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Agro-meteorological Indicators: Description, Review of Gaps and Recommendations

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Contents

1. Introduction

Climate is an essential component of the natural capital of many developing countries. Their climates are extremely variable from year to year, and recurrent drought and flood problems often affect entire countries over multiyear periods. The evidence of climate change from observations of the atmosphere and surface has grown significantly during recent years. At the same time new improved ways of characterizing and quantifying uncertainty have highlighted the challenges that remain for developing long-term global and regional climate quality data records. (IPCC, 2014).

Agricultural productivity is strongly dependent on water resources and climatic conditions, particularly in regions of the world that are particularly sensitive to climatic hazards. Some countries, where economic and social situations are often unstable, are extremely vulnerable to changes in environmental factors. It is especially the case in countries where technological buffering to droughts and floods is less advanced, and where the main physical factors affecting production (soils, terrain, climate) are less suited to farming. Crop production is consequently extremely sensitive to large year-to-year weather fluctuations. Crop diseases or pest infestations are also weather-dependent, and tend to cause more damages in countries with lower technological levels.

Agricultural weather and climate data are necessary to expedite generation of products, analyses and forecasts that facilitate agricultural cropping and management decisions, irrigation scheduling, commodity trading and markets, fire weather management and other preparedness strategies for calamities, and ecosystem conservation and management. So, agricultural planning and use of agricultural technologies need agrometeorological products and applications. In agricultural meteorology, observations of the physical and biological factors in the environment are crucial. Meteorological considerations in the agriculture help in assessing the performance of plants and animals because their growth is a result of the combined effect of nature (genetic characteristics) and nurture (their response to the environment).

The effects of anomalies of a weather element on a given crop are location specific. For the similar temporal distribution of weather parameters, different crops will react differently and the effects of weather or weather-induced stresses and occurrence of pests and diseases are critically dependent on the state and stage of crops during which these phenomena occur. Thus, the prerequisite for these special forecasts will vary among and within the seasons, from place to place, from crop to crop, and with the nature of operations, like, cultivation, postharvest processing, and so on.

Detailed observations and real-time dissemination of meteorological information, quantification by remote-sensing (radar and satellites), and derived indices and operational services are important for strategic agro-meteorological decisions in the short-term planning of agricultural operations at different growth stages. A well organized, and automatic production (if possible) and coordinated dissemination of agrometeorological information and related advisories and services are essential. Strategic decisions contain “average cost”- type decisions in sustainable agriculture with low external inputs, regarding timing of cultural practices, such as ploughing, sowing/planting, mulching, weeding, thinning, pruning and harvesting. They also include, particularly for high-input agriculture, “high cost”-type decisions, such as the application of water and extensive chemicals and the implementation of costly crop protection measures.

1.1 Importance of Agrometeorology and its Indicators

Agrometeorology is an interdisciplinary science in which the main scientific disciplines involved are atmospheric science and soil science, which are concerned with the physical environment, and plant science and animal science (including their pathology, entomology, and parasitology, etc.), which deal with the contents of the biosphere.

For optimum crop growth, specific climatic/weather conditions are required. Agrometeorology thus becomes relevant to crop production because it is concerned with the interactions between meteorological and hydrological factors on the one hand and agriculture, in the widest sense including horticulture, animal husbandry, and forestry, on the other. Its objective is to discover and define such effects and to apply knowledge of the atmosphere to practical agricultural use. The field of interest of an agrometeorologist extends from the soil surface layer to the depth down to which tree roots penetrate. In the atmosphere he or she is interested in the air layer near the ground in which crops and higher organisms grow and animals live, to the highest levels in the atmosphere through which the transport of seeds, spores, pollen, and insects may take place. As new research provides a better understanding of the meteorological phenomena, there is increasing interest in remote sensing and interactions between oceans and the atmosphere in shaping seasonal conditions.

Without quantitative data, the provision of agro-meteorological planning, forecasting, research and services by agrometeorologists cannot suitably assist agricultural producers to survive and to meet the ever-increasing demands for food and agricultural by-products. Such data are also needed to measure the impacts of agricultural undertakings and developments on the environment and climate.

