Impact of Climate Change on Plantation Crops

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Impact of Climate Change on Plantation Crops

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THE EDITORS

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Dr. Soora Naresh Kumar is Principal Scientist at the Centre for Environment Science and Climate Resilient Agriculture, Indian Agricultural Research Institute, New Delhi, 110012, INDIA. His major research contributions include i) Assessment of regional impacts of climate change on wheat, rice, maize, sorghum, soybean, mustard and coconut; adaptation gains and vulnerable regions for these crops, reported in India's National communication to UNFCCC, IPCC reports, for policy support ii) Socio-economic impacts of climate change, implemented community level participatory adaptation iii) Lead scientist of InfoCrop models, compared models in global group of modellers under AgMIP iv) Developed simulation models for coconut (InfoCrop-COCONUT-CocoSim), green gram, spinach and grapes (VitisMod) and released InfoCrop version 2. and 2.1 being used in 44 countries. v) Quantified carbon sequestration potential,responses of coconut, areca nut and cocoa to elevated temperature and CO_2 vi)Characterized drought impacts on coconut, identified *in situ* tolerant palms, developed drought management strategies, characterized coconut germplasm for fatty acid profile. Current research interests include developmentand implementation of adaptation framework in climatically challenged areas; developing integrated assessment methodologies for managing agriculture in extreme weather events and climate change scenarios and developing processed based simulation models for various crops. Published about 100 high impact journal papers. A globally travelled scientist, winner of several awards and is a fellow of scientific societies. Carried out national assignments by the Govt. of India; IPCC-AR5 report expert-reviewer; member in global group of crop modelers; Network coordinator, ICAR-Network project on climate change (2010-2013); Invited by Parliamentary Forum on Global Warming and Climate Change to deliver a lecture. Member, Wheat Expert Group-Modelling, Wheat Initiative.

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— *Editors* —

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Foreword

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Plantation crops, an integral part of the horticulture, provide livelihood security to millions of people. They blend effectively with environment, contributing to sustaintability, conservation of biodiversity and stable ecosystem. Plantation sector plays vital role in employment generation and poverty allievation in rural area, contributing 12.72 per cent to total exports and 75 per cent of the agricultural produce although they occupy 2 per cent of the cultivable area.

Plantation crops are mainly confined in the economically and ecologically vulnerable regions, plays a crucial role as far as the issue of sustainability is concerned. General circulation models project increases in the earth's surface air temperatures and other climate change in the middle or later part of the 21st century, and therefore crops such as coconut, arecanut, cocoa, cashew, oil palm, rubber, coffee and tea will be grown in a much different environment than today. The 2nd National Communication to the United Nations Framework Convention on Climate Change projects an all-round warming over the Indian subcontinent of 1-4°C towards 2050s. The monsoon rainfall in some parts of the southern peninsula, where plantation crops are largely cultivated, is predicted to decrease by 10-20 per cent, along with a decrease in the number of rainy days. Climate change will affect plantation crops through higher temperatures, elevated CO_2 concentration, precipitation changes, increased weeds, pest, and disease pressure, and increased vulnerability of organic carbon pools.

The ecosystem services rendered by plantation crops need to be understood, assessed and realized for resilient plantation systems in India. New crop varieties, cropping systems, and agricultural management strategies are needed for long-term adaptation of plantation crops to climate change. I hope that book on "**Impact of Climate Change on Plantation Crops"** would be of immense help to plantation researchers, extension personnel, policy planners, students and plantation managers, who are involved in plantation sector development and need to address issues related to climate change. I congratulate the editors for this timely compilation for the benefit of all the stakeholders.

Dr. T. Mohapatra

Secretary DARE and DG, ICAR

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Preface

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The plantation industry is important in many parts of the world, not so much interms of area occupied but because of its contribution to the agricultural grossproduct to the economy. In India plantation crops occupy less than 2% of total cultivable areabut generate over Rs16,000 million contributing about 12.72% of export of all commodities. India is leading in production of coconut, tea, cashewand arecanut and offers direct and indirect employment to millions of people.Plantations crops are perennial in nature, grown for quality and high value produce. Owing to their perennial nature, they also experience changes in climatic conditions during their life cycle. Since most of the plantations crops are grown in climatically sensitive areas, they are prone to climatic risks. Climate change is projected to increase the frequency and intensity of the climatic stresses, potentially threatening the productivity of plantation sector. Slow recovery of plantation during post-stress period causes perennial economic loss to the farmer. Thus, plantation farmer is more vulnerable to climate change.Therefore, assessing the effect of climate change on plantation crops isimportant. However, this task is difficult due toi) their size ii) slow growth ratesiii) slow response to external factors and iv) perennial nature.

Most of the plantations have very narrow range of climatic requirements for their optimal growth and yield, in terms of quantity and quality. The plantation crops have immense potential for carbon sequestration. However, research studies and hence the information on climate change impacts on plantation crops is relatively very less as compared to that on food crops. Nonetheless, several efforts by scientists in India have led to generation of quite a good amount of information on climate change impacts on plantation crops. The studies used innovative and integrated approaches as evident from different chapters. This book gives a summarizedinformation on the basics of climate change; climate change projections for India and Indian agriculture; climatic requirement, sensitive stages, impacts of climate change, adaptive strategies toovercome climate change effects on plantation crops viz., coconut, arecanut, cocoa, black pepper and cardamom, cashew, oilpalm, tea and rubber. The approaches used in studies to quantify theeffect of climate change variables under controlled conditions and simulation studies on coconut may also be applicableto other crops. The ways to make the plantation industry more sustainable under changing climates including the genetic and management options available for each crop are provided. Further, carbon sequestration potential of plantation crops is also presented.

