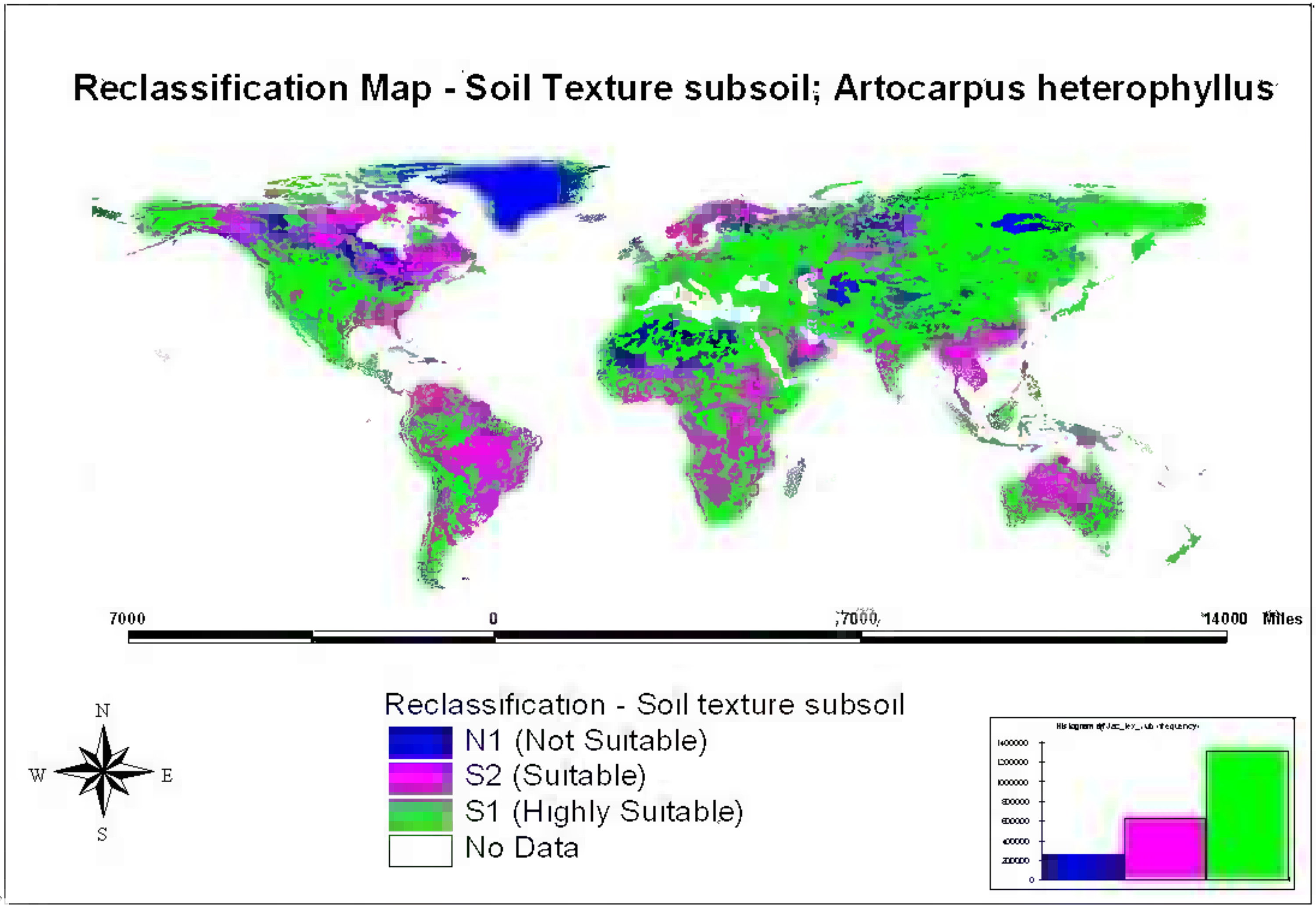

Reclassification Map - Min Temp Coldest month; Artocarpus heterophyllus
7000
0
7000
14000 Miles
Reclassification - Min Temp coldest month
N1 (Not Suitable)
S4 (Marginally Suitable)
S3 (Moderately Suitable)
S2 (Suitable)
S1 (Highly Suitable)
No Data
N
W
E
S