Agrometeorological services in developing countries (for e.g. Nepal) have to carry heavier responsibilities due to changing climate and increasing climate variability, greater population pressure and change in modes of agricultural practices. In the future, more and more demands for agrometeorological information and services are expected from farming communities with regard to technologies, farming systems and patterns, water management, and weather-based pest and disease control, preferably with local innovations as starting points. Thus, future challenges will include the necessity to emphasize a bottom-up approach to ensure that forecasts, specific advisories and contingency planning reach even the small farmers, so that they are able to apply this information in their planning and day-to-day agricultural operations.

Agricultural data including the state of the crops and of animals are essential while the data (like weather and climate) are to be related to agricultural operations. For all sorts of agrometeorological applications, in order to make information available to assist farmers all the time at the field level, to prepare advisories and bulletins, and to allow for long term planning, it is necessary to combine the agricultural and the meteorological data. To make better use of the agrometeorological data in supporting agrometeorological services and to provide for effective transfer of the knowledge of agrometeorology to farmers at farm level, the science of information technology is also very useful.

1.2 Nature of Agrometeorological Data

Basic agricultural meteorological data are largely similar to those used in general meteorology. These data need to be supplemented with more specific data relating to the biosphere, the environment of all living organisms, and biological data relating to the growth and development of these organisms. For dynamic modelling, operational evaluation and statistical analyses, agronomic, phenological and physiological data are essential. Most data need to be processed for generating various products that affect agricultural management decisions in matters such as cropping, the scheduling of irrigation, and so forth.

As for supplementary data, geographical information and remote-sensing based data, such as images of the status of vegetation and crops damaged by disasters, soil moisture, and the like, should also be included.

Agrometeorological information includes not only every stage of growth and development of crops, floriculture, and livestock, but also the technological factors such as irrigation, plant protection, fumigation and spraying operations in agriculture. Additionally, agrometeorological information plays a critical role in the decision making process for sustainable agriculture and natural disaster reduction, with a view to preserving natural resources and improving the quality of life.

Basically agricultural meteorological data may be gathered by instruments on the ground and by remote-sensing. And, observed data gathered should have following information;

1. State of the atmospheric environment i.e. observations of rainfall, sunshine, solar radiation, air temperature, humidity, and wind speed and direction;
2. State of the soil environment i.e. observations of soil moisture (the soil water reservoir for plant growth and development) and soil temperature;
3. Data on organism response to varying environments/climate i.e. agricultural crops and livestock, their variety, and the state and stages of their growth and development, as well as the pathogenic elements affecting them;
4. Information concerned with the agricultural practices employed as each farm is an unique entity with combinations of climate, soils, crops, livestock and equipment to manage and operate within the farming system;
5. Information related to weather and climate disasters and their influence on agriculture;
6. Information relating to the spatial variations in weather and climate and the distribution of agricultural crops, and geographical information, including digital maps;
7. Metadata i.e. the observation techniques and procedures used.

2. Identification of Agrometeorological Indicators

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 irregularities 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 vigor of seeds and planting material during storage.

Thus, there is no aspect of agriculture that is immune to the impacts of weather and climate. Weather factors contribute to optimal crop growth, development and yield. They also play a role in the incidence and spread of pests and diseases. Susceptibility to weather-induced stresses and affliction by pests and diseases varies among crops, among different varieties within the same crop, and among different growth stages within the same crop variety. There are spatial variations in weather in an area at a given time, temporal variations at a given place, and year-to-year variations in climate for a given place and time. For cropping purposes, weather over short periods and year-to-year fluctuations in climate at a particular place over the selected time interval have to be considered. For any given time unit, the percentage departures of extreme values from a mean or median value, called the coefficient of variation, are a measure of variability of the parameter. The shorter the time unit, the greater the degree of variability of a given weather parameter. The intensity of the above three variations differs among the range of weather factors. Over short periods, rainfall is the most variable of all parameters, both in time and space. In fact, for rainfall the short-period interannual variability is large, which means that variability needs to be expressed in terms of the percentage probability of realizing a given amount of rain, or that the minimum assured rainfall amounts at a given level of probability need to be specified.

