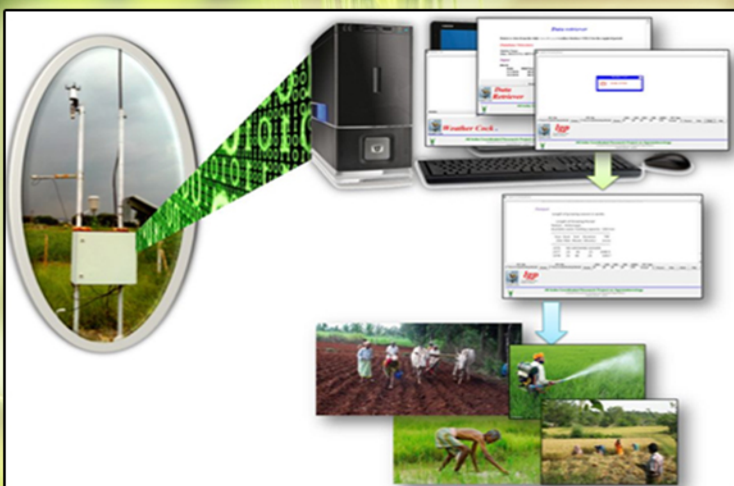
Agrometeorological Data Collection, Analysis and Management

ICAR Sponsored Training program for technical staff

25 July – 06 August 2016

Editors
P Vijayakumar,
AVM Subba Rao &
MA Sarath Chandran



All India Coordinated Research Project on Agrometeorology
ICAR-Central Research Institute for Dryland Agriculture
Santoshnagar, Hyderabad - 500 059

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Lecture Notes

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P Vijayakumar, AVM Subba Rao and MA Sarath Chandran

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Acknowledgements

It is a great privilege for us to express our profound sense of gratitude to Indian Council of Agricultural Research (ICAR), New Delhi for its funding the Training Program on ‘Agrometeorological Data Collection, Analysis and Management’ during 25 July to 6 August 2016. The encouragement and guidance received from Dr Ch Srinivasa Rao, Director, CRIDA is acknowledged with thanks. We express our sincere thanks to all the resource persons from different parts of the country and also the scientists from CRIDA for their efforts in providing lecture notes. We are also thankful to Shri IR Khandgonda, A Mallesh Yadav, D Harini, O Bhavani, VM Sandeep, VP Pramod, V Narasimha Rao, P Pani and K Vijayalakshmi and for their technical and secretarial assistance.

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Basic concepts of Agrometeorology

B.V. Ramana Rao

Retd. PC (AICRPAM), CRIDA

Life demands food. The production of food depends upon four factors namely

- Plant and genetic material, Weather, Soil and Water

Many other factors like management practices, size of the holding and enterprising nature of the farmer may also contribute to the success or failure of agricultural production. But weather plays a more decisive role. The farmer will have very little control on the weather. Weather will influence the agricultural production through its effects on soil chemistry and physics, plant growth and development, yield and yield components and in every phase of animal growth and production as well. So, the basic philosophy of agricultural meteorology is to make use of the science of meteorology in the interest of food production. Agricultural meteorology can be broadly defined as the science which deals with the interaction between the atmosphere and the plants and farm animals.

Therefore, the aim of agricultural meteorology is to make use of all the products of meteorological services including

- Historical data base, which can be analysed for crop planning, soil and water management strategies, identification of extreme weather events that might cause decline in productivity and evaluate the climatic shifts including inter seasonal and intraseasonal variability of weather factors trends, if any that might provide clues on climate change and if possible the impact of such variability on crop production.
- Long, medium and short range weather forecasts issued by the meteorological department for taking decisions in crop planning and management, impact of changing weather conditions on biotic interferences to the crop growth and guide the extension officials and farmers from time to time.
- Global weather parameters like El Nino, Southern Oscillation etc which may have severe effect on seasonal climates within different agroclimatic regions and their impact on crop production.

Agricultural Climatology:

The agricultural production potential primarily depends upon the availability of moisture in the soil through precipitation (water received over the soil from the atmosphere either in solid or liquid form) and the soil moisture storage capacity which depends upon the clay content and depth of the soil. The other important factor is the thermal regime. The growth and development of the crops is generally believed to take place when the mean daily temperatures are above 5°C. In tropical regions, the mean daily temperatures are much higher than 5°C throughout the year and therefore crops can be grown round the year, if water is available. In high altitude locations and in the interior regions beyond tropics, the mean daily temperatures will be less than 5°C during the winter season and therefore arable crop production is restricted to warm weather season only.

Therefore, the agricultural climates all over the world are classified based on the two parameters i.e., the moisture regime and thermal regime.

Crop growth and development:

The distinction between crop growth and development can be recognized by the fact that growth represents the increase in weight and volume of the total plant or various plant organs while development represents the consecutive phenological stages through which it passes. The two processes, growth and development are inter related. The factors influencing crop production can be divided into three major groups:

(i) Yield defining factors like radiation.
(ii) Yield limiting factors like water availability and nutrients.
(iii) Yield reducing factors like weeds, pests and diseases.

Phases of crop growth:

Generally, the crops can be considered to pass through important phases which can be distinguished from each other clearly under ideal conditions.

(i) During the first phase, the crop consists of individual plants which do not shade each other and the growth rate increases. A major part of the assimilates is invested in leaf growth and the increase in leaf area is proportional to the solar radiation intercepted. The plant weight increases at constant rate when water is not a limitation.

(ii) During the second phase, crop covers the soil completely and growth rate is constant if there is no limitation of water. A major part of the dry matter accumulation during the phase depends upon the growth rate and duration of the phase.

(iii) The crop is maturing and the growth rate is decreasing

The major environmental factors influencing phenological development are temperature and day length. The crops have a threshold temperature below which no growth takes place. By summing the daily temperatures above certain the threshold value (base temperature) during a particular phase, the number of thermal units (sometimes referred as degree days) required for completion of the phase can be obtained. The fraction of thermal units made available to the crop compared to the thermal units required for a particular phase will provide a numerical value of the development stage.

Starting from the date of sowing, the first phase covers germination of seeds, emergence of seedlings and vegetative phase. The second phase covers fifty per cent flowering, grain formation and grain filling stages. The third phase covers physiological and harvest maturity stages.

Potential Evapotranspiration:

Evaporation of water takes place from the soil as ‘soil evaporation’ and the leaves of the plants as ‘transpiration’. The combined loss of water due to evaporation from soil and transpiration from the crop is called ‘Evapotranspiration’. The water loss due to evapotranspiration depends upon the ‘water availability’ to the plants through soil moisture storage, rainfall and or irrigation. Therefore Penman (1948) introduced the concept of ‘potential evapotranspiration’ (PET) which is defined as the maximum amount of water that can be lost through evapotranspiration from short grass covering the entire soil when water is not a limiting factor. He developed a mathematical expression which is popularly known as Penman’s method for computing the potential evapotranspiration using weather data such as temperature, wind speed, vapour pressure deficit, radiation etc. At many of the places, the data required for estimating the potential evapotranspiration may not be available. Therefore, Thornthwaite (1948) also developed a formula to calculate the potential evapotranspiration using temperature data. Later Monteith improved the Penman’s equation for more reliable estimation of PET which is now widely used as Penman-Monteith’s equation.

Crop water requirement (ET_0):

The actual amount of water required by the crop for evapotranspiration is called water requirement of the crop. The water requirement of the crop depends upon what is known as Leaf Area Index (LAI) i.e., the leaf area of the crop per unit area of the soil.

The water requirement of the crop is equal to the potential evapotranspiration when the leaf area index is 3.0 and slightly increases with increase in leaf area index beyond 3.0.

When the crop canopy is not completely shading the ground, the crop intercepts only a part of the photosynthetically active radiation (the solar radiation that forms the visible light and it is approximately about 0.45 times the incoming solar radiation) depending upon the leaf area index and it is given by the formula

$$f_n = f_0(1 - e^{-k*LAI})$$

where f_n = Intercepted photosynthetically active solar radiation
f_0 = Incoming photosynthetically active radiation
k = Extinction coefficient for visible light which depends upon the geometry of the crop
LAI = Leaf area index

When the crop is not fully shading the ground, the crop uses only a part of the incoming radiation and therefore, the water requirement of the crop is lower than the potential evapotranspiration.

The crop water requirement can be estimated using the equation

$$ET_0 = K_c * PET$$

Where K_c = Crop coefficient which depends upon LAI
PET = Potential evapotranspiration

Actual Evapotranspiration (AET):

When there is no shortage of water to the crop, the actual evapotranspiration of the crop is same as the water requirement of the crop. Otherwise the actual evapotranspiration is equal to the amount of water available in the soil as soil moisture storage.

Total Dry matter production:

The total dry biomass produced by the crop during its life cycle is known as total dry matter production (DMP). The total dry matter production from a well managed crop without being affected by biotic interferences like weeds, pests and diseases and not subjected to weather hazards like floods, high temperatures, cold waves etc is directly proportional to the water used by the crop. It is also directly proportional to the total photosynthetically active radiation (PAR) intercepted by the crop during its life cycle.

DMP α Total water used by the crop for evapotranspiration during its growth cycle.

DMP α Total PAR intercepted by the crop during its life cycle.

Economic yield:

Crops are not grown for just total biomass production. The crops are therefore grown for their storage organs like tubers, pods or grains. These storage organs grow only during the later part of the growth cycle after roots, leaves and stems have been produced. The grain yield can be estimated from the total dry matter production using the relationship

Grain yield = Total dry matter production x Harvest Index

Therefore, harvest index is the ratio of grain yield to the total dry matter production and generally ranges from 0.3 to 0.4 depending upon the nature of the crop.

Climatic classification:

As the agricultural production potential of a region is mostly governed by two factors namely precipitation (P) and potential evapotranspiration (PET), the climates are generally classified using the concept of moisture index (MI) which is given by the formula

$$\mathrm{MI} = \left(\frac{\mathrm{P-PET}}{\mathrm{PET}}\right) \times 100$$

Value of MI	Climate type
< -66.6	Arid
-33.3 to -66.6	Semi-arid
-66.6 to 99.9	Sub-humid
≥ 1.0	Humid

UNESCO also suggested a method of climatic classification based on the ratio of precipitation to potential evapotranspiration, which is as follows:

P/PET	Climate
< 0.20	Arid
0.2 to 0.50	Semi-arid
0.5 to 0.99	Sub-humid
≥ 1.00	Humid

In tropical countries, where temperature is not a limitation for growing crops / vegetation round the year, the UNESCO classification suggests the relationship between the climate and water availability period as follows, with the assumption that water received through precipitation is not lost through run-off and deep drainage.

Climate	Water availability period in days
Arid	< 73 days
Semi-arid	74 to 182 days
Sub-humid	183 to 364 days
Humid	365 days

Therefore, the cropping patterns under rainfed conditions in tropical regions can be related to the climatic type as follows:

Climatic region	Cropping pattern under rainfed conditions
Arid	Grasses, shrubs, short duration pulse crops and pearl millet
Semi-arid	Short, medium and long duration crops, Inter cropping systems if the soils are deep with high water holding capacity
Sub-humid	Rainfed rice based cropping systems, horticultural crops
Humid	Rice based cropping systems, plantation crops

Therefore, climate of the region plays a major role in the choice of crops and cropping systems under rainfed conditions in tropical regions depending upon the nature of the soil.

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Monsoon: concept and its features

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Introduction

In an agricultural country like India, the success or failure of the crops and water scarcity in any year is always viewed with the greatest concern. A major portion of annual rainfall over India is received during the southwest monsoon season (June–September). Regional rainfall has large year-to-year fluctuations. Monsoon affects the livelihood of millions of people in Africa and Asia. Agriculture, irrigation and power generation is closely linked with the monsoon rains in this part of the world. A study of monsoon is therefore important for research scientists as well as operational forecasters. The term 'monsoon' is derived from an Arabic word 'mausim', which means season. The word monsoon is applied to such a circulation, which reverses its direction every six months, i.e., from summer to winter and vice-versa.

Monsoon is a large-scale seasonal wind system, blowing over vast areas of the globe, persistently in the same direction, only to be reversed with change of season. They affect the largest land masses. Asia is the only continent in the world having regular visits of monsoons of completely reversing and persistent wind regimes. Australia and Africa are also affected by monsoons, though not to the same extent as Southeast Asia. North America also shows monsoonal tendencies. But here monsoon wind is neither persistent, or the seasonal wind shifts are so consistent.

Following the Great Indian Drought of 1877, H.F. Blanford, who had established the India Meteorological Department in 1875, issued the first seasonal forecast of Indian monsoon rainfall in 1884. Later, in the early part of the 20th century, Sir Gilbert Walker initiated extensive studies of global teleconnections which led him to the discovery of Southern Oscillation. Walker introduced, for the first time, the concept of correlation for long-range forecasting of the Asian summer monsoon and his findings are relevant even today.

Walker and Hadley Cells

The principal monsoon of the world are the summer and winter monsoon of Asia and the monsoonal circulations over west and east Africa. These monsoons appear to be dominated by circulation that are either aligned in a north-south or an east-west direction. The rising branch of each circulation is located near a source of heat while the descending limb occurs over a heat sink. These cells are named Hadley and Walker cells.

Principal Rain bearing systems

Some of the important rain bearing systems are: (i) monsoon lows/depressions in the Bay of Bengal; (ii) fluctuations in the intensity of location of a monsoon trough over the plains of India and Pakistan; (iii) mid tropospheric low pressure systems over the Gujarat coast; (iv) off-shore vortices, and (v) low-level equatorial jet stream along the eastern coast of Africa.

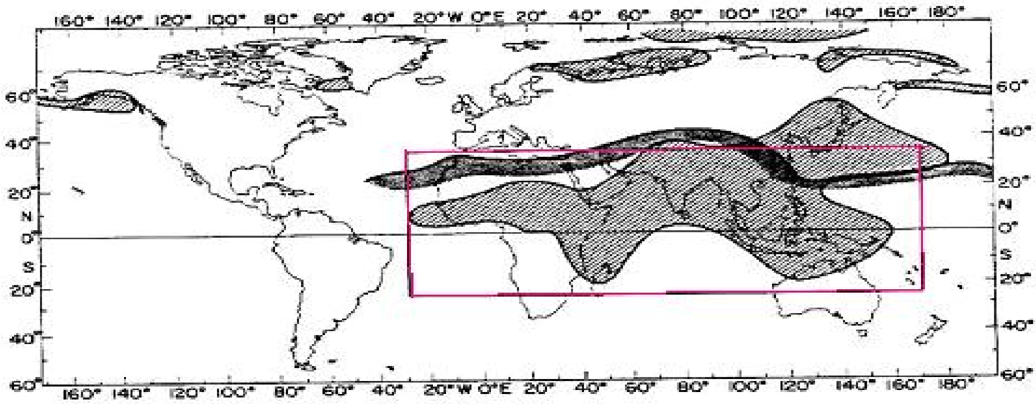

Fig.1: Map showing the areas affected by monsoon (Ramage, C.S., 1971). Hatched area is Monsoonal and the rectangle broadly indicates the extent of the monsoon regime

Ramage (1971) prescribed the boundaries of the monsoons to an area enclosed between 35°N and 25°S and between 30°W and 173°E (Fig.1). The phenomena of monsoon is explained by different theories, such as (a) differential heating of land and water (b) seasonal shifting of the tropical and inter-tropical wind belts, (c) upper atmospheric wind movements and jet streams and (d) most recently linked to El Nino and La Nina effects

Regional aspects of monsoon:

Regional features of monsoon occur on a smaller scale but more often coupled with the planetary scale flow patterns. Broadly the world over, following four regional components of summer and winter monsoon have been identified:

Monsoon Areas

1) Summer monsoon over Indian sub-continent, east and south-east Asia
2) West African monsoon
3) Winter monsoon over east and Southeast Asia
4) Australian summer monsoon.

Indian monsoons:

Features of Indian monsoons are:

a) Tropical location of Indian sub-continent, b) Himalayas- the mountain barrier to the north of the land mass, cold and dry air mass c) monsoon is controlled by high and low centres developed over north-western region of the Indian sub-continent, d) high temperatures (about 40-45° C) creates pressure gradient over India, e) extreme low pressure points (up to 700 mb) that develop in the NW region, actively attract the prevailing wind from the Indian Ocean, f) Continental Tropical Convergence Zone (CTCZ) shifts to the northern plains (30°N), g) series of atmospheric depressions, j) retreating monsoon (also called north-east monsoon) starts from northern regions by first week of October, k) north-east monsoon is also accompanied by cyclones causing large scale damage to life and property along the eastern coast of India.

South-west monsoon:

Indian agriculture is a gamble in the hands of monsoon. Southwest monsoon prevails from June to September over India; it gives 70% of Indian annual rainfall. The regions receiving the largest amounts of rainfall are along the west coast of India and the states of Assam and West Bengal in north-east India. The summer (south-west) monsoon approaches India from south-westerly direction. The normal date of arrival of the monsoon over Ceylon and the islands in the Bay of Bengal is towards the last week of May. There after, it reaches the extreme south of the Indian peninsula about a week later (June 1).

The onset of southwest monsoon over Kerala signals the arrival of monsoon over the Indian subcontinent and represents beginning of rainy season over the region. From 2005 onwards India Meteorological Department (IMD) has been issuing operational forecasts for the monsoon onset over Kerala using an indigenously developed statistical model with a model error of ± 4 days.

Advance of monsoon over Andaman Sea

The normal date of advance of monsoon over Andaman Sea is 20th May. It is expected that monsoon flow will start appearing over Andaman Sea by the following week and is likely to cover the Andaman Sea around to its normal date. Past data suggest absence of any one-to-one association between the date of monsoon advance over Andaman Sea and the date of monsoon onset over Kerala (Fig.2).

Northern Limit of Monsoon (NLM)

Southwest monsoon normally sets in over Kerala around 1st June. It advances northwards, usually in surges, and covers the entire country around 15th July. The NLM is the northern most limit of monsoon up to which it has advanced on any given day.

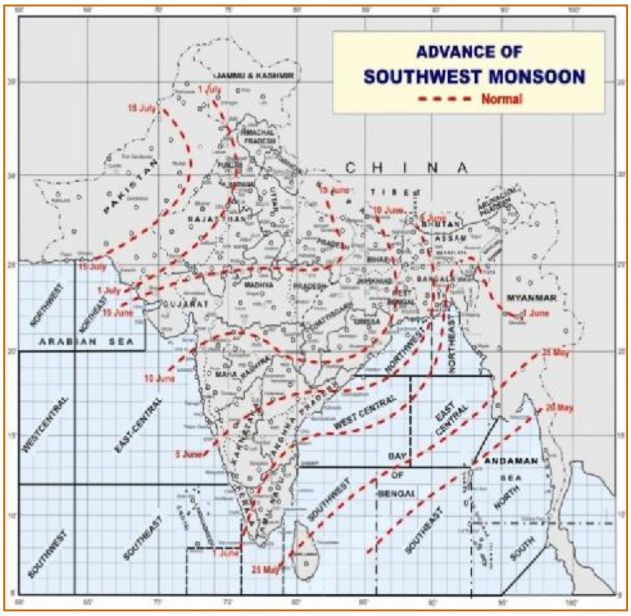

Fig.2. Normal onset date of monsoon over India

On set of the Monsoon

As the sun moves northwards across the equator in the northern hemisphere, the continents surrounding the Arabian Sea begin to receive large amounts of heat; not only in the form of radiation from the sun but also as heat emitted from the earth's surface. As a consequence of this larger input of heat, a trough of low pressure forms over this region. It extends from Somalia northwards across Arabia into Pakistan and northwest India. Towards the end of May, the heat low is well established and a southwesterly wind spreads northwards over the Arabian sea, the bay of Bengal and the Indian sub-continent. The onset of southwesterly winds over the west coast of India is often sudden, it is referred to as the burst of the monsoon over India (Fig.2).

SOUTH-WEST MONSOON ONSET OVER KERALA

The criteria declaring the onset of monsoon over Kerala are:

RAINFALL : If after 10th May, 60% of the available 14 stations enlisted, viz. Minicoy, Amini, Thiruvananthapuram, Punalur, Kollam, Allapuzha, Kottayam, Kochi, Thrissur, Kozhikode, Thalassery, Kannur, Kasargode and Mangalore report rainfall of 2.5 mm or more for two consecutive days, the onset over Kerala be declared on the 2nd day, provided the following criteria are also in concurrence.

WIND FIELD : Depth of westerlies should be maintained upto 600 hPa, in the box equator to Lat. 10ºN and Long. 55 ºE to 80ºE. The zonal wind speed over the area bounded by Lat. 5-10ºN, Long. 70-80ºE should be of the order of 15 - 20 Kts. at 925 hPa. The source of data can be RSMC wind analysis/satellite derived winds.

OUTGOING LONGWAVE RADIATION (OLR): INSAT derived OLR value should be below 200 Wm^{-2} in the box confined by Lat. 5-10 ºN and Long. 70- 75 ºE.

Progress of monsoon

The subsequent progress of the monsoon may be conveniently traced in the form of two branches of the monsoon, namely, the Arabian Sea branch and the Bay of Bengal branch. We first consider the Arabian Sea branch, which gradually advances towards north to Bombay by June 10. The advance from Trivandrum to Bombay is achieved in about ten days, and is fairly rapid.

In the meantime, the progress of the Bay of Bengal branch is no less spectacular. It moves towards north to the central Bay of Bengal and rapidly spreads over most of Assam by the first week of June. On reaching the southern periphery of the Himalayan barrier, the Bay branch of the monsoon is deflected westwards. As a consequence, its further progress is towards the Gangetic plains of India rather than towards Burma. The arrival of the monsoon at Calcutta is slightly earlier than at Bombay. The normal date of arrival at Calcutta is June 7, while the Arabian Sea branch of the monsoon normally reaches Bombay by June 10.

By mid-June the Arabian branch spreads over Saurashtra-Kutch and the Central parts of the country. Thereafter, the deflected currents from the Bay of Bengal and the Arabian Sea branch of the monsoon tend to merge into a single current. The remaining parts of west UP, Haryana, Punjab and the eastern half of Rajasthan experience first monsoon showers by the first of July. The arrival of the monsoon showers at a place like Delhi often raises doubts, whether the first monsoon showers will arrive from the east as an extension of the Bay of Bengal branch or from south as an extension of Arabian Sea branch. By mid- July the monsoon extends into Kashmir and remaining parts of the country, but only as a feeble current because by this time it has shed most of its moisture. The normal duration of summer monsoon varies from two to four months over various regions. It begins to withdraw from Punjab and Rajasthan by the middle of September. The withdrawal of the monsoon is a far more gradual process than its onset. In general terms, the monsoon usually withdraws from north-west India by the beginning of October and from the remaining parts of the country by the end of November.

Early or late onset of monsoon does not provide any clue as to its total behaviour in terms of its rainfall. It also does not give any indication whether the monsoon will progress normally. But it is usually observed that the progress of monsoon is arrested after its initial northward movement by about 500 km. For further progress a fresh surge is necessary, which is created by low pressure developed northwards along the coast carrying with it the monsoon current. The sea level trough hardly extends about 100km westward. High intensity rainfall occurs even in the sector ahead of depressions and cyclonic storms. The extent of area over which rainfall occurs may be of the order of about 800-1000 km around the storm centre. As the system dissipates, the extent of rainfall increases but with much reduced intensity. The monsoon depressions, even while they are on land, derive necessary moisture either from Bay of Bengal or the Arabian Sea or both, depending on their location.

Break monsoon

The summer monsoon is associated with short period rainfall fluctuations. The hundred-day monsoon over India from 1 June to mid September is characterized by heavy rain followed by lean periods. A period of lean rainfall is known as a "break monsoon", where rain fall shifts towards the Himalayan Mountain region.

Monsoon Trough

This is a semi-permanent feature of the monsoon. Monsoon trough over India at surface (1000 h Pa) runs from Ganganagar to Calcutta, roughly parallel to the southern periphery of the Himalayan mountains. Vertically this trough extends up to about 6 kilometres. At about 4 km, it runs from Bombay to Sambalpur. It's position is by no means unique nor stationary. It shows north-south migrations both at the surface and in depth.

Withdrawal of the Monsoon

The monsoon begins to withdraw from northern India around mid-September (Fig.3). By the end of October it has usually withdrawn from the region north of 15°N and from Bangla Desh and Mayanmar. Finally it withdraws form the extreme south of the Indian Peninsula and Sri Lanka by December. About the time of the monsoon withdrawal, the subtropical westerly jet stream again reappears over the northwestern end of the Himalayas. Thereafter, it moves southwards to its usual location south of the Himalayas by the end of October. The easterly jet which has a feature of the onset disappears rapidly after the recession of the monsoon by early October. This system is associated with movement of sub-tropical anticyclone.

Some features of Withdrawal SW Monsoon

a) Withdrawal from extreme north-western parts of the country is not attained before 1st September.
b) After 1st September: The following major synoptic features are considered for the first withdrawal from the western parts of NW India.
    i) Cessation of rainfall activity over the area for continuous 5 days.
    ii) Establishment of anticyclone in the lower troposphere (850 hPa and below)
    iii) Considerable reduction in moisture content as inferred from satellite water vapour imageries and tephigrams.

Further Withdrawal from the Country

- Further withdrawal from the country is declared, keeping the spatial continuity, reduction in moisture as seen in the water vapour imageries and prevalence of dry weather for continuously 5 days.
- SW monsoon lastly withdraws from the southern peninsula and hence from the entire country only after 1st October, when the circulation pattern indicates a change over from the south-westerly wind regime.

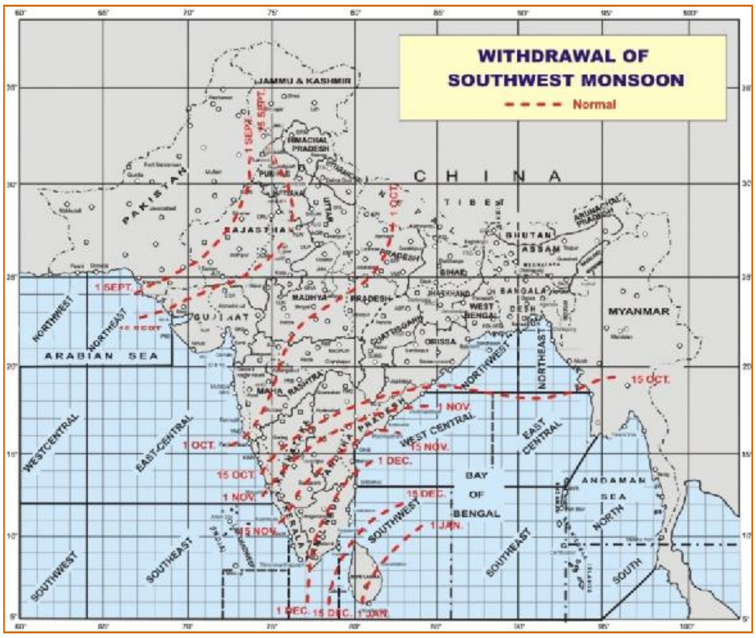

Fig.3. Normal withdrawal date of monsoon over India

North-east monsoon or winter monsoon:

The south-west monsoon period is the principal rainy season over most of India. But over Tamilnadu in peninsular India, the principal rainy season is from late October to December. This is known as north-east monsoon. The spectacular change that takes place between the two monsoons is the change of the wind direction from south-west to north-east over the Bay of Bengal, the Indian peninsula and Arabian Sea. An interesting question that often raised is concerned with the possibility of the south-west and the north-east monsoon co-existing over the extreme south of the Indian peninsula. It may be recalled in this context that the winter monsoon sets in over the southern half of the peninsula in October. Although it may seem theoretically possible for both monsoon systems to affect peninsular India, in reality, such situations are comparatively rare. The south-west monsoon is for all practical purposes in the last stages of its withdrawal toward the end of October. The onset of north-east monsoon is a gradual process. It is often difficult to specify its period of arrival over Tamilnadu, which is the main beneficiary of its rainfall. In fact, on many occasions there is no clear distinction between the withdrawal of summer monsoon over peninsular India and the onset of winter monsoon. North-east monsoon season is also the season of cyclonic storms in the Bay of Bengal. Though they are destructive in nature, they give copious rainfall over the areas in their path. In this respect, they may be considered as necessary evils. Rainfall in the southern states of Tamilnadu, Andhra Pradesh, Karnataka and Kerala during November and December is attributed by and large to the winter or north-east monsoon.

Monsoon Mission

In 2012, Earth System Sciences Organization (ESSO) of Ministry of Earth Sciences (MoES), Government of India, launched the "National Monsoon Mission" (NMM) with a vision to develop a state of the art dynamical prediction system for monsoon rainfall on all different time scales (ESSO, 2012).

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Measurement of solar radiation

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Radiation: The transfer of heat from a hot body to cold body without any material medium in between the two bodies is called radiation.

Solar radiation: The outer surface of the sun is estimated to be around 6000°K. Therefore sun emits radiation. The radiation emitted by the earth is electromagnetic radiation ranging in wave lengths from 10nm to 10,000nm. One nano meter is equal to one billionth part of a meter. The entire range of solar radiation from 10nm to 10,000nm wave length is called solar spectrum. The solar spectrum consists of four distinguished bands of radiation as follows.

10 nm to 399 nm	Ultraviolet radiation
400 nm to 700 nm	Visible radiation
700 nm to 4000 nm	Near Infra red radiation
4000 nm to 10,000 nm	Far infrared radiation

It is the visible radiation from wavelength of 400nm to 700 nm is used by the plants for photosynthesis and therefore it is also called as Photosynthetically Active Radiation (PAR).

Approximately 45 per cent of the energy is visible radiation, 4 to 5 per cent will be ultra violet radiation and remaining of it will be infra red radiation.

Usually bodies at higher temperature will emit more short wave radiation and bodies at lower temperature will emit more of long wave radiation.

Terrestrial Radiation:

The radiation emitted by the earth is called terrestrial radiation. The average temperature of the surface of the earth is 300°K.

Temperature in degrees K

= 273 + Temperature in degrees centigrade

As the earth's surface is at much lower temperature than the sun, the earth emits mostly long wave radiation.

Scattering of Radiation:

The ultra violet radiation coming from the sun will be absorbed by the ozone present in the stratosphere. When the radiation coming from the sun enters earth's atmosphere. The process of scattering occurs when small particles and gas molecules diffuse part of the incoming solar radiation without altering the wave length. The radiation in the blue color band is mostly diffused and scattered in the atmosphere and therefore the sky appears blue.

Absorption of radiation:

The water vapor and some of the gases like Carbon dioxide, methane etc present in the atmosphere will absorb some of the radiation coming from the sun.

Albedo: A certain part of the radiation coming from the sun is reflected back in to the earths atmosphere. The amount of radiation reflected back depends upon the color of the earths surface. Snow cover can reflect about 80 per cent of the radiation. It will be about 10 per cent in case of forests and 20 per cent in case of bare soil. The fraction of incoming solar radiation reflected back by the surface is called Albedo. The cloud tops also reflect some of the incoming radiation.

Heating of the ground:

The incoming solar radiation finally reaches the earths surface after scattering and absorption in the atmosphere and reflection at the earths surface. It gets absorbed at the earths surface and some of it gets transferred in to the lower layers of the soil surface.

Net radiation:

Net radiation is the difference between the incoming solar radiation and outgoing radiation(including albedo and terrestrial radiation). It is the amount of net radiation that will be used for evapotranspiration and photosynthesis of the crops.

Therefore we need to know the techniques of measuring

i. Incoming solar radiation
ii. Scattered radiation
iii. Terrestrial radiation
iv. Photosynthetically Active radiation
v. Albedo and
vi. Net radiation

Pyranometer measures diffuse and direct radiation. It consists of a horizontal black surface covered with a glass dome. The black surface absorbs the incoming radiation and the change in temperature of the black element is measured with a thermopile (a set of thermocouples). The radiation received is proportional to the current produced by the thermocouple. When the pyranometer is shielded, it measures the scattered radiation.

Pyrgeometers use silicon domes to transmit infra red radiation and have an internal thin film coating that blocks short wave solar radiation from reaching the thermopile detector. Pyrgeometer are used for measuring terrestrial radiation.

Par is measured using line quantum sensors integrated over its one metre length. It is also used to measure sunlight under plant canopy where light field is not uniform. The instrument makes it easy to measure under canopy light in many plots quickly and consistently.

The Albedo meter is composed of two pyranometers, the up facing one measures global solar radiation and the down facing one measuring reflected solar radiation. The Albedo is calculated by dividing the reflected radiation by the global radiation.

The net radiometer is based on a thermopile sensor whose warm joints are in thermal contact with the receiver while the upper cool joints are in thermal contact with lower receiver. The temperature difference between the two receivers is proportional to the net radiation. The radiometers are usually covered in the polythene domes. The net radiation has to be measured at a height of 1 metre above the crop surface.

The importance of monitoring weather parameters in crop insurance schemes

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Agricultural production in India is still vulnerable to vagaries of monsoon rainfall in spite of rapid technological advancements like 1) Availability of high yielding varieties 2) Improved crop management practices and increased irrigation availability and effective control of pests and diseases and etc, over last few decades. Majority of Indian farming community which broadly comprising of small and medium farmers are often subject to climate extremes such as droughts, floods, heavy rainfall events, heat and cold waves, frost, hail storms during the crop growing season. The probabilities of occurrence of such climate extremes and associated crop damages and production losses are common in tropical countries like India. Compensation to the resource crunched farmers in the form of crop insurance seems to be the best option for speedy recovery from the losses incurred during the season. It provides security and stability to farm income by protecting the farmers' investment in crop production and then improves their risk bearing capacities. Crop insurance scheme is based on the fundamental principle of insurance business in which risk is distributed across space and time.

For successful implementation of any crop insurance scheme operating presently in the country, proper monitoring of accurate weather parameters at the identified locations throughout the crop life cycle is important. Since these ongoing schemes requires recording weather data right at the locations, the existing weather network stations operated by the national agencies which are mostly located at the district head quarters are not adequate to cover the entire cropped areas, where crop is grown and insured. In order to avoid such difficulty, the government allowed few private entrepreneurs for monitoring and supply of daily weather data of high quality by strictly adopting the norms laid out by world Meteorological Organization (WMO) and India Meteorological Department(IMD).The process of monitoring ,collection and supply of weather data to the insurance companies on a regular basis involves the following.