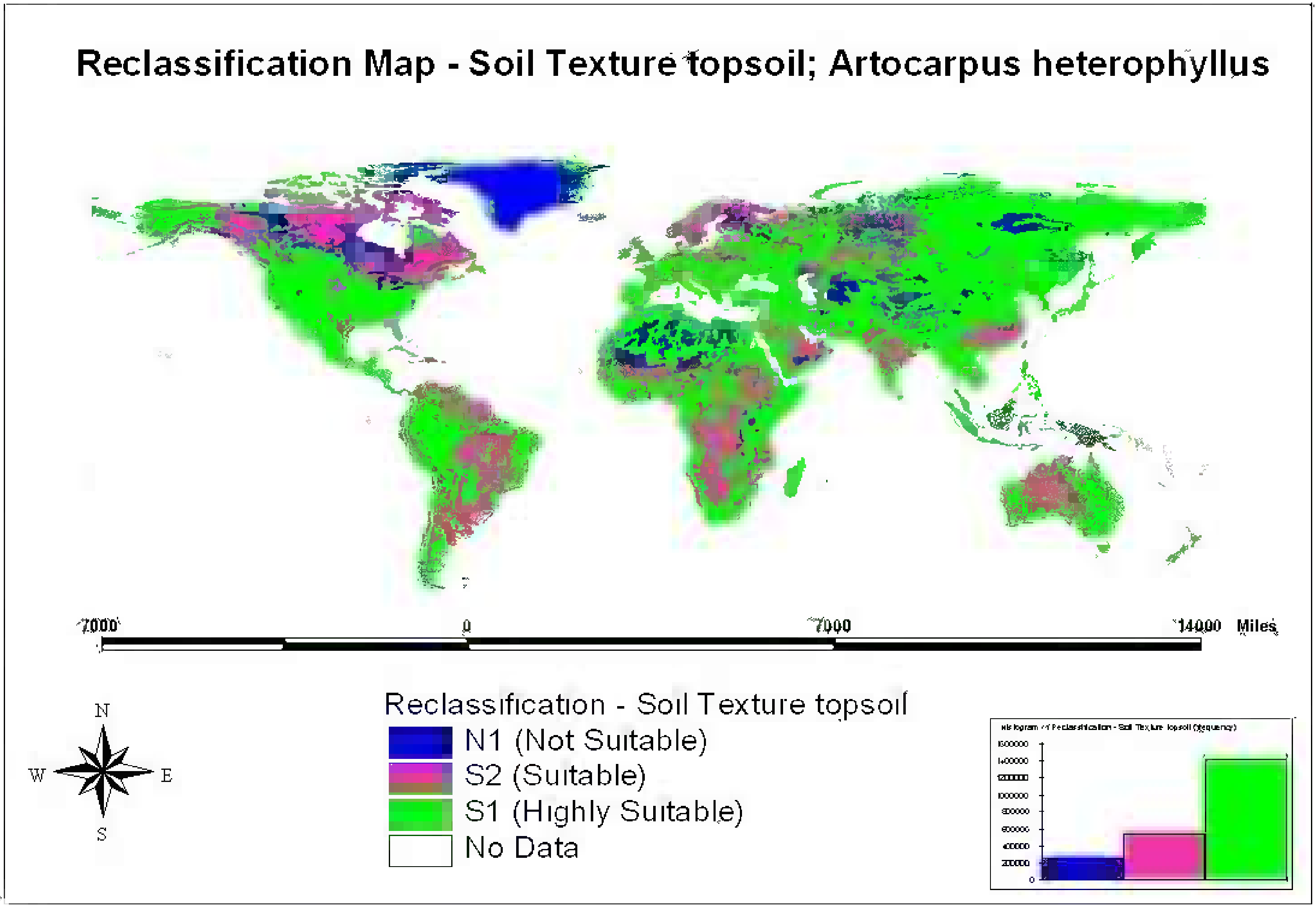

Reclassification Map - Max Temp. hottest month Artocarpus heterophyllus
7000
0
7000
14000 Miles
Reclassification - Max Temp hottest month
N1 (not Suitable)
S4 (Marginally Suitable)
S3 (Moderately Suitable)
S2 (Suitable)
S1 (Highly Suitable)
No Data
N
W
E
S


Reclassification Map - No. of Frost Days; Artocarpus heterophyllus
7000
0
7000
14000 Miles
N
W
E
S
Reclassification - No of Frost days
N1 (Not Suitable)
S1 (Highly Suitable)
No Data

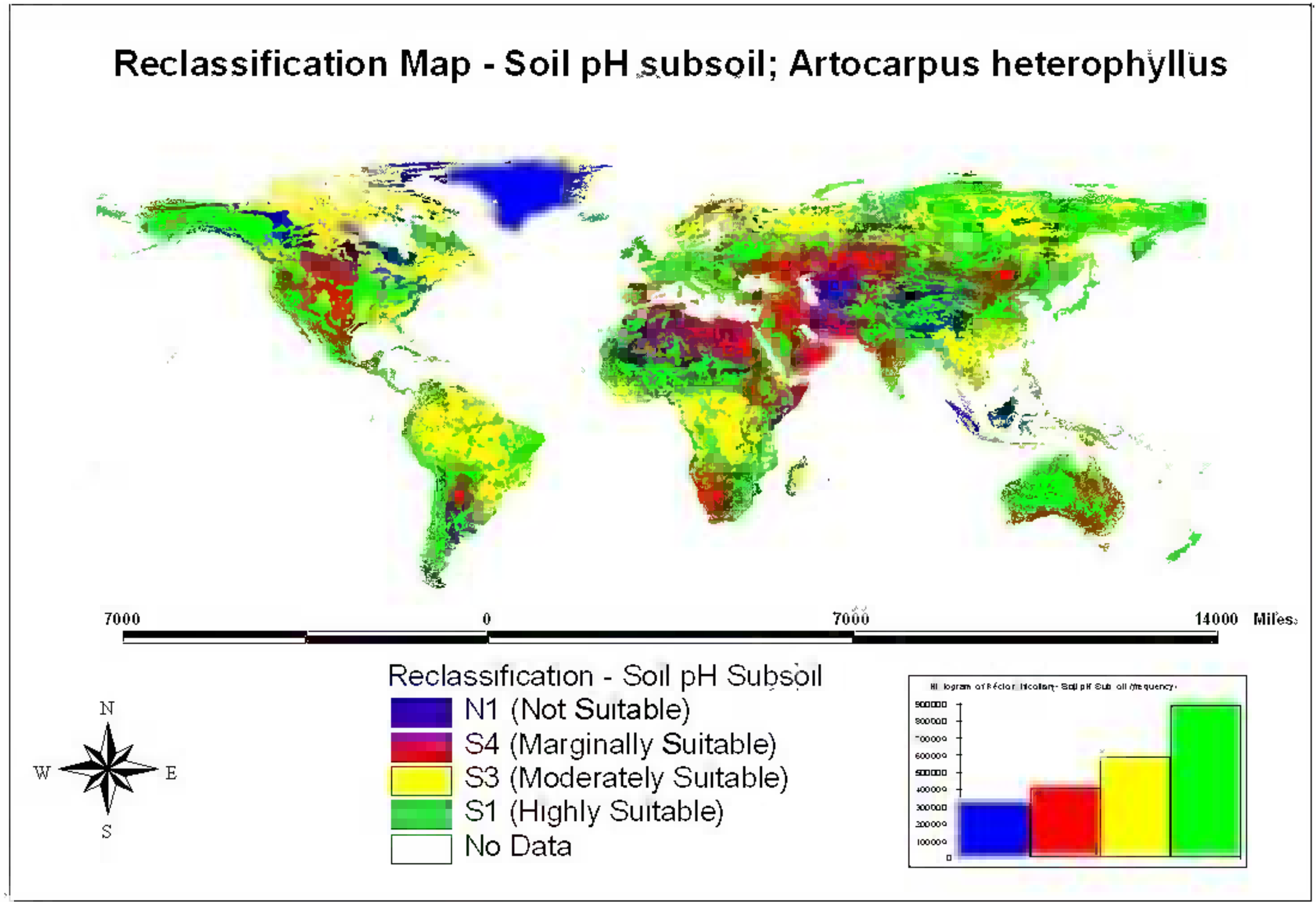

Reclassification Map - Soil Depth; Artocarpus heterophyllus
7000
0
7000
14000 Miles
N
W
E
S
Reclassification - Soil depth
N1 (Not Suitable)
S4 (Marginally Suitable)
S3 (Moderately Suitable)
S2 (Suitable)
S1 (Highly Suitable)
No Data
Histogram of Reclassification - Soil depth
1400000
1200000
1000000
800000
600000
400000
200000
0

