Chapter

Climatic Variation and Its Impacts on Yield and Water Requirement of Crops in Indian Central Himalaya

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Abstract

Climate is most important factor affecting agriculture, and issues related to climate and its implications have attracted attention of policy makers globally. The farm sector, particularly marginal ecosystems in mountains are vulnerable because of unpredictable variation and severe sink limitations. Efforts to impart resilience to farm and its allied sector are an urgent need. The climatic parameters play very important role to determine type of crops, cattle rearing and the life style adopted by the people. Moreover, weather has a significant impact on crop growth and development. Weather plays a vital role and affects the production and productivity of the crops. According to an estimate, weather contributes 67% variation in productivity and rest of the factors (soil, nutrient and management practices etc.) accounts for 33%. Therefore, there is a need of in-depth analysis of each meteorological parameters and identification of their trend over the years in order to identify and adapt suitable agriculture practices, better adaptable crops, varieties and their duration, time of field preparation, sowing time and irrigation as per the climatic conditions of the region. This will lead farming community to plan strategies of agriculture operation to obtain optimum yield. The climatic data from the meteorological observatory of ICAR-VPKAS, Hawalbagh located at mid hill condition (1250 m amsl) were analyzed for different periods (annual, seasonal, monthly, weekly). It was revealed that rainfall is decreasing over the years but significant ($P < 0.05$) decrease was recorded at mid hills. The maximum temperature is increasing significantly ($P < 0.05$) during post-monsoon and winter season however decreasing in monsoon season whereas minimum temperature is decreasing round the year. These changes in rainfall and temperatures are affecting production and productivity of the crops, as hills are largely rainfed. In terms of crop water demand, there is no need to apply irrigation during the rainy season except the transplanted rice. However, during the winter season as there is more than 60% of water deficit to irrigate the crops. The proper understanding of climate is necessary to bring sustainability in hill agriculture by adjusting crop sowing window and other operations as per suitability of the climate.

Keywords: agroforestry, climate change, Himalaya, meteorological data, productivity, sustainability

1. Introduction

Climate determines nature and productivity of farming systems' and allied farm enterprises. The climate over the Himalayan ranges varies from place to place due to complexities of the local relief features and type of weather systems. Weather is defined as the state of the atmosphere at a specific time and place. It defines the physical conditions of the atmosphere with respect to wind, temperature cloudiness, moisture, rainfall pressure and other parameters such as sunshine hour, evaporation etc. Climate pertaining to a region or a place can be defined as the sum of the weather conditions prevailing over a place over the years. In other words, climate represents average weather conditions over a long period. It comprises not only those conditions that can be obviously described as near average or normal, but also the extremes and all the variations. According to an estimate, weather contributes 67% of the variations in productivity and rest by the other factors viz., soil nutrient and management practices [1]. The climate affect the crop production, jeopardize the livelihood of people, and induced animal starvation. The recent severe drought of 2002 affected 300,000,000 people and monetary losses US $910,721,000 [2]. It is well known fact that there is little control over the climate and there is a very little chance to manipulate the weather. Therefore, there is a need of identification and adaption of suitable crops and varieties, as per the climatic conditions of the region.

The potential of climate as an agricultural resource has not been fully utilized and realized. As a result, several crops are grown traditionally without any knowledge of their suitability. Thus, on one hand, poor production and on the other, much of the production potential of these vast resources go untapped. However, it is inevitable to make adjustment with weather to harness the maximum benefit from available climatic resources. Therefore, knowledge of agro climatology of a region is a valuable tool for crop planning. The knowledge of climatic conditions also helps in identification and selection of forest trees, species and grasses. The proper knowledge of climate and its relationship with severity of insects and pests, diseases will be helpful for managing them and minimizing the losses. Therefore, knowledge of the climate is necessary to utilize resources efficiently for maintaining the production and regeneration capacity. As we know that, there is little control over the climate and there is very little chance to manipulate the weather. Therefore, there is a need of in-depth analysis of each meteorological parameters and identification of their trend over the years in order to identify and adapt suitable agriculture practices, better adaptable crops, varieties and their duration, time of field preparation, sowing time and irrigation as per the climatic conditions of the region.

One of the major challenges of the 21st century is to ensure food security for the burgeoning population. It is more pertinent to India, where population growth rate is high and it may surpass the China's population in near future. Although consequent to green revolution India in general has made remarkable progress in production of food and fiber since 1970's. However, India has to progressively match the production with population growth rate still to ensure food security, it has to go for climate smart sustainable agriculture. Agriculture is even more important as a primary source of livelihood for majority of the world's workforce. However, livelihood systems that are based on agriculture may face growing risk of crop failure, frequent incidence of pest and diseases and loss of livestock due to climate change

[3]. Crop production is a complex phenomenon and depends on abiotic (soil, weather, plant etc.) and biotic factors (insect, pest diseases etc.). Sudden change and frequent variation of these factors during different crop growth stages can bring drastic change in crop production and productivity. Warming trends were reported in Indian climate [4]. The decline in production in rice and wheat due to climate variation was reported [5, 6] though received rainfall higher than the mean rainfall of rice and wheat. This chapter deals with the impact of climatic variation and changes on natural resources and agricultural productivity.

1.1 Agroforestry and climate change

In the welfare of our nation and its economy, value of forests and trees is foremost. The indirect benefits are more than direct benefits to us through the trees [7, 8]. It is true that if the tree is present on the earth, the water will be available; if water is there, food will be available and due to food, we will exist. Our resources were first developed in the shadows of the trees because the trees give us food, fuel, fodder, shade and timber and improve fertility of land as well as increase water availability, prevent soil erosion and help maintain environmental balance [8, 9]. At present, due to burgeoning population and dwindling resources, importance of agroforestry has increased [10]. Due to the development of new systems, in modern agriculture such as agro-forestry is need of the hour in place of traditional agricultural landscape without reducing food production [11, 12].