1) Site selection for establishment of either manual or self recording Automatic Weather Stations (AWS)
2) Proper exposure of weather sensors to record true weather conditions
3) Collection of timely weather data, filling of missing weather data and quality checking for identification of faulty data and replace them with corrected values
4) Supply of processed weather data to the insurance companies that covers crop risks against extreme weather conditions.

Unless good quality weather data is supplied, the farmers shall be subjected to great financial loss in spite of being covered under these schemes. For example, the farmer is entitled to receive

50 percent of premium value of sum assured whenever a rainfall of above 10 mm is received during flowering stage. If the area covered under this scheme receives actually rainfall above 10mm and if the rain gauge does not show any rainfall due to its poor maintenance or wrong calibration etc, the farmers shall be recording very low crop yields due to flower drop that fetches meager amount from agricultural produce and simultaneously are also not compensated by the insurance companies. Therefore there is a great need for proper maintenance of weather stations and adaptation of strict quality control procedures as prescribed by National and International organization for effective implementation of crop insurance schemes.

Criteria for Site selection:

- Preferably it should be outside the town or village.
- The site should be preferably representative of climate, soil and agricultural condition of the area.
- No obstacles to be located in the vicinity of AWS from all directions
- Big trees, buildings should be avoided within a radius of at least twice the height of obstacle in the vicinity of AWS from all directions.
- Large water bodies should be avoided within 100m radius of the AWS
- It should be located over a single storied building with a terrace height of 10 to 15 feet and the terrace should be adequately covered with well watered flower pots to reduce the heat load of terrace on sensors.
- The site should have BSNL land line connection and also must have good signal strength of any mobile operator
- High voltage power lines should not cross over the AWS site and the cables should not be close to high power transmission lines
- Heavy vehicular traffic area should be avoided within a radius of 50 Mt
- The distance between host residence and the AWS site should be free from any obstacle for continuous monitoring.

Weather Data Quality Checking

Weather data consists of air temperature, rainfall, relative humidity, wind speed and direction, solar radiation, atmospheric pressure etc., collected at hourly intervals, gets downloaded either through GPRS modem, or FAX modem and goes through various stages of checking before it is certified. The procedure involved in checking the weather data by the Quality Control Team is as follows:

Identification of errors and gaps

- The first step after downloading the raw data is to check for any errors and data gaps in the downloaded data
- Errors can be of any extreme, abnormal and negative values of temperature, relative humidity, wind speed and rainfall

Gap filling and data correction

The primary purpose of quality control of observational data is to identify missing data, detection of errors and correction to ensure high accuracy for these data sets. After the Weather data is downloaded in to the server the data runs through '**Weather data manager'**- a broad featured quality control software with higher ranges of values as defined by IMD/WMO that allows to identify suspicious data sets such as extremes, abnormal and negative values of air temperature, RH, Rainfall, wind speed and drifting in-time settings .

Data Processing:

The identified abnormal values are corrected and filled by QC team firstly by comparative study of the associated weather parameters at the locations such as

i. dip in temperature after rainfall

ii. Increase in RH after rainfall

iii. Decrease in radiation before and during rainfall

iv. If the recorded values are well above /below climatic normals of the week/month , then treat it as suspect data

Missing data from the stations shall be filled by interpolating the values of the weather data recorded at the nearby location's AWS either maintained by NCML or other agencies such as IMD, State Governments using cluster based approach . Verification of any doubtful filled data values such as rainfall and temperature can be done by referring to satellite estimated values of rainfall and temperature available from different websites .

The following checks helps the QC team to validate and process the raw data further after passing through Weather Data Manager software:

a. **Rate of change of instantaneous data**: If the current hour value differs from previous value by more than the specified limit, then the current value should be flagged as doubtful. The limits are as follows"

S.No.	**Parameter**	**Limit for Suspect**	**Limit for Erroneous data**
1	Air Temperature	+ 3.0 °C	>3.0 °C
2	Relative Humidity	10%	15%
3	Atmospheric pressure	0.5hPa	2.0 hPa
4	Wind Speed	10mps	20mps
5	Solar Radiation	800 Wm^2	1000 Wm^2

b. **Minimum required variability of instantaneous values:**

If no change is observed in values over the last one hour, the value may be flagged as doubtful. It may then be subjected to further critical checks. The following are the limits prescribed for minimum required variability:

S.No.	**Parameter**	**Limit for Suspect**	**No Change Observation**
1	Air Temperature	0.1 ^{0}C	Over past 60 minutes
2	Relative Humidity	1%	Over past 60 minutes
3	Atmospheric pressure	0.1 hPa	Over past 60 minutes
4	Wind Speed	0.5 mps	Over past 60 minutes

c. **Internal Consistency Check:**

The internal consistencies of data are based on the relation between two parameters. The following conditions are fixed:

S.No.	**Condition 1**	**Condition2**	**Remarks**
1	Dew point temperature	< Air Temperature	
2	Wind Speed=0	Wind Direction =0	

3	Wind Gust	>Wind Speed	
4	Rainfall and Cloud Cover are suspect	Cloud Cover=0 and Rainfall value<Resolution of rain gauge	
5	Rainfall and Cloud Cover are suspect	Cloud cover=0 Precipitation>0	Possible due to snow pellet melt which can occur when cloud cover =0
6	Total sunshine hour and Solar radiation are suspect	Total Sunshine duration>0	Solar radiation=0
7	Rainfall and Duration of rainfall	Amount of precipitation>0	Precipitation duration=0

d. Monitor working conditions of sensors

QC team shall l check the data at validation screen to monitor the working conditions of the sensors. The details of the sensor problem are as follows.

Rain gauge problems:

- No recording of rain, when nearby stations reported rainfall
- Recording continuous rainfall values due to blockage by garbage collected in the rain gauge collector that obstructs free flow of water in to the tipping buckets. Only small flow of water passing through at the outlet of funnel results in continuous recording of rain though nearby stations records shorter durations. Immediately inform the maintenance team to clear the blockage. Tampering of rain gauges like pouring water or failure of tipping bucket mechanism
- Reporting of very high rainfall in shorter durations, reporting a four digit rainfall. Report to check cable connections

Temperature and humidity sensors:

- No recording of data only blanks are observed on the screen.
- Recording higher/ lower values than the nearby locations (differ by more than 3 degrees centigrade)

- No diurnal variations in temperature and humidity values
- Recording wrong values (not in acceptable range) such as continuous high negative values, min temperature is greater than max temperature; hi temp and low temp values are same continuously.
- Report first for cleaning the sensor and the problem still exist request for repair/replace ATHR sensor

Wind sensors:

- Recording very high/low values continuously, when nearby stations showing normal values
- No recording and reporting zero when nearby stations showing normal readings.
- Report for repair/replace of sensor

Date & time settings:

- Due to sudden changes in settings of date & time in the modem drift in time period is noticed in the data sets
- Report to data management team to set the modem to current date and time.

Low battery:

- Due to low battery or discharging of battery, data will not be recorded.
- Report to replace the battery

If any parameter values are erroneous or continuously reporting blanks/ zeros, then confirm that corresponding sensor is not working and send the remark to operational team to check/ replace the sensor immediately.

DATABASE MAINTENANCE

The raw data after thorough scrutiny and correction is updated in the data base as processed data. This data is compiled according to the client requirements and shall be dispatched as per the schedule and agreed formats

Crop Insurance schemes in India

Though the concept of crop insurance program was designed way back in 1920 in India, its effective implementation by the Government of India has started only after independence. A special study to frame out modalities of crop and cattle insurance in the country was initiated in 1947-48 by the Ministry of Food and Agriculture. The first aspect of the modalities of crop insurance was whether it should be on Individual Approach or Homogenous Area Approach. The study favoured homogenous area approach as this area would comprise of villages that are homogenous with respect to crop production and the annual variability of crop productivity would be similar. The homogenous areas to be treated as units and the individual farmers in those area units would pay the same rate of premium and receive the same benefits, irrespective of differential loss in individual yields. The Central Government introduced a Crop Insurance Bill in 1965 and circulated a model scheme of crop insurance on compulsory basis to constituent state governments for their views. Because of very high financial obligations none of the states accepted the scheme. On receiving the responses of state governments, the subject was again considered in detail by an Expert Committee headed by the Chairman, Agricultural Price Commission set up in July 1970 on the economic, administrative, financial and actuarial implications of the subject. Different experiments on crop insurance on a limited scale started in 1972-73.In order to protect the farmers from natural calamities and ensure to prepare for the next season with appropriate compensation/credit facility; the Government of India has implemented the following crop insurance schemes over the years.

The important current crop insurance schemes that are operating are as follows.

1) **National agriculture insurance scheme (NAIS):**

With the failure of comprehensive Insurance scheme in 1997 the GOI came up with a new scheme 'National agricultural insurance scheme', during 1999-2000.It was planned to cover all food crops (cereals and pulses), oil seeds, horticultural and commercial crops. This scheme was extended to all farmers, both loanees and non- loanees. Comprehensive risk insurance is provided to cover yield losses due to natural calamities which cannot be prevented. It operates on the basis of 1) area approach and on 2) individual basis. Area approach defines the area for each notified crop for wide spread calamities and where as individual basis covers for localized calamities such as hailstorms, landslides, cyclones and floods. The premium rates vary from 1.5% to 3.5% of sum assured for food crops. For horticulture and commercial crops, actual rates are charged .A subsidy of 50% the premium was given to small and marginal farmers. The subsidy on premium shall be equally shared by State and Central Governments and the subsidy has to be phased out over a five year period. The scheme was largely unsuccessful with low coverage and high claims to premium ratio. At present it is operating in a small cropped area covering about 15% of farmers.

2) **Weather based crop insurance (WBCIS):**

Crop yields are mostly dependent on weather conditions during the season in addition to soils, seeds, fertilizers etc. Therefore an innovative weather insurance scheme was introduced in 2003 as the index based rainfall scheme. From kharif 2007, Weather Based Crop Insurance scheme (WBCIS) has been implemented across India. The scheme operates on the principle of "area approach" in selected notified reference unit area. Weather triggers for different crop growth stages of important food and commercial crops for different agro climatic region have been identified from research findings of Agricultural Universities and of ICAR Research Institutes. Weather data is monitored throughout the growing period by deploying Automatic Weather Stations (AWS) in the notified unit area. Farmers are eligible to receive payouts of the sum assured for that crop stage whenever the weather parameters exceeds the trigger value fixed for that stage. The major limitation of this system is that whenever a farmer lost his entire crop during a particular stage, the compensation according to the farmers may not be the maximum sum assured, but it will be the sum assured of the weather insurance covers operative during the stage. Under this scheme, overall claims ratio of few insurance companies was nearly 77%. The major advantage of the system in that payoff to the farmers is quick and they need not wait till the crop harvest is completed. As of today, many states like Maharashtra, Rajasthan, parts of M.P, Jharkhand, N.E regions, Karnataka, etc. have been implementing this scheme.

Since, India meteorological department cannot deploy AWS in the notified areas; many private entrepreneurs have entered in to the weather market in way of providing quality data to the insurance companies. Even in the remote places and inhospitable terrains, AWS have been established and 24 hr data is being recorded and supplied to various stake holders.

3) PRADHAN MANTRI FASAL BHIMA YOJNA (PMFBY)

Each crop insurance scheme has its own limitations and the actual sufferers are not adequately and timely not compensated. Studies have indicated that only 23% of the farmers have been covered under these schemes .In view of the short comings of the exciting crop insurance scheme, Pradhan Mantra Fasal Bhima Yojna (PMFBY) which has been launched recently is expected to cover 50% of farmers in the next 5 years period and shall replace all the other crop insurance schemes which integrate all the benefits in one single yojna. The premium rates in the existing crop insurance schemes have increased by about 25% of the sum assured in recent years. The PMFBY has drastically reduced the premium amount to 2% for kharif crops and 1.5% for rabi crops. It shall be 5% for commercial or horticultural crops. Farmers shall derive maximum benefits by paying minimal premium. The scheme entails immediate payment of 25% of the due compensation and the money will go directly to the bank accounts of the farmers. It also provides compensation for loss of seed plants and post harvest damages. It shall also assess the damage due to local calamities like hail storm, unseasonal rains, landslides and inundation of crop fields., Latest technologies like utilization of smart phones, remote sensing and drones shall be used to estimate the crop losses even at a remote place without delay. This scheme will be effective from 2016 kharif season onward.

Agroclimatic indices and their application

Dr P. Vijaya Kumar
Principal Scientist (Ag. Met)

Introduction

Climate plays a fundamental role in agriculture. The quantity and quality of yields can be affected by water stress, heat stress or frost or by pests and diseases. An agroclimatic index is a measure or indicator of an aspect of the climate that has specific agricultural significance. Agroclimatic or agrometeorological indices have great potential to quantify and communicate the impacts of climate change on agriculture. They can be used to describe the effects of climatic conditions on key agricultural aspects, including production, protection, fertilization, site selection, irrigation, etc. Therefore, agroclimatic indices can be very helpful for farmers in their decisions about crop management options and related farm technologies.

Temperature–Phenology–Growing Degree-day Concept

1. Standard degree-day method:

$$GDD = \sum [(Tmax + Tmin)/2] - Tbase$$

where (Tmax + Tmin)/2 is the average daily temperature

Tbase is the minimum threshold temperature for a crop

2. Maximum instead of means method:

$$GDD = \sum (Tmax - Tbase)$$

3. Reduced ceiling method:

where $Tmax \leq T_{ceiling}$, then $GDD = \sum (Tmax - Tbase)$, or

where $Tmax > T_{ceiling}$, then $GDD = \sum [(T_{ceiling} - (Tmax - T_{ceiling})) - Tbase]$

If maximum temperature (Tmax) is greater than the ceiling temperature ($T_{ceiling}$), then set Tmax equal to $T_{ceiling}$ minus the difference between Tmax and $T_{ceiling}$

Standard Degree-Day Approach

- If Temperature < Tbase, Degree-day = 0
- If Temperature > Tbase, Degree-day = Tavg – Tbase
- If Temperature > Topt, Degree-day = Topt - Tbase
- Tbase = 8
- Topt = 30

Avg. Temp.	Degree Day
7	0
15	7
30	22
40	22

Growing Degree-Days

- Growing degree-days (GDD), also called heat units, effective heat units, or growth units
- Are a simple means of relating plant growth, development, and maturity to air temperature.
- The concept is widely accepted as a basis for building phenology and population dynamic models.
- Degree-day units are often used in agronomy, essentially to estimate or predict the lengths of the different phases of development in crop plants (Bonhomme, 2000).
- A degree-day, or a heat unit, is the departure from the mean daily temperature above the minimum threshold (base) temperature. This minimum threshold is the temperature below which no growth takes place.
- The threshold varies with different plants, and for the majority it ranges from 4.5 to 12.5°C, with higher values for tropical plants and lower values for temperate plants.

Uses of Growing Degree-Day Methods

- The use of degree-days for calculating the temperature-dependent development of insects, birds, and plants is widely accepted as a basis for building phenology and population dynamics models.
- The simplicity of the degree day method has made it widely popular in guiding agricultural operations and planning land use.
- Most applications of the growing degree-day concept are for the forecast of crop harvest dates, yield, and quality.
- A potential area of application lies in estimating the likelihood of the successful growth of a crop or crop variety in an area in which it has not been grown before.
- Another application of the concept can be to change or modify the microclimate in such a way as to produce nearly optimum conditions at each point in the developmental cycle of an organism.

Limitations of Growing Degree-Day Methods

- Though the degree-day concept is simple and useful, it lacks theoretical soundness and has a number of weaknesses.
- Except for the modified equations, a lot of weightage is given to high temperature.
- No differentiation can be made among the different combinations of the seasons
- The daily range of temperature is not taken into consideration, and this point is often more significant than the mean daily temperature.
- No allowance is made for threshold temperature changes with the advancing stage of crop development
- Net responses of plant growth and development are to the temperature of the plant parts themselves, and they may be quite different from temperatures measured in a Stevenson's screen.
- The effects of topography, altitude, and latitude on crop growth cannot be taken into account.
- Soil fertility may affect crop maturity. This cannot be explained in this concept.

Photo thermal units (PTU):

PTU = Degree day (°C) * Day length (hours)

Helio thermal units (HTU):

HTU = Degree day (°C) * Actual bright sunshine hours

Thermal Interception Rate (TIR):

TIR=PARI/n (Tm-Ta)

Where

PARI = Photosynthetically active radiation intercepted by the crop,

n = No. of plants/m^2,

Tm = Mean daily temp and

Ta = base temp

Photo-thermal Quotient (PTQ)

It is calculated daily during the crop growing period using the formula

- If T < 4.5, PTQ/day = 0;
- If 4.5 < T < 10, PTQ/day = Solar Radiation * [(T – 4.5) / 5.5] /5.5;
- If T > 10, PTQ/day = Solar Radiation / (T - 4.5)

Where T is the daily mean temperature [(max + min) / 2] and PTQ is expressed as $MJ/m^2/day/°C$

Temperature and humidity index

- HTR was calculated as the ratio of daily average relative humidity and daily average temperature
- SHTR was calculated as the ratio of daily afternoon relative humidity and MXT

Table Average HTR (over years) in wheat along with average disease severity index (DSI) at different locations

Weeks	**Ludhiana**	**Faizabad**	**Kanpur**	**Sabour**
Weeks 1-3	3.1	3.4	3.2	3.5
Weeks 4-6	4.2	4.3	4.2	4.7
Weeks 7-9	5.8	5.6	4.9	5.3
Weeks 10-12	6.7	5.5	4.9	4.7
Weeks 13-15	5.6	4.4	3.6	3.8
Weeks 16-18	4.8	3.4	2.4	3
Average	5.0	4.4	3.9	4.2
Average DSI	31.4	30	8.8	19

Climatic Indices

Aridity Index (I_a) = [Water Deficit (WD) / Water Need (PET)] * 100

Humidity Index (I_h) = [Water Surplus (WS) / Water Need (PET)] * 100

Moisture Index (I_m) = I_h - I_a = (P – PET) / PET

Agroclimatic indices

Moisture Availability Index (MAI):

MAI = PD/PET

MAI is defined as the ratio of 75% rainfall Probability amount (PD) and PET

Moisture Adequacy Index:

It is defined as the ratio of actual evapotranspiration and potential evapotranspiration

MAI = AET/PET

is widely used in CWM.

Methodology for calculating MAI

- The AET required for calculating MAI can be obtained as an output parameter from water balance calculations
- Mostly Thornthwaite and Mather (1955) weekly water balance model is used
- The inputs to the water balance models are rainfall, potential evapotranspiration and available water holding capacity of the major soil type
- The weekly AET for weeks 1 to 52 of a year were obtained as output from this model. Weekly MAI for weeks 1 to 52 were worked out as ratio of weekly AET and PET values.
- Weekly MAI values during the crop season were averaged over the total number of weeks of the crop season for working out the average MAI.

Drought classification based on moisture adequacy index (MAI)

Category	**MAI threshold**
No drought	MAI > 0.75
Mild drought	MAI < 0.75 and > 0.50
Moderate drought	MAI < 0.50 and > 0.25
Severe drought	MAI < 0.25

Classification of agricultural droughts based on MAI

- Agricultural droughts during different seasons (years) were classified into four groups based on the average MAI during the season
- Frequencies of occurrence of all these categories of agricultural droughts viz., mild, moderate and severe in a mandal over the years were added up for assessing drought frequency of a mandal.
- Frequencies of droughts in all the mandals of a district were averaged to get the drought frequency of a district.
- Districts having drought frequency less than or equal to 20% were classified as safe, more than 20 to less than or equal to 40% as moderate and more than 40% as severe.

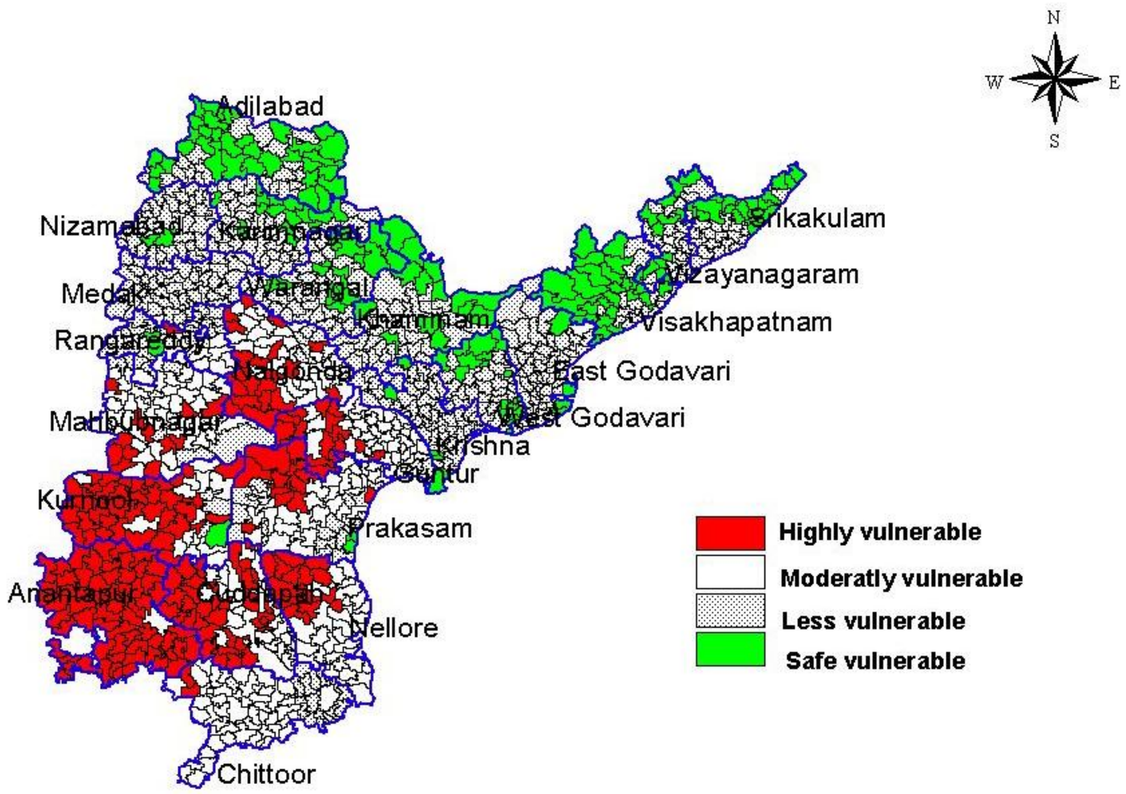
Drought Severity Index (DSI): Considering the agricultural drought frequency (number of years of different types of drought like mild, moderate and severe) and the severity based on MAI, an index called drought severity index has been devised (Eqn.). The formula for working out drought severity index (DSI) is as follows:

$$DSI = \frac{(0.0 * \text{No drought} + 0.25 * \text{Mild droughts} + 0.50 * \text{Moderate droughts} + 0.75 * \text{severe droughts})}{\text{Total number of years}} X100$$

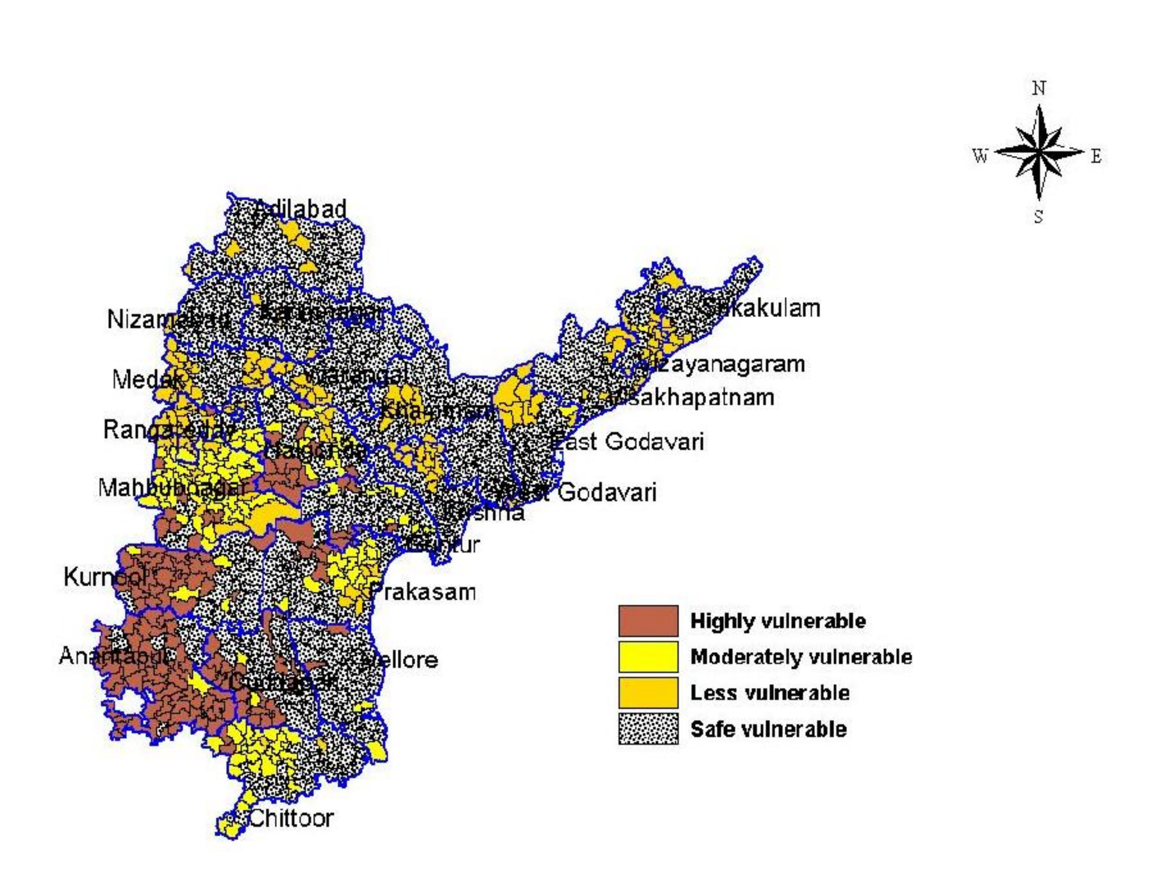
Drought classification based on DSI

Category	**DSI**
Safe (SF)	≤ (M - σ)
Less vulnerable (LV)	> (M - σ) and ≤ Mean
Moderately vulnerable (MV)	> Mean and < (M + σ)
Highly vulnerable (HV)	> (M + σ)

Categorization of mandals based on Drought Severity Index (without considering irrigated area)



Categorization of mandals based on Drought Severity Index (After considering irrigated area)



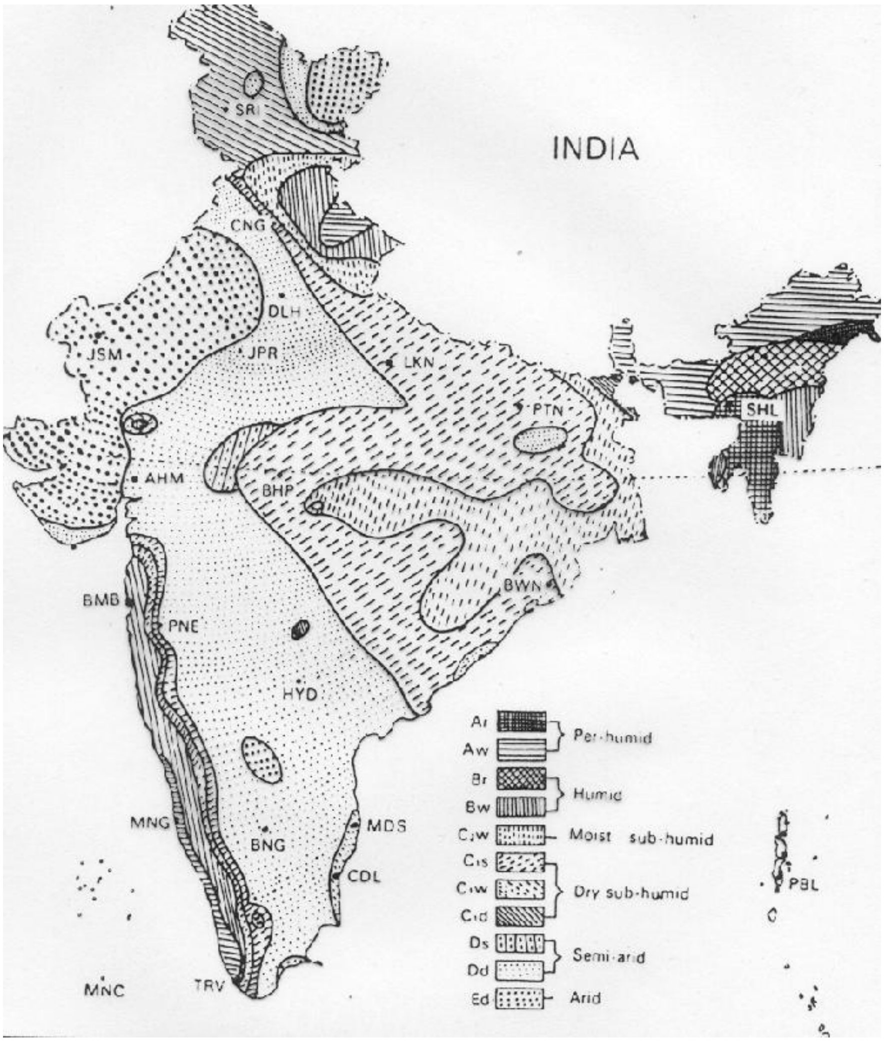
Classification of rainfed agro-ecosystem based on Moisture Availability Indices

Climate zone	Mean annual rainfall (mm)	Moisture index (%)
Extremely Arid	<300	<-80.0
Arid	300 - 500	-66.7 to -80.0
Semiarid (dry)	501 - 700	-50.6 to –66.6
Semiarid (moist)	701 - 1000	-33.3 to –50.5
Sub-humid (dry)	1001 - 1400	0.0 to –33.3

Agricultural planning can be done using agro-climatic information (moisture index)

Climatic Classification (Moisture Regime):

Source: Rao et al (1972)



Length of Growing Period - Criteria

Index of Moisture Adequacy (IMA) (AET/PET)	Type of water availability
0.00-0.24	Dry
0.25-0.49	Semi-dry
0.50-0.74	Sub-moist

0.75-0.99	Moist
1.00 and above	Humid

Water Requirement Satisfaction Index (WRSI) – developed by Frere and Popov, 1986-

- Meaningful indicator of how a shortage of rainfall may impact crop yields.
- Monitors water deficits throughout the growing season, and captures the impact of timing, amount and distribution of rainfall on staple annual rain-fed crops
- Basis of many drought early warning tools for the continent
- RFE data is used as the primary input into the WRSI model

WRSI for a season is based on the water supply and demand a crop experiences during a growing season

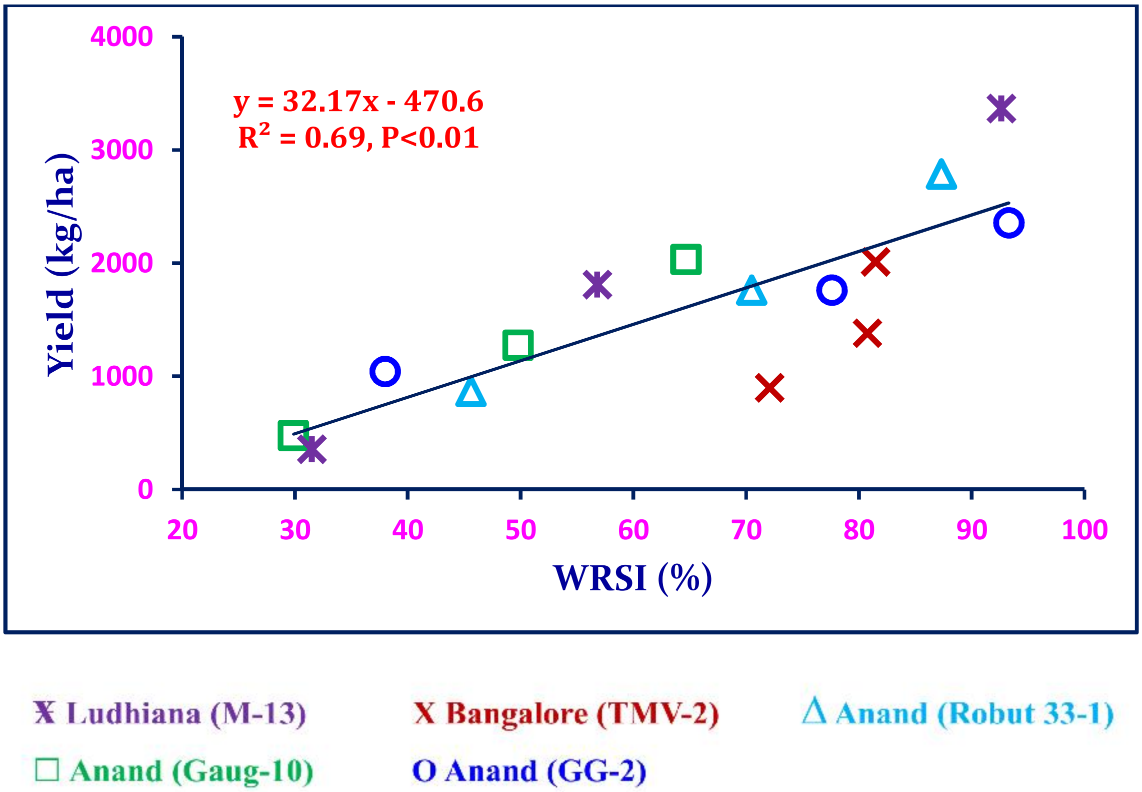
It is calculated as the ratio of seasonal actual evapotranspiration (AET) to the seasonal crop water requirement (WR)

$$WRSI = (AET/WR)*100$$

WR is calculated from the Penman-Monteith potential evapotranspiration (PET) using the crop coefficient (Kc) to adjust for the growth stage of the crop

$$WR = PET * KC$$

Relation between WRSI and yield of different cultivars at three centres



Aridity Anomaly Index (AI)

- This index is calculated on the basis of Thornthwaite's water balance.
- This is the ratio of water deficit (PET-AET) to water need (PET).
- The departure of the index from the normal expressed as percentage of the normal is called Aridity Anomaly index.