The publication of the book has become possible with the whole hearted supportand cooperation from all the contributors. It is hoped that this book will be usefulto all stakeholders involved in plantation research,extension, development and policy planning besides students and all those involved in assessing the impacts, and developing adaptationand mitigation strategies for improving plantations productivity in changing climates.

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Chapter 6

Cashew

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1. Introduction

Climate change that is defined by high atmospheric carbon dioxide (CO_2) concentrations (>400 ppm), increasing air temperatures (2-4 °C or greater), significant or abrupt changes in daily seasonal, and interannual temperature, changes in the wet/dry cycles, intensive rainfall and/or heavy storms, extended periods of drought, extreme frost, and heat waves and increased fire frequency, is expected to significantly impact terrestrial systems, soil properties, surface water and, stream flow (Patterson *et al.*, 2013), ground water quality, water supplies, and terrestrial hydrologic cycle (Pangle *et al.*, 2014). Agricultural productivity is sensitive to two broad classes of climate-induced effects: (i) direct effects from changes in temperature, precipitation, or carbon dioxide (CO_2) concentrations, and (ii) indirect effects through changes in soil moisture and the distribution and frequency of infestation by pests and diseases (IPCC 1996; 2001). Climate change impacts on agriculture are being witnessed all over the world, but countries like India are more vulnerable in view of the high population depending on agriculture and excessive pressure on natural resources. The warming trend in India over the past 100 years (1901 to 2007) was observed to be 0.51°C with accelerated warming of 0.21°C per every 10 years since 1970 (Krishna Kumar, 2009). Climate change projections made up to 2100 for India signify an overall increase in temperature by 2-4 °C with no substantial change in precipitation quantity. However, different regions are expected to experience differential change in the amount and distribution of rainfall that is likely to be received in the coming decades. It is projected that some parts of country will receive higher amount of rainfall. Another significant aspect of climate change is the increase in the frequency of occurrence of extreme events such as droughts, floods and cyclones. Climate change impacts are likely to vary in different parts of the country. Parts of western Rajasthan, Southern Gujarat, Madhya Pradesh, Maharashtra, Northern Karnataka, Northern Andhra Pradesh, and Southern Bihar are likely to be more vulnerable in terms of extreme events.

Climate change is a result from emission of greenhouse gases (GHGs), for example, carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O,) etc. in the past century that will cause atmospheric warming (IPCC, 2007). Agriculture is considered to be one of the major anthropogenic sources of atmospheric greenhouse gases (Lal, 2000). The atmospheric concentration of CO_2, CH_4 and N_2O and other GHGs have increased since the industrial revolution (1750 A.D.) due to natural and anthropogenic activities. The atmospheric concentration of CO_2 has increased from 280 parts per million by volume (ppmv) in 1750 to 394 ppmv in 2012 and is currently increasing at the rate of 1.9 ppmv year^{-1} (NOAA, 2012). Atmospheric CH_4 concentration has increased from about 715 to 1826 parts per billion by volume (Ppbv) in 2012 over the same period and is increasing at the rate of 7 ppbv year^{-1}. Similarly, the atmospheric concentration of N_2O has increased from about 270 ppbv in 1750 to 325 ppbv and is increasing at the rate of 0.8 ppbv year-1 (lPCC, 2007; EPA, 2013). In order to compare emissions from different sources, the global warming potential (GWP) of each gas is equated to the GWP of CO_2, For example, the GWP of 1 tonne of CH_4 is 24.5 times more potent than 1 tonne of CO_2 over a 100 year period (IPCC, 2007).

All these expected changes will have adverse impacts on climate sensitive sectors such as cashew. In India, cashew is habitually grown as a rainfed crop in ecologically sensitive areas for example coastal belts, hilly areas and areas with high rainfall and humidity, and therefore its performance primarily be influenced by climate. Cashew adapted well in west and east coast regions and subsequently spread to hilly and plain regions of Karnataka, Tamil Nadu, Gujarat, Chhattisgarh, and NEH States. There are both threats and opportunities for cashew sector with climate change, the key is in understanding the likely impacts and then managing the risks. Any variability in climate has direct impact on reproductive phase of cashew.With climate variability, there will be various impacts on cashew production such as reduction in yields, variation in flowering, fruit setting, nut development and kernel quality, incidence of pests and diseases and water stress. The increase in weather extremes like torrential rains, heat waves, mid waves and floods, besides year-to-year variability in rainfall affects cashew productivity considerably and leads to stagnation/decline in production across various agro-climatic zones. The challenge for cashew crop will be to improve yields in marginal lands under rainfed conditions where the harsh environment strongly limits crop growth, productivity and quality of the produce. Hence, adaptation and mitigation strategies are required to be formulated to minimize the climate change related impacts on cashew.