For optimal productivity at a given location, crops and cropping practices must be such that while their cardinal phased weather requirements match the temporal march of the relevant weather element(s), endemic periods of pests, diseases and hazardous weather are avoided. In such strategic planning of crops and cropping practices, short-period climatic data, both routine and processed (such as initial and conditional probabilities), have a vital role to play.

Occurrences of erratic weather are beyond human control. It is possible, however, to adapt to or mitigate the effects of adverse weather if a forecast of the expected weather can be obtained in time. Despite careful agronomic planning on a microscale to suit experience in local-climate crops, various types of weather events exist on a year-to-year basis. The effects of weather anomalies are not spectacular. Deviations from normal weather occur with higher frequencies in almost all years, areas and seasons. The most common ones are a delay in the start of the crop season due to rainfall vagaries in the case of rainfed crops (as observed in the semi-arid tropics) and temperature (as observed in the tropics, temperate zones and subtropics), or persistence of end-of-the season rains in the case of irrigated crops. Other important phenomena are deviations from the normal features in the temporal march of various weather elements. The effects of weather events on crops build up slowly but are often well spread out to destabilize national agricultural production.(see Annex 1)

The impacts of meteorological factors on crop growth and development are consecutive, although sometimes they do not emerge over a short time. The weather and climatological information should vary according to the kind of crop, its sensitivity to environmental factors, water requirements, and so on. Certain statistics are important, such as sequences of consecutive days when maximum and minimum temperatures or the amount of precipitation exceed or are less than certain critical threshold values, and the average and extreme dates when these threshold values are reached.

2.1 Different Indicators for Agriculture

Earth Observation indicators:
• Provide spatial information on vegetation greenness (health) • Show the consequences of a harmful event : information on location and extent of damage
Meteorological indicators:
• Derived from station measurements: lower spatial accuracy • Explain the causes of yield loss
Agrometeorological indicators:
• Derived with crop growth models • Describe plant growth and development, provide information on crop yield and on factors responsible for yield reduction

2.2 Agro-Meteorological Parameters (Indicators)

Important for Agriculture	**Forecast for Agriculture purposes**
1. Radiation and Sunshine 2. Air Temperature 3. Soil Temperature 4. Atmospheric Pressure 5. Wind Speed and Direction 6. Relative Humidity 7. Soil Moisture 8. Precipitation (clouds and Hydrometeors) 9. Evaporation and Water Balance Measurements 10. Fluxes of weather variables (derived from measured quantities)	1. Cloud cover 2. Bright Sunshine 3. Solar Radiation 4. Precipitation (Rainfall, Snowfall etc.) 5. Temperature 6. Relative Humidity 7. Wind speed and direction 8. Leaf wetness 9. Evapotranspiration 10. Soil Water balance 11. Extreme Events (See Annex 2)

2.3 Different types of agrometeorological indicators derivable from the basic data

Air temperature
i. Temperature probabilities;
ii. Chilling hours;
iii. Degree-days;
iv. Hours or days above or below selected temperatures;
v. Diurnal variability;
vi. Maximum and minimum temperature statistics;
vii. Growing season statistics i.e., dates when threshold temperature values for the growth of various kinds of crops begin and end.

Precipitation
i. Probability of a specified amount during a period;
ii. Number of days with specified amounts of precipitation;
iii. Intensity of precipitation
iv. Probabilities of thundershowers;
v. Duration and amount of snow cover;
vi. Dates on which snow cover begins and ends;
vii. Probability of extreme precipitation amounts.

Wind
i. Wind rose;
ii. Maximum wind, average wind speed;
iii. Diurnal variation;
iv. Hours of wind less than selected speed.

Sky cover, sunshine, radiation
i. Per cent possible sunshine;
ii. Number of clear, partly cloudy, cloudy days;
iii. Amounts of global and net radiation.

Humidity
i. Probability of a specified relative humidity;
ii. Duration of a specified threshold of humidity.

Free water evaporation
i. Total amount;
ii. Diurnal variation of evaporation;
iii. Relative dryness of air;
iv. Evapotranspiration.

Dew
i. Duration and amount of dew;
ii. Diurnal variation of dew;
iii. Association of dew with vegetative wetting;
iv. Probability of dew formation based on the season.

Soil temperature
i. Mean and standard deviation at standard depth;
ii. Depth of frost penetration;
iii. Probability of occurrence of specified temperatures at standard depths;
iv. Dates when threshold values of temperature (germination, vegetation) are reached.