To meet the needs of growing population conflict between forest and agricultural land has also increased; industrialization has generated pressure on land for many other demands [13]. Therefore, it is necessary to produce both agricultural and forestry products on the same piece of land to meet out the increasing demand of different products [14]. For this, plantations should be done on the agricultural land. Agroforestry helps in removal of carbon and other greenhouse gases from the atmosphere to mitigate climate change, reducing the impact of climate change and reduces the vulnerability [8, 11, 12, 15]. The different options to mitigate climate change include increasing carbon reducing activities such as carbon sequestration, to reduce emissions of bio-energy and biofuels in productive activities. Agroforestry is not only a large and low cost opportunity to mitigate climate change but also provides other services to the community [16]. Tree collects carbon dioxide (CO_2) from the atmosphere and converts it into carbon molecules through photosynthesis in leaves, which is responsible for growth of tree. One kilogram of dry wood contains $\sim$0.5 kg carbon. According to IPCC [17] tropical wet forest have carbon in above ground biomass of 65–430 t ha^{-1} and 44–130 t ha^{-1} in soil.

Tree provides leaves as manure for agriculture, help in farming directly and indirectly and provide food and fodder for human and animal [7, 8]. This may benefit from the same piece of land that help in self-catering as well as can reduce the risk, also helps in providing appropriate environment for crops and the market for products. Although this technique is very simple, still it provides complementary employment and a very small technical and economic cooperation is required. The tree is a blessing because it is very useful to the poor and provides various benefits and windfall profits due to different timings of reaping at low cost variation. The greatest significance of agroforestry is that the farmer's family can adopt it as a good activity without changing his business and trees are very cooperative in the agro-forestry [18]. Trees convert poisonous gas CO_2 into life saving oxygen (O_2). This action purify the air as well as help in preventing elevated temperature because trees absorb atmospheric carbon in the process of photosynthesis. In agroforestry, we should choose trees with short life cycle and fast growing in nature. India has diversified climate, different agricultural conditions and abundant wasteland in villages need to be considered while implementing various methods of forestry. Various agroforestry practices can be used based on climate of the place and utility, benefits and on need basis [7, 9, 19].

The provision of agro-forestry-based industries in National Agroforestry Policy (2014), will give a major boost to the agroforestry [20]. In 1981, our country's population was 236.7 million, which increased to 1.21 billion in 2011. However, there has been no increase in the country's geographical area. If population growth continues at this pace, by 2020 the population of our country will be more than 1.30 billion. Thus, the effects of increasing population and urbanization have impact on loss of forests, increased soil erosion and atmospheric pollution. Therefore, at present the agro-forestry tree planted portion will not only prevent soil erosion but also increase its productive power and will help to maintain environmental balance. Planting trees with crops will increase the returns from per unit land [19].

2. Climate and its variability at Mid hill Hawalbagh, Almora

The climate variability observed based on past years data of rainfall and temperature is summarized in next section. The rainfall variation showed that out of 55 years, the 24 years rainfall was below the normal rainfall. The annual rainfall showed decreasing trend and the rainy days with 50, 75 and 100 mm of rainfall are found increasing. Whereas, 25 mm rainfall rainy days are decreasing.

2.1 Rainfall characteristics

The precipitation is the primary input in the hydrological cycle and dominantly influences the complex hydrological phenomena. Precipitation is the main source of fresh water. Precipitation is any product of the condensation of atmospheric water vapor that falls under gravity. The main forms of precipitation include drizzle, rain, sleet, snow, graupel and hail. Rain is liquid precipitation, as opposed to non-liquid kinds of precipitation such as sleet, snow, and hail. The rainfall information is needed for management of natural resources and crop planning. Rainfall amount, intensity and its distribution are prime factors affecting plant growth, soil erosion and flood problems. This is more pertinent to state like Uttarakhand hills, which has only 10% area under irrigation. The distribution of rainfall in hills is very important because it not only influences hills but also downstream locations in plains. The excess rainfall may aggravate erosion in hills and floods in low-lying areas while deficit may cause drought and reduced river flow. Knowledge of rainfall pattern in a given geographical location enables the development of suitable strategies for agricultural planning and implementation.

2.1.1 Annual rainfall

Annual rainfall (1964–2018) data recorded at Agro-Metrological Observatory, Hawalbagh (Almora), showed variation from 650.8 mm in 1974 being lowest to 1496.0 mm in 1971 being highest with a mean of 994.8 mm. The standard deviation (SD) and coefficient of variation (CV) of annual rainfall were 208.7 mm and 21.0 per cent, respectively. It was observed that rainfall in 24, out of 47 years was higher than the mean. The annual average rainy days were 67 with SD 10.5 and CV 15.6 percent. The maximum number of rainy days (90) was recorded in the year 1977 with rainfall (1088 mm) and minimum (49) with rainfall (852.1 mm) in 1964. The highest annual rainfall (1496.0 mm) was recorded during 1971 in 85 days, while highest rainy days (90) received 1088 mm rainfall in 1977, respectively. Annual rainfall showed decreasing trend over the years.

