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Evaluation of the Suitability of Horticultural Crops under Prevailing Environmental Conditions - A Case Study of Punjab

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Alternate land use options such as horticultural crops help in ensuring efficient land resource utilization. Thus, it is essential to evaluate the agri-environmental conditions for economically viable and sustainable horticultural production. A study was carried out for land use planning of Rajpura block in Patiala district of Punjab. Under this study, soil-site suitability of horticultural crops were evaluated by considering key soil parameters such as texture, depth, slope, EC, pH, organic carbon content, erosion, drainage, and climate factors *viz.*, rainfall and temperature, etc. The soils of the block were interpreted to assess their suitability for various horticultural crops *viz.*, mango, grapes,

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banana, sapota, guava, pomegranate and citrus fruits. The mango cultivation was found suitable for almost 50% area and moderately suitable for 34% area. Soil-site suitability characteristics evaluation for grape cultivation revealed that around 34% area of the block is suitable while 50% area is moderately suitable. The banana and sapota crop cultivation was found to be highly suitable for approximately 45% area, whereas moderately suitable for 40% area. In context of guava and pomegranate, nearly 34% area was covered under suitable class and 50% area was covered under moderately suitable class, respectively. The citrus crops are highly suitable for this block which covers the maximum area of the block about 61% and moderately suitable for almost 23% area, respectively. The small fraction of the block, only 1.68% (476 ha) exhibits marginal suitability for the cultivation all fruit crops. The horticultural crop suitability maps were generated by using remote sensing and GIS tools. Hence, it can be concluded, the Rajpura block has vast dimensions for the horticultural farming which will lead to land resource management, sustainable land use planning and livelihood security of farmers of the block. This study will also help policy makers and stake holders for the horticultural developmental planning of this block.

Keywords: Horticultural crops; land resources; soil suitability; land use planning and livelihood security.

1. INTRODUCTION

Sustainable resource management considered as one of the most prominent issues in agriculture. Thus, effective land management necessitates appropriate land use planning (Geetha et al., 2019). Interplay between the economic sustainability and the environmental impact relies on management of its land resources (Rajesh et al., 2019). The evaluation of land suitability constitutes a critical component in the realm of land use planning, as it entails the examination of the land's capability to sustain various current and alternative uses. Therefore, evaluating land for agricultural planning involves a site-specific assessment of crop suitability. Crop suitability evaluation refers to the determining of suitability of a particular type of land based on the growing conditions required for a specific crop (Singh et al., 2018; Karthikeyan et al., 2019). The basic objective of assessing agricultural land suitability is to anticipate the potential and constraints of the land for crop cultivation (Pan and Pan, 2012; Abdel Rahman et al., 2016). Further, cultivating horticultural crops as an alternate land use options is essential to ensure the efficient utilization of land resources (Kumar et al., 2021). The government of India has proposed to double farmer's income by the year 2022. It is increasingly being recognized that horticulture will remain an integral component for the strategy to achieve this goal (Jha et al., 2019).

The horticulture sector is one of the most important agricultural enterprises which, supports nutritional security, poverty alleviation and employment generation (De, 2017; Taufique et al., 2021). The goal of horticulture is to enhance plant growth, yield, quality, nutritional value and resilience to pests, diseases and environmental pressures in plants. India is home to a wide array of commercially important horticultural crops, with 30.4% of the country's GDP stemming from horticulture. India ranks second, following China, in the production of both fruit and vegetable groups (Horticultural Statistics at a glance, 2017). It is projected that by 2030, the demand for fruits and vegetables will surge to 110 and 180 million tonnes, representing a 155% and 95% increase, respectively from the base year 2000 (Vision-2023, 2011). The production of fruits has risen from 50.9 million tonnes to 97.35 million tonnes and vegetables from 101.2 million tonnes to 184.40 million tonnes between 2004-05 and 2017-18. The fruit-crop-based horticulture production system is economically feasible and readily adaptable (Chundawat, 1993; Chadha, 2002). Integrating annual field crops with fruit crops leads to higher yields and incomes (Osman, 2003). The productivity of fruits and vegetables is crucial as they offer greater monetary returns than cereals per unit of land (Yedage et al., 2013). Among the potentially profitable tropical agricultural products are horticultural commodities, particularly vegetables and fruits (Hamdan and Rahman, 2015). Moreover, it is recognized as a promising sector to enhance farm income, ensure livelihood security and generate foreign exchange through exports (Jha et al., 2019). The impact of climate change on horticultural production represents a significant global concern. It is essential to determine the long-term trend in climatic fluctuations and their implications on the production of horticultural crop (Sharma et al., 2022). Through the adaptive strategies and ongoing research endeavors, the field of horticulture can not only persist but also flourish, thereby enhancing global food security and promoting sustainable agricultural practices (Chachar et al, 2023). The augmentation of horticultural production must be accomplished amidst the challenges and repercussions of climate change, particularly those related to alterations in seasonal patterns (Malhotra, 2017). Remote sensing methodologies play a critical role in evaluating the appropriateness of sites for horticultural crops. The selection of a suitable site for horticultural crops constitutes a crucial decision in guaranteeing the success of an agricultural enterprise (Singh et al., 2024). Keeping the economic viability of horticulture production system in mind the present study, *"Evaluation of the suitability of horticultural crops under prevailing environmental conditions - a case study of Punjab*" is intended to highlight the relevance of soil-site characteristics of an area to ensure sustainable horticultural development and livelihood security of the farmers without compromising the soil and environment health.

2. MATERIALS AND METHODS

2.1 Study Area

Rajpura block is situated within the latitudinal range of 30°24'50'' to 30°39'16'' N and the longitudinal range of 76°25'56'' to 76°49'14'' E, and covers an area of 283.15 km^2. It is located in the north-eastern region of the Patiala district in Punjab, at an altitude varying from 200 to 300 meters above the mean sea level, and is enclosed by Ghanaur and Patiala blocks towards the southeast (Fig. 1). The climate of the area is characterized as semi-arid and warm, predominantly dry with warm summers and cold winters, except for the monsoon season. The mean annual temperature recorded 23.2°C whereas the mean maximum temperature and the mean minimum temperature were recorded 29.8°C and 16.6°C, respectively. The mean annual rainfall was recorded about 758 mm.

2.2 Land Use

Agricultural activities are dominant in the area as about 87% of the entire geographical is under agricultural land uses. Rice, wheat, sugarcane, maize, potato, onion, cauliflower and various other vegetables are cultivated in this block but primarily dominated by rice-wheat system.