Weather hazards or extreme events
i. Frost;
ii. Cold wave;
iii. Hail;
iv. Heat wave;
v. Drought;
vi. Cyclones;
vii. Flood;
viii. Rare sunshine;
ix. Waterlogging.

(j) *Agrometeorological observations*
i. Soil moisture at regular depths;
ii. Plant growth observations;
iii. Plant population;
iv. Phenological events;
v. Leaf area index;
vi. Above-ground biomass;
vii. Crop canopy temperature;
viii. Leaf temperature;
ix. Crop root length

3. Description of Agrometeorological Indicators

3.1 Solar Radiation

Major stations should make detailed observations of radiation, including global solar radiation, photosynthetically active radiation (PAR) and net all-wave radiation. The spectral distribution of solar radiation influences the growth and development of plants and efforts should be made to include it in the observing program. Important components are ultraviolet, PAR and near-infrared radiation.

Solar radiation is the energy source that sustains organic life on earth. Crop production is in fact an exploitation of solar radiation. The shorter-than-visible wavelength radiation segment in the solar spectrum is chemically very active. When plants are exposed to excessive amounts of this radiation, the effects are detrimental. The ultraviolet radiation reaching the earth's surface is very low and is normally tolerated by plants. Solar radiation in the higher-than-visible wavelength segment, referred to as infrared radiation, has thermal effects on plants. In the presence of water vapors, this radiation does not harm plants; rather, it supplies the necessary thermal energy to the plant environment.

The visible part of solar radiation or light plays an important part in plant growth and development through the processes of chlorophyll synthesis and photosynthesis and through photosensitive regulatory mechanisms such as phototropism and photoperiodic activity. Light of the correct intensity, quality, and duration is essential for normal plant development. Poor light availability is frequently responsible for plant abnormalities and disorders. Virtually all plant parts are directly or indirectly influenced by this part of the spectrum. It affects the production of tillers; the stability, strength, and length of the culms; the yield and total weight of plant structures; and the size of leaves and root development (Rodriguez et al. 1999).

The length of day or the duration of the light period determines flowering and has a profound effect on the content of soluble carbohydrates present. The 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 other environmental factors are not limiting it, photosynthesis increases with longer duration of the light period (Salisbury, 1981).

The solar spectrum can be divided into the following eight broad bands on the basis of the physiological response of plants:

1. Wavelength greater than 1.000 µm: Most of this radiation absorbed by plants is transformed into heat without interfering with the biochemical processes.
2. Wavelength 1.000 to 0.700 µm: Elongation effects on plants.
3. Wavelength 0.700 to 0.610 µm: Very strong absorption by chlorophyll, the strongest photosynthetic activity, and in many cases strong photoperiodic activity.
4. Wavelength 0.610 to 0.510 µm: Low photosynthetic effectiveness in the green segment and weak formative activity.
5. Wavelength 0.510 to 0.400 µm: Strong chlorophyll absorption, strong photosynthetic activity, and strong formative effects.
6. Wavelength 0.400 to 0.315 µm: Produces fluorescence in plants and a strong response by photographic emulsions.
7. Wavelength 0.315 to 0.280 µm: Significant germicidal action. Practically no solar radiation of wavelengths shorter than 0.29 µm reaches the earth's surface.

8. Wavelength shorter than 0.280 µm:Very strong germicidal action. It is injurious to eyesight and when below 0.26 µm can kill some plants. No such radiation reaches the earth's surface.

The visible region (approximately 0.385 to 0.695 µm) of the solar spectrum is generally referred to as photosynthetically active radiation.

3.2 Air Temperature

Temperature is the intensity aspect of heat energy, and it is of paramount importance for organic life. Temperature governs the physical and chemical processes that in turn control biological reactions within plants. It controls the diffusion rate of gases and liquids within plants, and the solubility of plant nutrient substances is dependent on temperature. As such, environmental temperature has a primary role in plant growth and its geographical distribution over the earth.