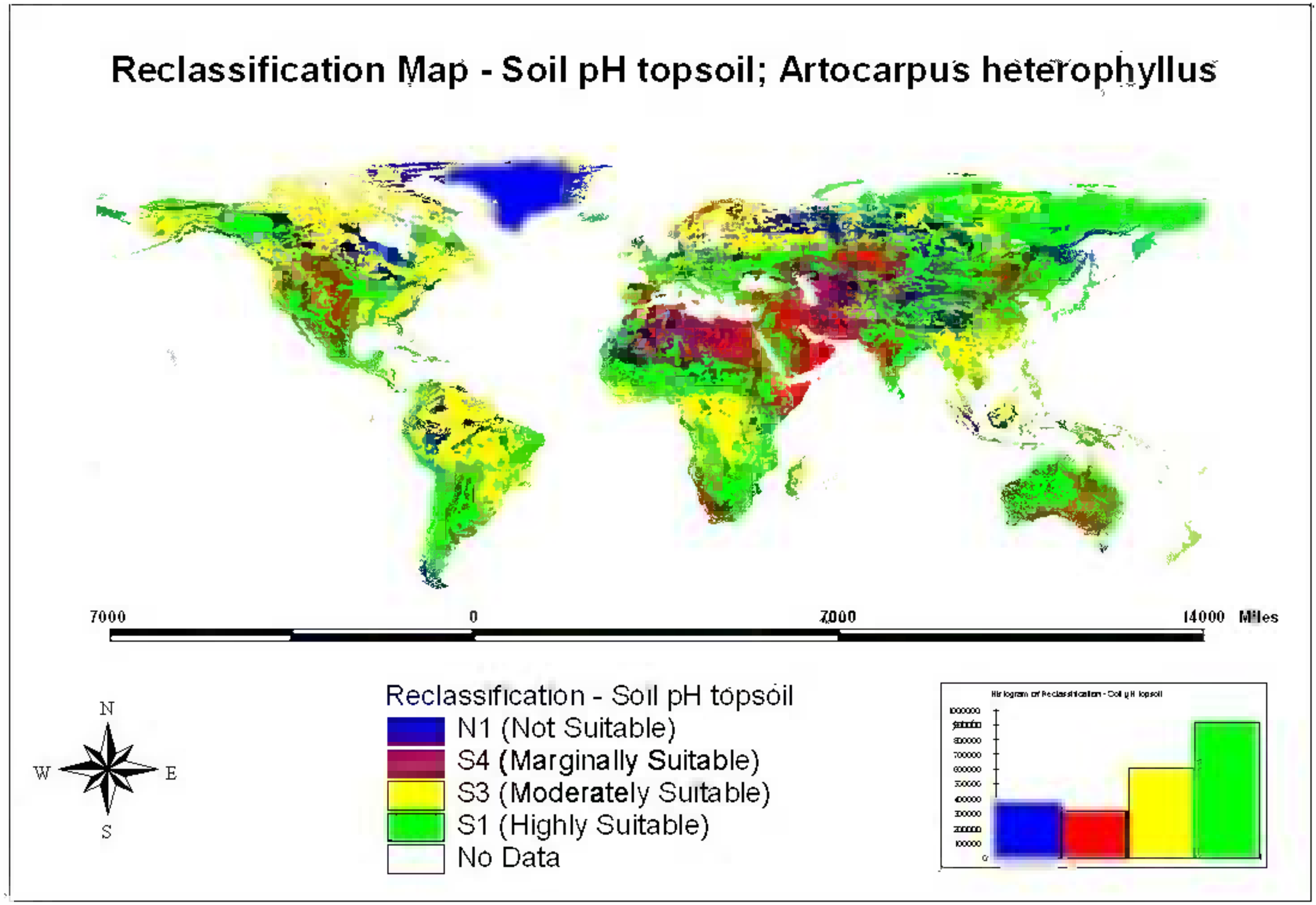

Reclassification Map - Soil Drainage; Artocarpus heterophyllus
7000
0
7000
14000 Miles
N
W
E
S
Reclassification - Soil Drainage
N1 (Not Suitable)
S4 (Marginally Suitable)
S3 (Moderately Suitable)
S2 (Suitable)
S1 (Highly Suitable)
No Data
1000000
900000
800000
700000
600000
200000
100000
0


Reclassification Map - Soil Texture subsoil; Artocarpus heterophyllus
7000
0
7000
14000 Miles
N
W
E
S
Reclassification - Soil texture subsoil
N1 (Not Suitable)
S2 (Suitable)
S1 (Highly Suitable)
No Data



Reclassification Map - Soil Texture topsoil; Artocarpus heterophyllus
7000
0
7000
14000
Miles
N
W
E
S
Reclassification - Soil Texture topsoil
N1 (Not Suitable)
S2 (Suitable)
S1 (Highly Suitable)
No Data


Reclassification Map - Soil pH subsoil; Artocarpus heterophyllus
7000
0
7000
14000 Miles
Reclassification - Soil pH Subsoil
N1 (Not Suitable)
S4 (Marginally Suitable)
S3 (Moderately Suitable)
S1 (Highly Suitable)
No Data
N
W
E
S


Reclassification Map - Soil pH topsoil; Artocarpus heterophyllus
7000
0
7000
14000 Miles
N
W
E
S
Reclassification - Soil pH topsoil
N1 (Not Suitable)
S4 (Marginally Suitable)
S3 (Moderately Suitable)
S1 (Highly Suitable)
No Data