2.3 Ground Water Resources

According to the 2013 assessment of Dynamic Groundwater Resources, the Rajpura block is classified as Over-Exploited (AMMP, 2017). The block has a total Ground Water Resources available is 2421.02 million cubic meter (mcm) and total potential granular zones available are 72 m upto a depth of 300 m. Majority of the land area being irrigated through tube wells.

2.4 Assessment of Soil Suitability for Different Crops

The determination of the relative suitability of crops were established by analyzing soil site attributes and crop requirements, utilizing predefined suitability criteria as referenced in previous studies (Naidu et al., 2006; Sys, 1985; Sehgal, 1996). The concept of land utilization types for land evaluation, proposing a classification system for land based on its intended use (FAO, 1976). There are two orders viz., S for suitable lands and N for unsuitable lands, each indicating the level of suitability. Furthermore, order S is sub-classed into S1, S2, and S3, while under order N into two sub-classes i.e., N1 and N2, reflecting various degrees of suitability within each order. The assessment of classes within the Orders is conducted by evaluating the constraints imposed by factors such as climate (c), topography (t), wetness (w), salinity (n), soil fertility (f), and physical soil limitations (s).

2.5 Remote Sensing and GIS

The technological advancements in remote sensing and Geographic Information Systems (GIS), particularly in the domain of fruit crop applications, have experienced significant progress in recent decades. Furthermore, remote sensing provides a robust data framework essential for the establishment of baseline information regarding natural resources, which is a critical antecedent for the effective planning, execution, and evaluation of any developmental initiative (Pal et al., 2022). The synergistic application of Geographic Information Systems (GIS) in conjunction with remote sensing, is examined within the framework of spatial analysis, cartographic representation, and accurate navigation (Rai et al., 2023). The horticultural crop suitability maps of Rajpura block were generated under GIS environment.

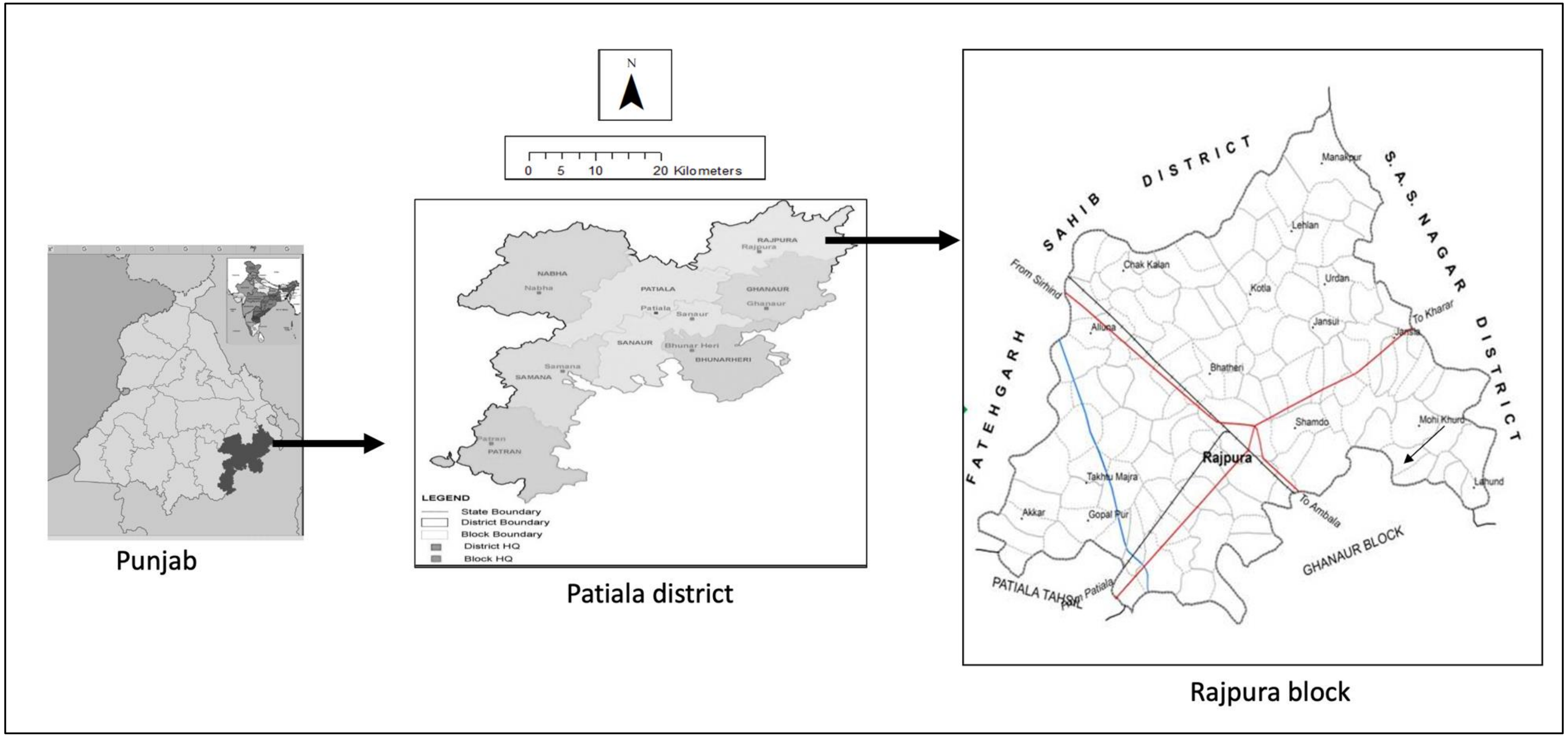

Fig. 1. Location map of Rajpura block, Patiala district, Punjab

3. RESULTS

3.1 Physiography and Soils

The block is located within alluvial plains of the Ghaggar River. The parent material within the block consists of alluvium that originated from the sedimentary bed of the Shivalik range. Alluvial plain is categorized into old alluvial and recent alluvial plains with nearly level (0-1%) to very gently (1-3%) slopes. The soil surface properties of the block have been analyzed (Table 1). The soils are very deep, somewhat excessively drained to somewhat poorly drained and loamy sand to silty clay soils. Soil limitations include drainage, alkalinity, salinity, sodicity, soil texture and poor soil fertility. Major soils are medium in organic carbon content, low to high in nutrient holding capacity. Cation exchange capacity (CEC) of the soils of block varies from 5 to 27 Cmol (p+) kg^{-1} (Meena et al., 2024).