Weather indices used for WII in India

- Many indices have been tried for weather index insurance in India.

(i) ***Total seasonal rainfall index:***

- For this index, total rainfall is often expressed as a factor of normal rainfall or historical average rainfall.
- Rainfall indices based on total seasonal rainfall ignore the significance of rainfall distribution and focus solely on the total rainfall received during the crop season.
- A significant number of crop failures were due to the occurrences of long dry spells, and these may not be reflected in total rainfall.

- The approach of total rainfall also disregards the importance of rainfall in critical phenological stages.

(ii) Weighted rainfall index:

- A weighted rainfall index may be defined as
- Weighted rainfall index = $\sum_{t \in} w_t \, (r_t - \bar{r}_t)$
- Where W_t denotes the weights

r_t denotes realized rainfall

and $\bar{r}_t$ is the historical average rainfall

- Products based on such indices have been sold by ICICI Lombard in Kharif 2003 and AIC and IFFCO Tokyo in Kharif 2004 and 2005.
- Limitation of weighted rainfall index is that it provides scope for cross-subsidization across different rainfall periods.
- For example, higher rainfall in a period of low significance (weight) could compensate for poor rainfall in a period of high significance (weight)

(iii) Multiple phase weather index:

- For such an index the growing season is divided into sequential phases of varying duration, mostly chosen to correspond to the crop growth stages.
- For each phase, rate of payment is linear and payment is triggered if the total rainfall in the phase (r_p) is below the rainfall trigger (Trigger r_p).
- Multiple-phase rainfall indices do not fully capture the conditional impact of rainfall in different phases on yield.
- For example, a farmer will receive maximum claim payment if there is sufficiently low rainfall in all phases but complete crop loss in one phase is not sufficient to trigger a maximum claim payment even if it is sufficient to destroy an entire crop.

(iv) Consecutive Dry Days (CDD) Index:

- Another approach to capture adverse rainfall events is to construct an index equal to the maximum consecutive number of dry days within a specified period, when a dry day is defined as a day with rainfall below a threshold value.

- CDD index = maximum number of consecutive days with r (Actual) < r (Threshold)

(v) Excess / untimely Rainfall Index:

- Lot of damage to crops is caused due to heavy and continuous rainfall within a short period during maturity and harvest phases.
- The indices that have been designed to capture wet spells are dependent on consecutive rainy days or aggregate rainfall over a period of two to four consecutive days or a linear function of rainfall in each phase.

(vi) Low temperature or frost indices:

- Indices designed to offer some protection against adversely low temperatures are defined as a function of minimum temperature in the cover period.

(vii) High temperature indices:

- Indian Agricultural Research Institute (IARI) and AIC designed phase-based high temperature index for wheat crop in Rajasthan for the *Rabi* 2007 season, when the claim payment to farmers in respect of each phase was a function of the mean temperature for that phase.
- In 2010, ICICI Lombard sold product for wheat crop, for which claim payments depended on excess daily temperature rather than on excess average phase-wise temperatures.

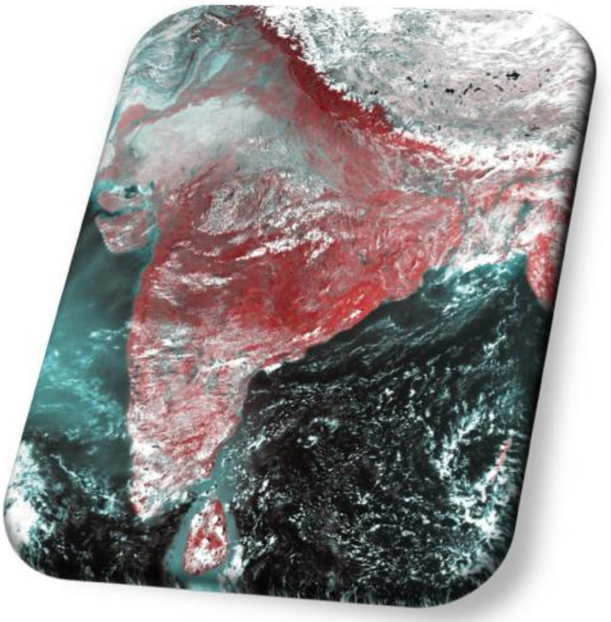
Development of weather indices at CRIDA

- CRIDA entered into an MoU with AIC for developing weather indices initially for three crops – Wheat, Groundnut and Cotton
- Weather indices are being developed by analyzing long-term (15-20 years) detailed crop and weather data generated at 25 cooperating centres of AICRPAM

Satellite-based Indicators

Different types of vegetation indices used to monitor the health and condition of the crops/ vegetation

- Difference Vegetation Index
- Ratio Vegetation Index
- Infrared Percent Vegetation Index
- Perpendicular Vegetation Index
- Soil Adjusted Vegetation Index
- Weighted Difference Vegetation Index
- Greenness Vegetation Index
- Atmospherically Resistant Vegetation Index
- Normalized Difference Vegetation Index
- Normalized Difference Wetness Index
- Enhanced Vegetation Index



Conclusion

Agroclimatic indices can be very helpful for farmers in their decisions about crop management options and related farm technologies. However, each index only represents a specific aspect of the climate that may or may not be relevant for the growth of a certain crop type. To guide land managers and planners, different indices have to be aggregated in a comprehensible manner. Thereby, possible interactions between different climate indices need to be taken into account. For example, a certain number of growing degree days may only be suitable for the growth of a specific crop if the precipitation sum is also within a suitable range.

Crop -Weather Relationships

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Agrometeorology demonstrates its strengths in identifying the variability or change in climate of any region or location by analyzing and characterizing the trends of different weather parameters. The trends prompts to look into the variability in the crop yields and the relation between weather and climate. This leads to classification of crop growing environments, development of crop and pest weather calendars. These are the tools for developing weather based agro advisories and contingencies when there are aberrations in normal weather.

Importance of weather

Weather plays an important role in agricultural production. It has a profound influence on crop growth, development and yields; on the incidence of pests and diseases; on water needs; and on fertilizer requirements. This is due to differences in nutrient mobilization as a result of water stresses, as well as the timeliness and effectiveness of preventive measures and cultural operations with crops. Weather aberrations may cause physical damage to crops and soil erosion. The quality of crop produce during movement from field to storage and transport to market depends on weather. Bad weather may affect the quality of produce during transport, and the viability and vigour of seeds and planting material during storage.

Though weather or climate is the least manageable natural resource, understanding of its interaction with agricultural parameters was found to be a powerful tool to develop weather based management strategies in agriculture that will enhance benefits from positive interactions and minimize the losses from negative interactions (Virmani, 1994).

The principal weather parameters which affect crop growth and yield are: Precipitation (amount and distribution), air temperature (Maximum and Minimum), moisture content of the air (Relative humidity, SVPD), solar radiation or sunshine hours and wind speed.

Changes in concept of crop-weather relationship studies

Over the years, lot of changes in the concepts of crop-weather relationships have been evolved. The crop-weather relationship studies in earlier years were based on statistical techniques like correlation, simple and multiple regression, step-wise regression, etc. It was believed by Agrometeorologists working on dryland agriculture that rainfall is main factor for variation in yields of dryland crops. Crop yields were related with rainfall during different stages of the crop growth to identify the critical stages of the crop. Experience and logic prompted them to look for some more parameters other than rainfall for accurate prediction of crop yields. Though total amount of seasonal rainfall showed some amount of relation with final yield, it was not representing the actual water available for plant growth as it does not account the losses through drainage, runoff and also the influence of the water holding capacity of the soil. The proposition of potential Evapotranspiration concept simultaneously by Penman (1948) and Thornthwaite (1948) and the introduction of water budgeting by Thornthwaite (1948) and the modification of the same by Thornthwaite and Mather (1955) brought in an appropriate independent variable, i.e., water use or Evapotranspiration for prediction of crop yields. Later, de Wit (1958) developed an equation to relate dry matter yield (Y) to transpiration as:

$$Y = m\ T/E_o$$

Where T is transpiration in cm, E_o is average free water evaporation rate (cm/day) and m is a crop factor.

The ratio of actual evapotranspiration to potential Evapotranspiration (AE/PE) known as Index of Moisture Adequacy (IMA) has found its use, later, in crop-weather relationship studies. The non-accountancy of crop factor in water balance models was corrected by introduction of models by researchers like Frere and Popov (1979), Ritchie (1972), etc. The simple (FAO) water balance model developed by Frere and Popov (1979) introduced an index called Water Requirement Satisfaction Index (WRSI) for predicting crop yields.

Although water supply plays a dominant role in agriculture, other climatic factors also influence the performance of crops and to understand the effect of more weather parameters, multi-variate crop-weather relationships were developed.

All these statistical models developed with data from a given place though have higher predictability, suffer from location-specific bias. To overcome the site-specific problem, concerted scientific effort for development of dynamic crop simulation models which are generic in nature and are applicable universally was initiated across the globe.

Effects of different weather parameters

Solar radiation:

Crop production is in fact exploitation of solar energy. Solar energy (solar radiation) is the driving force and only source of energy for photosynthesis (Monteith 1973).It is one of the main factors influencing biomass, yield and its quality. When water and nutrients, diseases and insects are not limiting factors, crop growth is determined by the amount of solar radiation intercepted and carbon dioxide assimilated. Three aspects of solar radiation are important for plant processes: Intensity, duration (i.e., photoperiod or day length), and quality. Low intensity of solar radiation during grain filling phase negatively influences grain yield of cereal crops.

Leaf is the principal photosynthetic functional unit, therefore its efficiency on the capture and use of solar energy determines the vegetable productivity. The area and arrangement of foliage (the canopy architecture), determine the interception of solar radiation (LI) by a crop and the distribution of irradiance among individual leaves. Leaf area and arrangement change during the life of a crop and, by leaf movement, even during the course of a single day. Maximum crop production requires complete capture of incident solar radiation and can only be achieved with supporting levels of water and nutrients (Loomis and Connor, 2002).

The length of the day or photoperiod determines flowering and has a profound effect on the content of soluble carbohydrates present. A majority of plants flower only when exposed to certain specific photoperiods. It is on the basis of this response that the plants have been classified as short day plants, long day plants and day neutral plants. When any other environmental factors is not limiting, the longer duration of photoperiod increases photosynthesis.

Radiation and water use efficiencies:

Radiation use efficiency (RUE**)** and water use efficiency (WUE) are of outstanding importance in crop simulation models. They can be used for simulation of crop yield using either of the following equations.

Yield = Radiation absorbed*RUE*HI (1)

Yield = Total water use*WUE*HI (2)

Where HI is the harvest index of a crop

The 1^{st} equation is used in water unlimited and light limited conditions and the 2^{nd} equation is used in water limited conditions.

Radiation Use Efficiency:

The concept of resource capture introduced for the first time by Monteith (1977) showed that the accumulated dry matter production of a wide range of crops and orchards in Britain was linearly related to accumulate intercepted solar radiation. The radiation use efficiency is the direct outcome of this concept because RUE is nothing but the slope of the linear relation between accumulated dry matter and cumulative radiation. The RUE defined as the quantity of biomass produced per unit of intercepted radiation (g MJ^{-1}), provides a measure of the "efficiency" with which the captured radiation is used to produce new plant material. In the absence of stress, RUE is often conservative, ranging between 1.0 and 1.5 g MJ^{-1} for C_3 species in temperature environments (Russell *et al*., 1988), 1.5 to 1.7 g MJ^{-1} for tropical C_3 species (Monteith, 1990) and up to 2.5 g MJ^{-1} for tropical C_4 cereals. RUE values of some important crops were given in Table 8. Though in the early studies, it was reported to be stable, subsequent studies of RUE showed large variability due to both physical factors (Vijaya Kumar *et al*., 1996) and biological factors (Wright *et al*., 1993).

Table 8. Radiation and water use efficiency of some crops

Crop	**RUE (g/MJ)**	**WUE(g/Kg)**
Maize	1.5	2.9-6.7
Sorghum	1.2	2.9-6.7
Groundnut	0.4	1.4-3.3
Soybean	0.75	1.4-3.3
Wheat	1.2	1.25-2.5
Castor	1.2	0.88-1.31
Chickpea	0.62	2.1-4.1
Pigeon pea	0.9-1.3	0.6-0.7

Water Use Efficiency:

Using the approach of Tanner and Sinclair (1983), a mechanistic expression relating biomass accumulated to the amount of Evapotranspiration, i.e., water use efficiency was derived. In other words, water use efficiency (WUE) is the amount of dry matter produced by a crop per unit of water transpired. Initially, WUE was considered to be conservative parameter (de Wit, 1958). Later, it was observed that, WUE of many species is inversely proportional to the mean value of saturation vapour deficit of the atmosphere in both water limited and energy limited conditions (Tanner and Sinclair, 1983). WUE of C_4 cereals were observed to be higher than C_3 species. WUE of crops grown during milder post-rainy season were higher than those grown during summer.

Temperature:

Temperature is an important factor not only to plants but also for all the biological species because of following factors: (a) Physical and chemical processes within the plants are governed by temperature. (b) The diffusion rate of gases and liquids in soil-plant-atmospheric system changes with temperature.

Temperature affects crops by causing (i) variations in duration of phenological events or crop development. (ii) variation in magnitude and time of occurrence of peak in biomass, (iii) significant increase / decrease in growth rates, (iv) variation in growth pattern deviating from sigmoidal curve and ultimately affecting grain yield or harvest index.

Crop development and weather:

Development refers to the timing of critical events in the life cycle of a plant. Duration of growth for a particular species or cultivar is usually almost directly proportional to temperature, over a wide range of temperature. Duration of particular stage of growth for a particular species could be predicted using the sum of mean daily air temperatures (Wang, 1960). Several synonymous terms have been used to describe the process of summation of temperatures to predict plant growth duration (Nuttonson, 1955). These include the terms degree-days (°C d), day-degrees, heat units, thermal units and growing degree days.

Growing degree-days (GDD):

Concept of GDD was discussed earlier in this chapter. Since 1730, when Reaumer introduced the concept of heat unit or degree-day, it has been used successfully in Agricultural Sciences.

In spite of some limitations, degree-day concept with some modifications is widely used for forecasting crop development and maturity. Degree days provide good approximation for insect growth also. An opposite effect to degree days is observed in some temperate fruit trees. They require certain amount of chilling days or hours below a certain temperature before they set to fruit.

Combined influence of temperature and photo-period

Though development of crops is mainly driven by temperature, some plant species respond to photo-period or day length. The photo thermal effects on phenology in many crops were reported. For all tropical and sub-tropical species, the warmest temperature combined with shortest photo period hastened flowering and fruit maturity (Keating *et al*, 1998). However, all temperate species both flowered and matured sooner at the warmest temperature combined with longest photo period.

Temperature thresholds

Every crop and crop variety has its threshold minimum, optimum and maximum temperature requirements known as cardinal points. They are:

Minimum temperature: It is the temperature below which no growth occurs. For typical cool season crops, it ranges between 0 and 5°C and for hot season crops; it is between 15 and 18°C,

Optimum temperature: It is the temperature at which maximum plant growth occurs. For cool season crops, it ranges between 25 and 31°C and for hot season crops between 31 and 37°C.

Maximum temperature: It is the temperature above which the plant growth stops. For cool season crops, it ranges between 31 and 37°C and for hot season crops; it ranges between 44 and 50°C.

Low temperature affects:

Low temperature affects several aspects of crop growth, *viz*., survival, cell division, photosynthesis, water transport, growth and finally yield.

High temperature affects:

High temperature adversely affects mineral nutrition, shoot growth and pollen development resulting in low yield. Adverse effects of high temperature during critical growth stages of some major crops were mentioned in Table 9.

Table 9. High temperature effects on key development stages of five major arable crops

Crop	**Effect**
Wheat	T > 30°C for > 8 hrs can reverse vernalisation
Rice	T > 35°C for > 1 hr at anthesis causes spike let sterility
Maize	T > 36 °C reduces pollen viability
Potato	T > 20°C reduces tuber initiation and bulking
Cotton	T> 40ºC for more than 6 hours causes bolls to abort

Source: Acock and Acock (1993)

Rainfall or water use:

Rainfall is an important parameter in agriculture. All plants need water to survive and rainfall is the main source providing water to plants. While normal rainfall is vital to healthy plants, too much or too little rainfall can be harmful to crops. Plants need varying amounts of rainfall to survive. Desert plants require small amounts of water while tropical plants need much higher rainfall. Water is an essential component in the process of photosynthesis. The movement of water out of the plant stomata, known as transpiration is an inevitable consequence of assimilation of carbon dioxide. As transpiration or water use and photosynthesis are inter related, a linear relation between crop yield and seasonal transpiration was established by Hanks (1974) as follows:

$$Y=m*(T/E_0)$$

Where Y=Yield, T=Seasonal transpiration and E_0 is average seasonal free water evaporation and m is a crop factor. This equation gave very good fit for several crops grown in different years in different locations.

During the growth of many plants there are periods during which they are especially susceptible to drought stress-for example the time of transition from the vegetative to the reproductive phase in cereals. The magnitude of the water deficit is important in addition to its timing and duration.

The effects on yield of a water shortage at different growth stages of a number of crops are reviewed in Doorenbos and Kassam (1979), where the response of yield to water supply was quantified through the yield response factor (K_y), which relates relative yield decrease to relative evapotranspiration deficit. Values of K_y for individual growth periods and for the total growth period for several crops are presented in Table 10.

Table 10. Yield response factor (K_y), the relative decrease in yield per relative deficit in evapotranspiration, for different crop growth periods (Doorenbos and Kassam 1979)

Crop	**Vegetative period**			**Flowering period**	**Yield formation**	**Ripening**	**Total growing period**
	Early	**Late**	**Total**				
Cotton			0.2	0.5		0.25	0.85
Groundnut			0.2	0.8	0.6	0.2	0.7
Maize			0.4	1.5	0.5	0.2	1.25
Pea	0.2			0.9	0.7	0.2	1.15
Potato	0.45	0.8			0.7	0.2	1.1
Safflower		0.3		0.55	0.6		0.8
Sorghum			0.2	0.55	0.45	0.2	0.9
Soybean			0.2	0.8	1.0		0.85
Sugarcane			0.75		0.5	0.1	1.2
Sunflower	0.25	0.5		1.0	0.8		0.95
Winter Wheat			0.2	0.6	0.5		1.0
Spring Wheat			0.2	0.65	0.55		1.15

Soil water and its role in agriculture:

The availability of moisture in the soil is a prerequisite for the survival and growth of plants. The capacity of soil for storing available water can be expressed conveniently in terms of maximum available soil moisture in the root zone. Soil acts as a store-house for moisture, where moisture accumulates upto a certain value, which is called field capacity during periods of excess precipitation. The water contained in the soil above field capacity is not available to crops due to quick drainage to lower layers. The water contained below permanent wilting point (WP) is also not available to crops as it is tightly held by the soil particles. Thus, it is generally considered that the amount of water held in the soil, between field capacity and permanent wilting point is water available for crop use. This is a widely accepted view and is followed by most of the workers for irrigation purposes. The rate of availability of moisture to crops within field capacity and permanent WP and its effect on crop growth is an important factor in determining crop growth. scientists made extensive field tests on perennial fruit crop and stated that water is equally available for plant growth at all levels, between field capacity and permanent WP. Their experiments show that favorable conditions of soil moisture extend from the field capacity to about the permanent WP. This view is still being accepted and adopted by agricultural scientists and in irrigation scheduling

Techniques to evaluate Crop-weather Relationship

The three commonly used approaches are: (i) Correlation techniques (ii) Crop weather analysis model (iii) Crop growth simulation models

Correlation analysis provides a measure of the degree of association between variables. Regression analysis describes the effect of one or more variables (independent variables) on a single variable (dependent variable).

Regression and correlation procedures can be classified according to the number of variables involved (a) Simple (If only 2 variables, one independent and another dependent) (b) Multiple (If more than 2 variables)

The procedure is termed linear, if underlying relationship is linear or non-linear, if otherwise

Regression equations are broadly of four types:

(i) Simple linear regression (ii) Multiple regression (iii) Simple non-linear regression (iv) Multiple non-linear regression

Simple and multiple regressions widely used for crop weather relationship studies can be written as

$$\mathbf{Y=a+b*X}$$

Y is the dependent variable, example-Yield

X is the independent variable, example-Rainfall, temperature etc

$$Y=a+b1*X1+b2*X2+\dots\dots+bk*Xk$$

k =Number of independent variables

R^2 is coefficient of determination

There must be enough observations to make n greater than (k+1)

Multi Collinearity:

Multi collinearity in regression equations occurs when predictor variables (independent variables) in the regression model are more highly correlated with other predictor variables than with the dependent variable. It commonly occurs when a large number of independent variables are incorporated in a regression model.

Searching for best regression:

There are 2 ways in which relationship between dependent variable and k independent variables be specified (i) Based on accepted biological concepts, secondary data, past experience etc. (ii) Based on the data collected

Four procedures commonly used for specification of appropriate relationship between X and Y are (a) Scatter Diagram (for simple regression) (b) Analysis of variance technique (not relevant for CWR studies) (c) Test of significance technique (for elimination of unnecessary variables) (d) Step-wise regression technique (for identifying the sequence of importance of each variable)

Standardizing variables:

The following standardization procedures help to reduce experimental error and biases (i) Yields from different varieties to be adjusted to a “standard” “base” variety (ii) Weather variables are to be measured within specific stages of plant development rather than within specified weeks or months (iii) Yields are to be culled to remove those reduced by disease, hail, pests and other factors (iv) Reduction in experimental error can be accomplished through use of simulated evapotranspiration amounts rather than precipitation, to measure effects of droughts

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Crop Water Requirements

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Introduction

Water is one of the most important natural resource for agriculture. It is becoming a scarce resource in India due to many reasons and causing concern over the ever-increasing population and food self-sufficiency. India is a country with various landforms ranging from lofty mountains to ravine, deltas and also including high altitude forest of Himalayas, sprawling grasslands of Indo-Gangetic plains, peninsular plateaus of South-East and South-West India and many other geological formations. The climate of India is full of extremities; for example, its temperature varies from arctic cold to equatorial hot and rainfall from extreme aridity with less than 100 mm in Thar Desert to per-humid with world's maximum rainfall of 11200 mm at Mowsinram in the state of Meghalaya. Due to presence of a wide range of geological and climatic conditions, Indian agriculture is diverse and complex with both irrigated and dry land areas, capable of producing most of the food and horticultural crops of the world. For the purpose of planning, better management of natural resources to curb environmental degradation and to give impetus to the agricultural productivity for food and nutritional security to its ever increasing population. India has an estimated 142 million hectare (Mha) cultivated area of which about 57 Mha is irrigated and remaining 85 Mha is rainfed. Each crop requires water at different stages of crop growth. Water requirement depends on the crop type, season existing soil moisture and other related factors. Crops like sugarcane grown in heavy soils require the more water, whereas crop like wheat and other grains require less amount of water and are grown in sandy loam soil. The crop like cotton, maize requires normal quantity of water.

Crop water requirement

The amount of water required to compensate the evapotranspiration loss from the cropped field is defined as crop water requirement. On the other hand, irrigation water requirement for crop production is the amount of water, in addition to rainfall, that must be applied to meet a crop's evapotranspiration needs without significant reduction in yield. Water requirement depend mainly on the nature and stage of growth of the crop and environmental conditions. Different crops have different water-use requirements under the same weather conditions. Hence the crop coefficients appropriate to the specific crops are used along with the values of reference evapo-transpiration (ETo) for computing the consumptive use called as crop evapotranspiration (ETc) at different growth stages of the crop by water-balance approach. Crops will transpire water at the maximum rate when soil water is at field capacity.

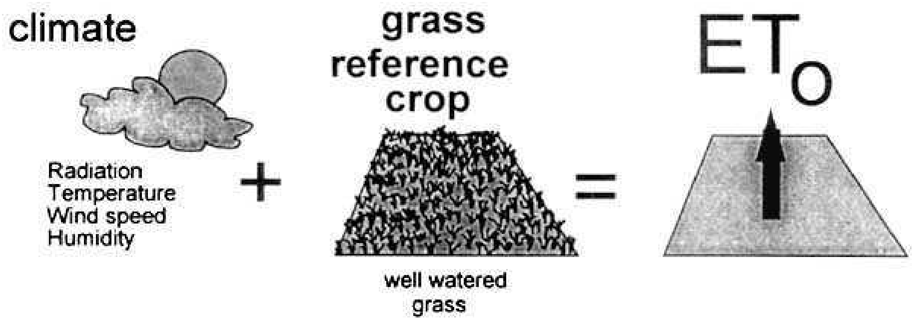


Fig.1.a. Reference Evapotranspiration

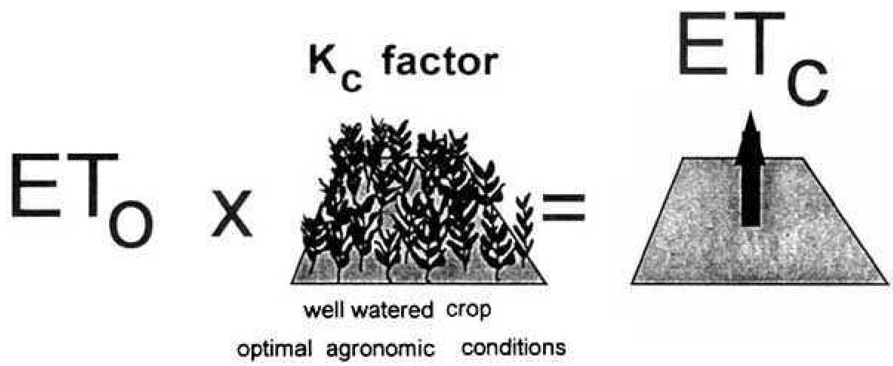


Fig.1.b. Crop evapotarnspiration

The same crop may have different water requirements at different places of the same country; depending upon the climate, type of soil, method of cultivation and useful rainfall. For better understanding of crop water requirement, it is prudent to have knowledge of functions of irrigation water.

For the most of the dry land crops other than rice, the water is initially lost through evaporation from the soil at the time of sowing .After the emergence of the seedlings, the leaves start intercepting the solar radiations coming from the sun. Consequently, the water is lost through evaporation from the leaves. With the gradual multiplication and expansion of the leaves, the crop canopy intercepts more solar radiation. Hence the transpiration from the canopy increases and gradually the soil evaporation decrease. When the crop fully shades the ground, the soil evaporation will be low and transpiration will be high. After the crop completes its reproductive cycle, the ageing (senescence) of the leaves starts and the leaf area intercepting the solar radiation would decrease. Measurements on the evapotransipiration losses from the dry land crops indicate that the water need of the crop will be about 0.3 to 0.4 times the evaporative demand in the beginning and its needs water almost at the potential rate (Slightly more than potential rate in case of some crops) after the crop canopy shades the ground. The crop continues to transpire water almost at the potential rate during its reproductive period and then onwards the water requirement declines to 0.5 times the evaporative demand when it attains maturity. Therefore, the total water requirement of the crop during its growth cycle (ET) can be approximately estimated as

$$ET = 0.8\ N * PET$$

Where N = Number of days from sowing to maturity; PET = Average rate of days of potential evapotranspiration in mm/day during the growing season.

For example, a sorghum crop of 110 days duration grown during the rainy season at Hyderabad requires about 352 mm of water (Ramana Rao and Ramakrishna, 1994). The water requirements of rice vary considerably depending upon the nature of the soil. In light soils, the drainage losses will be comparatively high and therefore the crop water requirement may be about 800 mm. In slightly heavier soils, the water requirements will be in the order of 600 to 650 mm. New methodology has developed for computation of crop water requirement more accurately using individual crop coefficients.

Computation of crop water requirements using CROPWAT Software

CROPWAT is a decision support system developed by the Land and Water Development Division of FAO for planning and management of irrigation. CROPWAT is meant as a practical tool to carry out standard calculations for reference evapotranspiration, crop water requirements and crop irrigation requirements, and more specifically the design and management of irrigation schemes (Smith, 1992 and Smith, 1993). It allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules under varying water supply conditions, and the assessment of production under rainfed conditions or deficit irrigation.

Procedures for calculation of the crop water requirements and irrigation requirements are based on methodology presented in FAO Irrigation and Drainage Papers No. 24 "Crop water requirements" and No. 33 "Yield response to water". The development of irrigation schedules and evaluation of rainfed and irrigation practices are based on a daily soil-water balance using various options for water supply and irrigation management conditions. Crop water use, consumptive use and evapotranspiration (ET) are the terms that are used interchangeably to describe the water consumed by a crop. Water requirement depend mainly on the nature and stage of growth of the crop and environmental conditions. Crops will transpire water at the maximum rate when soil water is at field capacity. Higher temperatures will increase transpiration from vegetation, boosting water requirements for both rainfed and irrigated crops.

Crop coefficient

Ratio of the crop ET_C to the reference ET_o is called the crop coefficient, Kc. The crop coefficient represents an integration of the effects of the following four primary characteristics that distinguish the crop from reference grass:

- Crop height
- Albedo
- Canopy resistance
- Evaporation from soil

Crop height influences the aerodynamic resistance term. Albedo is the reflectance of the crop-soil surface. Albedo is affected by the fraction of ground covered by vegetation and by the soil surface wetness. Albedo of the crop-soil surface influences the net radiation of the surface. Canopy resistance i.e. the resistance of the crop to vapour transfer is affected by leaf area (Number of stomata), leaf age and condition, and the degree of stomatal control. Evaporation from soil is the evaporation from especially exposed soil.

Factors affecting Kc

The Kc changes with the phenophases of the crop and in general it is low in the initial stage, slowly increases and attains high value during the grand-vegetative-growth period. During reproductive phase, it is uniform and later on decreases. Crop coefficient is dynamic in nature and varies according to crop characteristics, dates of (trans) planting, stage of growth and climatic conditions. Crop coefficient values for some crops which is available in CROPWAT (Table.1.).

Table.1. Crop coefficient values for some crops

Crop	Kc (initial)	Kc (mid-season)	Kc (end)
Small vegetables	0.70	1.05	0.95
Perennial vegetables	0.50	1.00	0.80
Rice	1.05	1.20	0.90-0.60
Sugarcane	0.40	1.25	0.75
Grapes (Wine)	0.30	0.70	0.45
Groundnut	0.40	1.15	0.60
Sorghum	0.30	1.00	0.55
Cotton	0.35	1.20	0.60

Detailed procedure for computing the crop coefficients are given in FAO Irrigation and Drainage Paper- 24 on Crop Water Requirements. These values may be very general, and more specific values for important crops developed through weighing type lysimeters at CSSRI, Karnal are given below Table.2. (Source : Sharma BR (2006)).

Table.2. Values of crop coefficients for different crops at Karnal, India

Crop	Crop growth stages				
	Initial stage	Crop development	Mid season stage	Late season stage	Average
Wheat	0.50	1.36	1.24	0.42	0.87
Rice	1.15	1.23	1.14	1.02	1.14
Maize	0.55	1.00	1.23	0.67	0.86
Sorghum	0.53	0.82	1.24	0.85	0.86
Berseem	0.63	1.09	1.29	0.40	0.85
Sunflower	0.63	0.82	1.12	1.23	0.95

Input

Calculations of the crop water requirements and irrigation requirements are carried out with inputs of climatic, crop and soil data. For the estimation crop water requirements (CWR) the model requires:

i) Reference Crop Evapotranspiration (ETo) values measured or calculated using the FAO Penman-Montieth equation based on decade/monthly climatic data: minimum and maximum air temperature, relative humidity, sunshine duration and wind speed;

ii) Rainfall data (daily/decade/monthly data); monthly rainfall is divided into a number of rain storms each month;

iii) A Cropping Pattern consisting of the planting date, crop coefficient data files (including Kc values, stage days, root depth, depletion fraction) and the area planted (0 -100% of the total area); a set of typical crop coefficient data files are provided in the program.

In addition, for Irrigation Scheduling the model requires information on:

iv) Soil type: total available soil moisture, maximum rooting depth, initial soil moisture depletion (% of total available moisture);

v) Scheduling Criteria – several options can be selected regarding the calculation of application timing and application depth (e.g. 80 mm every 14 days, or irrigate to return the soil back to field capacity when all the easily available moisture has been used).

Output

Once all the data is entered, CROPWAT 8 automatically calculates the results as tables or plotted in graphs. The time step of the results can be any convenient time step: daily, weekly, decade or monthly. The output parameters for each crop in the cropping pattern are:

- Reference crop evapotranspiration – ETo (mm/period);
- Crop Kc - average values of crop coefficient for each time step;
- Effective rain (mm/period) - the amount of water that enters the soil;
- Crop water requirements – CWR or ETm (mm/period);
- Irrigation requirements –IWR (mm/period);
- Total available moisture –TAM (mm);
- Readily available moisture – RAM (mm);
- Actual crop evapotranspiration – ETc (mm);

Calculation methods

The values of decade or monthly Reference Crop Evapotranspiration (ETo) are converted into daily values using four distribution models (the default is a polynomial curve fitting).The model calculates the Crop Water Requirements using the equation:

CWR=ETo*Kc*area planted.

This means that the peak CWR in mm/day can be less than the peak ETo value when less than 100% of the area is planted in the cropping pattern. The average values of crop coefficient for each time step are estimated by linear interpolation between the Kc values for each crop development stage. The "Crop Kc" values are calculated as Kc*Crop Area, so if the crop covers only 50% of the area, the "Crop Kc" values will be half of the Kc values in the crop coefficient data file.