2. Climatic Requirement

Cashew, a tropical nut crop can be found growing between 28°N and 28°S latitude. In India, cashew is grown in the coastal belt between 8°N and 28°N. Flowering time depends on the latitude. In Brazil and Tanzania, peak flowering is between August and September. The highest flowering occurs in October in Mozambique, while in Philippines it is March. In the west coast of India, flowering

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is from October to March. Whereas in the east coast of India, flowering is delayed by about 2-3 months. However, the crop is ready for harvest in summer, both in the north and south of the equator. As cashew grows at an elevation ranging from 0 to 1000 m above mean sea level (MSL) the The phenology of cashew is very much influenced by the altitude of the region. However, the productivity is the highest up to the altitude of 750 m above MSL. Low temperatures at higher altitudes have adverse effect on the crop. Flowering and fruiting are delayed irrespective of latitude at higher altitude. Low altitude areas with a mean rainfall of 1500 to 2000 mm is excellent for cashew. Damage to young trees or flowers occurs below the minimum temperature of 7° C and above the maximum of 45° C. Only prolonged cool temperatures will damage mature trees; cashew can survive temperatures of about 0° C for a short time (Ohler, 1979). Environments with maximum temperature ranging from 28 to 32 °C, minimum winter temperature around 19 °C and 70 to 80 per cent relative humidity are satisfactory for better output. Frost is detrimental to the crop Mandal (1992) (Table 6.1).

Table 6.1: Environmental Rating for Growing Cashew

Parameter	*Very Good*		*Good*	*Fair*	*Poor*
	Class I	*Class II*	*Class III*	*Class IV*	*Class V*
Altitude (m)	20	20-120	120-450	450-750	
Rainfall (mm/year)	1500-2000		1300-1500	1100-1300	900-1100
Proximity to sea (km)	<80	80-160	160-240	240-320	
Maximum temperature (°C)	28-32	32-33	33-34	34-35	
Minimum temperature (°C)	19	18-19	17-18		15-17
Humidity (per cent)	70-80	65-70	60-65		50-60
Occurrence of frost	None	None	Very rare	Once in 5 years	

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Though cashew can tolerate wide range of temperature but the optimum monthly temperature is between 24 °C and 28 °C. Cashew grows in the semi-arid regions like northern Mozambique where daily maximum temperatures exceeds 40 °C and in Assam, cashew survives up to 7 °C. It has been reported that cashew cultivation is not economical in regions where annual temperature falls below 20 °C for prolonged periods. In major cashew growing regions, the mean daily maximum temperature vary between 25 °C and 35 °C and the mean daily minimum temperature vary between 15 °C and 25 °C. The productivity of cashew is higher in regions where the mean annual temperature ranged from 22.5 °C to 27.5 °C and the minimum temperature ranges from 10 °C to 22 °C. The productivity is lower in regions where the minimum temperature drops below 10 °C. For flowering, cashew requires mild winter, that is low minimum surface air temperature ranging between 16 °C and 20 °C coupled with more dew nights. Cashew is highly sensitive to light and produces more foliage, flowers and fruits on braches exposed to sunlight than on the shaded branches. Bright sunshine (>9 h/day) with moderate dry weather is good for flowering. In Togo the optimum sunshine is held to be 2464 h/year with 1285 h in the flowering/fruit set period (November-March) which is only found in the north and centre of the country. In Brazil the optimum sunshine lies between 1500 and 2000 h/year, while the precise sunshine for Venezuela is considered to be an average of 2000-2400 h/year.

Cashew can survive under very high and low rainfall conditions. Although cashew can tolerate drought conditions but for proper vegetative development and regular fruit-setting, the average annual rainfall of 1,300 to 2,500 mm is considered to be suitable. The average annual rainfall distribution in cashew areas ranged from low rainfall (300-600 mm in Gujarat) to high rainfall (2700-3000 mm in west coast and NEH region) but the productivity is highest in regions with a mean annual rainfall distribution of 600-1500 mm. Cashew needs a clearly defined dry season of at least 4 to 5 months. A dry spell from January to May with occasional light summer rains ensures better cashew production. A well distributed North-East monsoon rainfall of about 500 mm during September to December and about 100 mm during February to April are good for successful production of cashew. Light rains during flowering do not affect the production but heavy rains during flowering affects the yield. Year to year variation in time of flowering of a variety is common even under uniform cultural and management practices. It signifies the influence of weather factors on flowering behavior of cashew. Unusual heavy rainfall between January and March may encourage high incidence of pest like tea mosquito bug (TMB) and reduce yield and quality. Cashew is highly sensitive to high relative humidity (more than 80 per cent) during the harvesting season. High relative humidity adversely affects the nut quality.