7.3 Appendix 3

LOCATION_I	ADM0	ADM1	ADM2	LOCATION_A	LOCATION_B	LATITUDE	LONGITUDE	SOURCE
1.00000	India	Karnataka	Hassan	Alur	Beduchuvalli	12.96696	75.98432	3.00000
2.00000	India	Karnataka	Tumkur	Tiptur	Konehally	13.26666	76.45000	3.00000
3.00000	India	Karnataka	Chitradurga	Hiriyur	Eswaragere	14.01856	76.76144	3.00000
5.00000	India	Karnataka	Tumkur	Tiptur	Manjunathpura	13.35863	76.43460	3.00000
6.00000	India	Karnataka	Tumkur	Tiptur	Harisamudra	13.32236	76.46247	3.00000
7.00000	India	Karnataka	Hassan	Arsikere	Narmnahalli	13.19175	76.38261	3.00000
8.00000	India	Karnataka	Hassan	Arsikere	Balehally	13.12482	76.37313	3.00000
9.00000	India	Karnataka	Hassan	Arsikere	B. Koplu	13.13019	76.36356	3.00000
10.00000	India	Karnataka	Tumkur	Tiptur	Bhydrahalli	13.34395	76.48341	3.00000
11.00000	India	Karnataka	Hassan	Alur	Mavanur	12.98262	76.02513	3.00000
12.00000	India	Karnataka	Hassan	Alur	Alur	12.97106	75.99003	3.00000
13.00000	India	Karnataka	Hassan	Arsikere	Manjenhalli	13.10387	76.29632	3.00000
14.00000	India	Karnataka	Chitradurga	Hiriyur	Mayasandra	13.96230	76.57462	3.00000
15.00000	India	Karnataka	Bangalore Rural	Aivarkhandpur	Hessaraghatta Lake Post	13.12929	77.49632	3.00000
16.00000	India	Kerala	Trissur	Thrissur	Madakathara	10.56665	76.25445	3.00000
17.00000	India	Kerala	Trissur	Thrissur	Kundukadu	10.58466	76.26593	3.00000
19.00000	India	Kerala	Trissur	Thrissur	Pananchery	10.55060	76.30837	3.00000
24.00000	India	Tamil Nadu	Thenni	Periyakulm	PTS Paduka	10.12846	77.51401	3.00000
27.00000	India	Karnataka	Chitradurga	Hiriyur	Babbur Farm	13.69004	76.65005	3.00000
28.00000	India	Karnataka	Tumkur	Tiptur	S. Lakkihalli	13.20049	76.40369	3.00000
34.00000	India	Karnataka	Tumkur	Madhugiri	Ranganathapura	13.67047	77.14829	3.00000
35.00000	India	Karnataka	Tumkur	Madhugiri	Gundkahalli	13.67200	77.17543	3.00000
36.00000	India	Karnataka	Bangalore Urban	Chik Banavar	Uruchickhalli	13.11446	77.48358	3.00000
40.00000	India	Tamil Nadu	Thenni	Periyakulm	Nandavanam	10.12544	77.51018	3.00000
41.00000	India	Tamil Nadu	Thenni	Periyakulm	Agamalai	10.12787	77.49026	3.00000
43.00000	India	Tamil Nadu	Thenni	Periyakulm	E. Pudukottau	10.13363	77.55674	3.00000
44.00000	India	Tamil Nadu	Thenni	Periyakulm	Kamartani	10.12637	77.59114	3.00000
46.00000	India	Gujarat	Valsad	Kaprada	Niloshi	20.27514	73.27052	3.00000
47.00000	India	Gujarat	Valsad	Kaprada	Lavkar	20.29376	73.26729	3.00000
50.00000	India	Gujarat	Vansda	Navsari	Kavdej	20.69689	73.27667	3.00000
51.00000	India	Gujarat	Vansda	Navsari	Limzec	20.72734	73.29633	3.00000
52.00000	India	Gujarat	Vansda	Navsari	Boriyach	20.70871	73.35284	3.00000
53.00000	India	Gujarat	Vansda	Navsari	Lachhakadi	20.70413	73.33431	3.00000
54.00000	India	Gujarat	Vansda	Navsari	Ghodmal	20.68619	73.32195	3.00000
56.00000	India	Gujarat	Vansda	Navsari	Mindhabari	20.73787	73.33169	3.00000
58.00000	India	Karnataka	Uttar Kannad	Haliyal	Dandeli	15.24192	74.62482	3.00000
59.00000	India	Karnataka	Uttar Kannad	Kumta	Hiregutti	14.55614	74.38559	3.00000
60.00000	India	Karnataka	Uttar Kannad	Ankola	Karehalli	14.75825	74.40294	3.00000
62.00000	India	Karnataka	Uttar Kannad	Ankola	Ganesh	14.56634	74.38596	3.00000
63.00000	India	Karnataka	Uttar Kannad	Ankola	Andle	14.58781	74.39402	3.00000
66.00000	India	Karnataka	Dharwad	Kalagataghi	Surshetty Koppa	15.19873	75.09390	3.00000
1284.00000	Oman	Dhofar	Marbat		innah Wad	17.00000	54.60580	1.00000
1285.00000	Saudi Arabia	Makkah	N.A.		Jedda	21.51690	39.21910	1.00000
1286.00000	Saudi Arabia	Makkah	N.A.		Jedda	21.51690	39.21910	1.00000
1287.00000	Oman	Muscat	Muscat		Muscat	23.60800	58.58930	1.00000
1288.00000	Oman	Al Batnah	Al Khabourah		Bitinah coast	23.75930	57.25150	1.00000
1289.00000	Oman	Dhofar	Salalah		Dhofar	17.03880	53.63830	1.00000
1290.00000	Oman	Dhofar	Taqah		Ethon Wadi	17.09550	54.33520	1.00000
1291.00000	Oman	Al Wusta	Al Wusta (1)		Muscat	21.00000	57.00000	1.00000
1293.00000	Yemen	Former North Yemen	North Yemen (1)		Mafhag	15.10120	43.90000	1.00000
1294.00000	Libya	Darnah	N.A		Benghazi RGN	31.00000	22.50000	1.00000
1295.00000	China	Yunnan	Yimen		Yunnan Province	25.00000	102.00000	1.00000
1296.00000	China	Hainan	Wenchang		Wen - chang - hsien (Hainan)	19.61670	110.71660	1.00000
1297.00000	China	Hainan	Ya Xian		Ngai - hsien (Hainan)	18.37200	109.15730	1.00000
1298.00000	China	Guangdong	Chaoan		Chau chu fu	23.65970	116.63750	1.00000
1299.00000	China	Guangdong	Chenhai		Ching hai	23.46670	116.75000	1.00000
1301.00000	India	Uttar Pradesh	Almora		Kumaon	29.83330	79.50000	1.00000
1302.00000	India	Madhya Pradesh	Sehore		Schore	23.19330	77.07670	1.00000
1303.00000	India	West Bengal	North 24 Panganas		Sasan	22.65950	88.58500	1.00000
1304.00000	India	Gujarat	Junagadh		Gir Forest	21.08330	70.83330	1.00000
1305.00000	India	West Bengal	North 24 Panganas		Sasan	22.65420	88.58430	1.00000