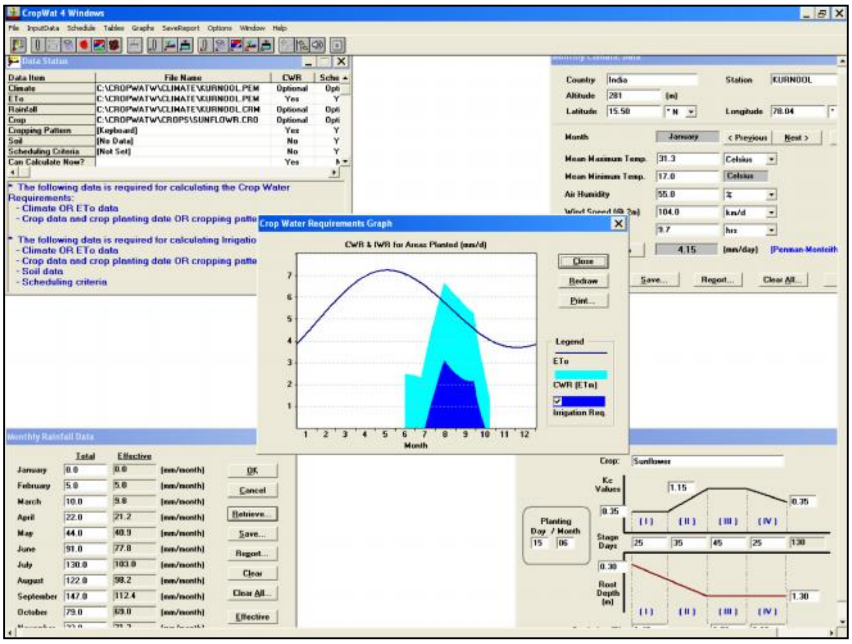
For crop water requirements and scheduling purposes, the monthly total rainfall has to be distributed into equivalent daily values. CROPWAT for Windows does this in two steps. First the rainfall from month to month is smoothed into a continuous curve (the default curve is a polynomial curve, but can be selected other smoothing methods available in the program e.g. linear interpolation between monthly values). Next the model assumes that the monthly rain falls in 6 separate rainstorms, one every 5 days (the number of the rainstorms can be changed). The model has available four Effective Rainfall methods (the USDA SCS method is the default).

For the scheduling calculations two options: Irrigation Scheduling and /or Daily Soil Moisture Balance can be selected. The Irrigation Scheduling option shows the status of the soil moisture every time new water enters the soil, either by rainfall or a calculated irrigation application. Daily Soil Moisture Balance option shows the status of the soil every day throughout the cropping pattern. User defined irrigation events and other adjustments to the daily soil moisture balance can be made when the Scheduling Criteria are set to “user-defined”.

Total Available Moisture (TAM) in the soil for the crop during the growing season is calculated as Field Capacity minus the Wilting Point times the current rooting depth of the crop.

Readily Available Moisture (RAM) is calculated as TAM * P, where P is the depletion fraction as defined in the crop coefficient (Kc) file. To avoid crop stress, the calculated soil moisture deficit should not fall below the readily available moisture.

The Main window of the software is shown below. The input data is given by clicking each module separately given on the top side pane of the window.



Irrigation Scheduling for Crops

Once we know the crop water requirements, the most important step is to supply the right quantity of water at right time through an appropriate application method to satisfy the crop water requirements. This is called irrigation scheduling and serves the objectives of high yield of good quality, attaining high water use efficiency without any damage to soil productivity and applying water at a reasonable cost. Different criterion suitable for different objective functions is available for scheduling irrigation to the crops and the important ones include the following:

Crop Growth Stages: Physiological stages of the crops are important criterion for irrigation scheduling to ensure good crop growth and yield. Commonly observed growth stages and the stages critical for irrigation for the important crops of the basin are given in Table 2. In case of a good rainfall around a given stage, the suggested irrigation should be avoided (Sharma BR (2006).

Table. 3. Important physiological and critical growth stages of crops for irrigation

Crop	Physiological stage	Critical stage
Wheat	Crown root initiation (CRI), late tillering, late jointing, flowering, milk and dough	CRI and flowering
Paddy	Early tillering, panicle initiation, flowering, milking and dough	Early tillering and flowering
Maize	Early vegetative growth, tasselling, silking and dough	Tasselling and silking
Sugarcane	Sprouting, tiller initiation, tillering and grand growth	Sprouting
Cotton	Branching, pre-flowering and boll formation	Pre-flowering and boll formation
Potato	Sprouting, stolonisation, stolon development; 20, 40,60 and 80% of tuber weight	Sprouting and tuberisation
Groundnut	Emergence, flowering, pod formation and pod development	Flowering and pod development
Mustard	Vegetative growth, flowering	Flowering

Climate change and crop water requirement

Water is an important for all forms of life and it is becoming scarce natural resource in the future owing to climate variability / change which aggravates the situation. Water resources are inextricably linked with climate. Climate change and variability would be the principal source of fluctuation in global food production, particularly in the semi-arid tropical countries of the developing world. In conjunction with other physical, social and political-economic factors, climate variability contributes to vulnerability to economic loss, hunger, famine and dislocation in the developing countries. Crop water availability shortage and excess affects the growth and development of the plants, yields and quality of produces. Climate change, affect the water availability resources, which in turn affect agriculture in many ways. For instance in soil plant processes with an increase in soil water deficit by changes in soil water balance. Long term climate change and its effect on crop water requirements of major cereal crops like wheat, maize, sorghum and millet in 2020 and 2050 were estimated by FAO CROPWAT program and the adaptation strategies to be taken to combat climate change effect were also discussed in this paper.

For estimation crop water requirement material as methodology is adopted as the required weather input files (Normal monthly weather data files for the period 1961-90 for maximum and minimum temperature, relative humidity, wind speed, sunshine hours and rainfall) for CROPWAT programme have been collected from FAO database software New_LocClimV1.1 (FAO, 2005) for the stations under study. To generate weather data files for 2020 and 2050, HadCM3 GCM (Global Circulation Model) output was used and by using this weather data files, crop water requirements for 2020 and 2050 was estimated. The data on district-wise area (from 1999 to 2006) for all crops taken for study has been collected from website of Directorate of Economics and Statistics, New Delhi

Impact of climate change on crop water requirements

Besides hastening crop maturity and reducing crop yields, increased temperatures will also increase crop water requirement. A study carried out by CRIDA (unpublished) on the major crop growing districts in the country for four crops, viz., wheat, maize, sorghum and pearl millet indicated a 2.2 % increase in crop water requirement by 2020 and 5.5 % by 2050 across all the crops/locations. The climate scenarios for 2020 and 2050 were obtained from HadCM3 model outputs using 1960-1990 as base line weather data (Table 4).

Table 4: Estimated crop water requirement (mm) of four crops in major growing districts of the country under projected climate change scenario

District (State)	**1990**	**2020**	**2050**	**% change over 1990 in**	
				2020	**2050**
Wheat					
Sirsa (Haryana)	281.8	293.1	301.4	4.0	7.0
Hardoi (UP)	475.0	488.2	502.2	2.8	5.7
Sangrur(Punjab)	391.1	405.4	416.3	3.7	6.4
Maize					

Udaipur (Raj)	388.8	392.4	400.9	0.9	3.1
Karimnagar (AP)	424.7	433.4	440.0	2.0	3.6
Jhabua (MP)	424.5	430.6	441.9	1.4	4.1
Pearl Millet					
Barmer (Raj)	337.8	338.6	347.4	0.2	2.8
Nashik (Maha)	284.2	289.9	296.9	2.0	4.5
Gulburga (Kar)	325.2	333.5	344.0	2.6	5.8

Adaptation strategies

The results of the study clearly indicate that, the impact of climate change could increase crop water requirement and influence negatively on yield levels unless their need is fulfilled. It is big challenge in the coming decades about increasing food production with less water particularly when the major river basins will have limited water resources and reduction in ground water availability. Improved water management practices that increase the productivity of irrigation water use may provide significant adaptation potential for all land production systems under future climate change. A number of adaptation policies are suggested in literatures. The policies suggest specific measures for water resources and agriculture that could reduce the potential adverse effects of climate change on crop evapotranspiration and yield. Micro-irrigation and resource conservation technologies (RCTs), economizing on water is to be promoted in a big way. The conjunctive use of water and diversification of rice-wheat is required for solving the emerging problem associated with climate change. At the same time, improvements in irrigation efficiency are critical to ensure the availability of water both for food production and for competing human and environmental needs. High volume of waste water needs to be utilized for irrigation after their proper treatment. Options for autonomous adaptation are already available to farmers and communities to cope with the future water shortage related risk management and production enhancement activities. These include (i) Adoption of varieties with increased resistance to high temperature and drought (ii) Modification of irrigation techniques, including amount, timing or technology (iii) Improved water management to prevent water logging, erosion and leaching (iv) Adoption of efficient technologies to 'harvest' water (v) Conserve soil moisture (e.g. crop residue retention), and reduce siltation and saltwater intrusion (vi) Modification of crop calendars, i.e., timing or location of cropping activities (Bates et al 2008).In general, projections suggest that the greatest relative benefit from adaptation is to be gained under conditions of low to moderate warming, and that adaptation practices that involve increased irrigation water use may in fact place additional stress on water and environmental resources as warming and evaporative demand increase

Conclusion

It is highly imperative that these resources be used most judiciously to ensure sustainable agriculture development and productivity. This, in turn requires knowledge of crop water requirements (CWR) in different agroclimatic zones / micro level. Judicious utilization of available water resources is the need of the hour and natural resource base of agriculture, which provides for sustainable production, is shrinking and degrading, and also adversely affecting production capacity of the ecosystem. Hence, it is imperative to understand water requirement of different crops, critical stages at which irrigation is required.

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Agroclimatic Database Management System

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Reliable and long-term agroclimatic data are needed for undertaking climatic analyses, particularly those aiming to assess climate variability and change and their impact on agricultural production. Data on crops, varieties, and production at district-level for several years is needed to understand the variations in agricultural productivity and changes in the cropping patterns at the region. Data on crop morphology, phenology and yield characters obtained from the various field experiments conducted by the State Agricultural Universities and ICAR Institutes in the country, when made available at one location and provided easy access, will be of great use to quantify crop -weather relationships and validating the crop-growth simulation models. Use of meteorological instruments and dedicated meteorological observers and organizations in country have paved the way for the availability of a very long-period weather data in India. With the availability of electronic computer systems, database management has become a reality.

"Database is a collection of non-redundant data, sharable between different application programs"

Conventional method:

The conventional method of handling data is to store it in a *file.* User requires application programs to manipulate the data stored in files.

> **Example:** Agromet Department in a SAU contains data on different weather parameters as recorded at the various research stations under the SAU.

Database management following conventional method requires application programs or software to:

- Add new stations and related data
- Calculate means, sums etc. on weekly and monthly basis
- Compute derived parameters and indices
- Generate various reports

These application programs are developed according to the needs of the user. New programs are to be added to the system as need arises. New files with different record format may have to be added after some time. New programs have to be developed or existing programs updated to manipulate the data in the new files. Thus, as the time goes by, more files and more application programs are created. In file management system, data declarations and executable statements are all part of the application program, while the actual data is in a file. If any changes are made in data file structure, all the application programs that use this particular data file need modifications. Any program that does not reflect this change will suffer "**Data Inconsistency**".

Some other disadvantages of this scheme are:

- Files may have more redundant data
- Data stored in such files may not be secure

Therefore, this method of handling data is not suitable and we need a system specifically for managing a database i.e., Database Management System.

Database Management System

A database management system (DBMS) is a set of application programs that acts as a layer between the physical database and its users. All the requests from users for access to the database are handled by the DBMS. One general function provided by the DBMS is shielding database design details to users.

Features of DBMS:

1. **Data Independence:**

A database management system with its catalog facility helps to achieve application programs "Data Independence". It also provides for a centralized management and control of data avoiding the "Data Inconsistency" that is faced in conventional file system. This also allows sharing of data, thus avoiding data redundancy.

2. **Data Integrity:**

DBMS overcomes the problem of data inconsistency by providing integrity constraints with data definition.

3. **Data Representation:**

DBMS provides conceptual representation of data, which frees users from the details of how data is stored.

4. **Data Security:**

DBMS ensures security of data by providing different security and access levels to different types of users. Therefore rights of users on database can be controlled effectively.

5. **Data Concurrency:**

DBMS takes care of multi-user issues by providing powerful locking mechanisms. It places automatic locks on database and records when any operation that affects the data takes place. These prevent updating of record or field by more than one user at a time in a multi-user environment.

6. **Data Sub language:**

DBMS provides DDL (Data Definition Language), DCL (Data Control Language) and DML (Data Manipulation Language), which allow defining data structure, data control and easy retrieval / updating of data.

Data Models Supported by DBMS

Three most popular data models are:

- Hierarchical Model

- Network Model
- Relational Model

Hierarchical Model:

IBM has developed the Hierarchical Model database management system in 1968, also known as Information Management System (IMS). A Hierarchical Model is a simple parent-child structure or tree structure; each child can have only one parent. The data is represented as a collection of trees. Data items are grouped into logical records.

Network Model:

The Network Model was designed as an improvement over hierarchical model. Here multiple parent-child relationships are allowed. This reduces data redundancy and provides easy access to information. It consists of a database of records where each record has a pointer to the record preceding or following record.

Relational Model:

The Relational Model eliminates explicit parent-child relationships. There are no pointers maintained and records are logically connected by key values. Hierarchical and network models deal with one record at a time while relational model reads and writes data in units of a set of records. In this model, data is organized in the form of tables comprising rows and columns. Any row is identified by a column or set of columns that form a primary key. Dr. E.F. Codd of IBM has proposed the relational model in 1985. He presented 12 rules that a database must obey if it is to be considered as truly relational.

Codd's Twelve Rules:

1. Information Representation at the logical level.
2. Guaranteed Access
3. Systematic treatment of Null values
4. Dynamic catalog based on relational model
5. Comprehensive data sub-language
6. View updating
7. High-level update, insert, delete
8. Physical Data Independence
9. Logical Data Independence
10. Integrity Independence
11. Distribution Independence
12. Non-Subversion Rule

No currently available relational DBMS fully satisfies all twelve of Codd's rules. But it has become a common practice to compile 'score-card' for commercial relational DBMS products to show how well they satisfy each of the rules.

Concepts of Relational Model:

The relational DBMS takes its concepts from Relational Algebra.

In a relational literature, tables are considered as relations, rows are termed as tuples and columns as attributes. The equivalent terms used by different people are

Relational Model	Programmer	User
Relation	File	Table
Tuple	Record	Row
Attribute	Field	Column

A domain is a pool of values from which the actual values appearing in given column are drawn. The relational model provides a relational language, called SQL (Structured Query Language).

Quality checking and Agromet Database development

Quality of agromet data is essential for proper understanding the weather of the watershed and for later computing the derived parameters for interpretation. Instruments in the observatory are to be inspected by authorized personnel once in every year by comparing with standard equipment and identifying the calibration error and calibration drift, if any. Meteorological observer needs to be trained in following the times of observations, maintaining of instruments, recording the measurements with sincerity and keeping the data forms and books. Agromet data once collected needs to be entered in to a computer in the form of an MS-Excel file or a MS-Word file. Agromet Databases can be developed using the data of one watershed or multiple watersheds using software like MS-Access with the help of professional software developers. While developing databases, crop and soil data may also be considered for inclusion. Suitable data retrieval programmes and software for computing derived weather parameters like reference crop evapotranspiration, water surplus, water deficit and various agroclimatic indices are to be developed along with the databases.

General guidelines regarding agrometeorological observations:

Observations should be taken in as little time as possible (to avoid vitiation due to presence of the observer). Punctuality is a matter of prime importance in recording the observations. Faithful recording is important and every observation should be recorded as faithfully as read. Each observation must be written down in the meteorological register immediately after it is taken. Each observation must be checked after it is noted down in the meteorological register to make sure that no mistake has been made. The observatory surroundings need to be maintained in such a way that there are no tall buildings or trees nearby which may affect the weather measurements. The positions of the instruments must never be changed.

Important agromet data entry forms of the IMD are:

1. CWS 1 MET-1 (AGRI)-1 - Agromet observations
2. CWS 2 MET-1 (AGRI)-2 - Micrometeorological observations
3. MET-T-149 - Hours of bright sunshine observations
4. MET-1 (AGRI)-56 - Pocket Register for agromet observations
5. MET-1 (AGRI)-65, CWS-27 (a) - Dew observations
6. MET-1 (AGRI)-66, CWS-27 (b) - Dew observations

Benefits of automated measurements are:

- AW Stations can run for weeks and months without attention. Weather can be monitored from indoors; data can also be easily read direct from the console display. Detailed weather conditions may be viewed at any distance from the station itself, for example over the Internet.
- Routine activities like setting of maximum and minimum thermometers, emptying raingauge, change of sunshine card etc., are not required.
- AW Stations automatically record maximum and minimum values for all weather elements through each day and keep track of total daily, monthly and yearly rainfall.
- Much greater within-the-day details are available, like complete pattern of wind speed & direction.
- Derived parameters like degree days, reference crop evapotranspiration can be computed using specific software

Choosing and setting up of AWS

While choosing, budget will obviously be one important factor, but there are other key considerations like:

- Which sensors? Recording of the basic meteorological parameters is the minimum requirement. However, very often, value of meteorological data is increasingly appreciated after the station is installed. More and more parameters are required to be monitored and hence, planning initially (by choosing a suitable datalogger) for having the option of adding more sensors later will help. Measurement of UV intensity, leaf wetness and soil moisture may become more relevant in the near future.

- Sensor sensitivity is an important factor, however a balance between accuracy, cost and data application is required.

- Communication and data transfer mechanisms, special data handling requirements like a live weather reporting website on Internet.

- Memory requirements of the datalogger in case of long-period unattended operation to be worked out. Other important factors are the availability of matching software for data download, export to various other software applications like spreadsheets or databases, automated graphical display of parameters, computation of derived parameters like PET and indices for pest and disease forecasting.

- The AWS should be located in such a place that it represents the general agroclimatic conditions of the area. Height of the sensors and other exposure criteria are similar to that of a manual observatory, such that the data generated from the AWS is comparable and reliable to that generated from a manual observatory. The AWS is to be installed initially near a manual observatory and the data compared for a few days and then only is shifted to the proposed location.

- Datalogger program should be optimised for power and memory usage and checked thoroughly for any bugs.

- Proper protection against lightening, theft and damage is to be ensured.

To summarize, Agromet Database management system includes:

- Data acquisition, entry, storage and archiving
- Data quality control
- Designing an appropriate AgrometDatabase management system with a scope for scalability
- Computer hardware and software
- Data access and application software development
- Data administration and monitoring
- Policy on data sharing

Applications of the Agromet Database management include:

- Climate change assessment and impact studies
- Crop weather modelling
- Developing strategies for sustainable agricultural production
- Urban and tourism development
- Coastal zone management
- Resource characterization and research prioritization

Statistical Analysis of Agromet Data including Rainfall Probability

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1. Introduction

Statistics: Statistics is the science, which deals with the collection, analysis and interpretation of numerical data.

Descriptive Statistics: The values that summarize or describe the data collected are known as descriptive statistics. Descriptive statistics are used to describe the basic features of the data in a study. They provide simple summaries about the data.

We have two objectives for our summary:

i) We want to choose a value that shows how different *units* seem similar. Statistical textbooks call the solution to this objective, a *measure of central tendency.*

ii) We want to choose a value that shows how they differ. This kind of statistic is often called a *measure of statistical variability*.

2. Measures of Central Tendency

They give us idea about the concentration of the values in the central part of the distribution. They enable us to comprehend the significance of whole in a single effort. Most commonly used measures of central tendencies are:

a) **Arithmetic Mean (AM):** It is simply the sum of observations divided by the number of observations.

A.M. = (Sum of observations)/ (Number of observations)

It is denoted by $\bar{x}$.

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i = \frac{1}{n}(x_1 + \cdots + x_n)$$

where, $\bar{x}$ is Arithmetic Mean of n observations, x_i is value of ith observation, and n is total number of observations.

Now, we will show how to calculate the Arithmetic Mean. Our example will use the ages of four young children: { 5, 6, 8, 9 }.

Calculation of the mean/average $\overline{x}$:

We have n = 4 because there are four children and

Age of first child = $x_1 = 5$

Age of second child = $x_2 = 6$

Age of third child = $x_3 = 8$

Age of fourth child = $x_4 = 9$

Replacing n with 4

$$\overline{x} = \frac{1}{4}\sum_{i=1}^{4} x_i$$

$$\overline{x} = \frac{1}{4}(x_1 + x_2 + x_3 + x_4)$$

$$\overline{x} = \frac{1}{4}(5 + 6 + 8 + 9)$$

$$\overline{x} = 7$$

b) **Median:** The value that divides the series into two equal parts; the value such that the number of observation above it is equal to the number of observations below it. It is also called the positional average.

Methodology to Compute Median:

Case I: When the number of observations in the series is odd:
Arrange the given series in ascending order or descending order of magnitude.

The central value will become the Median. If there are n observations in the series then $\left(\frac{n+1}{2}\right)$th observation in the arranged series will become the Median.

Example: Find out the median of the following series: 25, 20, 15, 35, 18

Solution: Ascending order of the series is 15, 18, **20**, 25, 35.

Here n = 5

The central value = $\left(\frac{5+1}{2}\right)$ = 6/2 = 3

Therefore median = 3rd observation in the arranged series = 20

Case II: When the number of observations in the series is even:
Arrange the given series in ascending order or descending order of magnitude.

Take the average of the two central values. If there are n observations in the series A. M. of $\left(\frac{n}{2}\right)$th and $\left(\frac{n}{2}\right)$+1 th observations in the arranged series will become the Median.

Example: Find out the median of the following series:8, 20, 50, 25, 15, 30

Solution: Ascending order of the series is 8, 15, **20**, **25**, 30, 50.
Here n = 6
The central values are 6/2 = 3 and (6/2)+1= 4
Therefore, median = A.M of 3rd and 4th observations in the arranged series
= (20+25)/2 = 45/2 = 22.5

c) **Mode:** It is the value, which occurs most frequently in a set of observations.

Example: Mode of the series: 20, 18, 22, 20, 19, 14, 18, 20 is 20

It is possible that there is no mode in a series. It is also possible that there are several modes in a series.

Remarks: It is important to keep in mind that arithmetic mean is influenced by extreme value in a series but Median is not.

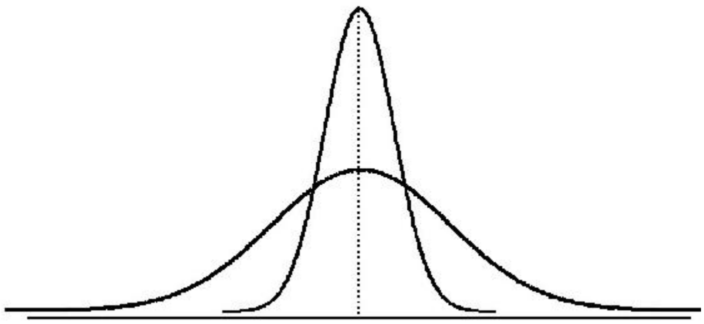
3. Measures of Dispersion

Consider the following three series:
7, 8, 9, 10, 11 - AM = 9 and Median = 9

3, 6, 9, 12, 15 - AM = 9 and Median = 9

1, 5, 9, 13, 17 - AM = 9 and Median = 9

See the following two distributions having same center but different scatteredness.



From the above, it implies that measures of central tendency are not adequate to give us complete idea of series/distribution. The measure that tells us about the spread or scatteredness of data values in a series or heterogeneity of the distribution is dispersion.

a) Range: Range is the simplest measure of dispersion. It is the difference between the largest and the smallest observations

$$\text{Range} = X_{largest} - X_{smallest}$$

Range of above referred three series are:

i) 11-7=4

ii) 15-3=12

iii) 17-1=16

Disadvantages of Range:

i) Ignores the way in which data are distributed

See the following two series

7, 8, 9, 10, 11, 12

7, 10, 11, 12, 12, 12

Range of both series is 12-7=5

ii) Sensitive to outliers

1,1,1,1,1,1,1,1,1,1,1,2,2,2,2,2,2,2,2,2,3,3,3,3,4,5 Range=5-1=4

1,1,1,1,1,1,1,1,1,1,1,2,2,2,2,2,2,2,2,2,3,3,3,3,4,120 Range=120-1=119

b) Standard Deviation

Most popular measure of dispersion is standard deviation.

Standard Deviation (Definition): Standard Deviation is the positive square root of the arithmetic mean of squares of the deviations of the given values from their Arithmetic Mean. Sample standard deviation is denoted by s.

$$s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left[\left(x_1 - \bar{x}\right)^2 + \left(x_2 - \bar{x}\right)^2 + \ldots + \left(x_n - \bar{x}\right)^2\right]}$$

where

$\bar{x}$ is Arithmetic Mean of n observations

x_i is value of ith observation.

n is total number of observations.

Example: Yield obtained by a random sample of 8 rainfed rice farmers in a village is as under. Compute standard deviation.

Data (x_i): 10 12 14 15 17 18 18 24

Solution:

n = 8 Mean = $\bar{x}$ = 16

$$S = \sqrt{\frac{(10-\bar{X})^2 + (12-\bar{X})^2 + (14-\bar{X})^2 + \cdots + (24-\bar{X})^2}{n-1}}$$

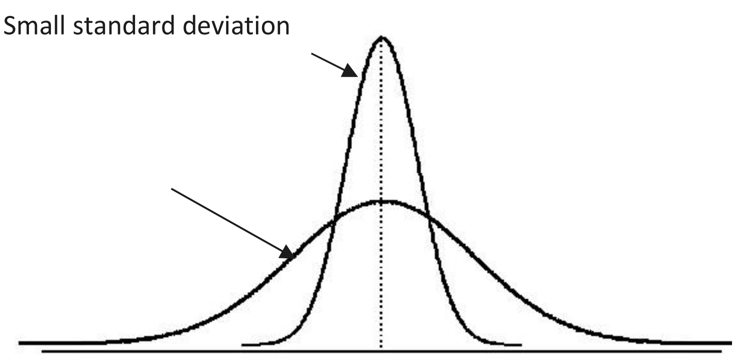
$$= \sqrt{\frac{(10-16)^2 + (12-16)^2 + (14-16)^2 + \cdots + (24-16)^2}{8-1}}$$

$$= \sqrt{\frac{126}{7}} = 4.2426$$

Interpretation of Standard Deviation

Standard deviation measures how spread out the values in a data set are. More precisely, it is a measure of the average distance of the data values from their mean. A large standard deviation indicates that the data points are far from the mean and a small standard deviation indicates that they are clustered closely around the mean. If all the data values are equal, then the standard deviation will be zero.

Let us consider the above-referred three series. The Standard Deviation(s) of the three series are 1.41, 4.24 and 5.66 respectively. It reveals that series 1 is more homogenous than series 2 and 3. Similarly series 3 is more heterogeneous or scattered as compared to series 1 and 2.



The standard deviation is always a non-negative number and is always measured in the same units as the original data. For example, if the data are distance measurements in meters, the standard deviation will also be measured in meters.

C. Coefficient of Variation (CV)

Let us divide the SD by mean. This shows the variation per unit mean. If we express this as percentage (%) it is called Coefficient of Variation (CV).

$$CV = \left(\frac{S}{\overline{X}} \right) 100$$

It allows comparison of the variation of populations that have significantly different mean values by depicting variation relative to mean.

The importance of CV can be appreciated in the event of comparing two or more sets of data measured in different units. Say per capita income of US (in dollars) and India (in rupees) are to be compared. CV is the right choice as it is independent of units.

4. Exploratory Data Analysis

Before we begin analyses, examine data of all our variables.

listen to the data:

catch mistakes

see patterns in the data

try to characterise operating process / underlying phenomenon.

Classical sequence: Problem > Data > Model > Analysis > Conclusions

Exploratory: Problem > Data > Analysis > Model > Conclusions

Exploratory Data Analysis is data driven involving Graphical presentation. It begins with 5-Number Summary.

5-Number Summary: Min, Q1, Median, Q3, Max

Arrange data in descending order

- Find Q1=1/4 data lies below this point

- Find Median= 1/2 data lies below this point
- Find Q3=3/4 data lies below this point
- Find Max score and Min score

Rainfall probability: Minimum rainfall expected for a given probability can be computed from percentiles . Say 25 percentile rainfall is x mm, we can say with 75% probability that rainfall expected for the given region will be more than x mm

Visual summaries:

Box plot (needs 5 number summary)

Stem and leaf

Scatter plot

5. Correlation

If the change in one variable[1] affects a change in the other variable the variables are said to be correlated.

If two variables deviate in the same direction, i.e., if increase (or decrease) in one results in a corresponding increase (or decrease) in the other, correlation is said to be positive.

Examples:

1. Extent of irrigation and yield.
2. Fertliser nutrient use and yield.

If the two variables constantly deviate in opposite directions i.e. if increase (or decrease) in one results in a corresponding decrease (or increase) in the other, correlation is said to be negative.

Examples:

1. Pest/disease infestation and yield

Coefficient of Correlation: It is a measure of intensity or degree of linear relationship between two variables. It is denoted by r. It measures the relative strength of the linear relationship between two variables.

[1] Variable is a measurable characteristic, or attribute of an individual or a system – in other words, something that might be expected to vary over time or between individuals.
variable is a quantity whose value may vary over the course of an experiment (including simulations), across samples, during the operation of a system.

$$r = \frac{\sum XY - \frac{\sum X \sum Y}{N}}{\sqrt{(\sum X^2 - \frac{(\sum X)^2}{N})(\sum Y^2 - \frac{(\sum Y)^2}{N})}}$$

Numerical Example:

X	**Y**
1	2
2	5
3	6

$\Sigma XY = (1)(2) + (2)(5) + (3)(6) = 30$
$\Sigma X = 1 + 2 + 3 = 6$
$\Sigma X^2 = 1^2 + 2^2 + 3^2 = 14$
$\Sigma Y = 2 + 5 + 6 = 13$
$\Sigma Y^2 = 2^2 + 5^2 + 6^2 = 65$
$N=3$
$\Sigma XY - \Sigma X \Sigma Y/N = 30 - (6)(13)/3 = 4$
$\Sigma X^2 - (\Sigma X)^2/N = 14 - 6^2/3 = 2$
$\Sigma Y^2 - (\Sigma Y)^2/N = 65 - 13^2/3 = 8.667$
$r = 4 / \sqrt{(2)(8.6667)} = 4/4.16333$
$= .9608$

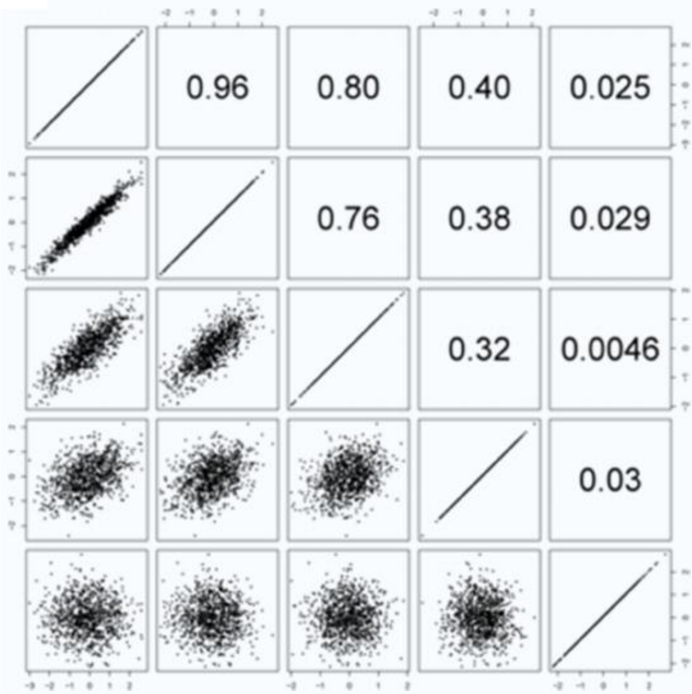
Correlation coefficient is free from units of measurements.
Range of correlation coefficient is –1 to +1.

r = 1 indicates perfect positive correlation. If closer to 1, stronger the positive linear relationship.

r = -1 indicates perfect negative correlation. If closer to –1, stronger the negative linear relationship.

r = 0 implies no correlation. If closer to 0, weaker linear relationship.

Diagrammatic representation of value of correlation coefficient and intensity of linear relationship.



Linear correlations between 1000 pairs of numbers. The data are graphed on the lower left and their correlation coefficients listed on the upper right. Each square in the upper right corresponds to its mirror-image square in the lower left, the "mirror" being the diagonal of the whole array. Each set of points correlates maximally with itself, as shown on the diagonal (all correlations = +1).

Correlation is only concerned with strength of the linear relationship. No causal effect is implied with correlation. Non-directional.No units for Correlation co-efficient. Range is -1 to +1.

Testing for the significance of the correlation coefficient, r:

To test the significance of the correlation coefficient, first we set up the null hypothesis as

Ho: There is no correlation between two variables (yield and no of rainy days during kharif season) or correlation between the two variables is zero. We can test the above Ho using the following test statistic

$t = r\sqrt{\frac{n-2}{1-r^2}}$ which follows t-distribution with (n-2) degrees of freedom.

Compare the calculated value with table value of test statistic for (n-2) degrees of freedom at α % level of significance (los) from Yates statistical tables.

If calculated value of |t| > table value of t for (n-2) df and at α% los, we reject the Ho and conclude that correlation coefficient between the two variables is not equal to zero. Otherwise we say that data doesn't show enough evidence to reject the Ho hence we accept Ho.

6. **Linear Regression:**

Regression means 'stepping back or returning to the average value'. Regression coefficient measures average functional relationship between two or more variables in terms of the original units of the data. It provides a mechanism for prediction or forecasting as estimates are made for a variable from knowledge of the values of one or more other variables.