3.2 Soil-site Suitability for Fruit Crops

3.2.1 Soil-site suitability for Mango (*Mangifera indica*)

Mango known as the national fruit of India and thrives particularly well in tropical and subtropical climates. It is cultivated in almost every state of India, contributing to about 56 percent (%) of the global mango production. Cultivation of the mango fruit necessitates specific soil conditions such as a depth exceeding 200 cm, comprising sandy loam, silt loam, clay loam, and loam textures, with the ability to sustain a pH level of up to 8.7 through effective nutrient management. The soil composition within the region has been meticulously analyzed to align with the requirements of mango cultivation, with the distribution across various suitability units (Fig. 2). About 50.8% areas found to be suitable for mango cultivation, while 33.51% and 1.68% moderately and marginally suitable, respectively.

3.2.2 Soil-site suitability for grapes (*Vitis vinifera*)

Grape is considered as berry type fruit and non-climacteric in nature. Regions with an annual rainfall exceeding 100 cm are deemed most suitable for grape cultivation. Generally, higher yields of grape can be obtained from deep, fertile soils. Ideal conditions for grape cultivation include a soil depth ranging from 100 to 150 cm, with textures such as sandy loam, silt loam, clay loam, and loam, as well as well-drained soils. The optimal temperature range is between 25°C and 30°C. To achieve maximum crop production, a mean relative humidity of 50–60% is ideal. The assessment of soil-site suitability characteristics for grape fruit indicated that 34.36% of the examined area is deemed suitable, whereas 49.95% of the area is categorized as moderately suitable, and 1.68% of the area is classified as marginally suitable, respectively (Fig. 3).

3.2.3 Soil-site suitability for banana (*Musa paradisiaca* L.)

Banana is considered one of the most popular fruits due to health benefits. Optimal conditions for banana cultivation encompasses soil types that are deep, rich in loam, slightly salty clay loam, with a pH in the range of 6 to 7.5. Soil suitability revealed that 44.62% of the block area found to be suitable for banana cultivation while, 39.69% area evaluated to be moderately suitable. However, only1.68% area found to be marginally suitable for banana the cultivation under the existing soil-site conditions (Fig. 4).

3.2.4 Soil-site suitability for sapota (*Manilkara zapota*)

Sapota commonly referred to as *Chiku*, is a tropical crop predominantly cultivated in India for its fruit. The crop thrives in various soil types, particularly deep alluvium, sandy loam and well-drained soils with pH 6.0 to 8.0. Conversely, shallow clay soils with underlying hard pan or high calcium contents are deemed unsuitable for sapota cultivation. The soils of the block have been interpreted to assess their appropriateness for sapota cultivation indicated that 44.62% area found to be highly suitable, while 39.69% evaluated to be moderately suitable for its cultivation (Fig. 5).

3.2.5 Soil-site suitability for guava (*Psidium guajava*)

Globally, guava is cultivated in tropical and subtropical regions. It is abundant in vitamins A, B, and C. The fruits undergo processing to prepare jams, jellies and often serving as popular pastry fillings. The cultivation of guava requires deep soils exceeding 100 cm, encompassing textures such as sandy loam, silt loam, clay loam and loam, while also requiring soils devoid of salinity and alkalinity and possessing good drainage. The optimal temperature range for guava cultivation falls between 28°C to 32°C. Soil-site suitability evaluation revealed that 34%

area found to be suitable for guava cultivation while, 50.31% area found to be moderately suitable for its cultivation (Fig. 6).

3.2.6 Soil-site suitability for pomegranate (*Punica granatum*)

Pomegranate shows adaptability to a wide range of climatic circumstances and exhibits resilience against drought. It holds the distinction as a beloved table fruit in tropical and subtropical regions. It thrives both in lowlands and elevations scaling up to 2000 meters above mean sea level. It requires deep soils exceeding100 cm depth, encompassing textures like sandy loam, silt loam, clay loam and loam, free from salinity, alkalinity, and possessing good drainage. Optimal temperature conditions for pomegranate growth range from 30°C to 34°C. Evaluation of soil suitability indicated that about 34.36% area found to be suitable for pomegranate cultivation while, 49.95% area evaluated to be moderately suitable for its cultivation (Fig. 7).