3. Climate Change Impacts

The rainfed cashew crop is highly sensitive to changes in climate and weather, especially during reproductive phase. High temperature (>34.4 °C) and low RH (<20 per cent) during afternoon cause drying of flowers. The maximum temperature, humidity and rainfall are the major climatic factors that influence the productivity of cashew. According to Prasada Rao *et al.* (2010), the maximum temperature plays a crucial role on nut size and kernel weight of cashew during the nut development stage. Haldankar *et al.* (2003) reported that the relative humidity during pre-flowering phase is the main factor which explains yield variation in cashew plantations. The unusual rains between November and December inordinately delay reproductive phase of the late flowering varieties. Unseasonal rainfall and heavy dew during flowering and fruiting intensify the incidence of pests and diseases as well as deterioration of nut quality. For example, a rainfall of about 201 mm received at ICAR-DCR experimental farm during 15-25 March, 2008 adversely affected the yield and quality of nuts. Large quantity of nuts which could not be picked up in time germinated in the field itself. The nuts could not be dried in time due to non-availability of good sunshine hours resulting in poor quality of nuts. The surplus moisture in raw cashewnut damages the kernel inside by changing its colour from white to cream. The nut yield losses due to unseasonal rains were estimated to be between 50 and 65 per cent in March, 2008.

Cashew genotypes vary noticeably in their heat units (day °C) requirement. Early variety (Anakkayam-1) requires only 1953 heat units for reproductive phase,

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while late variety (Madakkathara-2) requires 2483 heat units. Cashew kernel weight is positively correlated with heat units especially for mid and late varieties. Continuous rains without critical dry spells and late winter rains delay the bud break in cashew. A dry spell of 7 days is usually necessary 30 days prior to the bud break. Late and extended winter rains reduce the number of bright sunshine hours invariably which results in delaying of bud break and better availability of soil moisture during flowering (December and January). For example incessant rains received at Pilicode (Kerala) until November in 1998 delayed the bud break. The delay in bud break was prominent in early varieties. In late varieties, bud break was normal, because the required dry spell of 7 days was met 22-26 days before bud breaking (Prasada Rao *et al.,* 2001).

Cashew is infested by numerous insect pests, thereby limiting the production considerably. One of the main reasons for reduction of cashew nut yield is the occurrence of an important sucking insect pest, tea mosquito bug (TMB) (*Helopeltis antonii* Signoret) during the cropping season. The production loss from the TMB alone is estimated to be about 30 per cent.This pest has got potential to cause 100 per cent loss in yield in severe cases. The incidence and severity of the pest is highly dependent on climate and weather factors. The minimum temperature plays a vital role in the incidence of pest population and is negatively correlated with the TMB pest incidence (Godse *et al.,* 2005). The favourable minimum temperature for TMB incidence ranges between 13-18 °C. Low temperature (12 °C) is antagonistic for pest build up.

Apart from the damage caused by the infestation of TMB, infection of the panicles by the fungal pathogens, *viz.,* *Colletotrichum gleosporoides* and *Gleosporium mangiferae* have been reported to cause drying up of young shoots, inflorescence and immature nuts in cashew. The characteristic symptom is the drying of floral branches. The symptoms appear as minute water soaked lesions on the main rachis and secondary rachis. The incidence is very severe when cloudy weather prevails. The incidence of this disease is being reported from different new locations in which it was not prevalent earlier. High relative humidity in forenoon during December - February both in 1997 and 1998 and the minimum temperature of 18-20 °C were found to be favourable for sporulation by fungi. A significant increase in dewfall was one of the most important factors which favoured the growth, sporulation and spread of fungi. Cloudiness leading to low bright sunshine hours (2 h/day) followed by dewfall triggered the growth, sporulation and spread of fungal pathogens causing inflorescence blight during 1998-99 in Kannur and Kasaragod districts (Prasada Rao, 2002).

4. Extreme Events of Weather Impacts

Changes in temperature and precipitation patterns together with occurrence of extreme events due to climate change are a major threat to future cashew sector. The Tsunami in coastal Tamil Nadu on 26 December, 2004 harshly affected cashew crop. Most of the standing crop was inundated with salty sea water ingressing in the mainland. Salinity is a major environmental stress and is a substantial constraint to crop production. Salt affected soils are the soils that contain considerable amounts of

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soluble salts and or sodium on the exchange complex. The high amount of soluble salts (in saline soils) and of sodium on the exchange complex (in sodic soils) hinder crop growth and have rendered them barren (Gupta and Abrol, 1990). In saline soil the available moisture range is low and crop has to spend extra energy to extract water from the soil because of high osmotic potential of the soil solution. These also adversely affect water and nutrient availability. Most of the cashew varieties are sensitive to salinity. Rise in sea water level due to climate change conditions may adversely affect the cashew plantation. Electrical conductivity of 1.48 dS m^{-1} in irrigation water is a threshold tolerance for precocious cashew during the initial growth (Carneiro *et al.,* 2002).

'Thane' cyclone with a very high wind speed created havoc in Cuddalore district of Tamil Nadu and Pondicherry on 30 December 2011. The entire cashew area of Panruti, Cuddalore and Kurinjipadi taluks of Cuddalore district were totally devastated. The extent of damage to cashew trees in Vridhachalam taluk was 60-70 per cent due to decrease in the wind speed away from the coast. A team of scientists of AICRP-Cashew Centre at Regional Research Station (Tamil Nadu Agricultural University), Vridhachalam visited and surveyed the 'Thane' cyclone affected area and the recommendations of the team to cope up with the situation include i) Removal of uprooted trees for new planting, ii) Mass replanting programme, iii) Government support for laying out a borewell for every 10 acres for establishment of the new plants, iv) Government support programmes for raising annual crops like pearl millet, blackgram, horsegram, groundnut and kodo millet upto five years etc.