Dependent vs Independent variables:

In regression analysis, there are two types of variables. The variable, which is used to predict the variable of interest, is called the independent variable and the variable we are trying to predict is called the dependent variable. In regression analysis independent variable is also known as regressor or predictor or explanatory while the dependent variable is also known as regressand or regressed or explained variable or criterion. The independent variable is denoted by X and dependent variable by Y. Changes in Y are assumed to be caused by changes in X. Relationship between X and Y is described by a linear function

Simple Vs Multiple Linear Regression:

Study of only two variables at a time is considered in simple linear regression. But quite often the values of a particular phenomenon is affected by multiplicity of factors necessitating studying more than two variables at a time, which is called multiple linear regression.

Regression Equation: $Y = {}_0 + {}_1 X + £$

where Y is dependent variable, X is independent variable

${}_0$ is intercept, ${}_1$ is regression coefficient, £ is random error assumed to be distributed with zero mean and constant variance.

Interpretation of Regression Coefficient

Regression coefficient explains the impact of changes in an independent variable on the dependent variable. Say estimated value of ${}_0$ is b_0. Then b_0 is the estimated average value of Y when the value of X is zero (if X = 0 is in the range of observed X values).

Say estimated value of ${}_1$ is b_1 . Then b_1 measures the estimated change in the average value of Y as a result of a one-unit change in X. Units of regression coefficient will be that of the units of dependent variable

$$b_1 = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sum (x_i - \bar{x})^2}$$

$$b_0 = \bar{y} - b_1\bar{x}$$

Where $\bar{x}$ and $\bar{y}$ are averages of X and Y variables, respectively.

Multiple Linear Regression Model:

Multiple Regression Model with k Independent variables will be

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_i X_i + \ldots + \beta_k X_k + \varepsilon$$

Testing of Regression Coefficient

F test for overall significance

Ho: $\beta_i = 0$ (for all i)

Test statistic F = MSR/MSE

Where MSE is Mean sum of squares due to regression and MSE is Mean sum of squares due to error.

Are Individual Variables Significant?

Use t-test for individual variable slopes.
It tests if there is a linear relationship between the variable X_i and Y

Hypotheses:

H_0: $\beta_i = 0$ (no linear relationship)

H_1: $\beta_i \neq 0$ (linear relationship does exist between X_i and Y)

Test Statistic:

$$t = \frac{b_i - 0}{S_{b_i}}$$

(df = n – k – 1)

Where S_{bi} is the standard error of b_i.

Step-wise Regression

Backward Regression:

Begins with all variables and drops variables one by one based on significance of regression coefficients (e.g. Removal $p>0.1$).

Forward Regression:

Begins with most significant variable and adds one by one based on significance of regression coefficients (Eg: Entry $p<0.05$)

7. **Testing of hypothesis - small sample tests**

The aim of this section is to draw inferences about a population from a sample.

7.1 One Sample t-Test

Assumptions:

i) Population from which sample is drawn is normal.
ii) The sample is drawn at random.

Constraints:

i) Size of the sample is small (less than 30)
ii) Population S.D. is not known

Null Hypothesis: $H_0: \mu = \mu_0$

Test statistic:

$$t = \frac{\bar{x} - \mu_0}{\frac{s}{\sqrt{n}}},$$

with $(n - 1)$ degree of freedom.

where, $$s^2 = \frac{1}{(n-1)} \sum_{i=1}^{n} \left(x_i - \bar{x}\right)^2$$

Conclusion: If calculated t is greater than t table value for (n-1) degree of freedom at required level of significance, the null hypothesis is rejected. Otherwise null hypothesis is accepted.

7.2 Two Sample t-Test

Assumptions:

i) Population from which samples are drawn is normal.
ii) The samples are drawn independently and at random.
iii) Population S.D.s are equal

Constraints:

i) Sizes of the samples are small (less than 30)
ii) Common population S.D. is not known

Null Hypothesis: $H_0 : \mu_1 = \mu_2$

Test statistic:

$$t = \frac{(\overline{x}_1 - \overline{x}_2) - (\mu_1 - \mu_2)}{s_p\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}},$$

Where, S_p is Pooled S.D.

$$s_p^2 = \frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2},$$

With $(n_1 + n_2 - 2)$ degree of freedom.

$$s_1^2 = \frac{1}{(n_1 - 1)} \sum_{i=1}^{n_1} \left(x_{1i} - \overline{x_1}\right)^2$$

s_2^2 may be computed using a similar formula.

Conclusion: If calculated t is greater than t table value for $(n_1 + n_2 - 2)$df at required level of significance, the null hypothesis is rejected. It is concluded that there is significant difference between two means with respect to character under consideration. Otherwise null hypothesis is accepted.

7.3 Paired t-Test

When to use paired t-test:

The sample sizes should be equal and the two samples are not independent (sample observations are paired together).

For example difference in the performance between two brothers of the same family, difference in performance of a group of children before and after training may be tested using this test.

Assumptions:

i) Population from which samples are drawn is normal.
ii) The paired sample is drawn at random.
iii) Population S.D.s are equal

Constraints:

i) Sizes of the samples are small (less than 30) and equal
ii) Common population S.D. is not known

Null Hypothesis : H_0 : $\mu_1 = \mu_2$

Test statistic:

$$t = \frac{\overline{d}}{\sqrt{\frac{S_d^2}{n}}}$$

With $(n - 1)$ degree of freedom.

where, $\overline{d} = \frac{1}{n}\sum_{i=1}^{n} d_i$ and $d_i = x_{i1} - x_{i2}$

x_{i1} = Observation from 1st sample in the ith pair,

x_{i2} = Observation from 2nd sample in the ith pair, and

n = Number of pairs

$$S_d^2 = \frac{1}{n-1}\sum_{i=1}^{n}\left(d_i - \overline{d}\right)^2$$

Conclusion: If calculated t is greater than t table value for (n-1) df at required level of significance, the null hypothesis is rejected. Otherwise null hypothesis is accepted.

7.4 Testing Equality of Several Means

This test is carried out using the technique of Analysis of Variance (ANOVA). ANOVA is a technique of partitioning total observed variation according to different sources of variation. The test finally used in this technique to verify equality of several means (more than 2) is known as F test.

H_0: There is no difference among the means of groups with regard to characteristic under study

The skeleton ANOVA looks as under:

Source of Variation	Degree of Freedom	Sum of Squares (SS)	Mean of Sum of Squares (MSS)	F calculated
Between Groups	P-1	BGSS	BGMS = BGSS/(P-1)	F = BGMS/EMS
Error (Within Groups)	N-P	ESS = TSS - BGSS	EMS = ESS/(N-P)	
Total	N-1	TSS		

Where, TSS = (SS of each observation) – (CF)

CF = Square of Grand Total/ Total No. of observations

BGSS = Sum of {(Square of Group Total)/No. of observations in the group} - CF

Conclusion: If F (cal) > F table value for (P-1), (N-P) df at required level of significance, the null hypothesis is rejected. Otherwise null hypothesis is accepted.

8. Some resources for analysis

OPENSTAT

Freely downloadable. It takes a memory of about 5 MB only. Input data files prepared in MS Excel can be imported into OPENSTAT. It is windows based and menu driven. It can be downloaded from *www.statprograms4u.com.*

MS Excel

Versions of MS excel coming with MS Office 2003 onwards also contain Add-in 'Analysis Tool Pack'. Most of the commonly used statistical tools like descriptive statistics, correlation, regression, t test, ANOVA etc. are covered in this module. In case of Office 2007, one can activate this by *Office Button → Excel Options → Add-Ins → Analysis Toolpak VBA→ Go→ OK.*

R

Very powerful, popular and free statistical software that can be down loaded from internet. It can be download from http://cran.r-project.org/bin/windows/base. It can be used by advanced learners only as there is no menu driven modules. One has to learn its syntax, though simple, to carry out the analysis.

IASRI-SSCNARS

It is an IP authenticated service made available for National Agricultural Research System (NARS) of India by Indian Agricultural Statistics Research Institute, ICAR. Statistical analysis of data can be done online. The concerned link is http://stat.iasri.res.in/sscnarsportal. Any NARS organization can approach IASRI for accessing this facility.

Suggested Readings:

1. S.C. Gupta and V.K. Kapoor (1998) Fundamentals of Mathematical Statistics (9^{th} Ed.) Sultan Chand & Sons. New Delhi.

2. A.M. Goon, M.K. Gupta and B. Dasgupta (1998) Fundamentals of Statistics-1 (7^{th} Ed.). The world Press Pvt. Ltd. Kolkatta.

Weather elements influencing plant disease

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The plant disease is an output of the interaction among host, pathogen, and the environment over a period of time. Given that a susceptible host and an aggressive pathogen are available, weather determines the intensity of the disease over time. The environment can affect both the susceptibility of the host (e.g. by creating stress in the plant) and the activity of the pathogen (e.g. providing moisture for spore germination). The pathogen and the host can affect each other's performance. The plant can also change its environment, by creating a microclimate around it that is either congenial or non-conducive for the pathogen. The important parameters of host that can influence disease development are susceptibility; growth stage and form; structure and density of the plant population and overall health. For pathogen, to cause disease, it should be present in the viscinity, pathogenic, adaptable with reproductive fitness and possess efficiency of survival and dispersal. The important weather parameters are temperature; rainfall/dew; leaf wetness period, wind, bright sunshine hours all of which are in turn influenced by soil properties. Each of the components of disease are briefly described below.

The Pathogen

The presence or absence of a pathogen is the main factor that determines occurrence of disease. For each given agro-climatic region, through co-evolution a set of pathogens get adapted and maintain equilibrium. However, due to commercial agriculture in the recent years, the balance between host and pathogen are disrupted either through introduction of new crop species or new varieties and hence, the disease scenario changes drastically. In such cases, introduction of a pathogen to an area from which it has previously been absent can cause major outbreaks of disease in plant communities. The amount of disease that develops is often determined by pathogenicity of the pathogen. Pathogenicity is nothing but the inherent ability of the pathogen to cause disease and is dependent on the pathogen's reproductive, dispersal and survival fitness.

The **adaptability** of the pathogen is determines the ability to infect resistant hosts or to survive in the changed environmental conditions. Adaptability is determined by the pathogen's genetic make up and reproductive efficiency. The spread of a disease and the formation of epidemics is reliant on the pathogen's ability to **disperse** rapidly over long distances. The foliar pathogens such as spores of cereal rusts, for instance, are known to cross continents over a few days time, while soil-borne pathogens have little scope for extensive spread. For a pathogen to cause disease in successive seasons, it must be able to **survive**during lean phase in absence of host. Some pathogens form spores or sclerotia that can survive in the soil for years, while others colonize alternative plant species until the primary host is cultivated. It is not only the mere presence of the pathogens but also their inoculum density that is crucial in determining the amount of disease. Generally, as the number of propagules increases, the level of disease increases, levelling off when the amount of disease reaches peak levels and when only a few uninfected plants available. The survival of propagules, and therefore the number of propagules available to cause disease, is heavily influenced by environmental factors.

The host

The development of disease in a plant community relies on the presence of individual hosts that are **susceptible**to that particular pathogen. If the majority of the population is susceptible to the pathotypes of a pathogen in the vicinity, an epidemic can occur.The best way of controlling disease is by planting species or cultivars that are not susceptible to pathogens of that area. The occurrence of disease can also be influenced by the host plant's **growth stage and form.** Some diseases are common in seedlings, while others are typical of mature plants. The growth stage of the population can also affect the microclimate around the plants; for example, the humidity and sunlight levels under the canopy. The **population structure and density**will also affect the development of disease in a plant community. The density of the main host species and the proportion of other plants that are not hosts within the community will determine the rate and extent of epidemic development. Crop plants tend to be densely planted, with no other species in amongst them, making them more susceptible to rapid spread of disease. Extensive, dense plantations can host spectacular epidemics, particularly if a new pathogen is introduced to the area. In addition, the general **health**of the host plant before infection is important in determining the success of a disease. Necrotrophs do well on poorly growing plants, while biotrophs thrive on a healthy host plant.

The Environment

The presence of a pathogen against a particular plant will generally not cause serious disease unless the environmental conditions are favourable. This includes the aerial environment and the soil (**edaphic**) environment. Human attempts at controlling disease usually involve manipulating the environment in some way. For example, breeding wheat cultivars to tolerate dry conditions allows Australian farmers to plant the crop in areas that are not favourable for pathogens such as powdery mildew and leaf rust. Properties of the **aerial environment** that influence disease development include moisture levels, temperature and pollution.

Moisture is particularly important to pathogenic bacteria and fungi. Rain splash plays an important role in the dispersal of some fungi and nearly all bacteria, and a period of leaf wetness is necessary for the germination of most airborne spores. By using water for dispersal, propagules are dispersed at a time when they are likely to be able to germinate as well. Because the process of germination and infection takes time, the duration of leaf wetness also influences the success of the infection. The duration necessary for infection varies with temperature. Usually, a longer period of leaf wetness is needed to establish an infection in cooler temperatures, as germination and infection are generally accelerated in warmer conditions.

Temperature also affects the incubation, or latent, period (the time between infection and the appearance of disease symptoms), the generation time (the time between infection and sporulation), and the infectious period (the time during which the pathogen keeps producing propagules). The disease cycle speeds up at higher temperatures, resulting in faster development of epidemics. The period of leaf wetness, combined with temperature information can be used to predict outbreaks of some diseases (infection periods) and be used to time preventative treatments, such as spraying. A recently recognised aspect of the aerial environment that can influence disease in plants is air **pollution**. A high concentration of pollutants can affect disease development and, in extreme cases, damage the plants directly by causing acid rain.

The **edaphic(soil) environment**affects soil-borne diseases, largely by determining the amount of **moisture**available to pathogens for germination, survival and motility. Germination and infection success also rely on the temperature of the soil. The **fertility** and **organic matter**

content of the soil can affect the development of disease. Plant defences are weakened by nutrient deficiency, although some pathogens, such as rusts and powdery mildews, thrive on well-nourished plants. Other diseases thrive in soils that are specifically low in organic matter.

Interaction between host, pathogen and weather

The pathogen, the host and the environment interact, usually in ways that are difficult to quantify and predict. Control measures can include sowing of a crop species early, to avoid exposing seedlings to a disease during the time of year that provides the best environmental conditions for the pathogen.

Prediction of disease outbreaks enables the effective use of control measures, such as chemical or biological treatments, the prediction of crop yields and of the market potential for that crop. Disease forecasting involves the use of **weatherdata** and **biologicaldata** to predict disease incidence. Usually, disease forecasting is only performed on economically important diseases, and as a method of cost reduction. If controlling a particular disease involves an expensive or time-consuming treatment, being able to predict outbreaks of the disease allows the treatment to be timed correctly, increasing its effectiveness, and reducing the cost compared to repeated treatments. Because environmental conditions vary from season to season, disease forecasting is necessary to predict the chance of disease in a certain set of conditions.

Disease can be forecast using computer modelling and empirical correlations relating to weather conditions, levels of inoculum, test plots and site factors and the predictions can then be communicated to growers. **Computer modelling**of plant diseases uses systems analysis to accumulate all the factors that affect the development of a certain disease into a computer-based model, and make predictions of disease under different environmental conditions. A disease needs to be well understood in order to formulate an accurate model, and models based on diseases that we know little about are generally not very accurate. The more straightforward approach of developing **empirical correlations** between particular weather factors and disease has had considerable success. This does not attempt a complete modelling of all factors involved in a disease, but only those most important in affecting the disease. The accuracy of the model can then be measured statistically by comparing its predictions to what actually happens.

Monitoring the weather is the most important consideration in disease forecasting, because of the overriding effect that weather has on disease development. While broad scale weather data has been used for disease forecasting, it is well known that the microclimate within the crop has a more direct impact on disease. Devices have been developed to monitor microclimate factors such as duration of leaf wetness and temperature, and with time, they will be affordable and accurate enough for widespread use on individual farms. Synoptic weather forecasting charts can be used to predict 'critical periods' - the occurrence of conditions favourable for disease development - so that farmers can spray their crop before it happens. There are now several self-calculating disease forecasting monitors available commercially that use environmental data and past season data to predict outbreaks of particular diseases.

Crop Microclimate and disease

The microclimate of the crop is the weather in the immediate vicinity of the crop, which is also sometimes referred to as weather at canopy level. Usually, the weather at the observatory and crop canopy is not same as at canopy level the weather is influenced by soil parameters. Since, the pathogens survive on plant parts, the weather in this region is more important than weather at the observatory level. For instance many foliar pathogens need a thin film of moisture on the leaf surface for development of infection structures which is usually termed as leaf wetness. The duration of leaf wetness determines the successful establishment of the pathogen on the host.Accounting for the microclimate can help in developing reliable weather based prediction systems for pathogens. However, it is not always possible to record microclimate in the crop canopy due to lack of infrastructure and trained manpower. An alternative could be to develop reliable indices that can explain the relationship between observatory and canopy weather data.

Microclimate also influences rate of disease development. It was observed that even when susceptible cultivar and aggressive inoculum were provided, the variable weather conditions resulted in different apparent infection rates ('r') and area under disease progress curve (AUDPC) over two years. Fro instance, in groundnut-late leafspot system, though the 'r' in kharif 2004 (0.0664) was similar to 'r' in kharif 2005 (0.0759), the AUDPC was relatively less in 2005 and compared to 2004, which indirectly signifies the role of microclimate which in turn is influenced by other crop husbandry practices including date of sowing. Similarly, analysis of disease progression data from three locations of Tamil Nadu showed that the 'r' values differed over seasons and across years.

Many foliar pathogens require free water to germinate; therefore, disease pressure should favor plants that are able to repel water. For a suite of 18 sympatric clover species, leaf traits were evaluated affecting leaf wetness and susceptibility to infection by the fungal pathogen *Stemphylium* sp., causal agent of *Stemphylium* leaf spot. Spore germination increased with time in free water, and the relative susceptibility of host plants to infection was proportional to the duration of water retention on leaves. Larger leaves captured more water and retained it longer. Unexpectedly, trichomes and leaf wettability did not affect water capture. For clovers planted within natural clover populations at two sites, infection was threefold greater at the wetter site. At the drier site, water retention on the leaf surface was an important predictor of infection rates across host species, but persistent fog and dew at the wetter site reduced the importance of rapid leaf drying. Hence it can be suggested that plant adaptations that reduce water retention on leaves may also reduce disease incidence, but the selective advantage of these traits will vary among habitats.

Because moisture and temperature influence the growth of fungi, characterizing weather conditions favorable for fungi may be used to predict the abundance and richness of fungi in habitats with different climate conditions. To estimate habitat favorability to fungi, the relationship of fungal abundance and species richness to various weather and environmental parameters was studied in the Intermountain West. Measures of moisture availability, such as relative humidity and vapor pressure deficit, explained more of the variance in fungal abundance and richness than did temperature. Weather variables that took into account the proportion of time habitats experienced favorable or unfavorable relative humidity and temperatures were the best predictors, explaining up to 56% of the variation in fungal abundance and 72% for fungal richness.

The persistence of leaf surface moisture, a condition critical for the development of most foliar fungal pathogens (Jones, 1986), plays a key role in the epidemiology of fungal diseases. Numerous studies have shown an increase in the incidence and severity of disease with increasing duration of leaf wetness (Cowling and Gilchrist, 1982; Evans et al., 1992; Filajdic and Sutton, 1992; Montesinos et al., 1995; Basallote-Ureba et al., 1999; Suheri and Price, 2000). Many foliar pathogens require extended periods in free water for spore germination, germ tube growth, and host penetration (Everts and Lacy, 1990; Wadia and Butler, 1994; Vloutoglou et al., 1996; Gilles et al., 2000). In natural ecosystems, foliar pathogens can exert important selection pressures on plants (Esquivel and Carranza, 1996; Gilbert, 2002), suggesting that the ability to repel water from a leaf surface may be an adaptation for the prevention of fungal infection. The mechanistic links between leaf water retention and fungal infection can provide a unifying framework for understanding variation in infection among plant species and across different habitats.

High relative humidity and several hours of free surface water are critical for both spore germination and successful infection (Huber and Gillespie, 1993; Cook and Whipps, 1993; Harrison et al., 1994). In addition, infection i.e., invasion of plant tissue by the fungus and disease i.e., the expression of symptoms such as lesions or necrosis (Agrios, 1998) on plants due to air-borne fungi are favored by temperatures of 15–40 C (Cook and Whipps, 1993; Griffin, 1994). Field studies on plant pathogens have demonstrated that high moisture and moderate temperatures favored the growth of fungi (Frolich and Snow, 1986; Griffin, 1994; Colhoun, 1973; Taylor, 1979; Rowan et al., 1999) whereas low relative humidity and extreme temperatures inhibited growth and spore germination (Harrison et al., 1994; Juniper, 1991). Other studies on soil fungi also show that prevalence differs among habitats and seasons and correlates positively with moisture and negatively with temperature (Harrison et al., 1994; Johansen and Rushforth, 1985). This apparent positive relationship between moisture and fungal growth and abundance may result from the high surface-to-volume ratio of fungi, making them vulnerable to water loss.

Conclusion

The positive association between habitat moisture and the incidence and severity of disease suggests that the selective pressures imposed on plants by pathogens may vary among habitats. However, the relationship of habitat characteristics to inoculum abundance, infection and disease is poorly understood. A systematic analysis of The role of microclimate in disease development can help in development of meaningful disease forewarning systems. However, not always the disease epidemic developments are associated with wet leaf surfaces and high humidity. For instance, powdery mildews prefer relatively dry weather conditions. Hence, while establishing relationships between diseases and microclimate, the nature of the pathogen has also to be considered.

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Micro-level Agromet Advisory Services

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Climate change and climate variability are now considered as the two most impacting aspects on agriculture in times to come. Climate change has necessitated us to start planning for agriculture in the climate change situations. Indeed, scientists are now looking forward to acclimatize to climate change; but the apprehension is – how well we can sustain our agriculture in these adverse times! Studies on various facets of climate change – assessment, vulnerability, mitigation, adaptation strategies etc have been performed for more than a decade, and it appeared for a while that farmers were not getting their due in terms of their preparedness – until the program on National Initiative on Climate Resilient Agriculture (NICRA) was envisaged in 2011. As part of this *Initiative*, AICRP on Agrometeorology (AICRPAM) is vigorously attempting to sensitize the farmers on the need to achieve climate resilience not only by using various agro-technologies under adverse weather conditions, but more so by adopting weather based farming operations for their agricultural sustenance, driving home the point – *prevention is better than cure*. Under the aegis of NICRA, Bijapur Centre of AICRPAM has been identified to take up this program at the high spatial resolution of Taluka / Block for timely dissemination of agromet advisories in Belgaum district of Karnataka. The district is an ideal choice for testing the efficacy of district level weather forecast at higher spatial resolution, as it encompasses both subhumid and semiarid climatic types which consist of five talukas each. Agroclimatically these correspond to: one taluka in hilly zone, four in northern transition zone and five in northern dry zone of Karnataka.

Role of agromet advisories in climate resilience of farmers

Numerous new technologies are being developed by agricultural scientists, but their success is restricted by increase in the frequency of aberrant weather situations occurring every year. To reduce any such negative influence, we need to impress upon the farmers to follow the weather and weather forecast and there upon take up preventive measures or withhold taking up the measures that would have negative influence or would get nullified with change in weather conditions. Adoption of agrometeorological advisories would not only help in reducing present day crop and economic losses, but also make them resilient to weather, climate and climate change in the long run.

The noble idea of weather based advisory service to the farmers conceptualised in 1980s, was based on the premise that the three-day medium range forecasts (MRF) issued by National Centre for Medium Range Weather Forecasting (NCMRWF) for individual agroclimatic zones would help the farmers to support their crop in adverse weather conditions. Since 2007 the MRFs are being issued by India Meteorological Department (IMD) for five-days at district level. While pre-2007 weather based advisories were disseminated through news paper bulletins and by post, they are being disseminated through mass media and uploading to IMD website now. Thus, while the farmers received the bulletins after the period of influence of forecast and advisory in the 3-day forecast period, the advisories uploaded to websites in the 5-day forecast period can be accessed by only a few farmers who are versed with the internet and communication technology, as the most farmers depend on the conventional mouth-to-mouth contact system for exchange of information. Hence, a system that uses both the conventional and the ICT methods in tandem was felt necessary and implemented in this AICRPAM-NICRA program in Belgaum district of Karnataka at micro-level.

Development and dissemination of agromet advisories under nicra

Agromet advisories are prepared with active collaboration between AICRPAM-NICRA and KVK-NICRA. The approach followed in development and dissemination of the advisories is pictorially presented in Fig 1. The information and communication technology is liberally utilised for this purpose.

The following information is used as input for preparation of agromet advisories for individual talukas once a week.

- Five-day weather forecast for Belgaum district sent by the Met Centre, Bengaluru (IMD) every Tuesday and Friday – email
- Taluka level ground truth of weather and crops sent by the designated Field Information Facilitators (FIFs) one day before the forecast (Monday for humid/Subhumid Talukas and Thursday for Semi-arid Talukas) – email or cell-phone call
    - Weather prevailed during the past week
        - Rainfall
        - Real-time extreme weather events like fog, hailstorm etc

- Crop status
    - Crops, varieties, crop stage
    - Soil moisture condition
    - Insects / diseases
    - Photographs of any visible problems faced by the crops in the field (email)
    - Interaction between AICRPAM-NICRA and KVK-NICRA for finalization of the content of the agromet advisory bulletin

Dissemination of Agromet advisory bulletins

The taluka-wise bulletins are immediately circulated through email among:

- Respective FIFs of various talukas
- Assistant Directors of Agriculture of all Talukas
- NGOs of respective Talukas

The NGOs and FIFs make multiple copies of the advisory and distribute to the selected progressive farmers and as well paste them at important places of farmers' gathering and schools in the village. These have helped the farmers not only to get ready to take up immediate field operation, but also get habituated to visit the place every week. Pasting the bulletins at the schools has enabled school children also to know about weather based farming operations, as today's children are tomorrow's citizens. The ADAs on the other hand forward the bulletins to the officials at *Raitha Samparka Kendras* (RSKs) for further action. The entire process of dissemination covers only a couple of hours to reach the farmers, and is the quickest possible mode of information transfer as on today.

Farmers' Feedback

The efforts of AICRPAM-NICRA were evaluated by getting feedback from the selected progressive farmers by both telephonic interactions and personal visits to their fields and their response was noted. The salient among them are:

- ✓ The advisories provided through FIFs are specific to the crops grown in their area.
- ✓ Information provided on management of pest and disease is very useful.
- ✓ The advisory was used for harvest and post harvest operations.
- ✓ For the first time we are knowing about weather information of our region and farm advice depending on weather conditions.
- ✓ Farmers in the semi-arid Talukas are not happy with the forecasts, and suggested that forecasts at Taluka level would be more helpful.

This lacuna needs immediate rectification. However, in order to improve the efficacy of the advisories, for the time being, the farmers were guided by the forecast messages provided by the Agrometeorologist through SMS/phone for taking up field operations suggested in the advisories, and this improved the farmers' confidence to follow the advisories.

Impact of NICRA agromet advisories

For successful agriculture, timeliness of various field operations – from pre-sowing to post-harvest – is of utmost importance. To ensure this, the weather forecast and the agromet advisories were provided to farmers through a network of local personnel without time lag.

By preparing the Agromet advisories separately for individual Talukas basing ground level information from the Taluka concerned, the advice the farmers got was more realistic. State Department of Agriculture Offices and NGOs have become active players in this program. With the efforts of AICRPAM-NICRA, the farmers who had never heard of availability of weather forecast and related advice for field operations have become enthusiastic to get involved with this program.

The entire process can be up-scaled by increasing the network of FIFs, uploading of ground truth onto the web rather than using the cell phones by FIFs and uploading the advisories by the AICRPAM-NICRA onto the web for further downloading and dissemination at village level by the FIFs. This will be a big leap in promoting resilience of the farmers to climate change considerations.

Capacity building of farmers

The procedure adopted in the project is facilitating only a few farmers. This has to be widened across farmers and villages and make many more farmers to be prepared for the eventualities of climate change. So, farmers' awareness programs were conducted in this context involving farmers from the neighbouring villages. They are informed about weather, weather forecasts, climate change, role of weather on farming operations, weather based agro advisories and their adoption for sustenance of agriculture. With a futuristic outlook, participation of school children in awareness programs is also being encouraged.

The beneficiary farmers themselves were made to speak at the Farmers' Awareness Programs and share their impressions so as to enhance the authenticity of the program. These farmers' awareness programs were conducted in villages rather than in towns or cities.

In spite of the limitations faced like non-availability of higher resolution weather forecast and limited accuracy of district level rainfall forecast, we have created awareness at grass root level about weather centric farm operations to reduce crop losses. The experience of the program indicates the urgent need to provide at least now-casts and short range forecasts to the farmers for their respective areas to take up preventive measures. With better and higher resolution forecasts in future, the farmers will definitely become very much pro-active to weather and weather based farming to enhance their capability towards climate smart and, therefore, climate resilient agriculture.

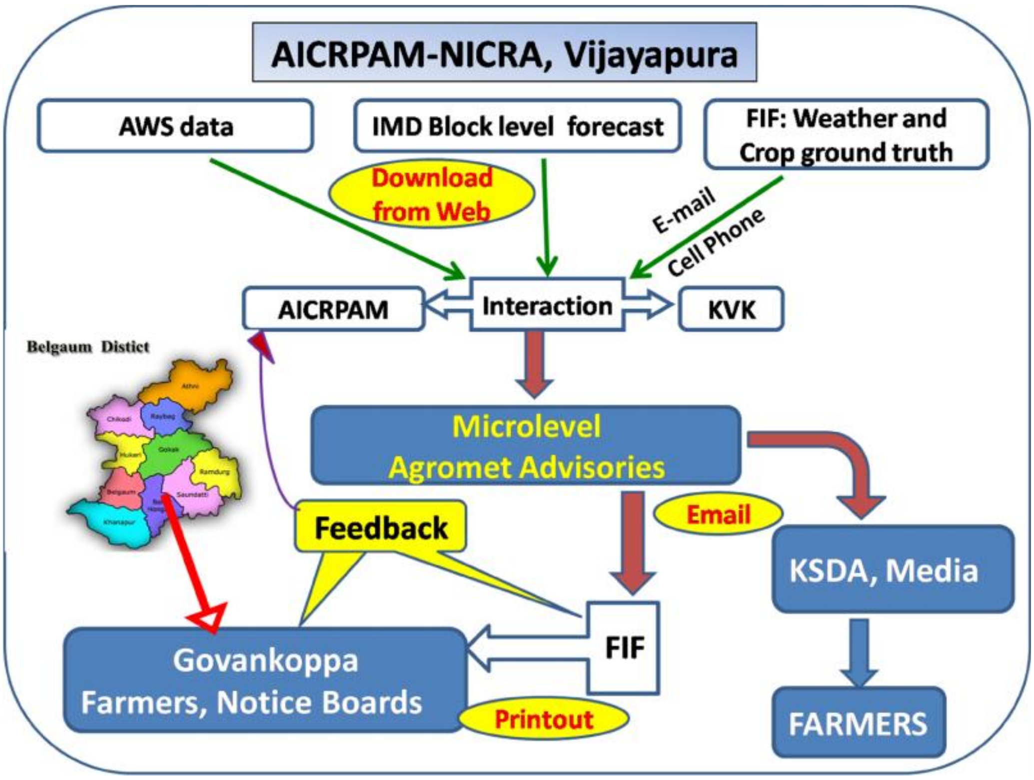

Fig 1. Flow chart for Microlevel Agromet Advisories in AICRPAM-NICRA project in Belagavi district, Karnataka

Water Balance by Thornthwaite & Mather And FAO Methods

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Introduction

Estimations of water balance components, *viz*., actual evapotranspiration(AET), water surplus (WS)and water deficit(WD) over a region are extremely important in the field of Hydrology, Agriculture, Ecology, etc. in identifying the regions suitable for different crops. Water balance computation is one of the important tools in applied climatology that has innumerable applications, *viz*., climatic classification, agricultural crop planning, water harvesting potentials, and in climate change studies, Thornthwaite (1948) developed the procedure to compute the water balance by considering the monthly rainfall and potential evapotranspiration (PET) a new terminology introduce by him.

The procedure was slightly modified in 1955 by Thorthwaite and Mather by introducing the soil moisture retention tables for different types / depth of soils. Due to its wide applicability, the water balance computational procedures are in great demand. FAO (1979) also brought out a monograph to compute crop-specific water balance by considering the weekly rainfall and the corresponding crop water requirements instead of potential evapotranspiration. The required crop water requirements are computed by multiplying the PET with crop coefficient (Kc) values.

All water balance models attempt to determine what happens to water that is applied to or fall on a given area. The water balance of a system is the difference between the inputs to the system and the flow of water out of the system or storage of water within the system. The inputs are generally precipitation or in some cases, irrigation although, depending upon the boundaries of the system, it could also include water brought into the system through run off. An equation describing the water balance may be written as:

$$\mathbf{P + I = R + D + ET + \Delta SM}$$

Where,

P = Precipitation
I = Irrigation
R = Surface runoff
D = Deep drainage
ET = Evapotranspiration
ΔSM= Change in soil moisture storage

A. Calculation of Water Balance by FAO Method (1979)

In order to compute the weekly water balance according to FAO method, it is necessary to have the following information at a place.

- Weekly rainfall (mm)
- Weekly potential evapotranspiration (mm)
- Weekly crop coefficients
- Available water holding capacity of the soil (mm)

Procedure for calculating weekly water balance

The different steps involved in the computation of the cumulative weekly water balance for the specific crop are detailed below:

Step-1:

- Enter weekly rainfall (PPT)

Step-2:

- Enter weekly potential evapotranspiration in the same units as rainfall (PET)

Step-3:

- Enter crop coefficients (KCR)

Step-4:

- Compute water requirements of the crop (WR)
- Water requirements of the crops are worked out by multiplying the potential evapotranspiration of the week by the crop coefficient of that week and also calculate total water requirement of the crop for the season by adding the successive water requirements week by week.