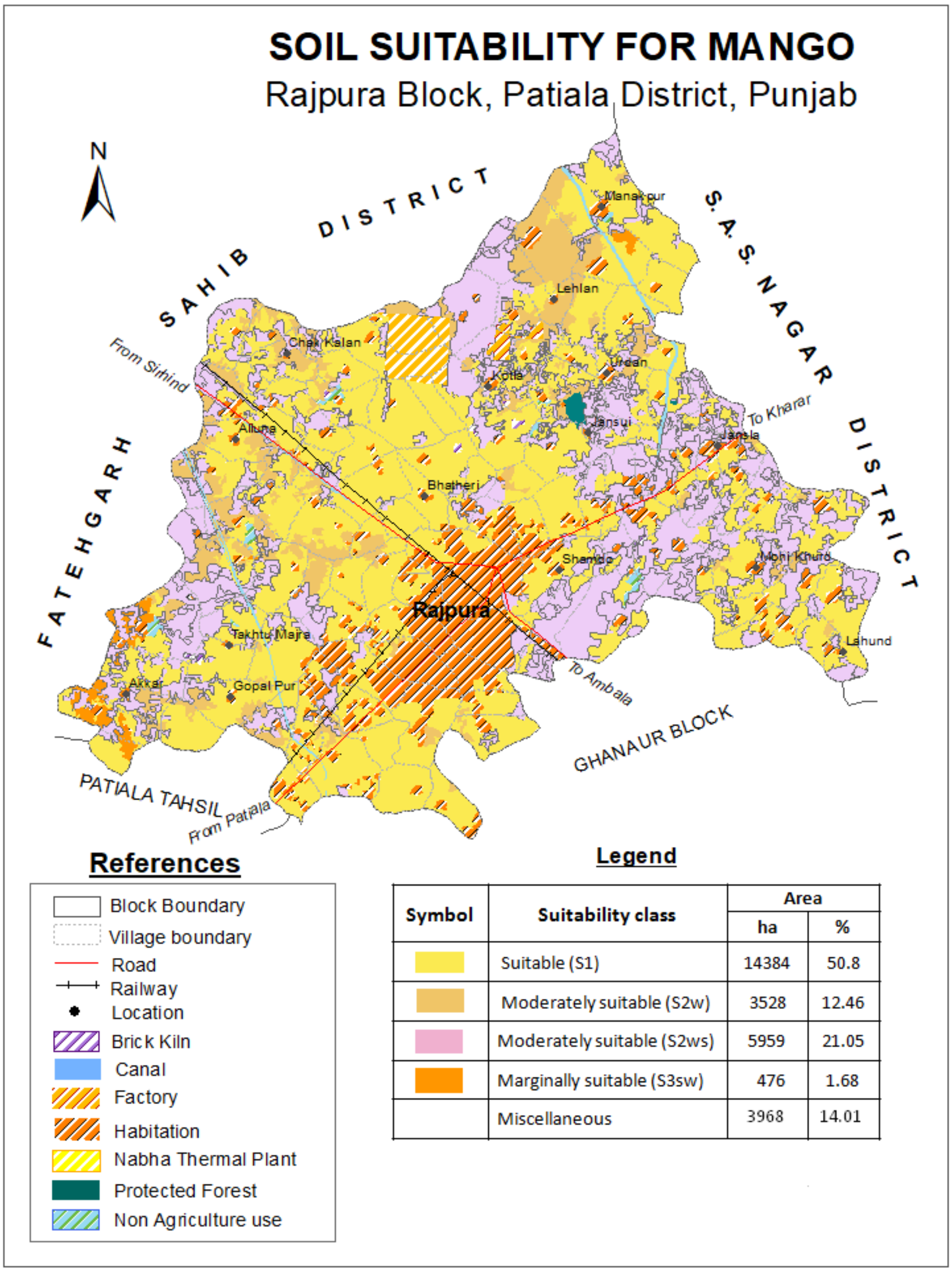

Fig. 2. Soil site suitability for mango

Table 1. Soil surface properties of Rajpura block, Patiala district, Punjab

Parent material	Landform	Slope	Depth	Drainage	Surface Texture	Soil pH	Soil salinity [EC(dsm^{-1})]	Organic carbon (%)	CEC Cmol (p+) kg-1	Base saturation (%)	$CaCO_3$ (%)
Alluvium	Old alluvial plains and recent alluvial plains	0-1 and 1-3%	Very deep	Some-what excessively drained to some-what poorly drained	Loamy sand to clay loam	7.3 to 8.6	0.01 to 0.9	0.3 to 1.2 %	5 to 27	87 to 98	0.2 to 0.9

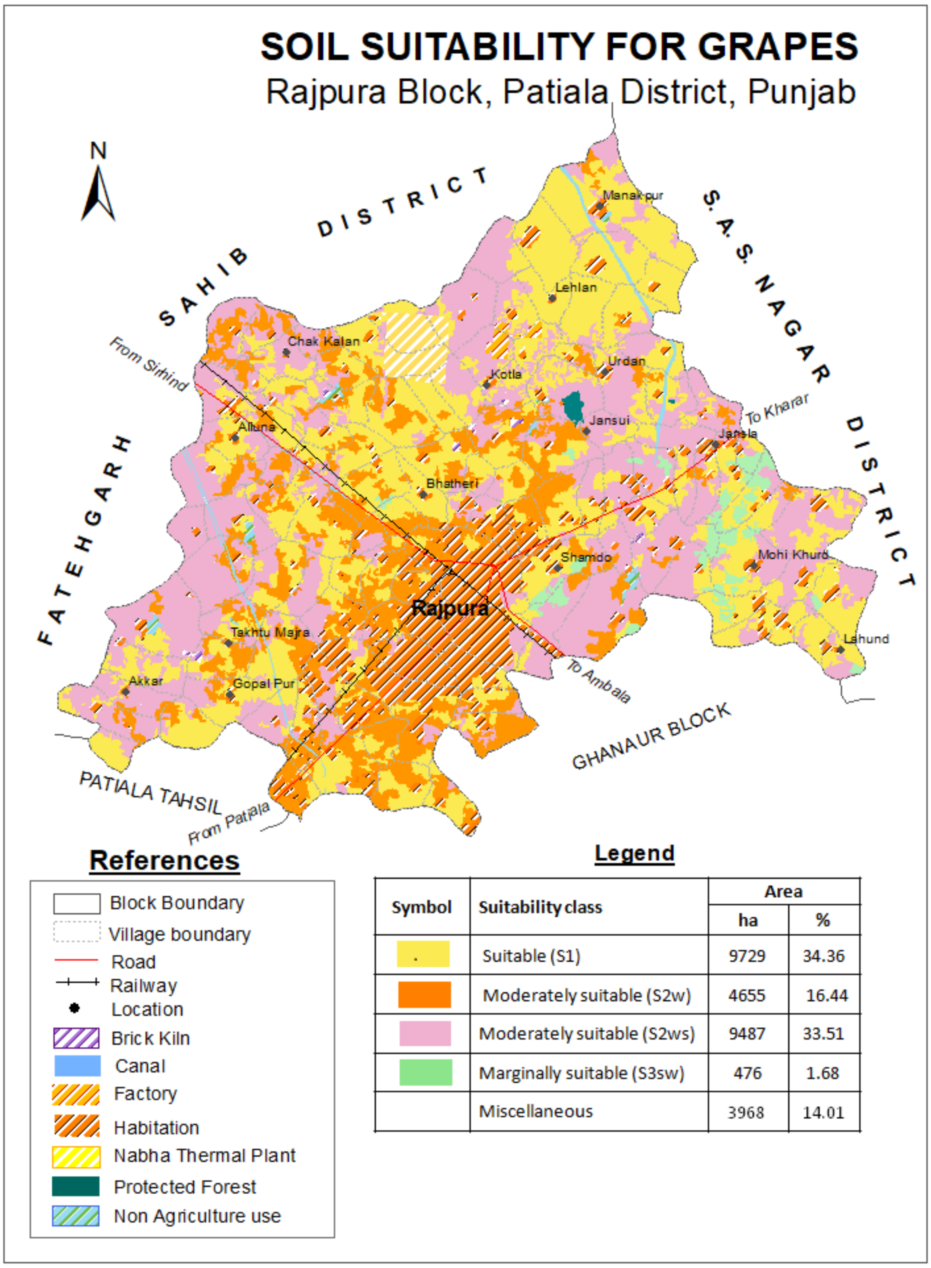

Fig. 3. Soil site suitability for grapes

3.2.7 Soil-site suitability for citrus

Citrus cultivation requires soil depth exceeding 150 cm. Soils characterized by sandy loam, silt loam, clay loam or loam texture, devoid of salinity and alkalinity and possessing good drainage considered good for its cultivation. The soil suitability evaluation of the block indicated that 61.42% area found to be suitable while 22.89% evaluated to be moderately suitable for citrus cultivation (Fig. 8).