Air temperature is the most important climatic variable that affects plant life. The growth of higher plants is restricted to a temperature between 0 and 60 C, and crop plants are further restricted to a narrower range of 10 to 40 C. However, each species and variety of plants and each age group of plants has its own upper and lower temperature limits. Beyond these limits, a plant becomes considerably damaged and may even be killed. It is therefore the amplitude of variations in temperature, rather than its mean value, that is more important to plant growth.

The midday high temperature increases the saturation deficit of plants. It accelerates photosynthesis and ripening of fruits. The maximum production of dry matter occurs when the temperature ranges between 20 and 30 C, provided moisture is not a limiting factor. High temperature can devernalize cryophytes, especially the buds of sun-exposed deciduous trees. When high temperature occurs in combination with high humidity, it favors the development of many plant diseases. High temperature also affects plant metabolism.

High night temperature increases respiration. It favors the growth of the shoots and leaves at the cost of roots, stolons, cambium, and fruits. It governs the distribution of photosynthetic among the different organs of the plants, favoring those which are generally not useful for human consumption. High night temperature also affects plant metabolism. It accelerates the development of noncryophytes.

Most crop plants are injured and many are killed when the night temperature is very low. Tender leaves and flowers are very sensitive to low temperature and frost. Plants that are rapidly growing and flowering are easily killed. Low temperature interferes with the respiration of plants. If low temperature coincides with wet soil, it results in the accumulation of harmful products in the plant cells. Frost also interferes with plant metabolism.

Sowing date, reflecting temperature conditions, significantly affected phenology (time to emergence, flowering, and maturity) and pod yield of groundnut. The observed responses appear to have been due to the effect of temperature differences on partitioning during the pod-filling phase (Ntare et. al. 1998).

Temperature and Photosynthesis

The rate of photosynthesis and respiration increases with an increase in temperature, until a maximum value of photosynthesis is reached. This value is maintained over a broad range of temperatures. Then, at considerably higher temperatures, when the enzyme becomes inactivated and various reactions are disturbed, photosynthesis decreases and ultimately stops.

The range of temperature in which photosynthesis is more than 90 percent of the maximum obtainable can be regarded as optimum. This range is narrower for net photosynthesis than for gross photosynthesis, because while gross photosynthesis is still operating at top speed in the optimum range of temperatures, the rate of respiration increases, diminishing the net photosynthetic yield.

High-Temperature Injury to Plants

Thermal death point of active cells ranges from 50 to 60° C for most plant species, but it varies with the species, the age of tissue, and the length of time of exposure to high temperature. It has been reported (Chang, 1968) that most plant cells are killed at a temperature of 45 to 55° C, but some tissues withstand a temperature of up to 105° C.

For aquatic and shade plants the lethal limit is 40 °C, and for most xerophytes it is 50° C, when the plants are exposed to a saturated atmosphere for about half an hour. High temperature results in the desiccation of the plant and disturbs the balance between photosynthesis and respiration. Once the temperature exceeds the maximum up to which growth takes place, plants enter a state of quiescence. When the temperature becomes extremely high, a lethal level is reached. At temperatures higher than the optimum cardinal, the physiological activity declines as a consequence of inactivation of enzymes and other proteins. Leaf functions are disturbed at about 42 °C, and lethal effects on active shoot tissues generally occur in the range of 50 to 60 °C.

Low-Temperature Injury to Plants

Exposure to extremely low temperatures and heavy snowfall damages the plant in several ways including suffocation, desiccation, heaving, chilling, and freezing.

Suffocation

Small plants may suffer from deficient oxygen when covered with densely packed snow. When suffocated, certain toxic substances accumulate in contact with roots and crowns and tend to inhibit the diffusion of carbon dioxide.

Physiological Drought and Desiccation

Spring drought sometimes occurs in cool climates. This results from excessive transpiration and a time lag in absorption of moisture from the soil, caused by a warm period when the soil is still frozen. The result is an internal moisture deficit sufficient to cause death of the twigs. The decreased water absorption by plants at low temperatures is the combined effect of the decreased permeability of the root membrane and increased viscosity of water. This results in increased resistance to water movement across the living cells of the roots.

Heaving

Injury to a plant is caused by the soil layer lifting upward from the normal position and causing the root to stretch or break at a time when the plant is growing. Sometimes the roots are pushed completely above the soil surface. After thawing, it is difficult for the roots to become firmly established, and the plants may die because of this mechanical damage and desiccation.