1306.00000	Bangladesh	Khulna	Satkhira		Katia	22.71660	89.10000	1.00000
1307.00000	India	Orissa	Dhenkanal		Pal Lahara PPL	21.45000	85.18330	1.00000
1308.00000	India	Karnataka	Dharwad		Bannikop	15.10000	75.71660	1.00000
1309.00000	India	Karnataka	Hassan		Belur	13.16660	75.86660	1.00000
1310.00000	Myanmar (Burma)	Yangon (Rangoon)	Hmawbi		Insein district (ADMD)	17.25000	96.00000	1.00000
1311.00000	Myanmar (Burma)	Arakan (Rakhine)	Ramree		Kyaukpyu	19.08830	93.86660	1.00000
1312.00000	Sri Lanka	Central	Kandy ADM2		Kandy PPL	7.29120	80.63430	1.00000
1313.00000	Sri Lanka	Central			Mutugalla Kulam (RSV)	7.96670	81.16660	1.00000
1314.00000	Sri Lanka	North Central			Matale PPL	7.46970	80.62130	1.00000
1315.00000	Sri Lanka	Central			Badulla (PPL)	6.98330	81.05000	1.00000
1316.00000	Sri Lanka	Northern	Jaffna		Elephant pass (PPL)	9.51670	80.40000	1.00000
1317.00000	Sri Lanka	Northern	Jaffna		Parantan (PPL)	9.43330	80.40000	1.00000
1318.00000	Sri Lanka	North Western			Puttalam (PPL)	8.03330	79.81660	1.00000
1319.00000	Malaysia	Selangor	N.A.		Ulu Gombak Forest reserve (FRST)	3.30000	101.78330	1.00000
1320.00000	Malaysia	Selangor	N.A.		Damansara (PPL) (New Village)	3.13330	101.63330	1.00000
1321.00000	Malaysia	Negeri Sembilan	N.A.		Tampin	2.48330	102.23330	1.00000
1322.00000	Malaysia	Negeri Sembilan	N.A.		Gemas	2.58330	102.58330	1.00000
1323.00000	Malaysia	Perlis	N.A.		Dayang Bunting	6.23330	99.83330	1.00000
1324.00000	Indonesia	Nusa Tenggara Timur	Timor Tengah Sela		Kapan (PPL)	-9.73330	124.28330	1.00000
1325.00000	Indonesia	Maluku	Maluku Tenggara		Saumlaki (PPL)	-7.95000	131.31670	1.00000
1326.00000	Indonesia	Jawa Tengah	Wonosobo		Java ISL	-7.50000	110.00000	1.00000
1327.00000	Malaysia	Sarawak	N.A.		Kuching (Borneo - Malaysia) PPL	1.55000	10.33330	1.00000
1328.00000	Indonesia	Maluku	Halmahera Tengah		Halmahera Pulau (ISL)	1.00000	128.00000	1.00000
1329.00000	Malaysia	Sabah			Kudat (PPL)	6.88330	16.83330	1.00000
1330.00000	Malaysia	Sabah			Elopura (PPL)	5.83330	118.11660	1.00000
1331.00000	Malaysia	Sabah			Mempakul (PPL)	5.30000	115.33330	1.00000
1332.00000	Malaysia	Sabah	N.A.		Lahad Datu (PPL)	5.00000	118.00000	1.00000
1333.00000	Malaysia	Sabah			Tenom (PPL)	5.13330	115.95000	1.00000
1334.00000	Malaysia	Sabah	N.A.		Batu Linting	5.46660	115.46660	1.00000
1335.00000	Malaysia	Sabah			Mempakul	5.30000	115.33330	1.00000
1336.00000	Philippines	Region 5	Ililo		Guimaras island (ISL)	10.58330	122.61660	1.00000
1337.00000	Australia	Queensland			Ayre Nth. Qld NK	-19.58330	147.41660	1.00000
1338.00000	Australia	Northern Territory			Port Bradshaw	-12.50000	136.83330	1.00000
1339.00000	Australia	Northern Territory			Elcho Island Settlement	-11.91660	135.75000	1.00000
1340.00000	Australia	Northern Territory			Pine Creek	-13.81660	131.81660	1.00000
1341.00000	Australia	Queensland			Brisbane	-27.50000	153.01660	1.00000
1342.00000	Vanuata				Vate, Ile (ISL)	-17.66660	168.41660	1.00000
1343.00000	New Caledonia				Dothio	-21.56660	166.10000	1.00000
1344.00000	New Caledonia				Tuane	-21.46660	168.03330	1.00000
1345.00000	Papua New Guinea	West New Britain			Atui (ISL)	-6.18330	150.58330	1.00000
1346.00000	Senegal	Kedougou	Bandafassi		Assirik	12.88330	-12.75000	1.00000
1347.00000	Sierra Leone	Eastern	Kenema		Bambawo	8.00000	-11.11660	1.00000
1348.00000	Sierra Leone	Northern	Port Lokko		Karine	8.74720	-13.07080	1.00000
1349.00000	Northern	Northern	Bombali		Kamalu	9.40000	-12.25000	1.00000
1350.00000	Liberia	Grand Bassa	No. 2		Fortsville	6.03000	-10.02130	1.00000
1351.00000	Burkina Faso	Yatenga	Oula		Ziga	13.41660	-2.31660	1.00000
1352.00000	Burkina Faso	Mou Houn	Boromo		Boromo	11.75000	-2.93330	1.00000
1353.00000	Ghana	Northern	Damango		White Volta	9.16660	-1.25000	1.00000
1354.00000	Ghana	Volta	Yingor		Ashanti	6.91670	0.53330	1.00000
1355.00000	Ghana	Upper West	Lambussie-Nandom		Lambusie	10.83330	-2.70000	1.00000
1356.00000	Ghana	Northern	Saboba-Zabzugu		Jamale(ge)	9.01660	0.35000	1.00000
1357.00000	Nigeria	Kunda	Igabi		Afaka forest reserve	10.58610	7.31360	1.00000
1358.00000	Nigeria	Niger	Borgu		Ilorin	10.88330	4.01660	1.00000
1359.00000	Nigeria	Niger	Mokwa		Jebba	9.13330	4.83330	1.00000
1360.00000	Nigeria	Kebbi	Zuru		Marafa	11.55000	4.76660	1.00000
1361.00000	Nigeria	Bauchi	Gamjuwa		Zalanga	10.61660	10.16660	1.00000
1362.00000	Nigeria	Kaduna	Sabon-Ga		Zaria	10.06660	7.70000	1.00000
1363.00000	Nigeria	Sokoto	Zurmi		Zurmi	12.78330	6.78330	1.00000
1364.00000	Nigeria	Sokoto	Zurmi		Zurmi	12.78330	6.78330	1.00000
1365.00000	Nigeria	Bauchi	Dass		Bauchi Plateau	10.00000	9.50000	1.00000
1366.00000	Nigeria	Kogi	Ankpa		Ankpa	7.36660	7.63330	1.00000
1367.00000	Nigeria	Kaduna	Ikara		Mudi	11.15000	8.21660	1.00000