2.1.2 Monthly rainfall

The mean monthly rainfall (1964 to 2018) is presented in **Table 1**. It is evident from table that each month received more than 130 mm rainfall during June to September. The highest rainfall (240.2-mm) with highest 14 rainy day was recorded in July followed by August with mean rainfall (210.0 mm) with average 13 rainy days. The monsoon months (June to September) regarded as effective months of rainfall or wettest months of the year. The average rainfall during October, November and December was 22.8, 6.2 and 20.3 mm respectively. The average rainfall during January, February and March months was 39.9, 50.7 and 42.4 mm with rainy days 3.0, 4.0 each for later two months 4.0 respectively. The rainfall of pre monsoon months *i.e.* the April and May was recorded 32.0 mm and 61.7 mm with rainy days 3.0 and 5.0 days respectively (**Table 1**).

2.1.3 Annual and seasonal rainfall and its variability

The annual rainfall showed decreasing trend (**Figure 1**). It was recorded that mean annual rainfall was 994.8 mm, highest annual rainfall (1496.0 mm) in the year 1971, lowest annual rainfall (650.8 mm) in the year 1974 and highest rainfall in single day (167.0) on 18th September 2010. Whereas, mean annual rainy days (68 days), highest rainy days in year (90 days) in the year 1977, lowest rainy days (49 days) in the year 1964 and 1966. The highest rainfall 72.3% occurred in monsoon season followed by summer (13.6%) winter (11.1%) and least in post monsoon (3%).

Month	Mean	lowest	Highest	Percent annual rainfall	CV (%)	Rainy days* (rainfall more than 2.4 mm)
January	39.9	0	113.3	4.0	79.7	3
February	50.7	0	153.4	5.1	76.0	4
March	42.4	0	195.4	4.3	89.1	4
April	32.0	0	153.2	3.2	88.7	3
May	61.7	0	179.2	6.2	72.8	5
June	134.8	7.5	342.5	13.6	56.9	9
July	240.2	96.5	493.2	24.1	39.1	14
August	210.0	65	374.5	21.1	34.0	13
September	133.7	8.8	463.5	13.4	73.4	8
October	22.8	0	210.4	2.3	162.9	2
November	6.2	0	66	0.6	202.5	1
December	20.3	0	107.7	2.0	127.8	1

Rainy days were rounded.

Table 1.
Mean, monthly rainfall characterization (mm) of month along with rainy days and CV (1964–2018).

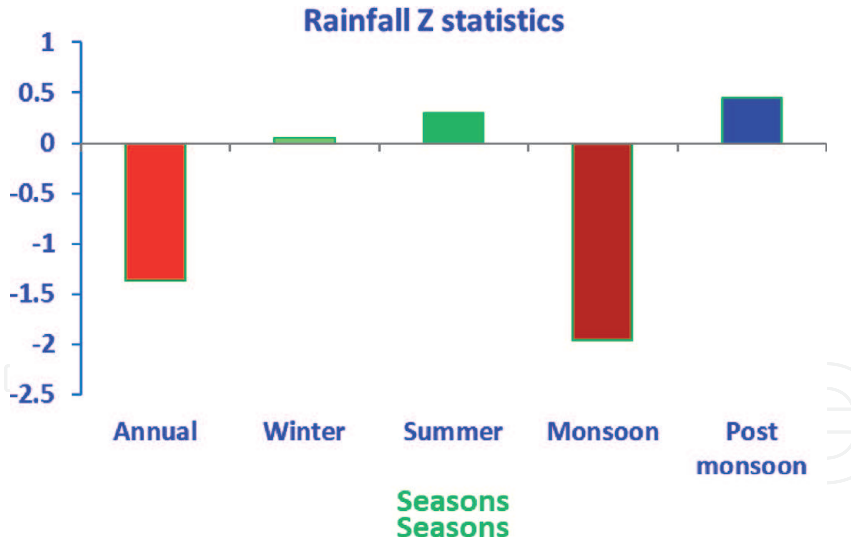

Figure 1.
Mann- Kendall test statistics for annual and rainfall data of different seasons.

2.1.4 Winter (December to February) and summer (March to May) rainfall

The out of 55 years, winter season rainfall was 30 years above the normal rainfall and rest years it was below the normal rainfall (**Figure 1**). The winter season rainfall have recorded slightly increasing trend. However, winter rainy days showing decreasing trend. The characteristics of the winter rainfall are mean rainfall (111.2 mm), highest rainfall (216.5 mm) in the year 2013, and lowest rainfall (13.0 mm) in the year 2016. The highest rainfall in single day (77.0 mm) on 18th February 2003] Likewise, mean winter rainy days (8.3 days); Highest rainy days in a year (15 days) in the year 1975; Lowest rainy days (2 days) in years 1964, 1967 and 2006}]. The summer rainfall in 22 years was above the normal and rest years, was below the normal (**Figure 1**). The summer rainfall and rainy days showed increasing trend (**Figure 1**). The mean rainfall was 136.1 mm, highest rainfall (369.5 mm) in 1983, lowest rainfall (29.0 mm) in 2013 and highest rainfall in single day (57.5 mm) on 7th May 1998. Similarly, mean annual rainy days were 12.4 days, highest rainy days in a year (23 days) in 1990 and lowest rainy days (4 days) in the years 1968, 1984 and 1992.