Chilling

Plants of tropical origin are damaged by exposure to mild chilling for two to three days. Plants of temperate origin withstand chilling for long periods without suffering any injury. Rice, cotton, and cowpea are killed when exposed to temperatures near 0 °C for about two to three days. Sudan grass and peanuts are injured by short exposure to chilling temperatures but recover if favorable temperature conditions return shortly afterward. Short duration mild chilling does not seriously injure corn, sorghum, and pumpkin plants. Plants of cool climate origin such as wheat and soybean are injured when exposed to prolonged chilling but recover with the return of favorable conditions.

Chilling injury of fruits is of particular interest because they are often stored and shipped at low temperatures. Symptoms of chilling injury to fruits include surface pitting, lesions, discoloration, susceptibility to decay organisms, and shortening of storage life. Fruits subjected to chilling injury do not ripen normally. The critical temperature at which chilling injury occurs is 8 to 12 °C for tropical fruits such as banana, avocado, and mango, and 0 to 4 °C for temperate zone fruits such as apple (Kozlowski, 1983).

Freezing Injury

Plant parts or an entire plant may be killed or damaged beyond repair as a result of actual freezing of tissues. Freezing damage is caused by the formation of ice crystals, first in the intercellular spaces and then within the cells. Ice within the cells causes more injury by mechanical damage disrupting the structure of the protoplasm and plasma membrane. Freezing of water in intercellular spaces results in withdrawal of water from the cell sap, and increasing dehydration causes the cell to die.

3.3 Soil Temperature

Soil temperature is an important environmental factor in plant growth and distribution. In comparison to air temperature, the amplitude of variation in soil surface temperature is much more pronounced because of the varying characteristics and composition of soil.

Soil temperature directly influences crop growth because the sown seeds, plant roots and micro-organisms live in the soil. The physicochemical as well as life processes in agriculture are also directly affected by the temperature of the soil. Under low soil temperature conditions, nitrification is inhibited and the intake of water by roots is reduced. Extreme soil temperatures injure plants and thereby affect growth.

Factors Affecting Soil Temperature

- Aspect and slope: These factors are of great importance in determining soil temperature outside the tropics. In the Northern Hemisphere, a south-facing slope is always warmer than a north-facing slope or a level plain. The reverse is the case in the Southern Hemisphere. The difference in soil surface temperature exceeds the difference in air temperature.
- Tillage: By loosening topsoil and creating mulch, tillage reduces the heat flow between the surface and subsoil. Because a mulched surface has a greater exposed area and the capillary connection with moist layers below is broken, cultivated soil has greater temperature amplitude than uncultivated soil. At noon, the air temperature 2.5 cm above the soil surface can be 5 to 10 °C higher in cultivated soil as compared to uncultivated soil.
- Soil texture: Because of lower heat capacity, sandy soils warm up and cool down more rapidly than clay soils; hence, they are at a higher temperature during the day and a lower temperature at night.
- Organic matter: Organic matter reduces the heat capacity and thermal conductivity of soil, increases its water-holding capacity, and has a dark color which increases its solar radiation absorptivity. In humid climates, because of a large water content, peat and marsh are much cooler than mineral soils in spring and warmer in winter. However, when organic soils are dry, they become warmer than mineral soils in summer and cooler in winter.

Soil Temperature and Crop Germination

Soil temperatures influence the germination of seeds, the functional activity of the root system, the incidence of plant diseases, and the rate of plant growth (Singh et al. 1998). Living tissues of many temperate plants are killed when they are exposed to a surface temperature of about 50 °C (Chaurasia et. al., 1985). Excessively high soil temperatures are also harmful to roots and cause lesions on the stem. Extremely low temperatures are equally detrimental. Low temperatures impede the intake of nutrients. Soil moisture intake by plants stops when they are at a temperature of 1 °C. Root growth is generally more sensitive to temperature than that of aboveground plant parts, meaning that the range between maximum and minimum temperature for roots is less than for shoots and leaves.