5. Adaptation and Mitigation Strategies

Adaptation strategies can work in two ways, by reducing vulnerability (susceptibility) to changing condition, or by increasing resiliency (to recovery) by reducing suffering during and immediately after the events (Bedsworth and Hanak, 2010). There are two basic counter measures regarding climate change, mitigation and adaptation (Mimura, 2010). Mitigation includes different measures, undertaken to reduce GHGs emission and increasing absorption of GHGs, which already emitted, and adaptation indicates different potential measures to protect the adverse effects of climate change. Some of the adaptation measures in common that the cashew sector can undertake to cope with future climate change include: Changing planting dates, planting different varieties, developing new drought and heat resistant varieties, salt tolerant varieties, adoption of intercropping, using sustainable fertilizer, weed management, more use of water harvesting techniques, supplemental irrigation, drip irrigation, fertigation, better pest and disease management etc. Climate change mitigation refers to efforts to reduce/ prevent emission of GHGs. Protecting natural carbon sinks like forests and oceans, or creating new sinks through silviculture or green agriculture are also elements of mitigation. In order to mitigate the ill effects of climate change on soil quality and to protect the soil and land resource, it is important to give more focus on adoption of soil and water conservation practices, mulching, cashew leaf litter retention and recycling, addition of animal based manures etc.

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5.1. Soil and Water Conservation Practices

Major cashew growing area in India is under undulated topography (steep slopes). As a rainfed crop, cashew experiences severe moisture stress from January to May. It adversely affects flowering and fruit set. The main aim of soil and water conservation practices is to reduce or prevent either water erosion or wind erosion, while providing the desired moisture for crop growth/production. Erosion by water is the most serious soil degradation problem in the humid tropical and sub tropical India. In India, soil erosion has been taking place at an average rate of 16.35 t ha^{-1} $year^{-1}$ (Dhruvanarayana and Rambabu, 1983), totaling an annual loss of 5334 million tonnes, nearly 29 per cent of the total eroded soil is permanently lost into the sea, and nearly 10 per cent is deposited in reservoirs. Remaining 61 per cent of the eroded soil is transferrable from one place to another. The soil erosion by water and wind result in loss of top soil and depletion of soil organic matter. Depletion of organic matter in soil discourages the activity of soil microflora responsible for decomposition of organic matter to enrich soil fertility. It becomes imperative for the land use planners to adopt appropriate conservative measures.

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In order to harvest the rainwater and to make it available to the cashew plant during critical period, an *in situ* soil and water conservation and rainwater harvesting are very important. Research work carried out at ICAR-DCR indicated that soil and water conservation measures such as modified crescent bund (at 2 m radius having a crescent shaped bund of 6 m length, 1m width and 0.5 m height on the upstream of the plant so that a trench of 6 m length and 50-75 cm deep will be formed while making the bund) and coconut husk burial (Trenches of size 5 m length, 1 m width and 0.5 m depth in the middle of 4 plants with coconut husk buried) were found effective in terms of higher yield, reduction in annual runoff and conserving moisture (Rejani and Yadukumar, 2010). It was shown that reduction in peak runoff and increase in recession time and groundwater recharge due to soil and water conservation practices (Deshmukh *et al.*, 1992). According to Badhe and Magar (2004), trapezoidal shaped staggered trenches (230/ha) having dimensions of 4.5 m length, 0.60 m top width, 0.30 m bottom width and 0.30 m depth were effective for reducing runoff and conservation of soil and nutrients. Mane *et al.* (2009) demonstrated that continuous contour trench (0.50 m x 0.60 m) is the best soil conservation practice for cashew on areas having 7 to 8 per cent slope.

5.2. Mulching

Cashew is often planted in areas which are totally dry and less fertile. Under such situations mulching is highly useful to conserve the soil moisture for a long period, protecting the soil from erosion and maintaining, restoring and improving soil organic carbon status. The basin area of cashew plants can be mulched either with green leaves or dry leaves and weeds soon after planting. Black polythene mulch was helpful to conserve soil moisture (Nawale *et al.*, 1985). Using coconut coir pith as soil mulch in cashew plantations resulted in 14.15 per cent more water retention and suppression of weeds to an extent of 73.52 per cent (Kumar *et al.*, 1989). Formation of terrace and crescent bund and mulching the base area with cashew leaf litter and other jungle growth available in the garden are helpful.

5.3. Green Manuring

Growing green manure crops like *glyricidia*, *sesbania*, sunhemp and cover crops between two rows of cashew have potential to improve soil moisture retention capacity and nutrient content. According to research studies at ICAR-Directorate of Cashew Research, Puttur, Karnataka, higher soil moisture content was observed in cashew orchard with *glyricidia* (17.0 to 18.6 per cent dry basis), sunhemp (17.8 to 18.3 per cent dry basis), sesbania (15.5 to 18.2 per cent dry basis) compared to control (15.5 to 17.0 per cent dry basis). The nutrient addition to soil was about 186 kg N, 23.6 kg P_2O_5 and 126.2 kg K_2O and 141 kg N, 17.9 kg P_2O_5 and 162.3 kg K_2O/ha through *glyricidia* and *sesbania*, respectively.