2.1.5 Monsoon (June to September) and post-monsoon (October to November) rainfall

The monsoon rainfall out of 55 years, 30 years was below the normal rainfall and it showed decreasing trend (**Figure 1**). The similar trend was observed with regard to rainy days. The mean rainfall was 718.8 mm, highest rainfall (1156.5 mm) in 2010, lowest rainfall (424.2 mm) in 2015 and highest rainfall in single day (167 mm) on 18th September 2010. Whereas, mean annual rainy days (45 days), highest Rainy days (60 days) in a years 1977,1988 and 2010 and lowest rainy days (27 days) in year 2009. The post monsoon rainfall in 36 years was below the normal rainfall and showed an increasing trend (**Figure 1**). The characteristics of post-monsoon rainfall exhibited mean rainfall (29.9 mm), highest rainfall (210.4 mm) in the year 1985, lowest rainfall (0.0 mm) in the years 1964, 1974, 1993, 1994, 2001 and 2017 and highest rainfall in single day (99.8 mm) on 13th October 1985. The mean annual rainy days were 2.0 days, highest rainy days in a year (11 days) in the year 1997 and lowest rainy days in year (0 days) in the years 1964, 1967, 1969, 1974, 1975, 1984, 1988, 1993, 1994, 2001 and 2017.

3. Estimation of crop water requirement in study area

Water requirement of the crops defines the quantity of water needed to meet the water losses through evapotranspiration of a disease-free crop under non restricting soil conditions, including soil, water and fertility and achieving the full potential under a given soil environment in a given time. Water requirement of the main *Kharif* and *Rabi* season crops (*i.e.* Vegetable pea, Barley, Rajma, Tomato, French Bean, Chili, Rice, Wheat, Maize, Soyabean, Okra, Mustard, and Cow pea) were calculated on the basis of Reference crop evapotranspiration (ET_o) on the monthly basis by using CROPWAT model based on FAO-Penman-Monteith's semi-empirical equation. The required weather data (min. and max. Temperature, rainfall, sunshine hours, wind speed, etc.) was collected from the automatic weather station. Reference evapotranspiration (ET_o) expresses the evaporative index of the atmosphere at a specific location. It is independent of crop type, stage of development and management practices. The reference evapotranspiration had been calculated using this Equation [21] in the following form:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (1)$$

Where,
ET_o = reference evapotranspiration [mm day^{-1}].
u_2 = wind speed at 2 m height [m s^{-1}].
R_n = net radiation at crop surface [MJ m^{-2} day $^{-1}$].
G = soil heat flux density [MJ m^{-2} day $^{-1}$].
T = mean daily air temperature at 2 m height [°C].
γ = psychrometric constant [kPa °C^{-1}].
Δ = slope of vapor pressure curve [kPa °C^{-1}].
$e_s - e_a$ = saturation vapor pressure deficit [kPa].

3.1 Crop coefficient

The crop evapotranspiration, (ET_c) is calculated by multiplying the reference crop evapotranspiration, (ET_o) by crop coefficient (K_c). Consequently, different crops will have different crop coefficients. K_c value varies with the type of crop, climate, soil evaporation and crop growth stages [21].

$$ET_c = K_c \times ET_o \quad (2)$$

Where,
ET_c = crop evapotranspiration [mm day^{-1}].
K_c = crop coefficient [dimensionless].
ET_o = reference crop evapotranspiration [mm day^{-1}].

3.2 Gross irrigation requirement

The gross irrigation requirement (GIR) accounts for losses of water included during conveyance and application of irrigation water to the field. The gross irrigation requirement is calculated by the ratio of net irrigation requirement to the irrigation efficiency.

3.3 Irrigation efficiency

Irrigation efficiency is defined as the ratio of amount of water beneficially used by plant as evapotranspiration to the amount of water applied to the plant area. The irrigation efficiencies under different methods *i.e.* 40%, 50%, 55%, 75%, and 90% are taken for border, check basin, furrow, sprinkler, and drip irrigation system, respectively [22].

3.4 Irrigation water requirement

The irrigation water requirement represents the difference between the crop water requirement and effective rainfall. Other factors or losses have minimal effect on irrigation water requirement and can be neglected [23] as shown in the equation below:

$$IR = ET_c - (P_e + G_e + W_b) \quad (3)$$

Where,
IR = irrigation requirement (mm).
Et_c = total crop evapotranspiration (mm).
P_e = effective rainfall (mm).
G_e = groundwater contribution from water table (mm).
W_b = water stored in the soil at the beginning of each period (mm).

3.5 Effective rainfall (P_e)

It is only a part of the rainfall that can be effectively used by the crop, depending on its root zone depth and the soil storage capacity. Total rainfall amount is not considered as effective rainfall; some part of rainfall may be lost through surface runoff, deep percolation or evaporation. FAO CROPWAT ver. 8.0 model could be used rainfall data and employs the USDA S.C. method approach to estimate effective rainfall on a daily basis or monthly basis.

4. Irrigation scheduling

Irrigation scheduling is the process of deciding the period and quantity of irrigation water during the crop growth under different irrigation methods [24]. Its main objective is to apply irrigation at the right period and in right amount. Irrigation amount is determined in terms of gross irrigation requirement and pumping time per application, while, irrigation time is based on depletion of soil moisture content of the crop root zone reached at critical point [25]. That is basically dependent on the consumptive use rate of crop and method of water application to the plant root zone [26]. The quantity of irrigation water for each treatment was calculated based on the soil moisture content before irrigation and root zone depth of the plant using the Eq. 1.4:

$$SMD = (\theta_{FC} - \theta_I) \times D \times Bd \times MAD \quad (4)$$

Where,
SMD = Soil moisture deficit (mm).
θ_{FC} = Soil moisture content at field capacity (%).
θ_I = Soil water content before irrigation (%).

D = Depth of root development (mm).
Bd = Bulk density of the particular soil layer (g cm^{-3}).
MAD = Management allowable Depletion (%).