In the tropics, high soil temperature causes degeneration of the tuber in potato. Optimum soil temperature for this crop is 17 °C. Tuber formation is practically absent above a soil temperature of 29 °C. Preconditioning of potato seed under specific temperatures has an important impact on germination. Seed stored at 27 °C showed the best germination, while that stored at 45 °C failed to germinate even after eight days of lowering the temperature in the germination environment to 17 °C (Pallais, 1995).

After germination, soil temperature is important for the vegetative growth of crops. For each species, a favorable soil temperature is needed for ion and water uptake. The daytime soil temperature is more important than the nighttime temperature, because it is necessary to maintain a favorable internal crop water status to match the high evaporation rate.

Cardinal Temperatures

Three temperatures of vital plant activity have been recognized, which are often termed cardinal points.

1. A minimum temperature below which no growth occurs: For typical cool-season crops, it ranges between 0 and 5° C, and for hot-season crops between 15 and 18° C.

2. An optimum 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.

3. A maximum temperature above which the plant growth stops: For cool-season crops, it ranges between 31 and 37° C, and for hot-season crops between 44 and 50° C.

The cardinal points can be measured only approximately because their position is related to external conditions, the duration of exposure, the age of the plant, and its previous treatment.

3.4 Frost

Frost is a climatic hazard that causes serious damage to standing crops in temperate and subtropical climates. Much distress can be avoided by properly understanding the characteristics of the frost, by using early warning information on frost, and by adopting frost protection measures. For this, the planning should begin before the crop is planted.

Frost is a weather hazard that occurs when the environmental temperature drops below the freezing point of water. It can be a white frost (also known as hoarfrost) or a black frost. White frost occurs when atmospheric moisture freezes in small crystals on solid surfaces. Black frost occurs when few or no ice crystals are formed because air in the lower atmosphere is too dry, but the damaging effect of the low temperatures on vegetation is the same as that of white frost.

Damage to plants from frost occurs because it results in freezing of the plant tissues. Freezing of plant tissues is a physical process triggered by ice nucleating bacteria, the intensity and duration of the night temperature to which the plants are exposed, and the plant growth stage (Woodruff, Douglas, and French, 1997). Green plants contain mostly water, and on freezing, the water expands and ruptures the cell walls of the plant tissues. Because of the presence of chemicals in the sap, plant tissues freeze at temperatures lower than 0° C, the freezing temperature of water. When frozen water melts, it leaks away from the cells. The rupturing of the cells and leakage of water results in the death of tissues, giving a typical "burn" appearance to the plants.

Plants show different symptoms of frost injury, depending on the stage at which freezing occurs. In the case of wheat, freezing stress can cause foliar injury and tiller death. Injury to developing foliage will not affect the crop yield because the plants can compensate. However, freezing injury during stem elongation can substantially reduce the final yield. Leaf injury can occur at any stage of development, and frozen leaves will appear dark in color. Slightly injured leaves will have yellow tips that should not be confused with the symptoms of nutrient stress (Youlang and Ellison, 1996). Injured stems appear discolored and often distorted near the nodes. Injury to young ears can cause the whole ear to die. At the booting stage, frost injury can damage the reproductive parts of some ears. The injury is easily detected after ear emergence because growth of floret and spikelet look stunted. During flowering, the reproductive parts of the plant may be damaged in some ears, and although they appear unaffected, they produce no grain.

Frost Forecast for Next One to Two Days

The meteorological conditions for frost occurrence are clear skies, inversion of temperature, and wind speed less than 7 kph. These weather conditions are normally associated with high pressure systems during the winter season. If the sky is clear, the atmosphere is comparatively calm during a cold evening, and the weather map on television shows that the area of interest falls well within a high pressure system, frost is expected during the next one to two nights.

3.5 Precipitation

Agricultural productivity is closely related to rainfall. Rainfed areas in the world contribute to an estimated 65 percent of global food production, while the remaining 35 percent is produced in the irrigated areas. In most parts of the world, rainfall is, for some parts of the year, insufficient to grow crops, and rainfed food production is heavily affected by annual variations in precipitation. A major part of the developed global water resources is used for food production.

Irrigation is an obvious option to increase and stabilize crop production. Major investments were made in irrigation during the latter half of the twentieth century by diverting surface water and extracting groundwater. The irrigated areas in the world, during the last three decades of twentieth century, increased by 25 percent (FAO, 1993). The expansion rate has slowed down substantially because a major part of the reliable surface waters have already been developed, while groundwater resources have become overexploited at an alarming rate.