Step-5:

- Compute (PPT-WR) for different weeks
- The difference between actual rainfall and water requirement expresses whether the rainfall is adequate to meet the demand of the crop, without, however, taking into account the water stored in the soil The negative value of the (PPT-WR) indicates, the water demand of the crop is not met by rainfall. In this case, the crop takes the water from the soil if water is available in the soil. The positive value of (PPT-WR) indicates, the water supply is more than the water requirement of the crop. The excess water goes to recharge the soil upto its capacity.

Step-6:

- Surplus (SPL)
- Surplus refers to quantity of water whenever the soil moisture reserve exceeds water-holding capacity of the soil

Surplus = (PPT-WR) + Previous week's soil moisture reserve – Available water holding capacity

Note: Whenever surplus occurs, the value of water holding capacity itself is the soil moisture reserve

Step-7:

- Deficit (DEF)
- When the difference between (PPT-WR) is negative, it indicates deficit. This refers to the short falls in the water requirement after taking soil moisture reserve into consideration.

- Deficit = (PPT-WR) (without sign) – Previous week's soil moisture Reserve

Step-8:

- Water requirement satisfaction index (WRSI)
- It is assumed that sowing takes place when at least 75 mm of rainfall has been accumulated. So index is assumed to be 100 at the beginning of crop growing season. This index will remain at 100 for the successive weeks until either a surplus of more than 100 mm or a deficit occurs. If a surplus of more than 100 mm occurs during a week and the rainfall during the same week has fallen in less than 3 days, the index is reduced by 2.1 units during this week and remaining at the level until a further stress period occurs. If the deficit occurs, the index is calculated by subtracting the percentage reduction during the week from the preceding week's index. The percentage reduction during the week is calculated as the ratio of deficit during the same week and total water requirement of the crop expressed as percentage. The calculation is pursued to the end of the growing season taking into account the fact that the index starts in the first week at 100 and thereafter can only remain at 100 or goes down. The index at the end of the growing season will reflect the cumulative stress endured by the crop through excesses and deficits of water and will usually be closely linked with the final yield of the crop, unless some other harmful factors (eg. pests and diseases, strong winds etc.) have predominant affects.

B. Calculation of Weekly Water Balance by Thronthwaite and Mather's method (1955):

To compute the weekly water balance according to Thronthwaite and Mather's method (1955), following information at a place is required.

- Weekly rainfall in mm
- Weekly potential evapotranspiration in mm
- Available water holding capacity of the soil in mm

Procedure to calculate weekly water balance:

The different steps involved in the calculation of weekly water balance are given below:

Step-1: Enter weekly rainfall (P)

Step-2: Enter weekly potential evapotranspiration (PET)

Step-3: Enter available water holding capacity of the soil (AWC)

Step-4: Compute (P-PET) for different weeks

The difference between actual rainfall and potential evapotranspiration expresses whether the rainfall is adequate to meet the atmospheric demand, without, however, taking into account the soil moisture stored in the soil. The negative value indicates that the atmospheric demand is not met by the rainfall. In this case, soil moisture is taken from the soil, if it is available in the soil. The positive value indicates that the water supply (rainfall) is more than the atmospheric demand. The excess water goes to recharge the soil up to its capacity.

Step-5: Surplus (SPL)

Surplus refers to quantity of water wherever the soil moisture reserve exceeds water holding capacity of the soil

$SM_i = SM_{i-1} + (P_i - PET_i)$

If SM_i is greater than AWC, surplus occurs

$SPL_i = SM_i – AWC$

$SM_i = AWC$

$AET_i = PET_i$

Step-6: Deficit (D)

When the difference between (P-PET) is negative, it indicates deficit. This refers to short falls in the atmospheric demand.

Compute accumulated potential water loss (APWL)

$APWL_i = \sum (P_i - PET_i)$

$SM_i = AWC * \exp(\left(\frac{-APWL}{AWC}\right)$

$AET_i = P_i + \Delta SM_i$ $\qquad$ $D_i = PET_i - AET_i$

Where, ΔSM is change in the soil moisture storage

$\Delta SM_i = SM_{i-1} - SM_i$

AET is actual evapotranspiration

SM is the soil moisture reserve

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Computations of Drought Indices

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Drought occurs when there is less rainfall than normal over an extended period of time, usually a season or more. It is a temporary condition even though it may extend to longer periods. Human activity increases the impact of drought due to higher water use that cannot be supported when the supply through rainfall falls below its normal. It occurs in both high and low rainfall regions. The deficit rainfall conditions increases the air temperature and decrease the relative humidity. Strong wind regime associated with the above conditions increases the water demand both for plant population and human beings considerably. As drought affects many economic and social sectors over the globe, the approaches taken to define drought reflect the regional differences. Also the impacts due to drought differ from one location to the other. Hence, several definitions have been developed over the period of time by a variety of disciplines. Wilhite (1985) has reviewed the literature and identified about 150 definitions of droughts. Though number of definitions for drought is available, it is now broadly categorized into four types, *viz*., Meteorological, Agricultural, Hydrological and Socio-economic which have international acceptance.

Criteria for Classification of Droughts

Thornthwaite (1947) classified droughts into four kinds, *viz*., permanent droughts, seasonal drought, contingent droughts and invisible droughts.

- ***Permanent droughts*** are the characteristic of direct climate.
- ***Seasonal droughts*** are found in climates which have well defined rainy and dry season and most of arid and semi-arid regions fall in this category.
- ***Contingent droughts*** refer to irregularity of rainfall, which is not regular to occur in any definite season.
- ***Invisible droughts*** occur in humid areas where rains do not supply enough water to counteract the water loss by ET.

Droughts are governed by three characteristics, *viz*., intensity, duration and spatial coverage. The severity of drought impacts is associated with the shortfall in rainfall within the season, the timing of onset and withdrawal of rainy season. The areas covered by severe drought evolve gradually and the maximum intensity centre shift from season to season and year to year. To evolve suitable computational methods for identification of droughts, several researchers and organizations over globe developed procedures using basic weather parameters and their deviations over their mean, which are widely used for identification of droughts. Since soil moisture and temperature affect the agricultural crops, climate derivatives computed from water balance and cumulative temperature differential of air and canopy temperature over a period were used in deriving methods for computing agricultural droughts. Remote sensing derived parameters were also put into use for defining drought conditions over a region in estimating the water stress on crops.

Based on the rainfall departures alone, the Drought Research Wing of IMD categorized droughts as follows:

Drought week	:	When rainfall in a week is less than half of its normal
Agricultural droughts	:	When four drought weeks (normal > 5 mm/ week) occur consecutively during mid May-October
Seasonal droughts	:	When seasonal rainfall is deficient by more than 2 σ
Drought year	:	When annual rainfall is deficient by 25 percent or more of the normal value
Severe drought year	:	When annual rainfall is deficient by 50 percent or more of the normal

Meteorological Drought

The criteria followed in India for identification of different scales of meteorological droughts (Kulshreshta, 1997) based on rainfall departures are given below:

Scale of drought		**Definition of drought in terms of % departure of rainfall from long-term average**
Spatial	**Temporal**	
Meteorological sub-divisions	Weekly and Monthly	Less than 25%
Meteorological sub-divisions	Seasonal	Less than 25%
Group of homogeneous neighbouring met sub-divisions, *viz*., northwest, Peninsular India, etc.	Weekly and Monthly	Less than 25%
Group of homogeneous neighbouring met sub-divisions, *viz*., northwest, Peninsular India,	Seasonal	Less than 10%

etc.		
India as a whole	Seasonal	Less than 10%

India Meteorological Department declares a year as All India Drought Year when the average annual rainfall of the current year falls below 10 percent of long-term mean annual rainfall and the area affected by drought conditions (either moderate or severe or combined) must be above 20 percent of the total geographical area of the country. The Irrigation Commission of India identified a region as drought prone when 20 percent of data recorded years experienced meteorological droughts over the period. Similarly, chronically drought prone regions are identified when more than 40 percent of the recorded years experience meteorological drought. Subrahmanyam, 1964,defined the drought intensities on the departures Aridity Index (**Ia**) which is defined as the ratio of Water Deficit (**WD**) to the Water need (**WN**) where **WD = AE-PE and WN=PE**. AE and PE are actual and potential evapo-transpirations computed from Water balance method of Thornthwaite.

Drought indices

For monitoring and assessment of various types of drought conditions at different scales, most important is the identification of suitable methodology with appropriate indices and computation procedures based on the availability of data and its applicability over a large area.

Various methods are available for estimation of droughts through rainfall using standard statistical procedures. WMO Bulletin No.138 (1975) reviewed the statistical analysis methods, *viz.*, normal rainfall, rainfall variability, frequency distribution, and deciles of rainfall, frequency of droughts in sequences, persistence, extreme values, and spatial correlation methods.

Unreliable data points, lack of standard procedures to compute indices of drought prevalence and intensity could lead to inefficient management of droughts. Drought indices like Percent of Normal (PN), Deciles, Standard Precipitation Index (SPI), Effective Drought Index (EDI) and Bhalme-Mooley Drought Index (BMDI) use only rainfall. These indices are not only simple to compute and perform better over other complex indices. The climate derivate such as Soil Moisture Index (SMI), Moisture Adequacy Index (MAI) and Aridity Index (Ia) and remote sensing derivatives, *viz.*, NDVI, etc. have also been developed and are extensively being in use over the years.

Rainfall-based indices

Rainfall is the single most important factor influencing the incidence of drought and many definitions available in literature use this variable singly or in combination with other weather variables.

Sikka (1999) reviewed various drought indices developed by research group of IMD and observed that Blanford in 1880 was the first to assess the drought years on the basis of annual rainfall followed by Eliot (1902) and Walker (1910, 1923 & 1924). Ramdas (1950) defined monsoon drought on sub-region scale over India if the rainfall over an area was deficient by 25 percent or more of the normal during the season. Chowdhary *et al* (1989) devised a drought index (DI) based on the area receiving less than 75 percent of the normal rainfall.

$$\text{DI} = \frac{Drought\ area - Mean\ drought\ area}{Standard\ deviation\ of\ drought\ area}$$

And had categorized drought as

DI > 3.0 Calamitous

DI > 1.0 and < 3.0 Moderate

DI > 0.5 and < 1.0 Slight

They computed droughts for the period 1875 to 1987 using the above criteria for India and concluded that droughts occur over 20 percent of area in the country once in 5 years, 33 percent once in 10 years and higher than 50 percent area only once in 50 years.

Parthasarathy *et.al* (1995) has identified major droughts in India as given below from the standard deviation values of annual rainfall deficiencies.

Rainfall deficiency	:	Drought classification
Up to 1.0 σ	:	**Drought**
1.0 to 1.24 σ	:	**Mild**
1.25 to 1.49 σ	:	**Moderate**
1.5 to 2.0 σ	:	**Severe**
> 2.0	:	**Phenomenal**

Van Rooy (1965) developed a drought anomaly index based on rainfall departure and mean of lowest ten values of rainfall series.

$$I = -3 + \frac{P - \overline{P}}{\overline{\overline{m}} - \overline{P}}$$

Where I is an anomaly index, P is actual precipitation $\overline{P}$ in the normal precipitation; m is the mean of the ten lowest values of P on record.

Percent of Normal (PN)

It is calculated by dividing the actual rainfall over a season by its Long-Term Average (LPA) or normal rainfall and multiplied by 100 percent (Pai DS *et al,* 2010)**.**

- The seasonal rainfall over the country as a whole is termed as deficient when rainfall is less than 90 percent of LPA**.**
- When rainfall is in between 90-110 percent of LPA, it is termed as normal.
- When the seasonal rainfall is deficient (<90% of LPA) and 21 to 40 percent of area of country is under drought, it is termed as All India drought.
- When the seasonal rainfall over the country is deficient (<90% of LPA) and more than 40 percent of area of the country is under drought, then it is called as All India severe drought.

Bhalme and Mooly Index

It is popularly termed as accumulated Negative Moisture Index (NMI). The values vary between normal to extreme drought conditions which is similar to Palmer's drought intensity classification.

NMI (m) = 100 ($\mathbf{P_{m\,tot}} - \mathbf{P_{m\,mean}}$)/e

Where $\mathbf{P_{m}}_{\text{mean}}$ is monthly mean rainfall

$\mathbf{P_{m}}_{\text{tot}}$ is total monthly rainfall of month m

e is the standard deviation

The negative values of NMI indicate the drought condition. The intensity of drought based on NMI value is as follows.

NMI Values	:	Drought condition
0.99 to -0.99	:	**Near normal**
-1.00 to -1.99	:	**Mild**

-2.00 to -2.99	:	**Moderate**
-3.00 to -3.99	:	**Severe**
-4.00 or less	:	**Extreme**

Standardized Precipitation Index (SPI)

SPI is an index developed by McKee *et al* (1993) based on the rainfall for the time scale of interest and is relatively less complex to compute. The versatility allows the SPI to monitor short term water supplies, such as, soil moisture, ground water supplies, stream flows, lakes and reservoir levels. For computations of SPI for any location, long-term rainfall data are desired. This data is fitted to a probability distribution which is then transformed into a standardized normal distribution so that the mean SPI for the location and desired period is zero.

The SPI represents the total difference of precipitation for a given period of time from its climatological mean and then normalized by the standard deviation of precipitation for the same period computed using the data over the entire period. It is written as

$$\mathbf{SPI} = \frac{\mathbf{a-A}}{\mathbf{Sd}}$$

Where **a** = current precipitation for a given period (Week, month)

A = long term normal of precipitation for the same period

Sd = standard deviation of precipitation for the given period

To compute SPI, long term precipitation data is fitted to a probability distribution which is then transformed into normal distribution, so that mean SPI for the location and for specific period is zero. Positive SPI values indicate greater than median precipitation while negative values indicate less than median values. McKee *et.al,* (1993) defined the criteria of a drought as an event that occurs whenever the SPI is continuously negative and reaches an intensity where SPI is -1.0 or less and the event ends when the SPI becomes positive. Therefore, using SPI, the duration and intensity of drought can be defined precisely.

As SPI is a normalized value, the wetter and drier climates can be represented in the same way. McKee *et.al*, (1993) used the following classification system for SPI value to identify drought intensities as follows.

S.No	SPI values	Intensity of dry/wet spells

1.	2.0 and above	Extremely wet
2.	1.5 to 1.99	Very wet
3.	1.0 to 1.49	Moderately wet
4.	-0.99 to +0.99	Near normal
5.	-1.0 to -1.49	Moderately dry
6.	-1.5 to -1.99	Severely dry
7.	-2.0 and less	Extremely dry

As the theory behind transformation and computational procedures are lengthy and time consuming, computer software for computation of SPI were developed by many Scientists. The readers are advised to download SPI program from the software http://drought.unl.edu/monitoringtools and compute the SPI values for identification of drought intensities

Deciles method

Deciles of rainfall are widely used in Australia and are more popular. This is an example of cumulative frequency distribution in which, the limits of each deciles of the distribution are calculated from the cumulated frequency curve or an array of data. The first decile is that rainfall amount, that would not exceed by the lowest 10 per cent of totals. The second decile is that rainfall amount that would not exceed by 20 percent of totals and so on. The decile ranges are the ranges of values between deciles, for example, the eight decile range represents the values between seven and eight deciles. The decile values provide a comprehensive picture of rainfall distribution at a place and knowledge of decile range into which a particular total falls gives useful information on departing from normal. The following are(Table 2.4) the decile ranges in classifying rainfall.

Table 2.4 : Rainfall distribution under different Decile ranges

Rainfall departure	Decile class (%)	Decile range
Very much above normal	Highest 10	10
Much above normal	80-90	9
Above normal	70-80	8

Slightly above normal	60-70	7
Normal	40-60	6 & 5
Slightly below normal	30-40	4
Below normal	20-30	3
Much below normal	10-20	2
Very much below normal	Lowest 10	1

Spatial correlation

For using this statistical technique, it is essential first to test the normality of rainfall data series to be correlated and if these are significantly different from normal, a transformation procedure should be applied. Maher (1968) studied the spatial association of rainfall over Australia using 100 stations data for the period 1900-1964. He has selected a master station and correlation coefficients were calculated for annual rainfall values between master station and each of the other stations in the region. Taking hypothesis that the population value of correlation coefficients r is not zero, then at 5 per cent significance the value of r were plotted and isopleths at 0.25 of r values were drawn relative to each station.By this, it would be possible to evaluate the degree and pattern of rainfall association when conditions are dry at the master station.

Palmer Drought Severity Index (PDSI)

Palmer (1965) developed an index to measure the departure of the moisture supply. This index was developed on the concept of supply and demand of the water balance equation taking into account more than just the precipitation deficit at specific locations. It indicates the standardized moisture conditions and allows comparison to be made between locations and months. The PDSI values are normally computed on monthly basis.

To compute the Palmer Index, long term climatological data is required to derive five constants which define the moisture characteristics of the climate of the region under study. The first step in the computation is the monthly water balance accounting for long period (30 years more). A two layer soil model was used and PE is estimated by any standard method. The upper layer is assumed to have 25 mm of available water at field capacity. The loss from the underlying layer depends on the initial soil moisture content as well as on PE and available water capacity (AWC) of the soil system. Runoff is assumed to occur only if both layers reach their combined moisture capacity. In addition to PE, three more additional potential terms such as Potential Recharge (PR), Potential Loss (PL) and Potential Runoff (PRo) are introduced. Potential Recharge is defined as the amount of moisture required to bring the soil in to its water holding capacity. Potential Loss is defined as the amount of moisture that could be lost from the soil by the evapotranspiration during rainless period. The Potential Run Off is defined as the difference between the potential precipitation and potential recharge.

From the results of summarized water balance computations, five constants for each of 12 months have to be generated. The constants are as follows:

1. α is the coefficient of evapotranspiration

   $$\frac{Mean\ of\ monthly\ evapotranspiration\ (ET)}{Mean\ monthly\ PE}$$

   It varies from 1.0 in humid climate to approaching 0 in extreme arid regions.

2. β is the coefficient of Recharge

   $$\frac{Mean\ monthly\ moisture\ gain\ (R)}{Mean\ maximum\ possible\ gain\ (PR)}$$

3. δ is the coefficient of loss

   $$\frac{Mean\ moisture\ loss\ (L)}{Mean\ poential\ loss\ (PL)}$$

4. γ is the coefficient of runoff

   $$\frac{Computed\ mean\ runoff\ (Ro)}{Mean\ potential\ runoff\ (PRo)}$$

5. The constant K is an empirically derived weighting factor that depends on number of measures of the moisture supply and demand characteristic of the climate in question

   K = 448.8 K’ / DK’

   Where D = $|P - \hat{P}|$

   $\hat{P}$ is the adjusted value of precipitation which is climatically appropriate for existing conditions

$$K' = 1.5\log_{10}\left[\left(\frac{\bar{E}+\bar{R}+\overline{R_o}}{\bar{P}+\bar{L}}+2.80\right)\frac{25.4}{\bar{D}}\right]+0.50$$

Where values are expressed in mm.

It is possible to compute the amount of precipitation ($\hat{P}$) that should have occurred in a particular month to sustain the evapotranspiration, runoff and moisture storage that could be considered as normal.

$$\hat{P} = \alpha PE + \beta PR + \gamma PRo + S_{PL}$$

This computed precipitation is an adjusted normal precipitation, which is dependent on antecedent weather as reflected by computed moisture storage and an anomaly of PE during the month. Over a long period, the mean of the computed precipitation is equal to the mean of actual precipitation. For a particular month, the difference between actual precipitation and computed precipitation provides a measure (d) of the degree to which the month was abnormally wet or dry. The moisture anomaly index Z = k*d provides a measure that is comparable in space and time.

The drought index (x) depends on the sequence of z values which was derived empirically is as follows

$$X_i = X_{i-1} + \frac{z}{3.0} - 0.103X_{i-1}$$

The values vary from -4.0 (extreme drought) to +4.0 (extreme wet)

Positive values show wet conditions and negative values shows dry conditions. The PDSI values between -2 and +2 would indicate normal. However, the sub-range of -1 to -2 is treated as mild drought. If the values range -2 to -3, it is termed as moderate drought and -3 to -4 indicate severe drought and the values below -4 are considered as extreme drought. A drought sequence is considered as a sequence of 3 or more consecutive months with PDSI value ≤ 2.0. A sequence of 6 or more months where the PDSI values are less than -2.0 is termed as a major drought event and the end of the drought sequence is taken where the PDSI value of the last month is ≤ - 2.0.

2.5.2 Climate derivate based indices

Researchers have evolved methods to estimate drought conditions using climate derivatives instead measured parameters which provides the actual field conditions experienced by agricultural crops. These methods are quite useful in crop management and agricultural planning.

Moisture Adequacy Index (MAI)

Weekly Moisture Adequacy Index which is defined as the ratio of AE by PE is computed from water balance procedure (Thornthwaite & Mather, 1955). Drought impact is related to moisture availability at certain crop growth stages, which is described in earlier section under agricultural droughts.

Soil Moisture Index (SMI)

The soil moisture index is defined as the ratio of actual soil moisture to that of the available soil water of that particular type of soil.

$$\textbf{SMI} = \frac{\textbf{Actual Soil Moisture}}{\textbf{Available Soil Water}}$$

Actual soil moisture either can be measured or estimated using weekly water balance approach of Thornthwaite and Mather (1955). These values are used in identifying the water stress period.

During the crop growing season, the weeks that record SMI above 0.75 are considered as drought-free. If SMI values vary between 0.50 and 0.75, the crop in these weeks is subjected to moderate drought condition and if SMI is in between 0.25 and 0.50, the crop is subjected to severe droughts and if SMI is less than 0.25, the crop is subjected to extreme drought conditions.

Crop Moisture Index (CMI)

The Crop Moisture Index (CMI) compliments the PDSI developed by Palmer (1968). It measures the degree to which crop water requirements are met, which is more applicable to short-term changes in moisture conditions and is not meant to assess long-term droughts. It is normally computed on weekly basis using the mean temperature, total weekly rainfall and the CMI value from the previous week. A simple water budgeting would estimates the CMI for each week. It is possible to use a combination of PDSI and CMI for drought monitoring. PDSI serve as a long-term drought monitoring tool and CMI may provide the progression of seasonal water shortages during crop growing stage.

2.5.3 Remote sensing based indices

Normalized Difference Vegetative Index (NDVI)

The index is based on the concept that vegetative vigour is an indicator of water availability. The crop/vegetation reflects high in near infrared due to its crop geometry and the health of crop and absorbs high in red reflected radiance due to its biomass and accumulated photosynthesis. (Murthy and Seshasai, 2010) Using these characteristics, of near infrared, red and middle infrared band, which indicates both the health and condition of crops, different types of vegetative indices have been developed. Among these, NDVI is a popular index due to its simplicity in calculation and easy to interpret. It is widely used in Remote Sensing Application Studies. NDVI is a transformation of reflected radiation in the visible and near infrared bands of NOAA AVHRR and is a function of green leaf area and biomass.

$$\textbf{NDVI} = \frac{\textbf{NIR} - \textbf{RED}}{\textbf{NIR} + \textbf{RED}}$$

Where, Near Infrared (**NIR**) and RED is reflected radiations in these two spectral bands

Water, clouds and snow have higher reflected radiation value in the visible region consequently NDVI assumes negative values for these features. Bare soil and rocks exhibit similar value in both visible and near IR regions and the index values are near zero. The NDVI values for vegetation generally range from 0.1 to 0.6, the higher index values are associated with greater green leaf area and biomass where as lower values of index show moisture stress under ideal climate conditions (Tucker, 1979). The severity of drought situation can be assessed by the extent of NDVI deviation from its long term mean value (Burgan and Hartford, 1996) which is given by

$$\mathbf{NDVI_{dev} = NDVI_i - NDVI_m}$$

Where $\mathbf{NDVI_i}$ is the monthly NDVI value

$\mathbf{NDVI_m}$ is long term average for the same month.

The NDVI values can be contaminated by high cloud cover during crop season due to visible band cloud masking or off-nadir viewing or insufficient cloud free passes in compositing period require validation before use in drought assessment. Heavy rains during crop maturity reduce the yields which are not detected by satellites. Therefore NDVI can be used as an indicator of crop development only after recording of significant spectral emergence of crops, which has a lag of 2-3 weeks.

Normalized Difference Water Index (NDWI)

Short wave infrared (SWIR) band is sensitive to moisture availability in the soil as well in crop canopy. Initially during crop season, soil background is dominant and hence SWIR is sensitive to soil moisture in the top 1-2 cm layer. With the development of crop, SWIR becomes sensitive to leaf moisture content. NDWI using SWIR can complement NDVI for drought assessment particularly in the beginning of the season

$$\text{NDWI} = \frac{(\text{NIR} - \text{SWIR})}{(\text{NIR} + \text{SWIR})}$$

where Near Infrared and SWIR are the reflected radiations in these two spectral bands. Higher values of NDWI signify surface wetness and lower values indicate leaf water stress.

Crop Micrometeorology

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Micrometeorology is the study of small-scale meteorological processes associated with the interaction of the atmosphere and the Earth's surface. The lower boundary condition for the atmosphere and the upper boundary condition for the underlying soil or water are determined by interactions occurring in the lowest atmospheric layers.

The scope of meteorology is limited to only phenomena which originate in and are dominated by the shallow layer of frictional influence adjoining the earth's atmosphere, commonly known as atmospheric boundary layer or planetary boundary layer. In particular, micrometeorology deals with the exchange of heat (energy), mass and momentum occurring continuously between the atmosphere and the earth's surface, including sub surface medium. Micrometeorology also includes the study of how air pollutants are diffused and transported within the boundary layer and the deposition of pollutants at the surface.

Boundary layer: The part of the troposphere that is directly influenced by the presence of erath's surface and that responds to the surface forcings with a timesacle of about an hour or less. These forcings include frictional drag, evaporation and transpiration, heat transfer, pollutant emission, and terrain induced flow modification. The boundary layer thickness is quite variable in time and space, ranging from hundreds of meters to a few kilometers.

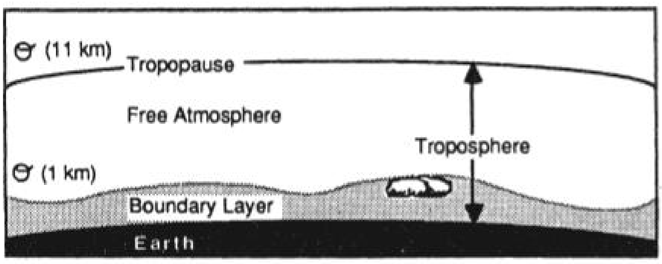


Fig. 1.1 The troposphere can be divided into two parts: a boundary layer (shaded) near the surface and the free atmosphere above it.

In many situations, atmospheric motions having time scales between 15 min - 1 h are quite weak. This represents a spectral gap that provides justification for distinguishing micrometeorology from other areas of meteorology. Phenomena studied by micro-meteorology are dust devils, mirages, dew & frost formation, evaporation, and cloud streets.

Micrometeorological division:

i) Ground surface

ii) Surface layer: It is a plane separating two different media i.e. air (fluid) and soil (solid), It is an important site for energy and mass exchange and conversion. It receives energy from sun and acts as a source of heat energy for all the atmospheric processes.

iii) Skin layer: 2-3 mm thickness above the ground surface up to 1.5 meters height. This is a thin layer adjacent to the surface ranging from few millimetres to 1.5 meters. The exchange of energy and mass is through the process of molecular conduction. Surface characteristic is dominant for exchange of energy. This is the layer, which has a direct significance to plants, animals and man. The environmental factors continually change in this layer. The nature of soil, type of plants grown, variable shading, and different wind protection methods are some of the factors responsible for these changes.

iv) Surface boundary layer: It a layer with 50-100 m thickness above the skin layer. The exchange phenomena is through eddies or through turbulent transfer. Temperature variation during day and night are observed in this layer. The wind structure is governed by surface characteristics, inhomogeneity, vertical distribution of temperature etc. Total heat in this layer is more than the total at the upper layer. Density variation is more pronounced. The effect of earth rotation is noticeable.

The main transformations of energy i.e. from radiant energy to thermal energy and sensible heat to latent heat take place in the surface boundary layer. It is also the region in which the transformation of mass i.e. liquid water to gaseous water vapour occurs.

It is the two layers (skin and surface boundary layers) with which all living organisms on the surface of the earth are concerned. The weather that prevails in this shallow layer is known as micro-weather or microclimate.

The surface boundary layer is important for the following reasons:

1. Plants, animals and man live in this layer.
2. All transformations of energy are taking place in this layer (solar radiation converted into heat only after reaching upon the surface of the earth).
3. Eo, ET and frictional wind drag largely originate at the earth- atmosphere interface.
4. Exchange of energy, momentum and mass i.e. water vapour between the earth’s surface and the atmosphere take place in the boundary layer.

v) Planetary boundary layer: It is 50-1000 m in thickness. The influence on wind is less. Temperature variation is very small. The air density is very small. Vertical motion of entities is less pronounced.

vi) Friction-less layer: This region is of relative equilibrium. The effect of surface friction is absent. The influence of earth's rotation is dominant. Majority of the radiant energy is absorbed, reflected and emitted in this layer. It lies above 1000 metre from the surface.

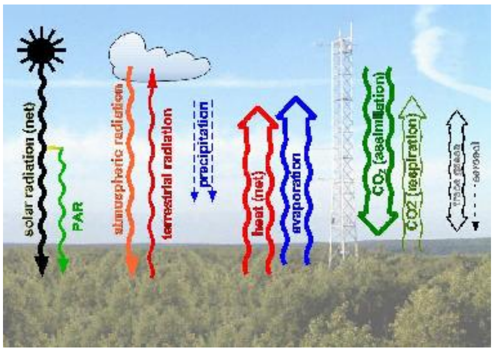


Fig. Atmosphere Biosphere Exchange

Crop Micrometeorology: It is a branch of micrometeorology that deals with the interaction of crops and their immediate physical environment.

The important topics in crop micrometeorology include heat transfer and gas exchange between soil, vegetation, and/or surface water and the atmosphere caused by near-ground turbulence. Measuring these transport processes involves use of micrometeorological (or flux) towers. Variables often measured or derived include net radiation, sensible heat flux, latent heat flux, ground heat storage, and fluxes of trace gases important to the atmosphere, biosphere, and hydrosphere.

Momentum, heat, water vapour, various gases, and particulate matter are transported vertically by turbulence in the atmospheric boundary layer and thus establish the environment of plants and animals at the surface. These exchanges are important in supplying energy and water vapour to the atmosphere, which ultimately determine large-scale weather and climate patterns.

Energy budget over a crop canopy: Energy is exchanged between the atmosphere and Earth surface. Solar radiation and atmospheric longwave radiation warm the surface and provide energy to drive weather and climate. Some of this energy is stored in the ground or oceans. Some of it is returned to the atmosphere, warming the air. The rest is used to evaporate water. These surface energy fluxes are an important component of Earth's global mean energy budget.

All organisms must balance energy inputs and outputs in order to maintain tissue temperatures within a given range. Plants have evolved a range of adaptations that allow them to balance energy gain and loss and so avoid becoming too hot or too cold. Energy budget equations quantify the energy gained and lost through different processes. The surface energy balance of the field (soil and crop) can be represented as:

$$\mathbf{Rn = H + LE + G}$$

Where, H = is the upward surface sensible heat flux: energy used to change temperature of atmosphere, LE = is the upward surface latent heat flux: energy used to change state of water, G = is the downward ground heat flux: energy used to change temperature of subsurface, and Rn = is the net downward radiative flux (longwave + shortwave).

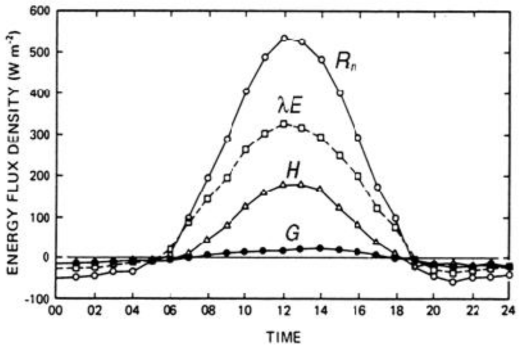


Fig. Diurnal cycle of the components of the surface energy budget in clear conditions at rural midlatitude site

Energy balance equation for different field situations, are:

1. Bare field: R_n = G + H + LE
2. Crop field: R_n = G + H + LE + P + M
3. Water surface: R_n = H + LE , G negligible, LE>H
4. Irrigated crop field: R_n = G + H + LE+ P LE>H
5. During night time : $R_n = R_L$
6. Desert area : R_n = G + H LE negligible
7. Mulched field : R_n = G

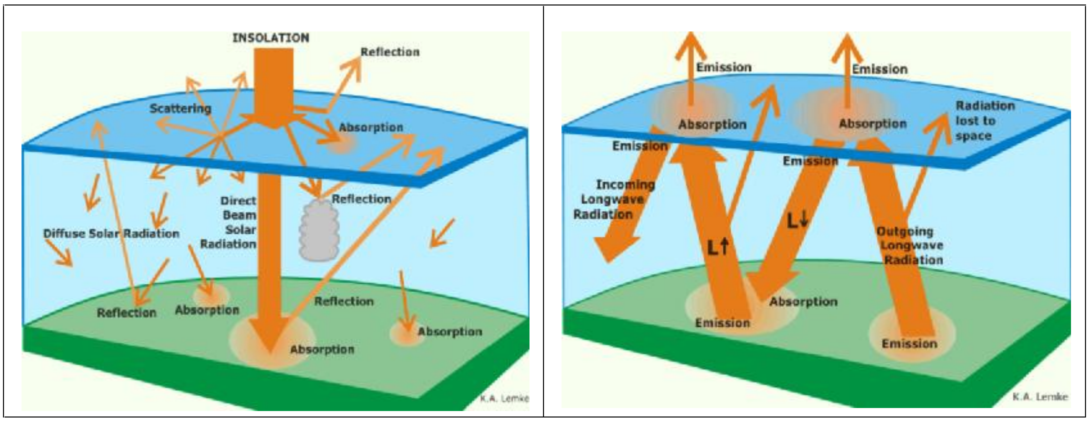
Bowen ratio: The nature of the ABL is determined by the balance between *H* and *LE*, which depends on surface moisture availability. A convenient parameter is the Bowen ratio, defined as: *B= H/LE.*

Radiation balance over a crop canopy: The radiation balance of plant canopies is an intricate interplay between absorption, reflectance, and transmission of energy by vegetation and soil over a range of wavelengths from the ultraviolet to infrared. Growth habit of the plants, plant density, and surface soil properties all influence the radiant energy regime of agricultural crops. Radiation interception by the crop canopy affects all components of canopy microclimate including the partitioning of evapotranspiration between evaporation directly from the soil and transpiration from the plant. Cultural practices from row spacing and seeding rate to variety selection strongly influence the local microclimate created by the plant canopy.