4.1 Management allowable depletion (MAD)

Producing optimal yield requires that the soil water content be maintained between an upper limit at which leaching becomes excessive and a lower point at which crops are stressed [27]. As water is removed from the soil through ET, there is a point below which the plant experiences increasing water stress. This point is known as the management allowable depletion (*MAD*). The typical MAD values considered are 33% for shallow-rooted, high value crops; 50% for medium-rooted, moderate value crops and 67% for deep-rooted, low value crops [28]. Selection of MAD value for different crops with respect to soil type, initial field capacity (FC), permanent wilting point (PWP), and threshold soil moisture content (TSMC) must be determined. Threshold soil moisture content ascertains what fraction of soil is allowed to dry before the next irrigation event. Threshold soil moisture content can be determined in the following form:

$$\theta_{TSMC} = \theta_{FC} – MAD\ (\theta_{FC} – \theta_{PWP}) \quad (5)$$

Where,
θ_{TSMC}: Soil moisture content at threshold level (%).
θ_{FC}: Soil moisture content at field capacity (%).
θ_{PWP}: Soil moisture content at permanent wilting point (%).
The determination of soil moisture content at threshold level is most important factor for irrigation scheduling on real time basis. This value varies with crop, soil, climate and crop growth stages. Whenever the soil moisture content at field capacity is depleted through ET, percolation losses, etc. to equal or below the θ_{TSMC} value, irrigation scheduling must be given otherwise crop yield and plant growth will be affect harmful way.

5. Estimation of water requirement of major crops using CROPWAT model

CROPWAT is a decision support tool developed by the land and water development division of FAO. CROPWAT model is extensively tested, widely accepted for calculation of crop water requirements based on soil, climate and crop data. In addition, the program allows the development of irrigation schedules for different management and the calculation of scheme water supply for varying crop patterns. CROPWAT ver. 8.0 model used weather data and employs the modified penman-monteith approach used to estimate reference evapotranspiration on a daily basis. The meteorological data was taken from Agromet Observatory, ICAR-VPKAS, Experimental farm Hawalbagh, Almora. The mean annual rainfall at experimental site was 1000.13 mm. The general soil properties of the experimental field were used in CROPWAT model. Based on the details of soil characteristics, total available water was taken 135 mm m^{-1} depth of soil. Infiltration rate was measured using double ring infiltrometer and the basic rate was 6.8 mm $hr.^{-1}$ and the unsaturated hydraulic conductivity was 0.77 cm h^{-1}. The estimation of irrigation water requirement (346–376 mm, 131–189 mm, 1.4 mm, 1.3 mm, 78.6 mm, 93.5 mm 104.1 mm, 176 mm, 96.9 mm, 16.2 mm, 18.3 mm, 15.5 mm, and 7.4 mm of Rice, Wheat, Maize, Soybean, Vegetable Pea, Rajma, Barley, Tomato, French Bean, chili, okra, mustard

Crop name	Crop water requirement (mm)	Effective rainfall (mm)	Irrigation water requirement (mm)
Vegetable pea	209.8	131.7	78.6
Barley	250	147.9	104.1
Rajma	123.3	29.7	93.5
Tomato	262.4	84.3	176
French Bean	166.9	70.1	96.9
Chili	310.6	370.7	16.2
Rice	434–505.9	464–491	346–376
Wheat	269.2–375.1	163–194.6	131–189
Maize	247.9	395	1.4
Soybean	350.6	494.4	1.3
Okra	234.9	470.1	18.3
Mustard	155	145.5	15.5
Cowpea	171.9	280.2	7.4

Table 2.
Estimation of irrigation water requirement of major crops grown on experimental site using CROPWAT model.

and cowpea crop, respectively) and irrigation schedule plan of major crop was calculated using CROPWAT Model as presented in **Table 2**.

5.1 Water budgeting equation

This equation could be used to measure evaporation, seepage from pond and volume of water available in pond. The water budget method of determining long term available water present in pond can be used as a standard for comparing other methods. This method is not most accurate, but could be used satisfactory for practical purpose. The volume of water available in pond can be calculated using this equation in the following form:

$$\sum_{i=1}^{12} P_p + \sum_{i=1}^{12} R_{cbt} - \left[\sum_{i=1}^{12} S_p + \sum_{i=1}^{12} Ev_p + \alpha \sum_{i=1}^{12} \sum_{j=1}^{n=crop} WR_{crop}\right] = \sum_{i=1}^{12} WS_p \qquad (6)$$

Where,

P_p = precipitation in surface area of pond (m^3),
R_{cbt} = runoff from conservation bench terraces areas or plain surface (m^3).
S_P = seepage losses from Pond (m^3),
Evp = evaporation losses from Pond (m^3).
W_{Rcrop} = water requirement of crop (m^3).
WS_p = water storage in pond (m^3).

6. Ways to increase carbon storage in tree based land use systems

Carbon sequestration can be enhanced by adopting plantations or agroforestry. Loss of carbon storage can be prevented by reducing felling of forests, blocking or reducing emissions from agricultural activities and by reduced use of energy, oil

Agroforestry/land use systems	Age	Average vegetation C (Mg ha^{-1} y^{-1})
1. Fodder bank, Segu, Mali,South Africa, Sahel	7.5	0.29
2. Live fense, Segu, Mali, South Africa, Sahel	8.0	0.59
3. Tree based intercropping, Canada	13.0	0.83
4. Park lands, Segu, Mali,South Africa, Sahel	35.0	1.09
5. Agrisilviculture, Chhatisgarh, Central India	5.0	1.26
6. Silvopasture, South Oreogaon, USA	11.0	1.11
7. Silvopastoralism, Kurukshetra, India	6.0	1.37
8. Silvopastoralism, Kerala, India	5.0	6.55
9. Cocoa agroforestry, Makoe, Cameroon	26.0	5.85
10. Cocoa agroforestry, Durialban, Costarica	10.0	11.08
11. Shaded coffee, South-West Congo	13.0	6.31
12. Agroforestry woodlots, Partorico	4.0	12.04
13. Agroforestry woodlots, Kerala, India	8.8	6.53
14. Home and farm garden	23.2	4.29
15. Indonesian homegarden, Sumatra	13.4	8.00
16. Mixed species stand, Puertorico	4.0	15.21
Source: [29].		