5.4. Site Specific Nutrient Management (SSNM)

It is another approach with potential to mitigate effects of climate change. The SSNM is critical for GHGs mitigation so as to reduce input cost and enhance nutrient use efficiency considerably. This approach facilitates cashew grower to invest only on deficient nutrients and omit nutrient application which was in sufficient range in soils. Various benefits of SSNM practice include lowering in input cost, higher nutrient use efficiency, and reducing GHGs particularly N_2O. Application of fertilizers particularly N during water stress escalates water stress problem further as higher N improves leaf canopy which results higher evapotranspiration. Using nitrification inhibitors, and fertilizer placement practices need further consideration for GHGs mitigation. Management of soil in combination with optimum soil moisture is essential to protect the plants during weather aberrations and overall reduction of CO_2, N_2O and CH_4 from soil. For example, increased rainfall in regions that are already moist could lead to increased leaching of minerals, especially nitrates. Increases in fertilizer applications would be necessary to restore productivity levels. Placement of fertilizer materials and split application of nutrients into soil will substantially improve both nutrient and water use efficiency. However, KNO_3 foliar sprays during intermittent droughts results in the adaptation of plants by closing stomata.

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5.5. Intercropping

Cashew takes 8 to 10 years for the canopy to cover the entire area under normal spacing. In hilly regions there is a possibility of soil erosion and weed growth during initial years of planting. Under such situations, intercropping not only minimizes erosion and conserves soil and moisture and also to realize higher returns from unit area during the early stages of cashew plantation. Growing field crops (groundnut, black gram and green gram), vegetables (cucumber and bottlegourd), tuber crops and fruit crops (pineapple), spices (turmeric, ginger and pepper) are suitable and profitable intercrops in cashew plantations. Ginger was recommended as an intercrop in the initial 3-4 years of cashew plantation in the west coast region. In east coast, crops like groundnut and cowpea are grown profitably under rainfed situations. Intercropped pineapple in cashew plantations has been adopted by farmers and resulted in 1.5 fold higher yield and net profit. Pepper vine and kokum are the other popular intercrops for enhancing the farm profitably as mixed crops grown in cashew orchards by trailing on to the stem of cashew in case of pepper and planting kokum in the middle of 4 cashew plants in west coast where rainfall is high.

5.6. Contingency Plan for Rainfall Deficit Management for Cashew

Cashew is planted under normal onset of monsoon during June to September. However, dry spells occur at various stages during the planting season resulting in early, mid-season and terminal droughts adversely impacting performance of the plants. The effect of drought is pronounced due to delays in onset of monsoon, prolonged breaks in monsoon and deficit rainfall. Contingent planning for rainfed cashew is important when the onset of monsoon is delayed. Small changes in climatic parameters can often be managed reasonably well by altering dates of planting. In case of normal onset followed by early season dry spell immediately after planting leading to poor crop establishment, gap filling, mulching, nutrient management etc. may be necessary. In addition, moisture conservation measures and life saving irrigation wherever possible are suggested. The irrigation through pitcher (hold pots) is recommended in dry land situations. In case of terminal drought in September to October due to dry spells or early withdrawal of the south west monsoon, crop management measures such as life saving or supplemental irrigation, if available, from harvested pond water or other sources are suggested as in the case of mid season drought wherever feasible.

Established plants survive even in adverse soil moisture conditions. The rainfall deficit or cessation of rains at early stage also adversely affects the nut yield particularly in late maturing varieties. In order to minimize the yield loss under such situations, one or two protective irrigations are highly beneficial. Supplemental irrigation of 200 L of water/plant once in 15 days during January to March from water collected in ponds through rain harvesting helps in flowering and nut development by improving the microclimate with increased humidity. It also leads to increased nut and kernel weight by reducing flower and nut drying to some extent. Drip irrigation during fruit development stages wherever water is available is helpful under drought situations to rainfed cashew crop. Normally for west coast of Dakshina Kannada, irrigation by drip at 20 L/tree/day for mature cashew plantations (10 to 15 years) is recommended. Research results indicated that yield can be doubled, if irrigated. Irrigation can be started after the commencement of flowering for better nut set, filling and yield. It has been reported that fertigation saved 50 per cent in the fertilizer requirement and doubled the cashew yield (Richards, 1993; Yadukumar and Mandal, 1994; Mishra *et al.,* 2008). To maintain the proper soil moisture regime, the harvesting of rain water and recycling them during deficit period is suggested. Moreover, adoption of soil conservation measures and installation of drip wherever water source is available will be helpful. Developing heat and drought tolerant cashew varieties by utilizing genetic resources that may be better adapted to new climatic and atmospheric conditions should be the long-term strategy.

In the recent past, continuous high rainfall in a short span leading to water logging. Heavy rainfall coupled with high speed winds in a short span are being experienced at various growth stages, of which the 2008 one was the most recent,

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significantly affecting the production of cashew. In addition to that, the amount and distribution of rainfall is becoming more and more erratic, causing greater incidence of drought and flood. The increase in frequency of heavy rainfall events in last 50 years over Central India points towards a significant change in climate pattern in India. Unseasonal rains received during harvesting season in Dakshina Kannada district of Karnataka caused considerable yield loss and deterioration of nut quality both in trees and on the ground. The contingency measures suggested are drying of collected matured fallen nuts immediately by sun drying/artificial drying in case there is not sufficient bright sun light.