Net Radiation = Q* = total in - total out

$Q^* = (K\downarrow - K\uparrow) + (L\downarrow - L\uparrow)$

Q=(incoming shortwave - outgoing shortwave) + (incoming longwave - outgoing longwave)*



Shortwave radiation	Longwave radiation

Short wave (solar) Radiation (K)

- incoming shortwave = $K\downarrow$

  $K\downarrow = (S+D)$ S=direct beam solar, and D=diffuse (scattered) solar
- outgoing shortwave = $K\uparrow$
  - reflected radiation
  - $K\uparrow = [a(S+D)]$
  - a=albedo: proportion of insolation reflected from a surface
  - insolation reflected by atmosphere & earth's surface
  - albedo varies geographically & temporally
  - net shortwave $(K\downarrow - K\uparrow) = (S + D) – [(S – D) \times a]$
  - absorbed radiation (direct & diffuse)

Long wave (terrestrial) Radiation (L)

- incoming longwave = $L\downarrow$
  - radiation emitted by atmosphere
  - determined by air temperature
- outgoing longwave = $L\uparrow$
  - radiation emitted by earth
  - determined by surface temperature

net longwave = $(L\downarrow – L\uparrow)$

Radiation Balance Summary

- net radiation = amount radiant energy available to do work
- net radiation = total in - total out

$Q^* = (K\downarrow – K\uparrow) + (L\downarrow – L\uparrow)$ or $Q^* = [(S + D) – \{(S – D) \times a\}] = (L – L)$

Momentum, heat, and mass exchange in crop canopy

Traditionally, the main motive for studying turbulent flow in the plant environment has been to understand the processes governing momentum, heat, and mass exchange between the atmosphere and the biologically active canopy. This exchange regulates the microclimate in which plants grow, provides them with carbon dioxide for photosynthesis, and removes the water vapor produced in transpiration. An understanding of its mechanisms is essential for a variety of applications in biology, hydrology, agriculture, and forestry, as well as being relevant to wider questions concerning the global balances of carbon dioxide and nitrogen. Because of these strong and diverse practical motives, most research into turbulence in the plant environment has been empirical and observational; several decades of effort by many workers have produced no general and successful theory.

a) Wind profile over plant canopy:

The crop acts as barrier to the flow of wind. The nature of the crop stand, the stems, leaves; reproductive organs etc. all influence the nature of the wind profile within and outside the crop canopy. Essentially, the position of the active surface barrier is increased when wind blows over a crop stand. The depth of this frictional layer depends on the roughness of the surface and as the roughness increases the depth also increases.

The mean wind profile is one of the most easily measured aerodynamic properties of a plant canopy: a vertical array of cup anemometers, sited between plants is usually used. Figure below shows examples of canopy wind profiles measured in a pine forest (EF Bradley, Australia, unpublished data) and in a maize canopy (OT Denmead, 1979 Australia, unpublished data).3 It is convenient to present the profiles in dimensionless form, using h and the mean wind speed u(h) at the top of the canopy as normalizers. Characteristically, the mean wind shear is high in the upper part of the canopy and very low to negligible in the lower part, where there is often a stem or trunk space largely free from leaves or branches. Another highly sheared layer occurs close to the ground.

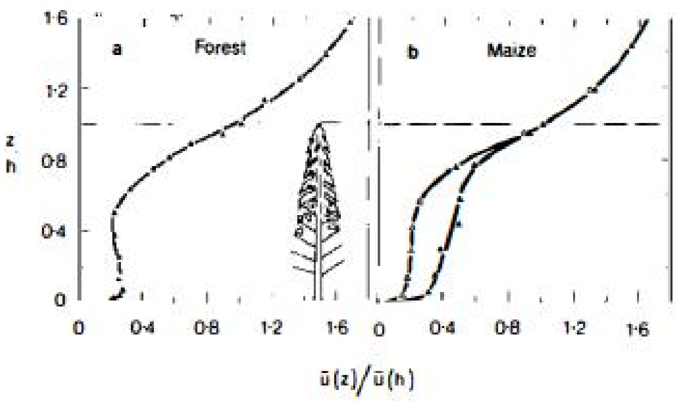


Figure 1 **(*a*) Profile of mean wind speed in a pine forest canopy (*h*=16 m); data averaged from 18 very-near-neutral one-hour runs. (*b*) Profiles of mean wind speed in a maize canopy (*h*=2.1 m) during periods of light wind [$\bar{u}(h)=0.88$ m s^{-1}, ▲] and strong wind [$\bar{u}(h)=2.66$ m s^{-1}, △].**

(Ref. Raupach, MR and Thom, AS 1981, Turbulence in and above crop canopies. *Ann. Rev. Fluid Mech.* **13**:97-129.)

(a) **Wind profile over a tall crop**

The wind profile over short crops may be expressed by a logarithmic equation.

$$u = \frac{1}{k}\left(\frac{2}{{}^{\circ}a}\right)^{\frac{1}{2}} \ln \frac{z-d}{z_0}$$

Where, $\boldsymbol{u_0}$ is the friction (or shear) velocity (m s^{-1}), $\boldsymbol{k}$ is the Von Kármán constant (~0.41), $\boldsymbol{d}$ is the zero plane displacement, is the surface roughness (in meters), z is the height above ground (m), and z_0 is the roughness length (m), τ is the turbulent shearing stress, and ρa is the air density (kg m^{-3}).

The length, z_o depends upon the shape, size, stiffness and density of the crop components.

(b) **Wind profile over short crops**

For short vegetation and for relatively smooth surfaces, the roughness parameter is relatively constant over a range of wind speeds.

$$u = \frac{1}{k}\left(\frac{2}{{}^{\circ}a}\right)^{\frac{1}{2}} \ln \frac{z}{z_0}$$

$$for\ \ \mathrm{Z} > \mathrm{H} > \mathrm{Z}_0$$

Profiles of meteorological elements: Microclimate in respect of the radiational, thermal, moisture and wind regimes prevalent in the field is represented in terms of profiles of net radiation, air and soil temperatures, vapour pressure, wind speed and CO_2.

Radiation profile: It is seen that the greatest depletion of net radiation usually occurs in the upper parts of the canopy. It is possible to manipulate the capture of radiation by changes in plant spacing and population and by changes in architecture of plant canopy it self. Hence our objective should be to maximize the absorption of useful energy especially at the lower canopy levels, which are not light-saturated.

Radiation and net radiation profiles: The net radiation profile within a crop indicates that the profile changes from a sharp increase of net radiation during high sun periods to small gradients during early morning and sunset. At night the slope of the profile is negative.

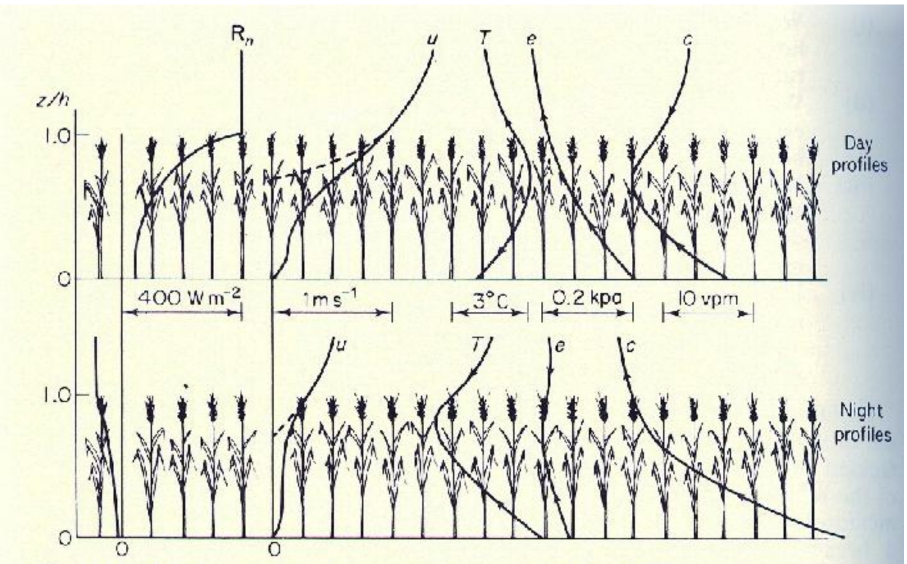


Fig. 14.1 Idealized profiles of net radiation ($\mathbf{R}_n$), windspeed (u), air temperature (T), vapour pressure (e) and CO_2 concentration (c) in a field crop growing to a height h plotted as a function of z/h. The pecked wind profiles represent an extrapolation of the logarithmic relation between u and $(z-d)$ above the canopy (see Chapter 7).

Temperature profile: During day time there is a temperature maximum near the mid of upper portion of the canopy. The temperature maximum occurs near the level of maximum leaf area where most of the solar radiation is absorbed. Above this level the profile is generally lapse, as it is typically above the canopy during daytime. Below this level, there is temperature inversion because the canopy is warmer than the soil surface underneath.

At night, temperature profiles in the lower levels of the canopy are close to isothermal since the canopy traps outgoing longwave radiation is being transmitted to the nocturnal sky. The profiles described here illustrate phenomenon of within canopy heat transfer is very general forms. The real situations are complicated by several factors. As the day progresses, for example, the stomatal resistances vary and the sources and sinks (locations and strengths) of sensible and latent heat undergo considerable change.

Relationship between energy balance and surface temperature

On a clear summer day in case of an ideal bare soil the following considerations can be found:

1. Energy is arriving at a faster rate than it is lost through absorption, scattering and reflection from a surface. That means input exceeds output. Due to accumulation of surplus energy, surface temperature is higher than the air. So, the maximum temperature does not coincide with the time of maximum energy input. Hence, the temperature continues to rise after the time of maximum energy input. The maximum temperature occurs at the time when input and output are equal. It occurs 1 or 2 hours after the receipt of highest energy i.e. 13:00 to 14:00 hours local mean time on a clear day.
2. Then temperature starts declining or dropping. It continues to drop as long as the rate of loss is greater than the rate of gain. Thus the minimum temperature occurs at the time where when input and output of energy are equal just before sunrise.
3. The air temp. rise more rapidly in the morning than it falls during the afternoon hours.

In case of ground surface covered with vegetation the following points can be noted,

a) The main heat exchange centre occurs just below the top of the crop canopy.
b) At night longwave radiation emitted from the crop gave rise to a minimum temperature just below the crown so that temperatures increase upward into the atmosphere and downward within the vegetation.
c) By day, the principal site of net radiation absorption is near the canopy crown, which is the level of maximum heating. Temperature decrease both upward and downwards from this level, hence the sensible heat is carried up into the air and down in to the crop. Then the temperature tends to drop and it continues to drop as long as the rate of loss is greater than the rate of gain. The minimum temperature occurs at the time when input and output balance.

2. **Day and Night temperature profiles**

During daytime temperature decreases with height and also with depth in the soil where as during night it increases with height in the atmosphere and with depth in the soil.

It is the level of maximum leaf area where most of the solar radiation is absorbed. Above this level the profile show a general decrease during daytime. Below this level, there is temperature inversion because the canopy is warmer than the soil surface underneath. At night, temperature profiles in the lower levels of the canopy are close to isothermal since the canopy traps outgoing longwave radiation is being transmitted to the night sky. However, the real situations are complicated by several factors. As the day progresses, the stomatal resistances vary and the sources and sinks of sensible and latent heat undergo considerable change.

A typical observation setup for micrometeorological study

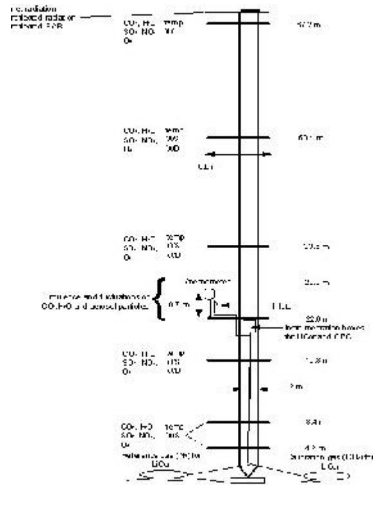


Fig.7 Micrometeorological station

Commonly used sensors for recording of different micrometerological parameters on mast

Sensors	Parameter

3-D sonic anemometer	u,v,w - m/s; Tvs - deg C
3-D sonic anemometer	u,v,w - m/s; Tvs - deg C
3-D sonic anemometer	u,v,w - m/s; Tvs - deg C
1-D sonic anemometer	w - m/s; Tvs - deg C
Platinum resistance thermometer	Temperature - deg C
UV Hygrometer	vapor density - gm/m^3
CO2 Concentration	density - gm/m^3
Prop-vane anemometer	u,v - m/s
Hygrothermometer	T - deg C; RH -%
Dew Point	Dew point - deg C
Pressure sensor	Pressure - mb
Rain gauge (Optical - ORG)	Rainfall rate - mm/hr
Net Radiometer	Net radiation - W/m^2
Precision Spectral Pyranometer	Global shortwave radiation - W/m^2
Precision Infrared Pygeometer	Global long wave radiation - W/m^2
Soil temperature sensor	Soil temperature - deg C
Heat flux plate	Soil heat flux - W/m^2
Surface temperature sensor	Surface temp. - deg C
Ultraviolet radiometer	Ultraviolet radiation
Dual beam ozone analyzer	O_3
Carbon monoxide analyzer	CO
Condensation nucleus counter	Condensation nuclei

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Application of GIS & Remote Sensing tools in Agriculture

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1. Introduction

Geographical Information System (GIS) and Remote Sensing tools and techniques are part of the Geospatial methods used extensively for survey, planning, design, development and assessment of innumerable processes, phenomena and for program implementation. In 1980s the concept of GIS was rolled out as a consequence of development and improvement of computing skills. The advent of space satellites fuelled the possibility of space-based remote sensing at the same time. At present satellite data obtained from remote sensing satellites form an important input for analysing temporal change in natural processes like rainfall, temperature, normalized difference vegetation index (NDVI), land use-land cover change (LULC and LCCC), soil erosion, agricultural production, drought and flood, monsoon activity etc., besides many others. India has developed the capability of developing and launching its own remote sensing, telecommunication and weather satellites. Data obtained from these are being used extensively for various applications in the country. For this lecture a short study of use of GIS and RS tools and techniques for watershed development and management is being presented, as rainfed agriculture is dependent on judicious use of limited water available in the region for agriculture.

Rainfed agro-ecological regions (AER) which encompass the semi-arid tropics (SAT) and hot dry and moist sub-humid regions of India includes over 95.09 m ha (28.98%) under the semi-arid climate and 3.19 m ha or 1 % of the land area under the transitional climate. Watershed-based development has been accepted as the template for agricultural development and economic planning of this region. In peninsular India average annual rainfall is 500 mm (300-800 mm), which occurs in 45-50 rainy days. Over 50% of this rainfall occurs by way of thunderstorm that lasts for a few hours. Considering such a rainfall pattern, it is essential to harvest, store and use rainwater for undertaking agriculture and other allied activities for the rest of the year. Intensive rainfall events induce severe soil erosion in bare or sparsely vegetated land that is common in the region.

Watershed Development and Management Program was initiated during 1980s to address these limitations of the rainfed AER (Planning Commission, 2001). Soil and Water Conservation Structures (S&WC) viz., check-dam, stone weirs, contour bund, live bunds, vegetative cover, key-line plantation, grass way etc. were planned to provide impediments to overland - runoff which induce soil erosion and depletion of nutrients from agricultural fields. Structures were laid to guide runoff to designated farm ponds and tanks for water harvesting on the surface, besides impounding water for facilitating deep percolation for groundwater recharge. Thus, Watershed Development Program (WDP) was considered the most comprehensive program for achieving agricultural and ecological sustainability in the rainfed regions in India. As India envisages sustaining an agricultural growth rate of 4.0 to 4.5 per cent in order to reduce food insecurity and poverty, while increasing rural purchasing power, it is essential to strive for achieving sustainable development through watershed development.

2. Watershed Development Program (WDP) in India

One of the primary reasons, in favor of watershed-based development in rainfed AER, is the enormous cost of major water projects like the under-construction Narmada river-valley project. Hence emphasis was shifted to augmenting water resources through small and decentralized projects and the WDP for rainfed regions in rural India, have remained the accepted strategy for rural transformation. Watershed Projects have been undertaken under six major national programs, viz. Drought-Prone Area Program (DPAP), Desert Development Program (DDP), National Watershed Development Project for Rain-fed Area (NWDPRA), Watershed Development in Shifting Cultivation Areas (WDSCA), Integrated Watershed Development Project (IWDP) and Employment Assurance Scheme (EAS) etc. by four Central Ministries of Govt. of India namely, Ministry of Rural Development (MORD), Agriculture (MOA), Environment & Forestry (MOEF) and Water Resources (WR). Significantly, 70 per cent of funds for watershed development in India are being spent under these six major programs. There are also, a lot of commonality in the WDP undertaken by these four ministries, in view of which, a inter-ministerial sub-committee (1999) evolved a common approach and principles for undertaking of WDP in India. The Perspective Plan of India envisages an holistic and integrated development of rainfed areas in the country on watershed –basis to cover app. 63 million ha at an estimated cost of Rs. 76,000 c*rore* or USD 1520 m (Planning Commission, 2005). A Technical Committee Report submitted to the Department of Land Resources (MORD) in January 2006 (Parthasarathy, 2006), estimates that at current level of outlay, it may take 75 years to complete watershed treatment in India. The Committee opined that if S&WC measures needed to be completed by 2020, the Government must allocate Rs. 10,000 crore (USD 20 m) annually for the purpose till then.

3. Evaluation of impact of Watershed Development Program (WDP) in India

Most of the studies undertaken to evaluate the impact of package of practices implemented under WDP have been based on qualitative data with some quantitative information for which econometric analysis had to be performed. All the studies faced two major problems due to which their scope of analysis was restricted. Firstly, baseline information of watershed villages is extremely difficult to obtain from Project Implementing Agencies (PIA) as there were no systematic methods or process put in place to collect and archive them; hence meaningful evaluation was always difficult. Next, periodic monitoring of WDP was neither undertaken by PIA nor the funding agency. As a consequence, most evaluation studies were forced to report on qualitative information only. These problems had been widely discussed and in more recent WDP, amendments have been made and a definitive process has been put in place to avoid similar problems. P.K. Joshi *et al* (2005) undertook meta-analysis of over 311 watershed projects and documented efficiency, equity and sustainability benefits. The authors point out that mean B: C ratio of a watershed program in the country was quite modest at 2.14. Internal rate of return was 22 % that was comparable with many other rural developmental programs.

To address these lacunae with reference to evaluation of sustainability of watershed projects in India, two research projects were undertaken at CRIDA under the *Ad-hoc* scheme and the ICAR National Fellow Scheme of the author to develop a methodology (Kaushalya et al., 2013)and a toolkit for evaluation of watershed development projects in the peninsular region of India since 2004 (Kaushalya et al., 2006 a& b, 2007, 2009, 2010). For this purpose, tools of Geo-informatics like GIS, Remote sensing techniques, DGPS and Spectro-radiometer were used to supplement information generated from actual field survey, soil analysis and socio-economic survey conducted in the selected watersheds and villages. Databases were created in ***MS-Access*** and thematic maps were drawn using ArcGIS. Multi-spectral satellite data were procured from NRSA for pre-project period i.e., 1998 and post-project periods, i.e., 2004 to 2006. The satellite imageries were interpreted to understand the processes of change using various indicators. A methodology was thus developed to generate baseline information for pre-project period for various parameters from field and satellite data which were in turn, used as sustainability indicators to assess sustainability of watersheds projects. In Figure 1 the modular scheme of the evaluation study has been depicted. The impact of non-implementation of WDP was compared in an untreated watershed in the vicinity for a clearer understanding.

4. Pre-field Activity

For evaluation of Watershed Development Projects (WDP) it is essential to select watersheds based on some pre-determined criteria. For our study in the AESR 7.2, five treated and an equal number of untreated micro-watersheds were selected in the districts of Rangareddy and Nalgonda in AP. The watersheds are located in the rural-urban divide zone at a distance 70 km from Hyderabad Urban Center. The pre-field activities undertaken prior to evaluation of the watersheds have been described in brief here.

4.1. Selection of watersheds

Our objective was to analyse which programs and agencies had implemented a sustainable watershed project in the study area. Hence projects developed by various agencies like the Dept. of Agri, Govt. of AP, - a line dept., NGO, research organization like CRIDA, MANAGE, NIRD, etc. was chosen for the study. As each of these PIA lay emphasis on various aspects, the outcome of the projects are very different. To capture these variations leading to difference in outcome of WDP five treated micro-watersheds were selected in five villages namely - Chintapatla near Ibrahimpatnam in Yacharam Mandal, Pamana in Chevella Mandal and Dontanpalli in Shankarpalli Mandal, Channareddiguda in Manchal Mandal – all in Rangareddy district and Gollapalli in Chintapalli Mandal in Nalgonda District.

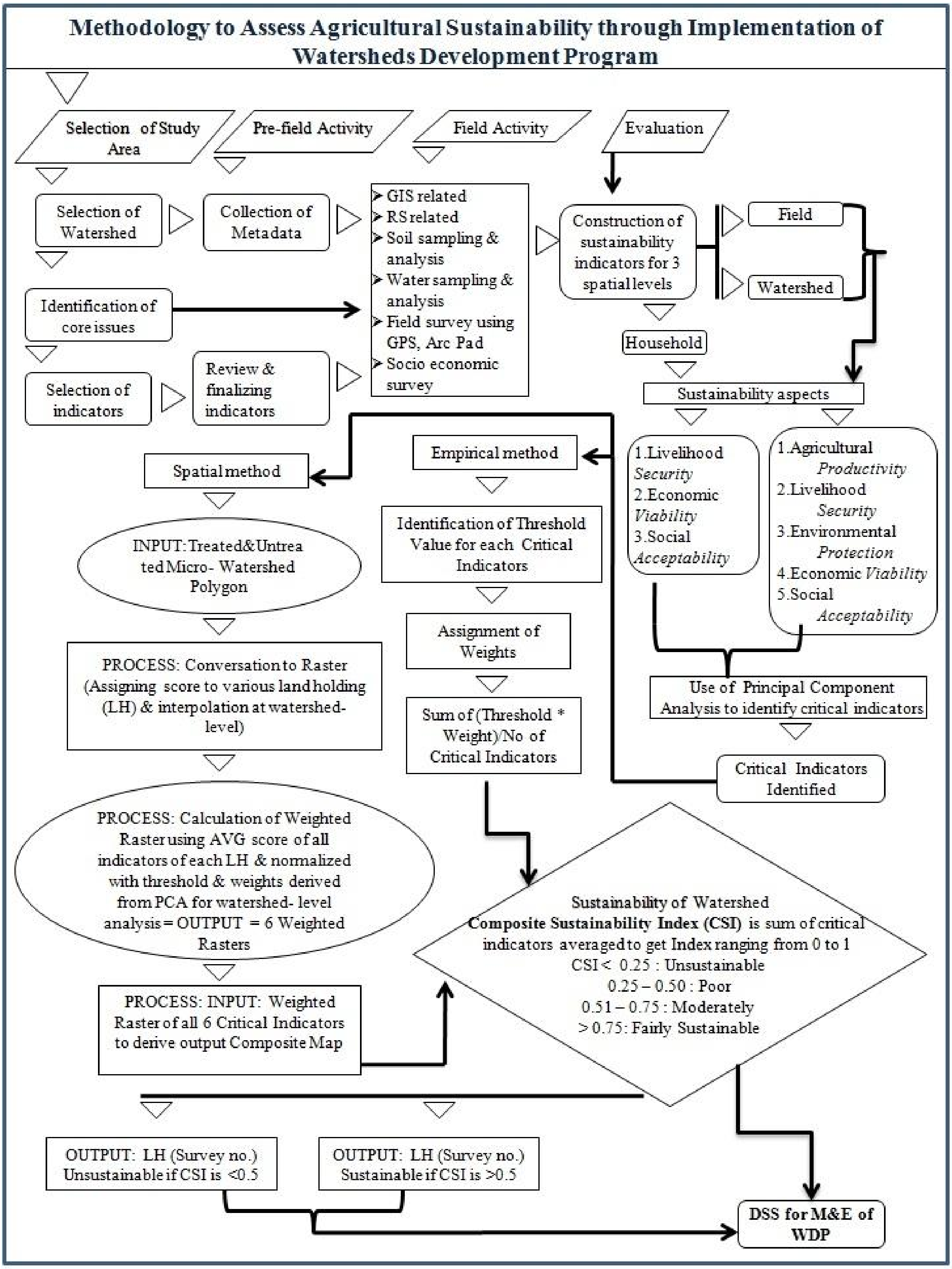

Fig.1: Methodology to monitor & evaluate sustainability of watershed projects.

4.2. Characterization of resource base in selected watersheds

The resources available in the various watersheds were surveyed and mapped using ArcGIS. Detail of this technique has been added in a later section in this paper.

4.3. Identification of core issues that affect agriculture in watersheds

After reconnaissance survey of selected watersheds and discussion with key informants, core issues that impact agriculture in the selected watersheds were identified. As these need to be addressed first to achieve sustainable development, the evaluation study and methodology is developed to address these issues

4.4. Identification and construction of relevant sustainability indicators

Based on the core issues, relevant indicators were developed to evaluate the various aspects of sustainable development. A set of fifty indicators was developed to evaluate the watershed projects under the NF scheme.

4.5. Methodology for identifying critical indicators

A methodology was developed to identify critical indicators for evaluating sustainability of watershed projects. The merits of this methodology are that it is helps in a quantitative evaluation that facilitates comparison of situation between two watersheds besides enabling mapping thus making the evaluation process easy, objective and useful. Wherever direct indicators were unavailable, surrogate indicators were developed and used for evaluation.

5. Field Activity

Fieldwork is an integral and crucial part of the study. At the initial stage a reconnaissance survey was undertaken in each of the watersheds identified for study. A transact walk was undertaken to survey the selected watersheds and villages for agricultural resource characterisation. A DGPS was used to geo-reference all resources and boundaries in the study area. Soil sampling sites and S&WC structures were also geo-referenced. Soil samples were brought to lab for analysis. In the next phase interviews of farm households were carried out using two structured questionnaires.

5.1. Watershed Survey - Transact Walk

5.2. Geo-referencing of sites using DGPS

A Trimble DGPS (Differential Global Positioning Systems) unit consisting of a base and a rover unit was used for geo-referencing the GCP, soil sampling sites, soil profile sites and S&WC structures in the study area. The unit was also used to update landholding boundaries that had changed owing to sub -division and fragmentation of land after mapping of the original cadastre (Photo 1).

Photo 1: Geo-referencing a check-dam in Pamana village near Chevella, RR District.

5.3. Measuring spectral signatures & collection of ground -truth information-

On an average more than a dozen visits was required to be taken for collection of ground truth information and for verification of the same in the field in each site annually during the study. Several of these trips were exclusively undertaken during cropping season for collection of spectral signatures of crops to facilitate interpretation of satellite data with reference to crop cover, change in land use and land cover and resultant NDVI conditions. A *Spectral Library* was developed to store typical spectral signature of various objects on ground during various seasons for facilitating interpretation of satellite data. Photo 2 indicates the use of a spectro-radiometer in the field.

5.4. Soil sampling

Mapping of soil fertility status is an essential requirement for analysing impact of improved practices implemented under watershed development projects. Over 450 soil samples were collected from various sites in the study area and analysed for 12 physico-chemical and biological parameters in the lab using standard methods.

Photo 2: Using a handheld spectro-radiometer (*Analytical Instruments Ltd*. USA) to collect spectral signature from paddy field at early growth stage in Gollapalli village.

5.5. Soil profile study

One typical soil profile was cut in each of the study site for establishing a baseline for facilitating long-term sustainability studies.

5.6. Socio-economic survey

Two questionnaires were specifically prepared for conducting socio-economic surveys at household and village-level in each of the study area. The questionnaire were structured in a manner so as to collect information for each for each of the sustainability indicator identified for the purpose. Wherever direct indicators were not available, information for surrogate indicators were collected.

5.7. Participatory Rural Appraisal (PRA)

A PRA was conducted specifically to identify core issues that affect agriculture in each of the watershed village.

6. Activities undertaken in Laboratory

The study involved several activities to be undertaken in the GIS, Soil Chemistry & Soil Physics Labs. While the interpretation and analysis of satellite data was undertaken in the GIS lab, storage and preparation of soil samples for analysis and finally batch-wise, analysis of soil samples was carried out in the Soil Physics and Soil Chemistry labs at the institute.

6.1. Applications in *ArcGIS* for analyzing sustainability of watershed projects -

One of the highlights of the research program was the application of GIS technique for evaluation of impact of LMP on rainfed agriculture. Watersheds were delineated and mapped using ArcGIS (ver. 9.0) software (Figure 2). All corollary data had to be collected and collated before preparation of map overlays for the study. Thematic maps for various aspects like slope, soil fertility status, cereal yield, etc., were prepared for deriving sustainability indicators (Figure 3). Map overlay of two or more themes helped in deriving numeric value for Sustainable Indicators. For instance, to evaluate impact of S&WC measures on soil fertility status and crop yield, overlay of maps of treated micro-watershed (TMW) with slope, soil macro - nutrient status. Correlation of location of S&WC measures with NDVI was deemed essential. Overlay of village cadastre over this outlay helped in quantifying the designated Sustainable Indicator. Other maps like NDVI derived from satellite data or land use and land cover maps helped in deriving and quantifying other sustainable indicator in a similar manner essential for evaluating NRM status in each land holding in the watershed.

6.2 Use of Geographical Positioning System (GPS)

An important highlight of the study likes the geo-referencing of various aspects of land management practices (LMP), natural resources management (NRM) and agricultural production systems (APS). After post-processing of GPS control points collected in the field, the data were imported and overlaid on the ArcGIS coverage and satellite data of the study areas. Using GPS points obtained using a *Trimble GeoXT* DGPS unit, a Digital Terrain Model (DTM) were prepared for each of the micro-watersheds. GPS units were used to update field boundaries in the village cadastre, to site S&WC structures in the watershed maps and satellite imagery and for preparing soil characteristic maps for the study. An important aspect of use of

DGPS unit was its help in creation of a geo-referenced database that is absolutely critical for undertaking long-term sustainability studies in future.