1368.00000	Nigeria	Borno	Maidugur		Pompomari	11.81660	13.06660	1.00000
1369.00000	Nigeria	Taraba	Gashaka		Gangumi	7.20000	11.41660	1.00000
1370.00000	Nigeria	Adamwara	Song		Kofare	9.33330	12.46670	1.00000
1371.00000	Nigeria	Taraba	Gashaka		Garbabi	7.83330	11.03330	1.00000
1372.00000	Togo	Centre	Tchaudjo		Sada	8.75000	1.26660	1.00000
1373.00000	Togo	Plateaux	Kloto		Atakpame	6.57670	0.75000	1.00000
1374.00000	Benin	Zou	Dassa		Dassa-Zoume	7.75000	2.18330	1.00000
1375.00000	Benin	Zou	Bante		Bante	8.41660	1.87660	1.00000
1376.00000	Zaire	Haut-Zaire	Ituri		Mahagi	2.30000	30.98330	1.00000
1377.00000	Zaire	Haut-Zaire	Ituri		Mahagi	2.30000	30.98330	1.00000
1378.00000	Zaire	Kivu	Sud-Kivu		Kahanda	-2.95000	29.05000	1.00000
1379.00000	Burundi	Bujumbura	Mutimbuzi		Rusisi (Risizi)	-3.35300	29.28330	1.00000
1380.00000	Burundi	Bujumbura	Nyabigina (Buj)		Bujumbura	-3.32650	29.31760	1.00000
1381.00000	Burundi	Bujumbura	Nyabigina (Buj)		Bujumbura	-3.32650	29.31760	1.00000
1382.00000	Burundi				Kuburantura	-2.91660	29.01670	1.00000
1383.00000	Burundi	Bundanza	Bundanza		Ferme de Randa	-3.15000	29.36660	1.00000
1384.00000	Equatorial Guinea	Annobon	N.A.		Pagalu Isle	-1.43330	5.63330	1.00000
1385.00000	Central African Republic	Ouaka	Bambari		Bambari	5.76190	20.68330	1.00000
1386.00000	Central African Republic	Ouham	Bossangoa		Bossangoa	6.50000	17.33330	1.00000
1387.00000	Nigeria	Adamwara	Mubi		Northern Province, 100 km nnw of G	10.16670	13.41660	1.00000
1388.00000	Cameroon				Mbere	6.85000	13.91660	1.00000
1389.00000	Cameroon	Extreme Nord			Kaele	10.10550	14.45050	1.00000
1390.00000	Equatorial Guinea	Annobon			Ambo	-1.40080	5.62620	1.00000
1391.00000	Yemen	Former South Yemen	Socotra		Hadibo	12.65000	54.02660	1.00000
1392.00000	Yemen	Former South Yemen	Socotra		Wadi Airi	12.33330	54.00000	1.00000
1393.00000	Somalia	Banaadir	Mogadisho		Mogadiscio	2.06670	45.36670	1.00000
1394.00000	Somalia	Bari	Qandala		Botiala	11.46670	49.95000	1.00000
1395.00000	Somalia	Tog-Dheer	Burao		Darraweima Tug	9.66670	45.33330	1.00000
1396.00000	Somalia	W. Galbeed	Hargeysa		Hargeisa	9.58330	44.06660	1.00000
1397.00000	Ethiopia	Hararge	Gursum		Errer valley, 22km SE. of HARDAR o	9.23330	42.25000	1.00000
1398.00000	Ethiopia	Shewa	Chebo&Gurage		Shewa Province, North bank of the	8.21670	37.75000	1.00000
1399.00000	Ethiopia	Hararge	Gara Muleta		Kumbi	8.56670	41.46660	1.00000
1400.00000	Ethiopia	Hararge	Dire Dawa-Isa-Gur		Dire Dewa	9.57670	41.86660	1.00000
1401.00000	Ethiopia	Hararge	Dire Dawa-Isa-Gur		Gota	9.51670	41.31660	1.00000
1402.00000	Ethiopia	Hararge	Harer Zuria			9.31660	42.11660	1.00000
1403.00000	Ethiopia	Gonder	Debre Tabor		Blue nile falls	11.48330	37.58330	1.00000
1404.00000	Ethiopia	Ilubabor	Gore		At Baro River, near the bridgeon t	8.21670	35.00000	1.00000
1405.00000	Ethiopia	Ilubabor	Gambela		Illubabor, Abbo to Gog	7.75000	34.41660	1.00000
1406.00000	Sudan	Darfur	Southern Darfur		Idd al Ghanam	11.48330	24.35000	1.00000
1407.00000	Sudan	Darfur			S. Darfar province 20 km South of	10.81670	22.09330	1.00000
1408.00000	Sudan	Darfur	Southern Darfur		Jesbel Marra	13.16670	24.36660	1.00000
1409.00000	Sudan	Kordufan	South Kordofan		Dilling	12.05000	29.65000	1.00000
1410.00000	Sudan	Darfur	Southern Darfur		Deleig	12.47670	23.26660	1.00000
1411.00000	Sudan	Eastern	Kassala		Gadaref	14.03330	35.40000	1.00000
1412.00000	Sudan	Darfur	Southern Darfur		Nyama	12.78330	23.55000	1.00000
1413.00000	Sudan	Northern	Northern		Dongola	19.16670	30.48330	1.00000
1414.00000	Kanya	COAST			Kenya Tama, upstream from oxbow at	-0.83330	39.83330	1.00000
1415.00000	Kenya	COAST	TANA RIVER		Tama	-1.25000	40.00000	1.00000
1416.00000	Kenya	N. EASTERN	MANDERA		Ghroha (Boran) Dandu	3.43330	39.90000	1.00000
1417.00000	Kenya	RIFT VALLEY	TURKANA		Lowdar	3.11670	35.60000	1.00000
1418.00000	Kenya	RIFT VALLEY	BARINGO		Chemolingot b.h.	0.96670	35.95000	1.00000
1419.00000	Kenya	EASTERN	MERU		Meru National Park	0.08330	38.33330	1.00000
1420.00000	Kenya	EASTERN	MERU		Thaicgu	0.18330	38.16660	1.00000
1421.00000	Kenya	NYANZA	HOMA_BAY		Nyanza prov.	-0.50000	34.50000	1.00000
1422.00000	Kenya	NYANZA	HOMA_BAY		Central Kavirondo	-0.25000	34.58330	1.00000
1423.00000	Kenya	RIFT VALLEY	NAROK		Ol. Str/s.	-1.80000	35.96660	1.00000
1424.00000	Kenya	COAST	TANA RIVER		Mnazini	-2.00000	40.08330	1.00000
1425.00000	Kenya	COAST	KWALE		Kwale District, Lungalunga - Ramis	-4.61670	39.16660	1.00000
1426.00000	Kenya	COAST	Mombasa		Mombassa	-4.05000	39.66660	1.00000
1427.00000	Kenya	COAST	KILIFI		Malandi	-3.21670	40.11660	1.00000
1428.00000	Kenya	COAST			Kilifi popl	-3.63330	39.85000	1.00000
1429.00000	Kenya	COAST	KILIFI		Kilifi Distr	-3.16670	39.66660	1.00000