The climatic change threats include likely increase of temperature, extreme weather conditions, increased water stress and drought, and desertification. All these may seriously increase the vulnerability of resource poor cashew farmers to global climate change. Policies that support crop insurance can provide protection to the farmers in the event of crop failure or lower production due to natural calamities. Some of the measures to cope up with climate change effects include weather based crop and an early warning system of environmental changes.

5.7. Pest and Disease Management

Tea mosquito bug (TMB) pest and inflorescence blight disease cause considerable damage to cashew. Incidence and severity of both are dependent on climate and weather factors. Need based sprays are recommended for TMB during most vulnerable periods of crops such as flushing, flowering and fruiting stage of the crop. Forewarning the outbreak of the dreaded inflorescence blight disease in west coast region of India is of utmost importance for its effective management. Proper training of cashew trees from early stages and timely pruning of side and criss-cross branches may ensure that microclimate is not congenial for build-up of sucking pests and inflorescence blight disease.

5.8. Carbon Sequestration

Cashew has substantial carbon sequestration potential for carbon sequester for mitigation of climate change and can also be grown in vast degraded/wasteland existing in cashew-growing regions. Soil carbon (C) has gained increased interest in the recent past owing to its importance in C sequestration studies and its potential impact on sustainable crop production. Carbon sequestration implies removing atmosphere carbon and storing it in natural reservoirs for extended periods (Lal, 2004; Srinivasarao *et al.,* 2013). Soil carbon sequestration is the process of transferring carbon dioxide from the atmosphere into the soil through crop residues and other organic solids, and in a form that is not immediately remitted. This transfer or "sequestering" of carbon helps off-set emissions from fossil fuel combustion and other carbon-emitting activities while enhancing soil quality and long-term agronomic productivity.

The C fixed in plants by photosynthesis and added to soil as above and below ground litter is the primary source of C in ecosystems (Warembourg and Paul, 1977). Although most carbon enters ecosystems via leaves, and carbon accumulation is most obvious when it occurs in above ground biomass, more than half of the

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assimilated carbon is eventually transported below ground via root growth and turnover and exudation of organic substances from roots. Numerous studies have convincingly proved that the inclusion of trees in the agricultural landscapes often improves the productivity of systems while providing opportunities to create carbon sinks.

Since C sequestration is an essential component of mitigation of green house gases, it is important to assess the sequestration potential of crops. It has been estimated that soil organic carbon sequestration potentially could offset about 15 per cent of the global CO_2 emission. Cashew has dense green leaves with good photosynthetic capacity and it can also be grown in high-density planting system. Cashew is suitable crop for C sequestration. It can be grown in vast degraded/ wasteland existing in cashew growing regions. Based on research undertaken at ICAR-DCR, it was found that, 7 years old trees of cashew genotype VTH-174 sequestered about 2.2 fold higher C under high density planting system (625 trees/ ha) as compared to normal density planting system (156 trees/ha). Carbon storage by cashew has been estimated as 32.25 and 59.22 t CO_2/ha at 5^{th} and 7^{th} years of growth, respectively under high density planting. The extent of C sequestered will depend on the amounts of C in standing biomass, age of the crop, tree density, variety etc.

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6. Future Line of Work

- ✰ Development of cashew varieties resistant to abiotic stresses like temperature, drought, salinity, floods etc.
- ✰ Development of climate resilient agro-techniques in order to suit unfavourable abiotic stresses.
- ✰ Development of crop simulation models for cashew.
- ✰ Assessment of new pest and diseases in the scenario of climate change and development of cost effective, eco-friendly approaches for management of emerging pests.
- ✰ Mitigation and adaptation strategies to cope up with expected climate change impacts on cashew required to be streng

References

Badhe, V.T. and Magar, S.S. (2004). Influence of different conservation measures on runoff, soil and nutrient loss under cashew nut in lateritic soils of south Konkan region. *Indian Journal of Soil Conservation*, 32(2), 143-147.

Bedsworth, L.W. and Hanak, E. (2010). Adaptation to climate change: a review of challenges and tradeoffs in six areas. *Journal of the American Planning Association*, 76, 477-495.

Carneiro P.T., Fernandes, P.D. and Gheyi, H.R. (2002). Germination and initial growth of precocious dwarf cashew genotypes under saline conditions. Revista *Brasileira De Engenharia Agricola E Ambiental*,6(2), 199-206.

Deshmukh, M.T., Sawke, D.P., Borude, S.G., Hurni, H. and Tato, K. (1992). Effects of platform bench terraces on the growth and yield of mango and cashew grafts. Erosion, conservation and small scale farming report. Department of Agricultural Engineering, Konkan Agriculture University, Ratnagiri, India, pp. 477-482.

Dhruvanarayana, V.V. and Rambabu, (1983). Estimation of soil erosion in India. *Journal of Irrigation and Drainage Engineering*, 109, 419-434.

Godse, S.K., Bhosle, S.R. and Patil, B.P. (2005). Population fluctuation studies of tea mosquito bug on cashew and its relation with weather parameters. *Journal of Agrometeorology*, 7(1), 107-109.