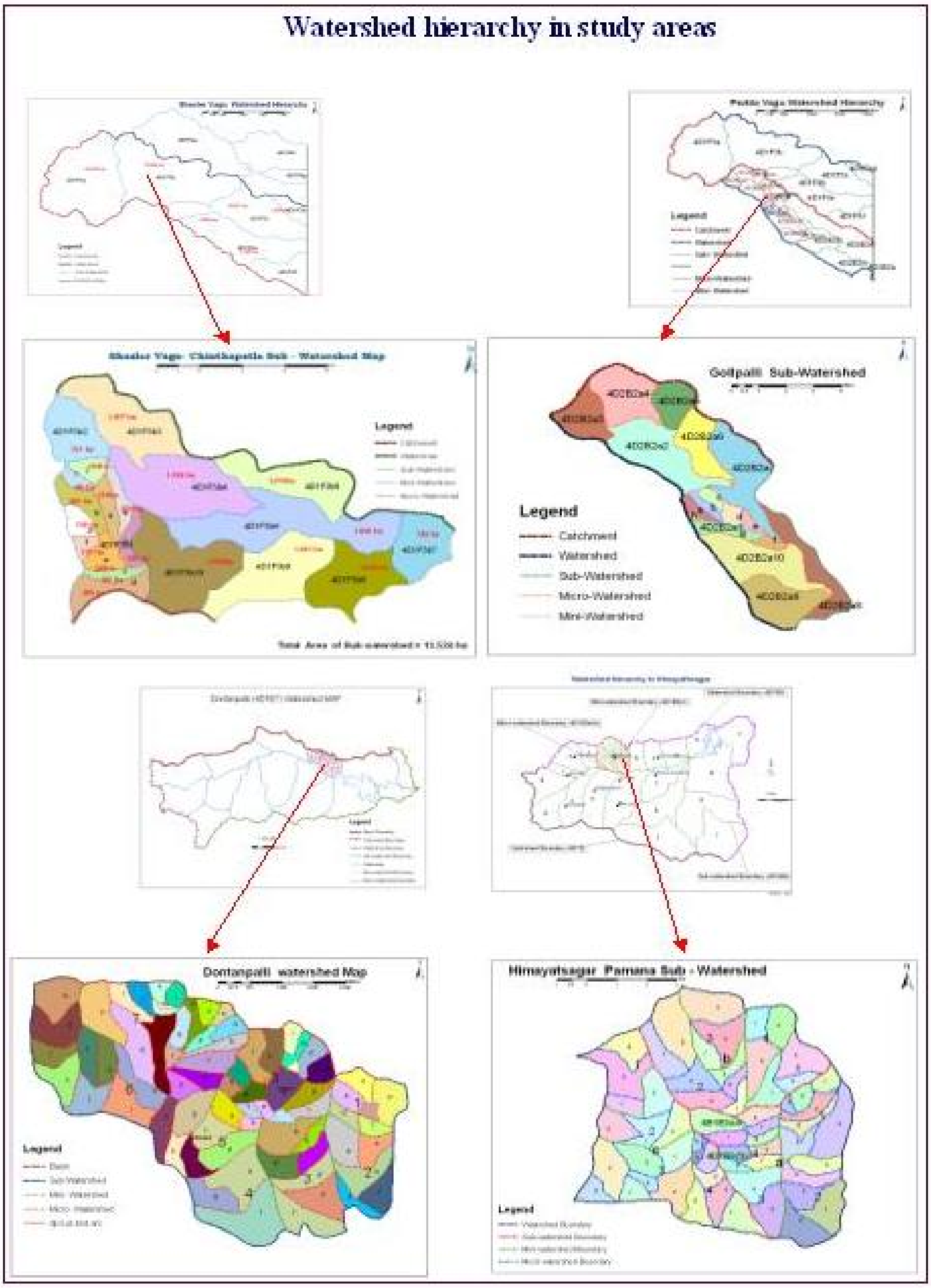

Figure 2: Delineating watershed boundaries using ArcGIS

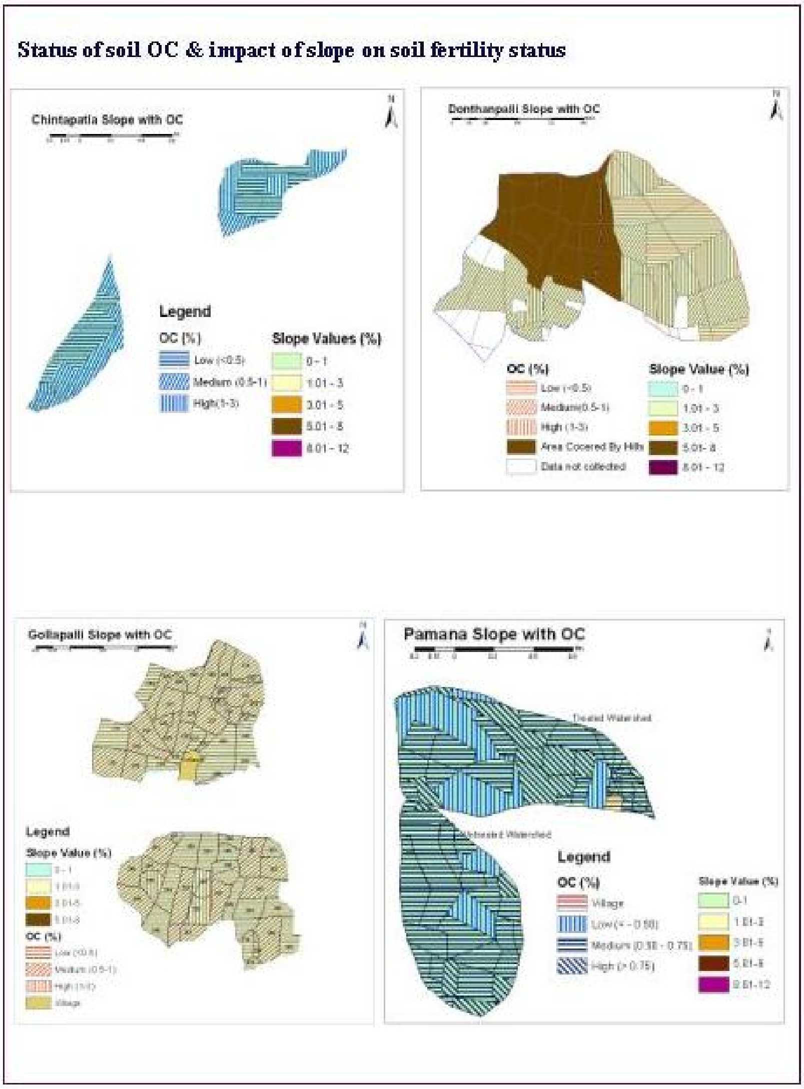

Figure 3: Map overlay to derive sustainability indicators of soil fertility and slope.

6.3 Interpretation of satellite data

For evaluating sustainability of watershed projects it was essential to compare the situation prevalent prior to implementation of WDP with the post implementation scenario. For this purpose, satellite data were procured from NDC, NRSC located in Hyderabad. Digital satellite data of IRS – 1D LISS III were procured for the pre–project period study for generating baseline info. As WDP were initiated in 1999 and 2000 in the study period, satellite data of two seasons viz., pre- and post monsoon data for 1998 and 1999 were procured from NRSA and interpreted using ERDAS *Imagine* (ver. 9.0). Analysis was undertaken to understand change in land use and land cover, drainage network, spread in extent of water bodies, NDVI, degradation of land, soil erosion, etc. The satellite data were also used to update maps that which had been mapped in 1970-71. The new road network, rail alignment and river network had to be mapped using

Virtual GIS – a module of ERDAS software and incorporated into ArcGIS for preparing the DTM and for surface analysis of study area. The sustainability indicators pertaining to slope, NDVI, deforestation, change in land use and land cover, crop diversity etc., could be obtained only from the satellite data. Periodic study of the situation in subsequent years was facilitated in a similar manner. Satellite data of IRS 1D were procured for the period 2000 to 2004. For 2005 and 2006 IRS P6 LISS III data were procured. To analyse change that had occurred in 2006, satellite data of IRS P6 LISS 4 - MX with 5 m resolution was procured and studied. To facilitate interpretation of satellite data handheld portable spectro-radiometer was used to collect spectral reflectance in fields. Use of remote sensing technique in the present study was found to be absolutely essential not only for increasing our understanding of various nuances of agriculture, but also to interlink the impact of various aspects of NRM on agriculture.

6.4 Studies on soil fertility status

Over 450 composite soils samples collected from the farmers' field in the ten micro-watersheds during 2005 and 2006 were analysed for 12 physico-chemical parameters. Soil samples were shade – dried, ground and sieved with 0.5 mm sieve and a sample of 50-100 gm was taken and stored for carrying out analysis for OC content. The rest of the soil was again sieved with a 2 mm sieve and a sample of 250 gm was drawn for undertaking the rest of analysis. Soil physico-chemical parameters analysed were pH, EC, CEC, Organic Carbon content, major nutrients - N, P, K, micro-nutrients - Cu, Fe, Mn and Zn. Biological properties analyzed were Microbial Biomass Carbon (MBC) and Dehydrogenase assay (DHA).

6.5 Creation of Database for field and watershed - related data

As mentioned earlier, the entire study helped to generate a large volume of data that was required to be archived in a format that would be readily usable at a subsequent period. As a result, a digital framework was developed and the data generated from each of the sub-program was stored utmost case has been taken to a relive the data which would be critical for developing applications at a later date. The database consists of socio-economic, soils and land management related information that were used to prepare GIS coverage for socio-economic analysis and evaluation of LMP and WDP. The database is compatible with other national databases and could be easily shared and integrated.

7. Evaluation of agricultural sustainability in watershed projects

The methodology created facilitates evaluation of impact of WDP on state of agriculture, cropping pattern, soil fertility status, water availability, rural livelihood options and economic condition of farm households in treated micro-watersheds. The impact can be compared with the situation prevalent in an untreated micro-watershed in the vicinity. It was assumed that such a comparison would help in a rational understanding of impact of improver practices as extraneous advantages or disadvantages of geographical, topographical or economical situations to both or/ either of the micro-watersheds could be nullified.

7.1. Thematic mapping, overlay & analysis – *application of GIS*

Various natural resources like soil, vegetation or agriculture pattern are depicted in maps prepared in GIS environment. Satellite data are used to study land use land cover pattern over a temporal resolution. Figure 3 indicates how natural resources are depicted in the form of thematic maps.

7.2. Land use and cover change studies (LCCS)

The land cover change were identified and mapped for deriving baseline data for constructing the sustainability indicators (Fig. 4).

8.0 Conclusion

In order to evaluate sustainability of WDP, it is essential to undertake a multidisciplinary approach using the tools indicated in this paper. Soil fertility status was evaluated in conjunction with socio-economic conditions prevalent in the selected watersheds. Application of GIS & RS was found to be useful to geo-reference sustainability indicators and in construction of baseline information for pre-WDP period so as to facilitate a comparison of the situation. Study of ten micro-watersheds in the five villages in AESR 7.2 undertaken during 2004-2008, indicates that rainfed agriculture on its own, has not been found to be very profitable which has lead to migration by rural population within the region to the urban areas. It was seen that most villages are predominantly peopled by marginal and small farmers and any rural development programs including WDP, must be fine–tuned for them, if sustainability has to be achieved.

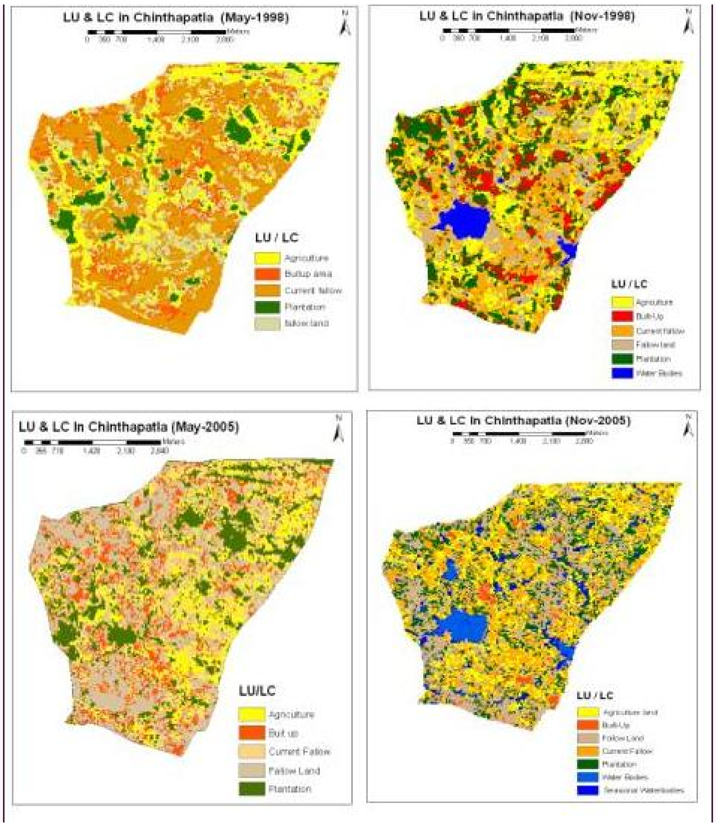

Figure 4: Land utilization pattern in Chintapatla village in pre-and post monsoon periods prior to, and after implementation of WDP in the village.

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Mitigation and Adaptation Strategies for Climate Change through Integrated Watershed Management

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Global Warming is one of the most important issues prevailing in the world affecting food systems as well as livelihoods globally. Besides, the effects of Climate change can be seen in the unprecedented heatwaves, cyclones, floods, salinization of the coastline and impacts on agriculture, horticulture, livestock and fisheries. Sixty percent of agriculture in India is rainfed supporting millions of small farm holder families for achieving food and nutritional security.

The goal of Integrated Watershed Management is to improve livelihood security by minimising the adverse effects of climatic variability while protecting or enhancing the sustainability of the environment and the agricultural resource base through suitable adaptation strategies. ICRISAT in partnership with the NARSs has developed an innovative and up scalable consortium model for managing watersheds holistically for improving livelihoods through an integrated approach. This approach of integrated and participatory watershed development and management has emerged as the cornerstone of rural development in the SAT.

Results of climate change analyses of India indicated that dryness and wetness are increasing in different parts of the country in the place of moderate climates existing earlier in these regions. ICRISAT's Hypothesis of Hope through future climate ready crops and Integrated Watershed Management could be a potential adaptation strategy to cope with the variability and changes anticipated.Dryland areas are more vulnerable to impacts of climate change. Our analysis of historical weather data has indicated that Semi-Arid area increased by 8.45 M ha in six states (Kesava Rao et al., 2013) namely, Madhya Pradesh (3.82 M ha), Bihar (2.66 M ha), Uttar Pradesh (1.57 M ha), Karnataka (0.23 M ha) and Punjab (0.17 M ha), which will result in more challenges for the country to achieve the goal of food and nutritional security along with improved livelihoods.

Rainfed Agriculture

An insight into the rain-fed regions shows a grim picture of water-scarcity, fragile environments, drought and land degradation due to soil erosion by wind and water, low rainwater use efficiency (35-45%), high population pressure, poverty, low investments in water use efficiency measures, poor infrastructure and inappropriate policies. Drought and land degradation are interlinked in a cause and effect relationship and both in turn are the causes of poverty. This unholy nexus between drought, poverty and land degradation has to be broken for ensuring food security. Land degradation due to accelerated erosion resulting in the loss of nutrient rich top fertile soil however, occurs nearly everywhere where agriculture is practiced and this can be irreversible.

The torrential character of the seasonal rainfall creates high risk for the cultivated lands. Thus, erosion leaves behind an impoverished soil on one hand, and siltation of reservoirs and tanks on the other. In addition to imbalanced use of nutrients in agriculture, farmers exploit the soil nutrient reserves. For example in the SAT India, a large number of on-farm trials conducted in more than 300 villages demonstrated that the current subsistence agricultural systems have depleted soils not only of the macro-nutrients but also of secondary nutrients such as sulfur and micro-nutrients such as zinc and boron. Widespread deficiencies of micro and secondary nutrients were observed in farmers' fields in various states of the SAT India. In Andhra Pradesh, B deficiency was not prevalent (in 85% of the 3650 fields sampled) followed by sulphur which was deficient in 79% of the farmers' fields and zinc was deficient in 69% of the farmers' fields. Phosphorus was deficient in 38% of the fields and potassium in 12% of the fields. In Karnataka state, out of around 90000 samples analyzed, boron deficiency was most prevalent (62% fields) followed by zinc (55%), sulphur (52%), phosphorus (41%) and potassium (23%). In Madhya Pradesh, (341 farmers' field sampled), boron deficiency was most prevalent (79% fields) followed by sulphur (74%), phosphorus (74%) and zinc (66%). In Rajasthan (421 fields sampled), the deficiency of sulphur was most prevalent followed by boron (56%), zinc (62%), phosphorous (36%) and potassium (15%). If these resources are not managed properly the impact of climate change will further deteriorate theses resources and the potential of the environments for agricultural production.

Evidences from water balance analyses (on farmers' fields around the world) show that only a small fraction (30%) of rainfall is used as productive greenwater flow to support plant growth and development. In arid regions only 10% of the rainfall is used as productive greenwater flow with 90% flowing as non-productive evaporation flow. i.e., nil or very limited blue water generation.

This indicates a large window of opportunity to improve the low current yields in rain-fed agriculture. Still, what is possible to produce on-farm will not always be produced, especially by resource-poor, small-scale farmers. This is because of labour shortage, insecure land ownership, capital constraints and limitation in human capacities. All these factors influence how farming is done in terms of timing and effectiveness of farm operations, investments in fertilizers and pesticides, use of improved varieties, water management, etc. So the final produce in the farmers' field is thus strongly affected by social, economic and institutional conditions. Moreover, investments in the rainfed agriculture pose serious challenges, as the large numbers of households are small, with marginal farmers and poor infrastructure facilities. Knowledge intensive extension efforts needed in the rainfed areas, suffer from limited information on the options available, social and economic constraints to adoption, lack of enabling environments and backup services, poor market linkages, weak infrastructure and low means to pay.

Integrated Watershed Management

In rural areas, most of the poor make their livelihoods on the use of natural resources, which are degraded and inefficiently used. This is because of the inadequate traditional management practices of managing agriculture as well as the fact that resulting crop yields are much below the expected potential yields. In addition, per capita availability of waterhas declined from 5,177 m^3 in 1951 to 1,545 m^3 in 2011 due to rise in population from 361 million in 1951 to 1.21 billion in 2011 (GoI 2014). ICRISAT has adopted an integrated genetic and natural resource management (IGNRM) approach to enhance agricultural productivity in rainfed areas, which is a powerful integrative strategy of enhancing agricultural productivity. While addressing the core issue of rural development, this approach maximizes synergies among the disciplines of natural resource management, crop improvement, and social sciences, along with people's empowerment through capacity-building measures.Watershed scale may be considered as the "entry point" for effective management of smallholder agro-ecosystems for improving livelihoods.

ICRISAT in the early1970s initiated research on watersheds for integrated use of land, water, and crop management technologies for increasing crop production through efficient use of natural resources, especially rainfall that is highly variable in the SAT and is the main cause of year-to-year variation in crop production in India. Improved watershed management on Vertisols more than doubled crop productivity, and rainfall-use efficiency increased from 35% to 70% when compared with traditional technology. This watershed model is more holistic and puts rural communities and their collective actions at centre stage for implementing improved watershed technologies with technical backstopping and convergence by consortium partners.

Rainfed agriculture is referred to as 'one ton agriculture'. However, long-term research at ICRISAT-India and other research institutions in Asia and Africa have shown that current crop yields are lower by two to five folds (Wani et al. 2003, 2008; Rockström et al. 2007). A long-term study at ICRISAT demonstrated that yields from rainfed system can be as high as 5.2 ton ha-1 yr-1, supporting 27 persons ha-1 yr-1, compared with 1.1 ton ha-1 yr-1 supporting only 6 persons ha-1 yr-1, as in traditional systems, managed through conventional farmers' practices Such high and sustainable production was without any supplemental irrigation. Nevertheless, it was inferred that utilizing supplemental irrigation using harvested rainwater could further result in increased yields and income.

Integrated watershed management comprises improvement of land and water management, integrated nutrient management including application of micronutrients, improved varieties and integrated pest and disease management is also recommended to bridge the yield gap. Watershed management program is one of the most suitable options for increasing water use efficiency and also as an adaptive strategy to cope with climate change effect in rainfed areas.Increased crop yields by two to four folds in Adarsha watershed demonstrated the impact of integrated approach.

Greater resilience of crop income in Adarsha Watershed, Kothapally (Rangareddy district, Andhra Pradesh) during the drought year 2002 was indeed due to watershed interventions. While the share of crops in household income declined from 44% to 12% in the non-watershed project villages, crop income remained largely unchanged from 36% to 37% in the watershed village.

Climate smart crops: As the length of growth period is changing along with the rainfall pattern and the temperatures, there is an urgent need to develop climate smart crops and ICRISAT led team is working on developing climate smart crops. For example, short duration chickpeas with drought tolerance have transformed chickpea cultivation in Andhra Pradesh resulting in increased productivity by 2.4 folds, production by nine folds during the past decade. Similarly short duration pigeonpea will fit into different agro-eco systems. All these developments could help us as an adaptation strategy for climate change impacts. For example, in Northern India even the temperatures in winter season goes up the chickpeas which have been adopted in Southern India can be fit well without any yield penalty as such.

Soil carbon sequestration

Importance of soil organic carbon (SOC) in sustainingproductivity is well known. Organic carbon (OC) serves assoil conditioner, nutrient source, substrate for microbialactivity, preserver of the environment and the majordeterminant for sustaining or increasing agricultural productivity. SOC status is sensitive to impact by humanactivities viz. deforestation, biomass burning, land usechanges and environmental pollution. It has been estimatedthat the land use change from natural to agriculture resultedin the transfer of 1–2 Pg C year-1 from terrestrial ecosystem to the atmosphere of which 15 to 17 % carbon is contributed by decomposition of SOC.

Results of long-term fertilizer experiments with rice-based double or triple cropping systems indicate soil’s capacity to store greater C, and maintain higher C in passive pools and that active fraction of soil C can be used as an indicator of soil health. The inclusion of active pool/labile SOC is expected to improve the performance of Century eco-system model in predicting SOC changes under different climatic conditions. Greenhouse gas emissions from the tropical Indian soils (both zeolitic and nonzeolitic) do not seem to contribute significantly to the global warming potential. The application of NPK plus FYM emerged as a cost effective technology for Indian farmers. In view of the potential of C sequestration by major zeolitic and non-zeolitic soils, the present SOC stock of about30 Pg can be further increased.

Scaling up activities, an example from Karnataka

Based on the learning of integrated watershed management approach over the last four decades ICRISAT-led consortium along with Department of Agriculture, Government of Karnataka has undertaken a mission mode approach for increasing agricultural productivity of rainfed agriculture in 24 districts of Karnataka. In this approach soil health assessment was used as an entry point and based on the observed widespread deficiencies of multiple nutrients (macro as well as secondary and micro nutrients) taluk-wise fertilizer recommendations were developed, disseminated to the farmers ensuring availability of needed inputs thru incentives. Along with soil test based fertilisers improved cultivar seeds, seed treatment as well as use of soil and water management interventions increased crop yields by 20 to 66 per cent over the farmers' practice. During four years (2009 to 2012) the project covered 3.73 m ha and 4.3 million farmers. During the four years individual farmers benefitted with a B:C ratio varying from 2.6 to 14:1 and total net value of increased production worked out to be US $ 240 million (Rs. 1267 crores).

The need to scale up the available technologies to enable the small farmers in developing countries to adopt climate smart agriculture to cope with the impacts of the climate change is immense and need to be taken up urgently. Most technologies are not reaching the small farm-holders and large yield gap exists between the current farmers' yields and the potential achievable yields. The science of delivery needs to be pursued vigorously to achieve the impacts through scaling up of technologies, products and knowledge to benefit millions of small farm holders across our country.

Impact of climate change on insect pests

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Abstract

Global circulation models predicted that global-average surface temperature would increase further by 1.4 to 5.8 °C by 2100 with atmospheric carbon dioxide (CO_2) concentrations expected to rise to between 540 and 970 ppm and with an altered precipitation over the same period. Since climate is the direct input into the agriculture production process, the agricultural sector has been a natural focus for research. The extensive review of information on impact of elevated CO_2 on insect pests revealed that 57 % studies were confined to lepidopteran followed by homopteran (16%) and coloepteran insects (6%). The increased consumption, reduced growth rates, extension of larval durations were documented under elevated CO_2 conditions. The variations in insect survival, development, geographic range, no. of generations and population size etc., were reported due to increased temperature. Significantly lower leaf nitrogen, higher carbon, higher relative proportion of carbon to nitrogen (C: N) and higher polyphenols content expressed in terms of tannic acid equivalents were observed in crop foliage grown under elevated CO_2 levels. The performance of the various lepidopteran and Homopteran insect pests (*Achaea janata*, *Spodoptera litura*, *Spilosoma obliqua*, *Helicoverpa armigera and Aphis craccivora*) on castor, groundnut and cowpea crops were studied and host mediated effect of elevated CO_2 on insect pests was quantified in our studies showed an increased consumption of foliage and extended larval duration. The selection of cultivar with change in duration, time of sowing/planting, tolerant variety for biotic stress and crop diversification can be the possible adaptation strategies which cope up with climate change effects on insect pests.

Key words: increased temperature elevated CO_2, biochemical constituents, lepidopteran insect pests, adaptation strategies

Introduction

There is now adequate evidence about the impending climate change and the consequences thereof. The fourth assessment report of IPCC observed that 'warming of climate system is now unequivocal, as is now evident from observations of increase in global average air and ocean temperatures, widespread melting of snow and ice, and rising global sea level' (IPCC, 2007). Though climate change is global in its occurrence and consequences, it is the developing countries like India that face more adverse consequences. Third IPCC report predicts that the global average surface temperature will increase further by 1.4 – 5.8^{o}C by 2100 with the increased atmospheric carbon dioxide (CO_2) from 540-970 ppm over the same period. Since climate is the direct input into the agriculture production process, the agricultural sector has been a natural focus for research.

Climate change projections made upto 2100 for India indicate an overall increase in temperature by 2-4°C with no substantial change in precipitation quantity (Kavikumar, 2010). However, different regions are expected to experience differential change in the amount 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. Last three decades saw a sharp rise in all India mean annual temperature (Venkateswarlu, 2010). Though most dryland crops tolerate high temperatures, rainfed crops grown during *rabi* are vulnerable to changes in minimum temperatures. Analysis of data for the period 1901-2005 by IMD suggests that annual mean temperature for the country as a whole has risen to 0.51^{o}C over the period Rising carbon dioxide will increase the carbon-to-nitrogen balance in plants, which in turn will affect insect feeding, concentrations of defensive chemicals in plants, compensation responses by plants to insect herbivory, and competition between pest species (Coviella and Trumble, 1999).

Insects are cold-blooded organisms - the temperature of their bodies is approximately the same as that of the environment. Therefore, temperature is probably the single most important environmental factor influencing their behaviour, distribution, development, survival, and reproduction. Generally the impacts of CO_2 on insects are thought to be indirect through the changes in the host crop i.e., the host mediated one. The information on influence of three major factors of climate change i.e., temperature, carbon dioxide and precipitation on insects is discussed under the following heads.

Increased temperature

Climate change resulting in increased temperature could impact crop pest insect populations in several complex ways. Although some climate change temperature effects might tend to depress insect populations, most researchers seem to agree that warmer temperatures in temperate climates will result in more types and higher populations of insects.

Increased temperatures can potentially affect insect survival, development, geographic range, and population size. Temperature can impact insect physiology and development directly or indirectly through the physiology or existence of hosts. Increased temperatures will accelerate the development of several types of insects (cabbage maggot, onion maggot, European corn borer, Colorado potato beetle). Possibly resulting in more generations (and crop damage) per year. In addition to the above observations some more predictions and generalizations were made by several researchers. The documented information on impact of elevated temperature on insect pests indicated that Northward migration of insects, developmental rates and oviposition, out breaks leading to epidemics, possibilities of introduction of invasive species were found to be increased. The effectiveness of insect bio-control by fungi**,** reliability of economic threshold levels, Insect diversity in ecosystems, parasitism by parasitoids were found to be increased under increased temperature conditions (Bale *et al.*, 2002; Srinivasa Rao *et al.*, 2009).

It is understood from the literature that increase in the surface temperatures would allow polyvoltine species with accelerated developmental rates allowing the earlier completion of life cycle and thus resulting in additional number of generations within a season. In case of, Aphids (Yamamura, 1998), *Plutella xylostella* (Morimoto et al.1998) and bark beetles *Ips typographus* (Jonsson et al. 2009). Additional generations of insects in temperate climates as a result of increased temperatures, necessitating more insecticide applications to maintain populations below economic damage thresholds (Rosemary Collier, 2009).

Insects that spend important parts of their life histories in the soil may be gradually affected by temperature changes as compared to those that are above ground simply because soil provides an insulating medium that will tend to buffer temperature changes more than the air (Bale *et al.*, 2002). Insect species diversity per area tends to decrease with higher latitude and altitude, meaning that rising temperatures could result in more insect species attacking more hosts in temperate climates. It is to conclude that the diversity of insect species and the intensity of their feeding have increased historically with increasing temperature.

Elevated CO_2 levels

The atmospheric CO_2 concentrations have increased by above 20% and elevated CO_2 effects the plant growth and range of physical and chemical characteristics of the plant/crop. These include reduction in the leaf nitrogen content, changes in the defense compounds, water content, carbohydrates and leaf thickness. Indications are that exposure to elevated CO_2 levels will increase the plant photosynthesis, growth, above ground biomass, leaf area, yield, carbon and C: N ratio. These changes can influence the food quality for herbivorous insects and was well reviewed (Hunter, 2001). These changes in the leaf quality are likely to have varied effect on the performance of insect herbivores. The information on effect of elevated CO_2 on insect pests was compiled and presented by Srinivasa Rao *et al.* (2008).

The possible impacts of elevated CO_2 (ECO_2) on growth and development, behavior of insect pests attracted the attention of researchers and several reviews of such studies were attempted to draw conclusions on the impact of elevated CO_2 on insect pest incidence. Most of the reviews (Coviella and Trumble 1998; Hunter, 2001; Srinivasa Rao *et al* 2006) are available in the literature indicating the impact of elevated CO_2 on insect pest incidence across various agro ecosystems. These reviews were mainly qualitative summaries of the studies and the conclusions drawn are not based on any statistical or quantitative analysis.
An alternative procedure to deal with the limitations of the qualitative synthesis of studies was put forward initially by Glass (1976) and came to be known as 'Meta-analysis'. The quantification of effect of elevated CO_2 on the growth and development of insect pests through statistical synthesis of published results or meta-analysis is attempted here. One of the extensively used measures in Meta analysis is the "effect size" which integrates the results from different experiments on a given subject into an index. This effect size gives the relative magnitude of the experimental treatment.
The mean effect sizes for various insect parameters varied significantly. Among the insect primary parameters consumption (2.94) and duration of insect species (0.751) were found to be significantly positive under eCO_2 and other parameters like weight (-0.46) and population

abundance (-0.05) of species were negative. Insect performance indices showed positive effect size for approximate digestibility, AD (1.281) and relative consumption rate, RCR (3.61) and negative with respect to efficiency of conversion of ingested food, ECI (-3.20), efficiency of conversion of digested food, ECD (-1.891) and relative growth rate, RGR (-1.072). Meta analysis of biochemical constituents of host plants indicated that the effect sizes were found to be negative (Nitrogen) and positive (Carbon and C: N ratio) indicating a significant variation of constituents under eCO_2 condition than ambient CO_2 condition. The implications and limitations of meta analysis were discussed.

Under elevated CO_2 conditions food consumption by the insect larvae, reproduction of aphids, predation by lady beetle, carbon based plant defenses were found to be increased. The reduction of insect development rates, response to alarm pheromones by aphids, parasitism, efficacy of transgenic *B. thuringiensis*, nitrogen-based plant defenses was reported by various authors.

Experiments at Central Research Institute for Dryland Agriculture (CRIDA)

Several experiments were conducted using open top chamber (OTC) facility to study the impact of elevated CO_2 levels on insects. Three square type open top chambers (OTC) of 4x4x4 m dimensions, were constructed at CRIDA, Hyderabad, two for maintaining elevated CO_2 concentrations of 700±25 ppm CO_2 and 550±25 ppm CO_2 and one for ambient CO_2. An automatic CO_2 enrichment technology was developed by adapting software SCADA to accurately maintain the desired levels of CO_2 inside the OTCs. The concentration of CO_2 in the chambers was monitored by a non-dispersive infrared (NDIR) gas analyzer. Castor, groundnut plants were grown in the three OTCs and also in the open, outside the OTCs.

- Larval duration or time from hatching to pupation in larvae of both the species (*Achaea janata* and *Spodoptera litura*) was significantly influenced by the CO_2 condition under which castor leaves offered to them. Larval duration of both species was extended by about two days when fed with elevated CO_2 foliage. Thus, larvae fed with elevated CO_2 foliage consumed more each day and over a longer period, resulting in considerably increased ingestion. (Srinivasa Rao *et al*. 2009).
- Significant influence of elevated CO_2 on life history parameters of *S. litura* on groundnut was observed. The percent variation of these parameters was significant under elevated CO_2 compared with ambient CO_2.

- The percent reduction of nitrogen content and increased percent of carbon, C: N ratio and TAE (Tannic acid equivalents) was significant in groundnut and castor foliage under elevated CO_2 in (Srinivasa Rao *et al*. 2008).
- Under elevated CO_2 conditions the increased population of aphids, *Aphis craccivora* was increased with reduced generation time on cowpea.
- *Helicoverpa armigera* larvae consumed higher amount of chickpea foliage resulting increased larval weights under eCO_2 conditions. These larvae extended their duration by two days.

Extremes of Precipitation

Many pest species favour the warm and humid environment. Both direct and indirect effects of moisture stress on crops make them more vulnerable to be damaged by pests, especially in the early stages of plant growth. There are fewer scientific studies on the effect of precipitation on insects. Some insects are sensitive to precipitation and are killed or removed from crops by heavy rains. A decrease in winter rainfall could result in reduced aphid developmental rates because drought- stressed tillering cereals reduce the reproductive capacity of overwintering aphids (Pons and Tatchell 1995). Some insects are killed or removed from crops by heavy rains - onion thrips (Reiners and Petzoldt 2005). Precipitation cause epidemiology of many pathogens, that depends on moisture for dispersal which in turn effects the insect population.

Impact of Climate change on distribution of insect species or shifts

Climate plays a major role in defining the distribution limits of a insect species. With changes in climate, these limits are shifting as species expand into higher latitudes and altitudes and disappear from areas that have become climatically unsuitable. Such shifts are occurring in species whose distributions are limited by temperature such as many temperate and northern species. It is estimated that there would be shift in the crop cultivation due to shifts in the climate change which in turn may cause shifts in incidence of pests. It is observed that a northward shift in the production of rice and maize in the northern hemisphere—major uncertainties remain in the distribution and magnitude of climate change outcomes particularly the pattern of pests. It is well understood that the distribution of insect species is well impacted by the change in climate and unforeseen shifts in species is expected.

Adaptation Strategies to Climate Change

There is several adaptation measures in general that the agricultural sector can undertake to cope with future climate change. These are changing planting dates, planting different varieties or crop species, development and promotion of alternative crops, developing new drought and heat-resistant varieties, higher adoption of intercropping,

Diversification can enhance economic stability by allowing the risks of production agriculture to be spread over a greater number of crops. Ideally, the crop mix should be complementary in nature. As many organic farmers grow a range of crops, it would be relevant to develop a means by which they could reliably select crops to combine, and simultaneously enjoy the benefits of reduced pest pressures. Pest pressures may be reduced in diversified systems for various reasons, most important being the encouragement of beneficial insect diversity and abundance and reduced ability of pests to locate their preferred feed. Providing already diversified growers with an additional benefit from combining certain crops should be a valuable contribution. Several studies indicated that diversification practices such as intercropping are beneficial because of lower damage by insect pests in these systems (Risch *et al.* 1983).The impact of duration and intercropping on insect pests and natural enemies was well documented (Srinivasa Rao *et al.* 2003). The significant effect of intercropping on various insect pests across different main crops indicated that in majority of the systems reduction of pest and proliferation of natural enemies was noticed across different field crops. One rational and cost-effective method may be the implementation of increased agricultural crop diversification. Crop diversification can improve resilience in a variety of ways: by engendering a greater ability to suppress pest outbreaks and dampen pathogen transmission, which may worsen under future climate scenarios, as well as by buffering crop production from the effects of greater climate variability and extreme events. Such benefits point toward the obvious value of adopting crop diversification to improve resilience, yet adoption has been slow. However, crop diversification can be implemented in a variety of forms and at a variety of scales, allowing farmers to choose a strategy that both increases resilience and provides economic benefits (Brenda 2011).

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