1430.00000	Kenya	COAST	KILIFI		Arabuko Sokoke, for	-3.33330	39.86660	1.00000
1431.00000	Kenya	COAST	TAITA TAVETA		Irima	-3.28330	38.53330	1.00000
1432.00000	Kenya	RIFT VALLEY	WEST POKOT		Turkwell Gorge	1.91670	35.33330	1.00000
1433.00000	Uganda	Moroto	Pian		Nabilatuk popl.	2.05000	34.56660	1.00000
1435.00000	Uganda	Moroto	Matheniko		Maroto	2.53330	34.65000	1.00000
1436.00000	Uganda	Kitgum	Lamwo		Madi Forest	3.73330	33.10000	1.00000
1437.00000	Uganda	Moroto	Kadam (Chekwii)		Kadam mt.	1.75000	34.70000	1.00000
1438.00000	Uganda	Masindi	Buliisa		Bulisa, popl t.c.	2.11670	31.41660	1.00000
1439.00000	Tanzania United Republic	Mara	Musoma		Zanaki popl.,r.h.	-1.71660	33.98330	1.00000
1440.00000	Tanzania United Republic	L. Victoria	L. Victoria		Musoma (ppl)	-1.50000	33.80000	1.00000
1441.00000	Tanzania United Republic	L. Victoria	L. Victoria		Mwanza Popl	-2.51660	32.90000	1.00000
1442.00000	Tanzania United Republic	Shinyanga	Shinyanga		Old Shinyanga	-3.55000	33.40000	1.00000
1443.00000	Tanzania United Republic	L. Victoria	L. Victoria		Mwanza Popl	-2.51660	32.90000	1.00000
1444.00000	Tanzania United Republic	Mara	Bunda		Kirawira Guard post	-2.16670	34.15000	1.00000
1445.00000	Tanzania United Republic	Arusha	Babati		Lake Manyara National park	-3.50000	35.83330	1.00000
1446.00000	Tanzania United Republic	Arusha	Mbulu		Mangola	-3.41660	35.43330	1.00000
1447.00000	Tanzania United Republic	Tanga	Pangani		Mwera popl	-5.53330	38.93330	1.00000
1448.00000	Tanzania United Republic	Tanga	Korogwe		Maramba popl t.c.	-5.05000	38.61660	1.00000
1449.00000	Tanzania United Republic	Tanga	Pangani		Bushiri estate	-5.35000	38.95000	1.00000
1450.00000	Tanzania United Republic	Tanga	Korogwe		Mikocheni	-4.68330	38.06660	1.00000
1451.00000	Tanzania United Republic	Tanga	Korogwe		Lushoto	-4.68330	38.06660	1.00000
1452.00000	Tanzania United Republic				Tanga popl	-5.16670	39.66670	1.00000
1453.00000	Tanzania United Republic	Tanga	Pangani		Mkaramo near Mkwaja	-5.78330	38.85000	1.00000
1454.00000	Tanzania United Republic	Kilimanjaro	Moshi		Pangani River	-3.53330	37.56660	1.00000
1455.00000	Tanzania United Republic	Tabora	Tabora		Tabora	-5.01660	32.80000	1.00000
1456.00000	Tanzania United Republic	Tabora	Urambo		Mkwaju, (Kiawahili) Gualula (Malag	-4.83330	31.66600	1.00000
1457.00000	Tanzania United Republic	Rukwa	Sumbawanga		Milepa, popl.	-8.06670	31.93330	1.00000
1458.00000	Tanzania United Republic	Kigoma	Kigoma		Katale	-4.98330	31.05000	1.00000
1459.00000	Tanzania United Republic	Rukwa	Mpanda		Ngumba = Kamba Ngombe	-7.51670	31.73330	1.00000
1460.00000	Tanzania United Republic	Kigoma	Kigoma		Kigoma (Dist)	-5.50000	30.00000	1.00000
1461.00000	Tanzania United Republic	Tabora	Iramba		Wembere River	-4.16670	34.18330	1.00000
1462.00000	Tanzania United Republic	Mbeya	Mbeya		Kiwere	-8.56670	34.48330	1.00000
1463.00000	Tanzania United Republic	Dodoma	Kondoa		Kondoa	-4.90000	35.78330	1.00000
1464.00000	Tanzania United Republic	Dodoma	Mpwapwa		Mpwapwa	-6.35000	36.48330	1.00000
1465.00000	Tanzania United Republic	Morogoro	Kilosa		Kidodi	-7.60830	36.99160	1.00000
1466.00000	Tanzania United Republic	Pwani	Rufiji		Rufiji dist	-8.00000	38.75000	1.00000
1467.00000	Tanzania United Republic	Morogoro	Morogoro		Uluguru, North f.r	-6.91670	37.70000	1.00000
1468.00000	Tanzania United Republic	Morogoro	Morogoro		Uluguru South f.r	-7.16670	37.66670	1.00000
1469.00000	Tanzania United Republic	Pawani	Mafia		Mafia Island	-7.83330	39.83330	1.00000
1470.00000	Tanzania United Republic	Morogoro	Morogoro		Turiani	-6.15000	37.60000	1.00000
1471.00000	Tanzania United Republic	Pwani	Rufiji		Dimani c.	-7.83330	38.90000	1.00000
1472.00000	Tanzania United Republic	Morogoro	Kilosa		River Mkata	-6.53330	37.45000	1.00000
1473.00000	Tanzania United Republic	Iringa	Ludewa		Livingstone Mountians	-9.75000	34.33330	1.00000
1474.00000	Tanzania United Republic	Iringa	Iringa		Ifuguru	-7.60000	35.05000	1.00000
1475.00000	Tanzania United Republic	Iringa	Iringa		Iringa	-7.76670	35.70000	1.00000
1476.00000	Tanzania United Republic	Mbeya	Chunya		Lake Rukwa	-8.00000	32.41670	1.00000
1477.00000	Tanzania United Republic	Morogoro	Ulanga		Mahenge	-8.68330	36.71660	1.00000
1478.00000	Tanzania United Republic	Iringa	Iringa		Ruaha Nat. Pk	-7.50000	35.00000	1.00000
1479.00000	Tanzania United Republic	Mbeya	Mbozi		Tunduma	-9.30000	32.76660	1.00000
1480.00000	Tanzania				Mbweni	-6.21660	39.20000	1.00000
1481.00000	Tanzania United Republic	Kusini-Pemba	Mkoani		Chuaka	-5.38330	39.78330	1.00000
1482.00000	Mozambique	Cabo Delgado	Mocimboa da Praia		Msalu River	-11.68330	40.41660	1.00000
1483.00000	Mozambique	Sofala	Chibabava		Chibabava	-20.29190	33.65940	1.00000
1484.00000	Mozambique	Nampula			Inhaca Isl	-26.00000	32.91670	1.00000
1485.00000	Mozambique	Zambezia	Nicoadala		Quelimane	-17.87860	36.88830	1.00000
1486.00000	Mozambique	Tete	Chiuta		Tete District	-15.50000	33.00000	1.00000
1487.00000	Mozambique	Tete	Mutarara		Mutarara	-17.44000	35.07380	1.00000
1488.00000	Mozambique	Zambezia	Morrumbala		Megaza	-17.13830	35.31550	1.00000
1489.00000	Mozambique	Zambezia	Morrumbala		Aguas Quentes	-17.41660	35.35000	1.00000
1490.00000	Mozambique	Tete	Cahora Bassa		Estima	-15.73720	32.77190	1.00000
1491.00000	Mozambique	Inhambane	Vilanculos		Cheline	-22.52850	35.09970	1.00000
1492.00000	Malawi	Southern	Chikwawa		lengwe game reserve	-16.25000	34.75000	1.00000