Table 3.
Carbon sequestration potential in vegetation of world's major agroforestry systems.

and fertilizer. It is the biggest practical alternative, low-cost as well as associated ecological advantages, compatibility to reduce poverty, role of the social dimension/expansion are the key to global climate change mitigation and adaptation [7, 9, 12]. Carbon storage in agroforestry remains in aboveground biomass (wood biomass), leaf group (foliage), shrub, vine, herb, dead biomass (dead wood, litter) and below ground biomass (roots), soil organic carbon etc. According to Nair et al. [29], the world's vegetation carbon sequestration ability by major agroforestry systems is listed in **Table 3**.

7. Status of agroforestry in Himalaya

In Himalayan region of India agroforestry is promising and distributed in large area in different forms. The area ranged from 4.95 in a watershed to 137 ha in of North-west Himalaya (**Table 4**). Carbon storage ranged from 3.31 to 31.71 t/ha in Indian Himalaya (**Table 5**).

System	Area (ha)	Region	Author
Cardamom agroforestry	27.59	North-East Himalaya	[30]
Agroforestry	4.95	North-West Himalayan Watershed	[31]
Willow based agroforestry	137	North-West Himalaya	[20]

Table 4.
Reported area under agroforestry systems of Himalaya.

Agroforestry system	C Storage (t/ha)	Region	Author
Silvopasture	31.71	Himachal Pradesh	[32]
Agrisilviculture	13.37		
Agrihorticulture	12.28		
Agrisilviculture	15.91	Uttarakhand	[33]
Agrihorticulture	12.15	Himachal Pradesh	[31]
Agrisilviculture	12.02	Uttarkhand	[34]
Silviculture	4.4	Uttarakhand	[35]
Silviculture	3.31–3.95	North-East Himalaya	[36]

Table 5.
Carbon storage of different agroforestry systems of Himalaya.

7.1 Oak high-density plantation

The experiments were conducted on high-density plantation of oak (*Quercus leucotrichophora*) for proper management of tree canopy with four lopping techniques. The lopping techniques included: pollarding at 1 and 2 meters (backwards cutting of the tree trunk so that the dense numbers of branches can be generated); Local practices (slightly above from where the branches split leaves and tender twigs removed in random manner); without disturbing the upper 1/3 part of the tree lower 2/3 part pruned for fodder leaves (lopping) (**Table 6**). It was found that at the age of 30 years oak tree can store 86.7 to 356.9 Mg ha^{-1} carbon stock, 317.2 to 1306.5 Mg ha^{-1} biomass carbon dioxide and carbon sequestration in the range of 2.9 to 11.9 per Mg per hectare per year were found in various cutting management [16].

7.2 Fruit based agrihorticulture

In the fruit based agrihorticulture system the highest carbon stock was found in pear + wheat (17.0 Mg ha^{-1}) followed by apricot + wheat, plum + wheat, hill lemon + wheat and wheat with 11.9, 10.0, 8.4 and 4.8 Mg ha^{-1} respectively, (**Figure 2**). Similarly, biomass carbon dioxide was 62.3, 43.6, 36.5, 30.9 17.6 Mg ha^{-1} in pear + wheat, apricot + wheat, plum + wheat, hill lemon + wheat and wheat, respectively [14]. Carbon sequestration in the range of 4.7 to 5.3 Megagarams carbon per hectare per year was found in different treatment.

Treatment	Carbon stock (Mg ha^{-1})	C sequestration (Mg ha^{-1} $yr.^{-1}$)	Biomass CO_2 (Mg ha^{-1})
Coppicing at 1 m	86.7	2.9	317.2
Local	169.6	5.7	620.6
Pollarding at 2 m	123.4	4.1	451.5
1/3rd top portion undisturbed	356.9	11.9	1306.5
Source: [16].			

Table 6.
Effect of different cutting management on carbon stock, carbon sequestration and biomass carbon dioxide.

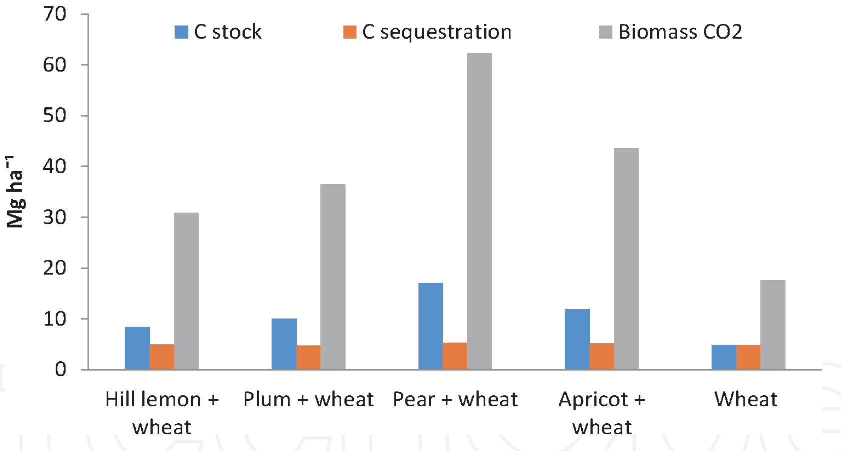

Figure 2.
Aboveground carbon stocks, carbon sequestration and biomass CO_2 in fruit tree based land use systems [8].