4. DISCUSSION

Soil is an important constituent of land as it plays a vital role in the determination of its land productivity (Nagdev et al., 2017). The detailed scientific appraisal of soil resources is essential to know its constraints, potentials, capabilities and their suitability for various uses (Mahapatra et al., 2019). Consequently, the soil attributes of the Rajpura block were systematically analyzed to ascertain the suitability of various horticultural species, including mango, grapes, banana, sapota, guava, pomegranate, and citrus, among others. The soils present within the Rajpura block exhibit a depth classified as very deep. Such very deep soils (exceeding 100 cm in depth) are deemed highly conducive for the cultivation of crops, corroborated by findings from Ismaili et al., 2024. The drainage classification ranged from somewhat excessively drained to somewhat poorly drained and the soil texture was identified as loamy sand to silty clay. The soils within the block reveal several constraints, including issues related to texture, drainage, sodicity, salinity, alkalinity, and diminished fertility levels. A majority of the soils display a medium concentration of organic carbon and possess a nutrient retention capacity that varies from low to high. Based on these pedological characteristics, a range of horticultural crops were assessed for their suitability (Fig. 9).

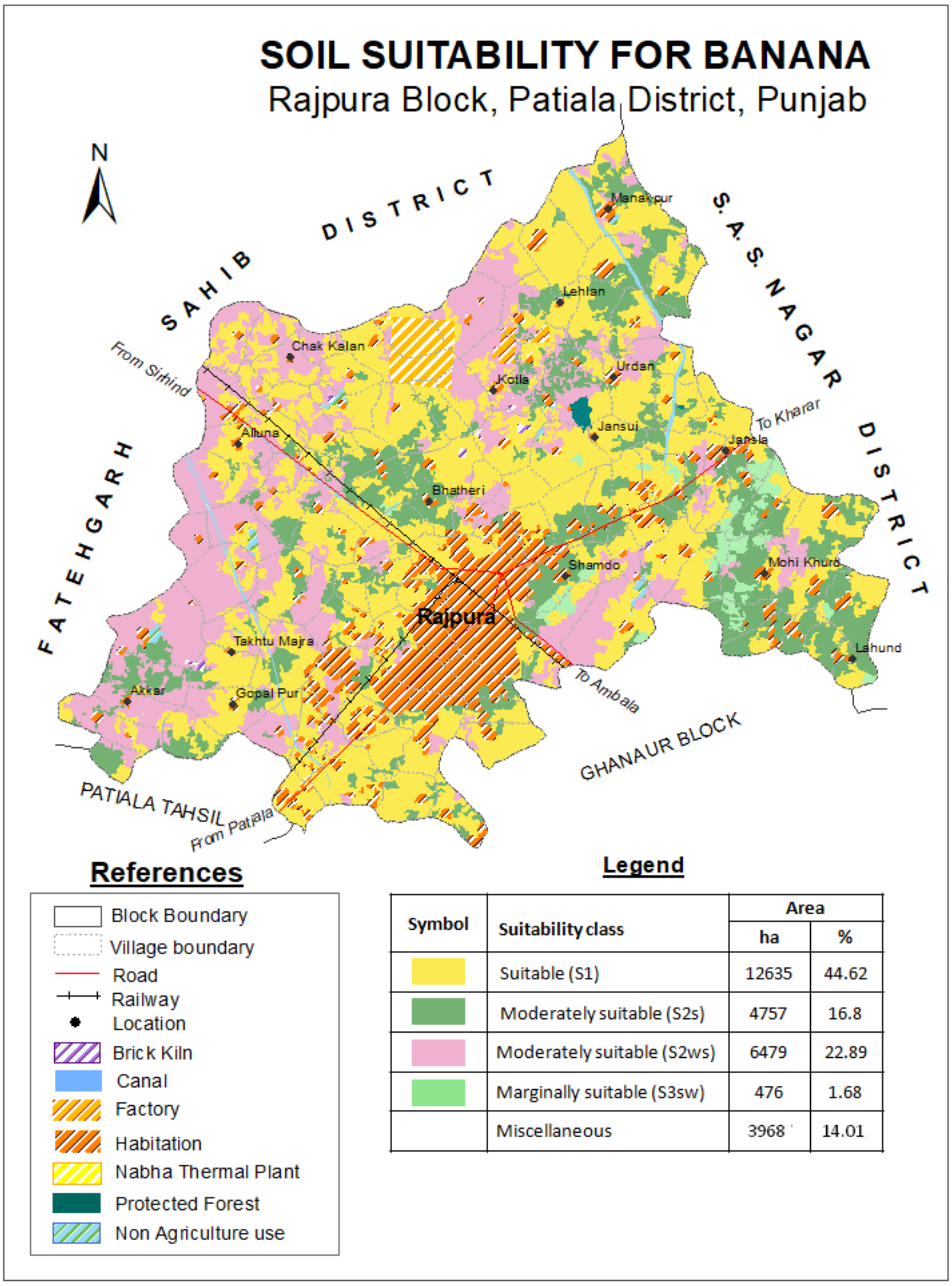

Fig. 4. Soil site suitability for banana

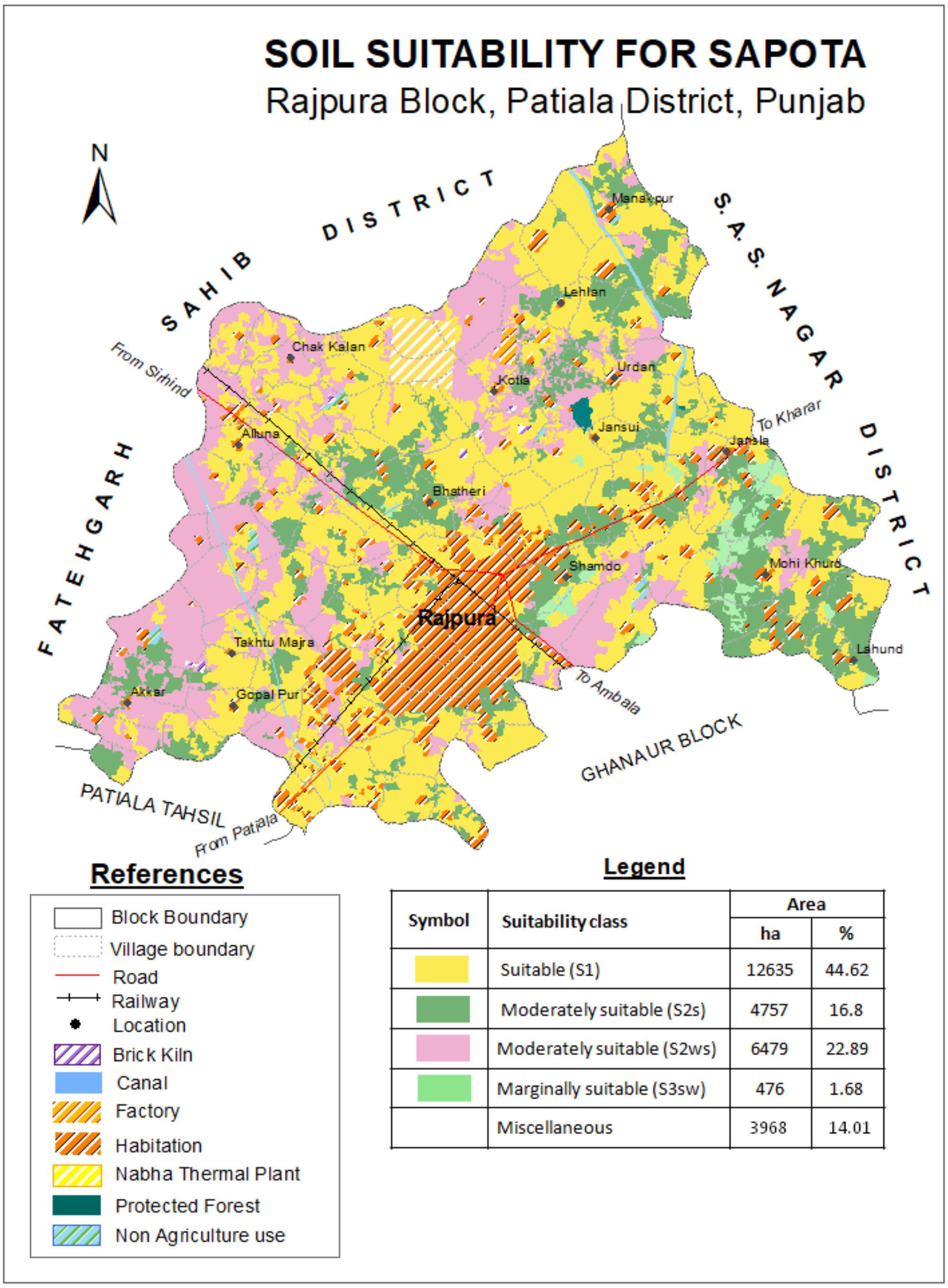

Fig. 5. Soil site suitability for sapota