1493.00000	Malawi	Southern	Chikwawa		Livingstone falls	-15.90000	34.73330	1.00000
1494.00000	Malawi	Southern	Mwanza		MPATAMANGA GORGE,	15.71660	34.73330	1.00000
1495.00000	Malawi	Southern	Zomba		Lake Chilwa (Malawi S)	-15.31670	35.71660	1.00000
1496.00000	Malawi	Southern	Mangochi		Monkey Bay	-14.08330	34.91660	1.00000
1497.00000	Malawi	Northern	Nkata-Bay		Chikale beach, Nkhata Bay	-11.60000	34.30000	1.00000
1498.00000	Malawi	Northern	Mzimba		Ngala	-12.55000	33.50000	1.00000
1499.00000	Malawi	Northern	Nkata-Bay		Sanga	-11.73330	34.30000	1.00000
1500.00000	Malawi	Northern	Karonga		Chilumba	-10.45000	34.26660	1.00000
1501.00000	Zambia	Southern	Sinazongwe		Siatwinda	-17.46660	27.31660	1.00000
1502.00000	Zambia	Lusaka	Luangwa		Feira	-15.61660	30.41660	1.00000
1503.00000	Zambia	Southern	Gwembe		Gwembe Dist.	-16.50000	28.00000	1.00000
1504.00000	Zambia	Northern	Kaputa		Lake Tanganyika	-8.51670	30.58330	1.00000
1505.00000	Zambia	Eastern	Petauke		Luangwa bridge	-14.98330	30.21670	1.00000
1506.00000	Zambia	Northern	Mpika		Mfuwe	-13.06660	31.81660	1.00000
1507.00000	Zambia	Eastern	Petauke		Luembe	-14.43330	30.46660	1.00000
1508.00000	Zambia	Eastern	Chipata		Chikoa	-13.41660	32.08330	1.00000
1509.00000	Zambia	Southern	Sinazongwe		Sinazeze	-17.13330	27.41660	1.00000
1510.00000	Zambia	Southern	Sinazongwe		Zeze	-17.15000	27.46660	1.00000
1511.00000	Zambia	Copperbelt	Kitwe		Kitwe	-12.81660	28.20000	1.00000
1512.00000	Zimbabwe	Mashonal East	Mudzi		Mkota (Reserve)	-16.83330	32.83330	1.00000
1513.00000	Zimbabwe	Matabel North	Binga		Sebungwe C.L.	-17.86660	27.20000	1.00000
1514.00000	Zimbabwe	Matabel North	Hwarnge		Deka	-18.66660	25.83330	1.00000
1515.00000	Madagascar	Toliary	Amboasary-Sud		Andohalhela	-24.08330	46.53330	1.00000
1516.00000	Madagascar	Toliary	Toliary Urban		Tulear	-23.35000	44.66660	1.00000
1517.00000	Madagascar	Mahajanga	Mahajanga Rural		Majunga PPL	-15.71660	46.31660	1.00000
1518.00000	Madagascar	Antananarivo	Antananarivo-Nord		Antananarivo	-19.91660	47.51660	1.00000
1519.00000	Seychelles				Aldabra	-9.41670	46.36660	1.00000
1520.00000	Seychelles				West island	-9.36660	46.21160	1.00000
1521.00000	Seychelles				North Island	-10.11660	51.18330	1.00000
1522.00000	Seychelles	Mahe Island	N.A.		Victoria	-4.61670	55.45000	1.00000
1523.00000	Seychelles				North end of island	7.60000	56.17000	1.00000
1524.00000	Seychelles				West island	-9.36660	46.21160	1.00000
1525.00000	South Africa	Eastern Cape	N.A.		Natal PPL	-30.75000	29.21660	1.00000
1526.00000	South Africa	Natal	Ndwedwe		Ndwedwe PPL	-29.50000	30.93330	1.00000
1527.00000	Mexico	Yucatan			Chunchucmill (PPL)	20.65000	-90.21670	1.00000
1528.00000	Mexico	Yucatan			Tixcalcupul (PPL)	20.53330	-88.26660	1.00000
1529.00000	Cape Verde	Sao Vicente	NA		Sao Vicente Ilha de, (ISL)	16.83330	-25.00000	1.00000
1530.00000	South Africa	Natal	Durban/Chats.		Durban (PPL)	-29.85080	31.01670	1.00000
1531.00000	United States				Hammocks (PPL)	25.66670	-80.44010	1.00000
1532.00000	Brazil				Rio de Janeiro (Prov)	-22.00000	-42.50000	1.00000
1533.00000	Belize				British Honduras (Belize) (PCLI)	17.25000	-88.75000	1.00000
1534.00000	VENEZUELA	NUEVA ESPARTA	Diaz		Margarita, Isle de (ISL)	11.00000	-64.00000	1.00000
1535.00000	Montserrat				Plymouth (PPLC)	16.70000	-62.21670	1.00000
1536.00000	BRASIL	Tocantins	Almas		Corrego Cangalha	-11.88330	-47.53330	1.00000
1537.00000	BRASIL	BAHIA	SALVADOR		Bahai (PPL)	-12.98330	-38.51660	1.00000
1538.00000	Trinidad and Tobago	Tobago			Store Bay	11.15000	-60.83330	1.00000
1539.00000	Belize	Toledo			Puebleo Viejo	16.18330	-89.13830	1.00000
1540.00000	Guatemala				Zacapa	14.96670	-89.53330	1.00000
1541.00000	ECUADOR	LOS RIOS	Quevedo		Pichilingue	-1.10000	-79.48330	1.00000
1542.00000	BRASIL	Amazonas	Tefe		Copaiba	-4.32580	-65.27880	1.00000
1543.00000	Costa Rica				Costa Rica, Gunacaste, On the road	10.45000	-85.66660	1.00000
1544.00000	El Salvador				Olomega Laguna (LK)	13.31670	-88.06660	1.00000
1545.00000	Cuba				Calabazar (Cuba) (PPL)	22.64020	-79.89100	1.00000
1546.00000	The Bahamas				Fresh Creek (bahamas) (PPL)	24.70000	-77.76670	1.00000
1547.00000	Dominican Republi				Moncion District (ADM2)	19.46670	-71.16670	1.00000
1548.00000	Barbados				Bridgetown (PPLC)	13.10000	-59.61670	1.00000
1549.00000	Jamaica				Kingston (PPLC)	18.00000	-76.80000	1.00000
1550.00000	Mexico	Sinaloa			Mazatlan (PPL)	23.21660	-106.21660	1.00000
1551.00000	Mexico	Chiapas			Yajalon (PPL)	17.23330	-92.33330	1.00000
1552.00000	Mexico	Michoacan de Ocampo			Tacupa (PPL)	18.40000	-100.66660	1.00000
1553.00000	Mexico	Mexico			Los Bejucos (PPL)	18.75000	-100.43330	1.00000
1554.00000	Mexico	Mexico			Paso Guayabal (PPL)	18.80000	-100.38330	1.00000

1555.00000	Mexico	Mexico			Tejupilco (PPL)	18.90000	-100.15000	1.00000
1556.00000	Guatemala	Peten			La Libertad	16.78330	-90.11660	1.00000
1557.00000	Mexico	Veracruz-Llave			Lomas de Arena (PPL)	20.16670	-97.09990	1.00000
1558.00000	Indonesia	Maluku	Maluku Tengah		Ambonia (ISL)	-3.66670	128.20000	1.00000
1559.00000	Philippines	Region 4	Rizal		Tanay (PPL)	14.50000	121.28330	1.00000
1560.00000	Philippines	Region 3	Zambales		Subic	14.88330	120.23330	1.00000
1561.00000	Philippines	Region 4	Quezon		Gumaca (PPL)	13.91660	122.10000	1.00000
1562.00000	Philippines	Region 4	Laguna		Los Banos (PPL)	14.18330	121.18330	1.00000
1563.00000	Tahiti (ISL)	Pare (ADMD)			Papeete (PPLC)	-17.53330	149.56660	1.00000
1564.00000	Fiji	Central			Suva	-18.13330	178.41670	1.00000
1565.00000	India	Karnataka	Bijapur		Hungund	16.06660	76.05000	2.00000
1566.00000	India	Karnataka	Bijapur		Atharga	16.98330	75.90000	2.00000
1567.00000	India	Karnataka	Dharwad		Ron	15.66660	75.73330	2.00000
1568.00000	India	Karnataka	Uttar Kannad		Mundgod	14.96660	75.03330	2.00000
1569.00000	India	Karnataka	Bijapur		Badami	15.91660	75.68330	2.00000
1570.00000	India	Karnataka	Bijapur		Nagral	16.10000	76.31660	2.00000
1571.00000	India	Karnataka	Shimoga		Ayanur	14.01660	75.43330	2.00000
1572.00000	India	Karnataka	Dharwad		Tadas	15.13330	75.11660	2.00000
1573.00000	India	Karnataka	Dharwad		Dhundsi	15.03330	75.13330	2.00000
1574.00000	India	Karnataka	Uttar Kannad		Dandeli	15.26660	74.61660	2.00000
1857.00000	India	Gujarat	Amnanbad	Bavala	Vansana	22.84440	72.18956	3.00000
1859.00000	India	Karnataka	Dharwad	Dharwad	Gunaragatti	15.53016	74.93830	3.00000