7.3 Agrihorticulture

Pecan nut (*Carya illinoinensis*) based agrihorticulture system in which pecan nut + lentil, pecan nut + wheat, lentil and wheat were grown (**Table 7**). Carbon stock of 23.9 and 25.3 Mg ha^{-1} with lentil and wheat and biomass carbon dioxide 92.85 and 87.78 Mg ha^{-1} with wheat and lentil was recorded, respectively [11]. In peach (*Prunus persica*) biomass C stock was recorded 19.4 Mg/ha under agrihorti system.

Therefore, in the context of climate change and to meet the need of rapidly growing population agroforestry is very important. Agroforestry is very essential for pollution free atmosphere and for feed as well as fuel, timber and the unemployed youth in the village could get jobs through agroforestry.

7.4 Silvipasture

In Silvipastoral system among trees oak (*Quercus lecotrichophora*) stored significantly high carbon (24.85 t/ha) as compared to rest trees (**Figure 3**). Whereas, among cutting management pollarding at 3 m height stored highest carbon stock (14.87 t/ha) than other cutting strategies.

7.5 Terrace and wayside plantation

Carbon stock was measured in linear strip plantation of Kachnar (*Bauhinia retusa*). In Kachnar terrace plantation highest @ 3.17 ± 0.88 t/1000 m length, carbon was stored in lopping of lower ½ (half) part and keeping top ½ parts undisturbed of the trees (**Figure 4**). However highest carbon stock of 2.60 ± 0.32 t/

Treatment	Carbon stock (Mg ha^{-1})	Biomass CO_2 (Mg ha^{-1})
Pecan nut + Lentil	23.92	87.78
Pecan nut + Wheat	25.30	92.85
Lentil	1.17	4.29
Wheat	2.50	9.17
Source: [11].		

Table 7.
Carbon stock and biomass CO_2 in pecan nut based agrihorticulture system.

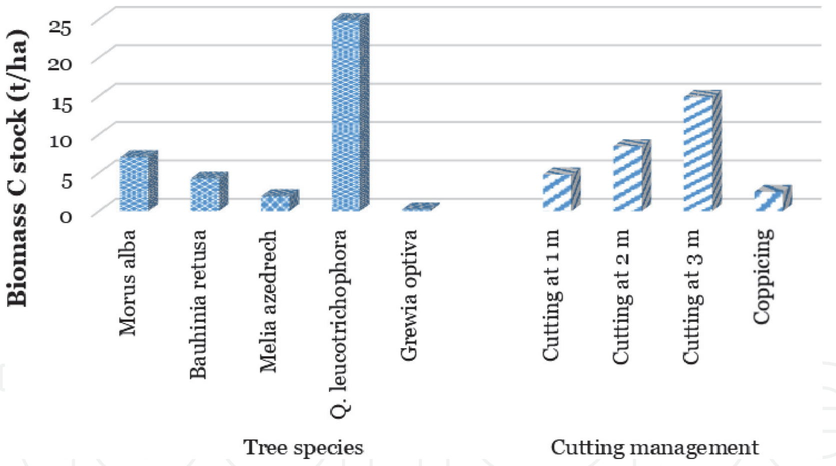

Figure 3.
Biomass carbon (C) stock in silvipastoral system on marginal land.

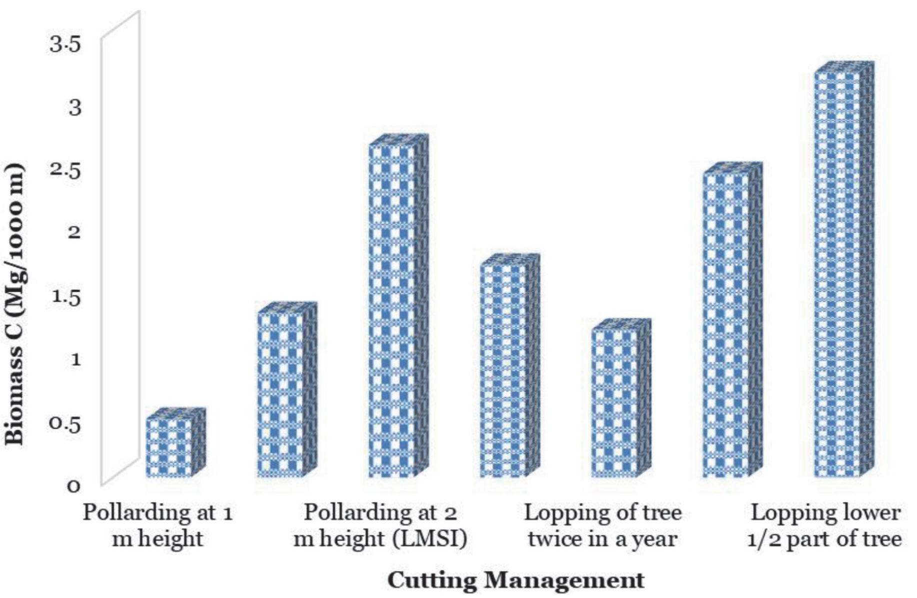

Figure 4.
Biomass C in terrace plantation of Kachnar cutting management in terrace plantation.

1000 m length, was recorded in lopping of lower 2/3 part and keeping top 1/3 undisturbed of Kachnar in wayside plantation (**Figure 5**).

7.6 Silvihorticulture

In silvihorticulture system, significantly high carbon stock (281.6 t/ha) was recorded in Kharik (*Celtis australis*) as shown in **Figure 6** followed by in oak (*Quercus leucotrichophora*), Kachnar (*Bauhinia retusa*) and least in Bhimal (*Grewia optiva*).