According to the established soil suitability criteria for the cultivation of mango fruit, it has been determined that approximately 50.8% of the area within the block is classified as suitable, while around 33.51% is categorized as moderately suitable for mango cultivation. The findings of the investigations suggest that the successful cultivation of mangoes necessitates the presence of well-drained soils (Salunkhe et al., 2023), with loamy, alluvial, aerated, and deep soils that are enriched with organic matter, exhibiting a pH range between 5.5 and 7.5, being regarded as the most conducive for optimal mango cultivation (Gangopadhyay and Bhattacharyya, 2021). Our research is corroborated by Ganeshmurthy et al. (2018), who articulated that the suboptimal productivity of mangoes may be attributed to various factors,

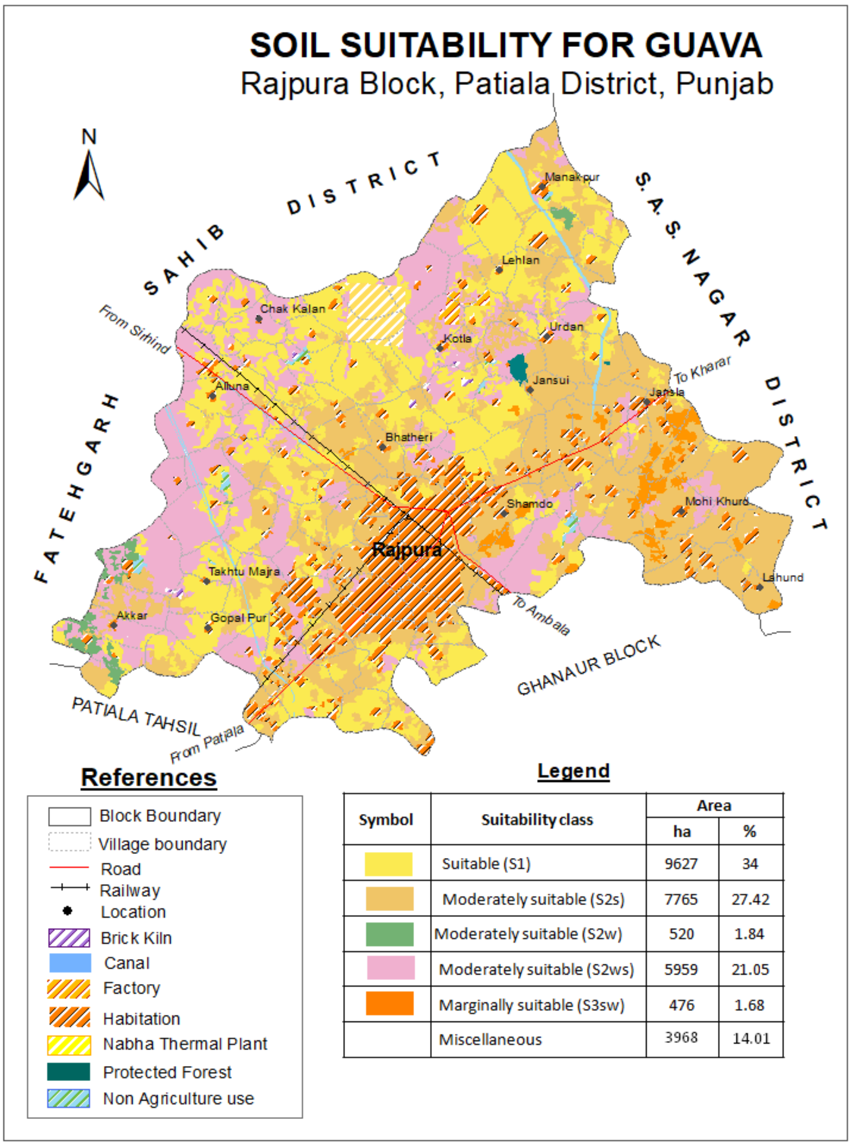

Fig. 6. Soil site suitability for guava

encompassing soil-related constraints, inadequate management practices of trees/orchards, climatic extremes, or a confluence of these determinants. Approximately 34.36% of the area within the block is classified as suitable, whereas about 49.95% is deemed moderately suitable for grape cultivation. Nonetheless, a limited number of studies have provided a comprehensive analysis of the soil suitability pertinent to grape cultivation. Harsha et al. (2023) reported that climatic conditions and soil characteristics are the most influential factors affecting grape growth and productivity, while Winter et al. (2018) further posited that grape cultivation management is impacted by various elements, including climate, water availability for irrigation, and soil type, thereby supporting our research findings. The banana plant is inherently a tropical species, thriving in elevated temperatures and requiring regular or well-distributed rainfall (Holando et al., 2022). Based on the soil suitability assessment for this block, it was observed that 44.62% of the area is classified as highly suitable, while 39.69% is evaluated as moderately suitable for banana cultivation. Sharma et al. (2023) presented