Gupta, R.K. and Abrol, I.P. (1990). Salt affected soils - Their reclamation and management for crop production. *Advances in Soil Science,* 12, 223-275.

Haldankar, P,M., Deshpande, S,B., Chavan, V.G. and Rao, E.V.V.B.(2003). Weather associated yield variability in cashewnut. *Journal of Agrometeorology*,5(2), 73-76.

IPCC, (2007). Agriculture. In: Metz, B., Davidson, OR, Bosch PRo (Eds.), Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom/New York, NY, USA.

IPCC, (2001). Climate Change 2001. Impacts, Adaptation, and Vulnerability, Contribution of Working Group II to the Third Intergovernmental Panel on Climate Change. In: McCarthy, J.J; Canziani, O.F; Leary, N.A; Dokken, D.J. and White, K.S. (Eds), Cambridge University Press, Cambridge, UK.

IPCC, (1996). Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific- Technical Analyses.

Krishna Kumar, (2009). Impact of climate change on India's monsoon climate and development of high resolution climate change scenarios for India. Presented at MoEF, New Delhi on October 14, 2009 (http: moef.nic.in).

Kumar, D.P., Subbarayappa, A., Hiremath, I.G., Khan, M.M. and Sadashivaiah (1989). Use of coconut coir-pith: a biowaste as soil mulch in cashew plantations. *The Cashew*, 3(3), 23-24.

Lal, R. (2000). World cropland soils as a source or sink for atmospheric carbon. *Advances in Agronomy*,71, 145-191.

Lal, R. (2004). Soil carbon sequestration impacts on global climate change and food security. Science, 304, 1623-1627.

Mandal, R.C. (1992). Cashew Production and Processing Technology. Agro Botanical Publishers (India), Bikaner, pp. 195.

Mane, M.S., Mahadkar, U.V., Ayare, B.L. and Thorat, T.N. (2009). Performance of mechanical soil conservation measures in cashew plantation grown on steep slopes of Konkan. *Indian Journal of Soil Conservation*, 37(3), 181-184.

Author Copy of the Chapter

Mimura, N. (2010). Scope and roles of adaptation to climate change. In: A. Sumi, K. Fukushi, and A. Hiramatsu, eds., Adaptation and Mitigation Strategies for Climate Change. Springer Tokyo Berlin Heidelberg New York. Ch.9.

Mishra, J.N., Paul, J.C. and Pradhan, P.C. (2008). Response of cashew to drip irrigation and mulching in coastal Odisha. *Journal of Soil and Water Conservation*, 7(3), 36-40.

Nawale, R.N., Sawke, D.P. and Salvi, M.J. (1985). Effect of black polyethylene mulch and supplemental irrigation on fruit retention in cashewnut. Cashew Causerie, 7(3), 8-9.

NOAA/ESRL. (2012). Available at http://www.esrl.noaa.gov/gmd/ccgg/trends.

Pangle, L.A., Gregg, J.W., McDonnell, J.J. (2014). Rainfall seasonality and an ecohydrological feedback offset the potential impact of climate warming on evapotranspiration and groundwater recharge. *Water Resources Research*,50, 1308-1321.

Prasada Rao, GS.L.H.V., Giridharan, M.P., Jayaprakash Naik, B., Gopakumar, C.S., Krishnakumar, K.N. and Xavier Tony (2001). Influence of weather factors on bud break, flowering and nut quality of cashew (*Anacardium occidentale* L.). *Indian Journal of Agricultural Sciences*,71(6), 399-402.

Prasada Rao, G.S.L.H.V. (2002). Climate and Cashew. AICRP on Agro Meteorology, Department of Agricultural Meteorology, College of Horticulture, Kerala Agricultural University, Kerala, India, pp. 1-100.

Prasada Rao, G.S.L.H.V., Rao, G.G.S.N. and Rao, V.U.M. (2010). Climate Change and Agriculture over India. PHI Learning Private Limited, New Delhi, India. 328 p.

Patterson, L.A., Lutz, B., Doyle, M.W. (2013). Climate and direct human contributions to changes in mean annual streamflow in the South Atlantic, USA. *Water Resources Research*,49, 7278-7291.

Rejani, R. and Yadukumar, N. (2010). Soil and water conservation techniques in cashew grown along steep hill slopes. *Scientia Horticulturae*, 126, 371-378.

Richards, N.K. (1993). Cashew Research in Northern Territory, Australia, 1987-1991. Tech. Bull. No. 202.

Srinivasarao, Ch., Venkateswarlu, B., Rattan Lal., Singh, A.K. and Sumantha Kundu. (2013). Sustainable management of soils of dryland ecosystems of India for enhancing agronomic productivity and sequestering carbon. *Advances in Agronomy*, 121, 253-329.

Warembourg, F.R. and Paul, E.A. (1977). Seasonal transfers of assimilated ^{14}C in grassland: plant production and turnover, soil and plant respiration. *Soil Biology and Biochemistry*, 9, 295-301.

Yadukumar, N. and Mandal, R.C. (1994). Effect of supplementary irrigation on cashewnut yield. Water Management for Plantation Crops - Problems and Prospects. Centre for Water Resource Development and Management, Calicut, Kerala, India, pp. 79-84

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