8. Conclusion

We conclude that the wheat yield decline due to higher maximum temperature and rice due lower temperature. Therefore, it is essential to know the effects of different weather factors on production and productivity. In view of climate change, it is also demand of the time to explore alternative of crop production system to reduce climate impact of climate change and its variation on agriculture

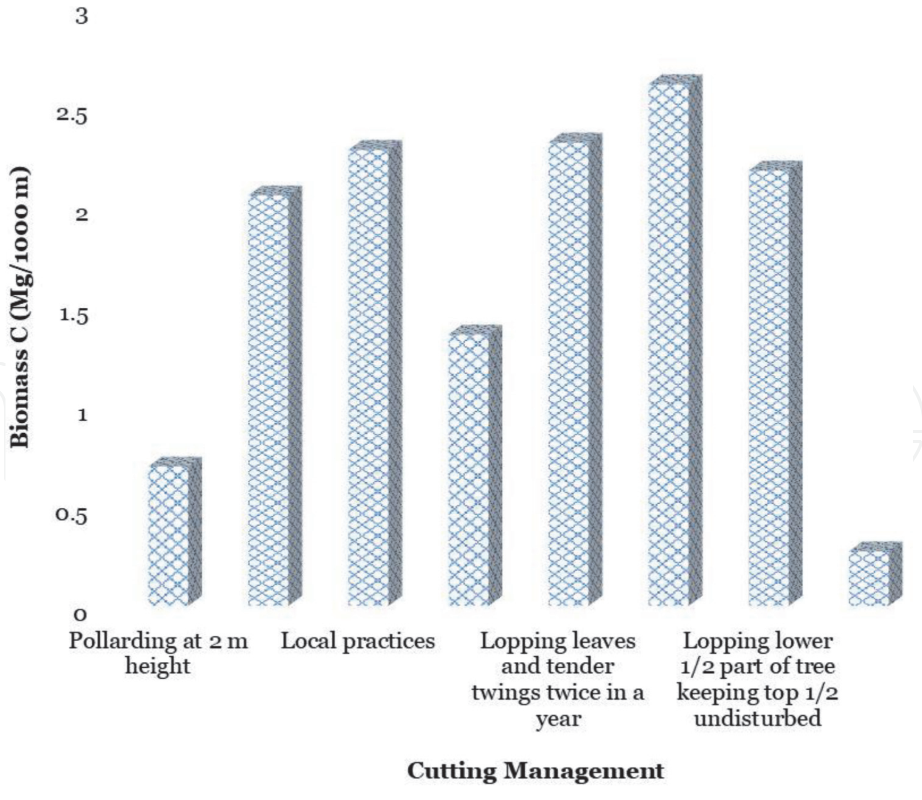

Figure 5.
Biomass C stock in wayside plantation with different cutting management in Kachnar in wayside plantation.

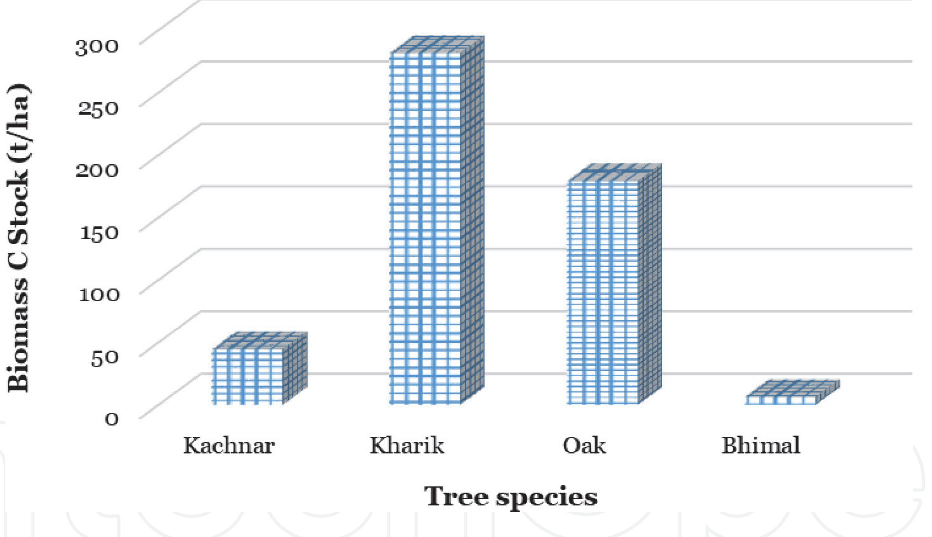

Figure 6.
Biomass C stock in different trees in silvihorticulture system.

and to maintain productivity of resources and also maintain and improve the health of resources. The inclusion of tree i.e. forest or horticulture along with crop will tremendously help in reducing climate change and variation effects on production system. Trees convert poisonous gas CO_2 into lifesaving oxygen (O_2). This action purify the air as well as help in preventing elevated temperature because trees absorb atmospheric carbon in the process of photosynthesis. In agroforestry, we should choose trees with short life cycle and fast growing in nature. India has diversified climate, different agricultural conditions and abundant wasteland in villages need to be considered while implementing various methods of forestry. Hence, to take along sustainability proper considerate of climate is necessary in hill agriculture through crop sowing window adjustment and other processes as per climate appropriateness.

Acknowledgements

The authors are grateful to the Director, Indian Council of Agricultural Research- Vivekananda Parvatiya Krishi Anusandhan Sansthan, Almora, Uttarakhand for providing necessary support.

Conflict of interest

The authors hereby declare that there is no conflict of interest.

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