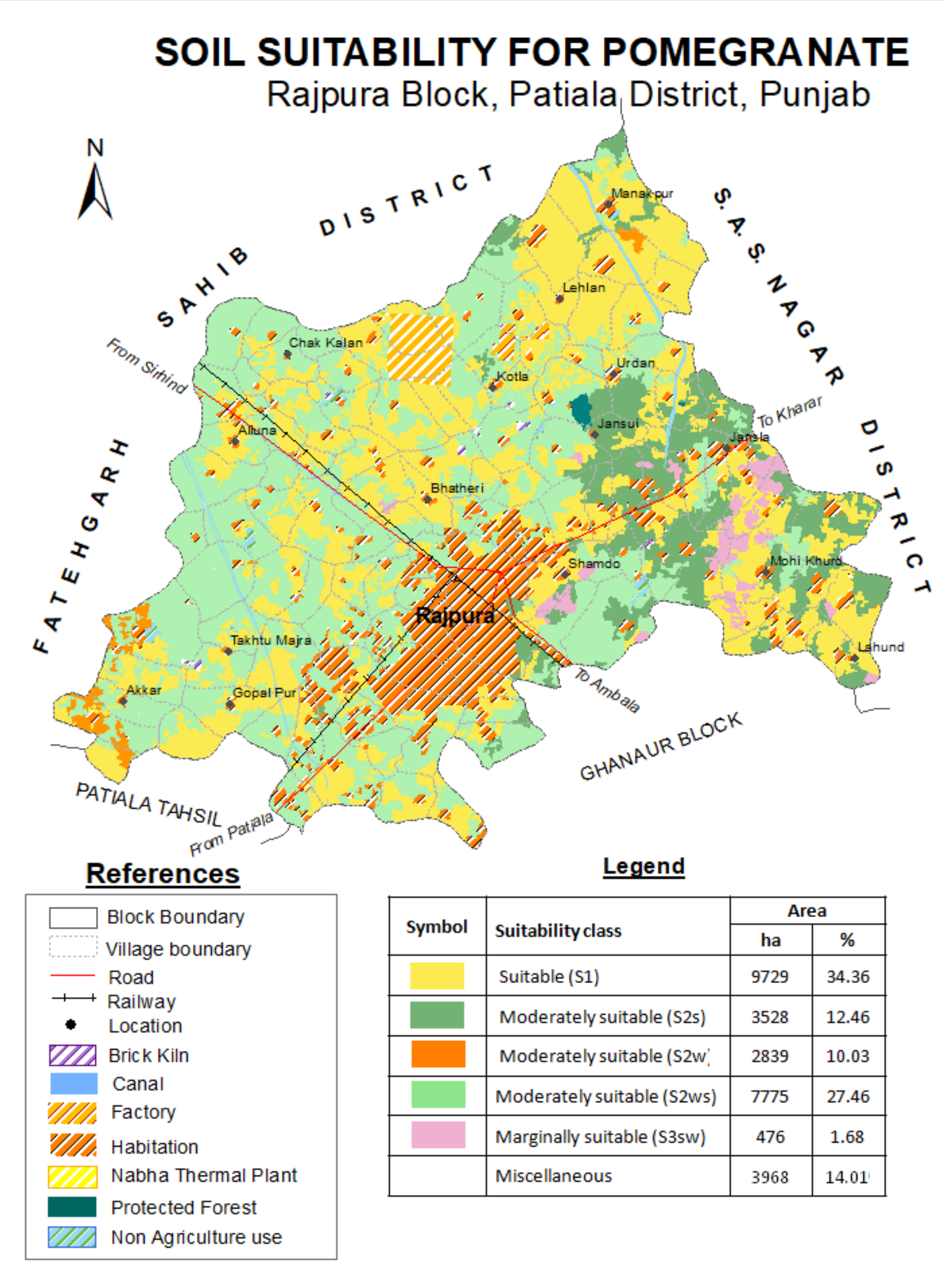

Fig. 7. Soil site suitability for pomegranate

findings closely aligned with our research, asserting that optimal growth of banana requires soils that are very deep, with a very slight acidity to mildly alkaline composition, rich in organic matter and containing substantial amounts of nitrogen, phosphorus, and potassium. Sapota, identified as a tropical fruit, thrives optimally at temperatures ranging from 11 to 34°C, along with deep, sandy loam soils being regarded as the most favourable for sapota cultivation (Jayachandran et al., 2023). It has been observed that 44.62% of the soils in the block are classified as highly suitable, while 39.69% are evaluated as moderately suitable for the cultivation of sapota. The assessment of soil-site suitability for guava indicated that approximately 34% of the area is classified as suitable, while around 50.31% of the area is categorized as moderately suitable, respectively. Guava is capable of flourishing in various soil types, encompassing alluvial to lateritic soils, with optimal crop yields documented following a growth duration exceeding 150 days (Bhargawa et al., 2023). The outcomes of our research

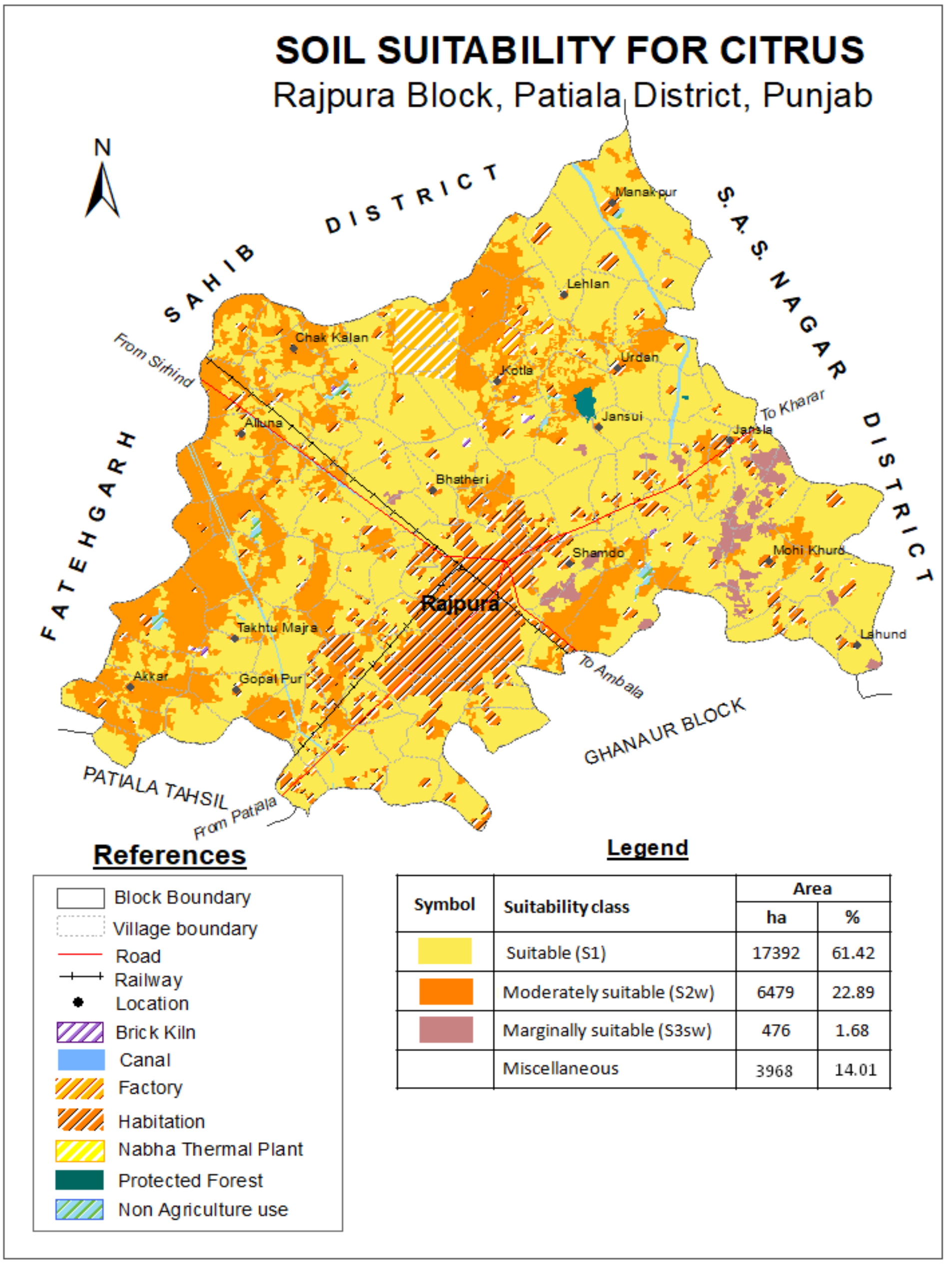

Fig. 8. Soil site suitability for citrus

are in substantial concordance with the findings reported by Baloda et al. (2014) and Kumar et al. (2021). The prevailing hot, dry, and arid to semi-arid climatic conditions of the region are conducive to the cultivation of pomegranates (Marathe et al., 2016). The soil-site suitability evaluation for pomegranate identified that approximately 34.36% of the area is deemed suitable, while nearly 49.95% is classified as moderately suitable, respectively. Our research results exhibit a similarity with the conclusions drawn by Thale et al. (2020). Citrus crops are adaptable to nearly all types of soils, provided that there is sufficient soil aeration and adequate allowance for root penetration to the requisite depth. The most favourable conditions for their cultivation are found in deep, loamy, well-drained soils with a pH range of 5.5 to 7.5. Approximately 61.42% of the block is deemed suitable, while 22.89% of the block is classified as moderately suitable for pomegranate cultivation. Wu et al. (2022) also reported the suitability of citrus crops which also supports our research work. A small segment of the block, specifically 1.68% (476 ha), is identified as marginally suitable for the cultivation of all fruit crops.

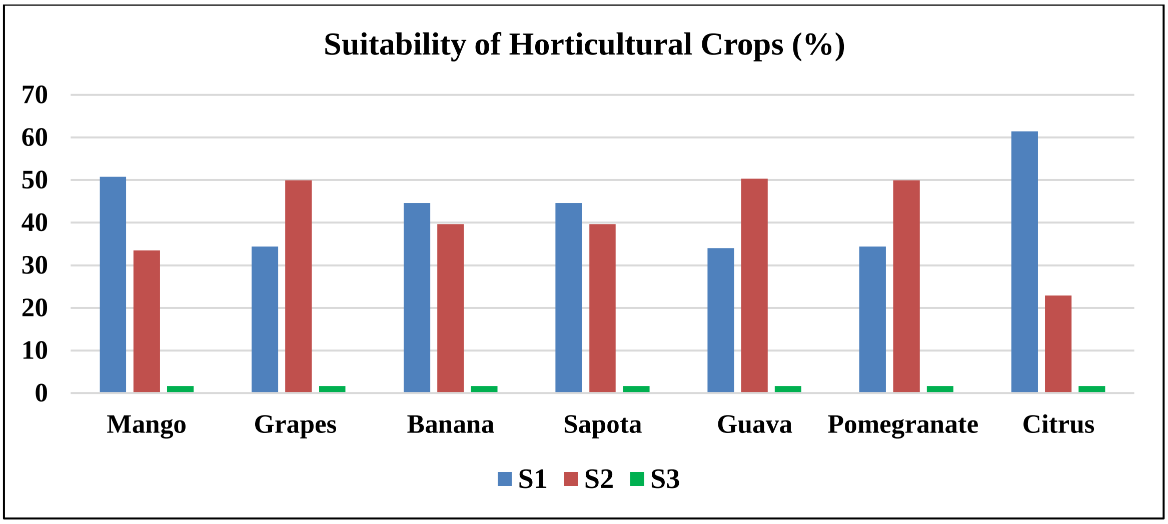

Fig. 9. Soil-site suitability for horticultural crops

5. CONCLUSIONS

The cultivation of the horticultural commodities particularly the fruits are potentially profitable production system. The economic viability along with production sustainability helps not only the livelihood security but also the self-sufficiency and reliance of an area in production. Therefore, soil and site characteristics need to be evaluated for cultivation of different fruit crops. The study proposed suitability of various fruit crops depicting highly suitable, moderately, and marginally suitable areas in Rajpura block for various fruit crops. Nearly, 50% area of the block is suitable (S1) for the cultivation of mango while 34% for grapes, 45% for banana and sapota, 34% for guava and pomegranate and 61% for citrus crops, respectively. The area about 34% is moderately suitable (S2) for the cultivation of mango, and 50% for grapes, 40% for banana and sapota, 50% for guava and pomegranate and 23% for citrus fruits, respectively. The small part of the block i.e., 1.68% (476 ha) is marginally suitable (S3) for all fruit crops. The thematic crop suitability maps greatly assist the planners in effective implementation of strategies aiming to enhance productivity.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declared that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have not been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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