With water resources becoming scarce, waters of inferior quality are increasingly used. Excessive use and poor management of such irrigation water has had, in some cases, detrimental effects on soil quality, causing whole areas to be taken out of production or requiring the construction of expensive drainage works. Defining strategies in planning and management of available water resources in the agricultural sector will become a national and global priority.

An inadequate and variable water supply and extremes of temperatures are the two universal environmental risks in agricultural production. High temperatures in tropical climates limit the production of crops native to temperate latitudes, and low winter temperatures in high latitudes are a check on growing crops native to tropical areas. Inadequate and variable water supply, however, has a negative impact on crop production in every climatic region. The problem is more pronounced in tropical and subtropical semiarid and arid climates in which the water losses in evaporation and evapotranspiration are very high throughout the year. Management of water resources is a much greater and more universal problem than any other factor of the environment.

Not all rainfall that falls in a field is effectively used in crop growing, as part of it is lost by runoff, seepage, and evaporation. Only a portion of heavy and high-intensity rains can enter and be stored in the root zone, and therefore effectiveness of this type of rainfall is low. With a dry soil surface with no vegetation cover, rainfall up to 8 mm/day may all be lost by evaporation. A rainfall of 25 to 30 mm may be only 60 percent effective with a low percentage of vegetative cover. Frequent light rains intercepted by a plant canopy with full ground cover are close to 100 percent effective (FAO, 1977).

In most parts of the world crop production depends on rainfall. Knowledge of the probable dates of commencement and end of the rainy season and the duration of intermittent dry and wet spells can be very useful for planning various agronomic operations such as preparing a seedbed, manuring, sowing, weeding, harvesting, threshing, and drying. This results in minimizing risk to crops and in optimum utilization of limited resources including water, labor, fertilizer, herbicides, and insecticides. There are critical periods in the life history of each crop, from sowing to harvesting. With knowledge of frequency of occurrence of wet and dry spells, a farmer can adjust sowing periods in such a way that moisture-sensitive stages do not fall during dry spells. Under irrigated farming, irrigation can be planned using data regarding consecutive periods of rainfall to satisfy the demands for critical periods. Knowledge of wet and dry spells can also help a great deal in improving the efficiency of irrigation-water utilization.

Effective rainfall and its significanceThe primary source of water for agricultural production for most of the world is rainfall. Three main characteristics of rainfall are its amount, frequency and intensity, the values of which vary from place to place, day to day, month to month and also year to year. Precise knowledge of these three main characteristics is essential for planning its full utilization.

Information of the amount, intensity and distribution of monthly or annual rainfall for the most important places in the world is generally available. Long-term records of daily rainfall have been compiled for years; norms and standard deviations have been worked out; floods and droughts have been defined and climatic zones of potential evapotranspiration less precipitation have been mapped from rainfall patterns and crop studies. Investigations using electronic computers are continuously in progress and efforts are being made to predict future trends in order to refine planning.

In spite of voluminous data on weather, all is not yet known that should be known about rainfall. Certain simple entities have baffled planners right up to the present. One of these is "effective rainfall".

In its simplest sense, effective rainfall means useful or utilizable rainfall. Rainfall is not necessarily useful or desirable at the time, rate or amount in which it is received. Some of it may be unavoidably wasted while some may even be destructive. Just as total rainfall varies, so does the amount of effective rainfall. The importance of precise knowledge on the subject of effective rainfall needs little elaboration. The useful portion of rainfall is stored and supplied to the user; the unwanted part needs to be conveyed or removed speedily.

Most rain water is used in agriculture for crop production. Therefore, the first point which arises is whether the available rainfall is adequate and well distributed for crop-raining. If it is inadequate, can it be supplemented with timely irrigation? If not, what type of agriculture should be practised? If irrigation can be supplied, bow should it be designed, operated and maintained? What are the water requirements of crops during the growing season as well as during different periods of growth and development and how far are these needs met by rainfall? How can excess rain water be disposed of and how can waste be reduced by changing management practices? Finally, what would all this cost? Without the necessary information on these basic points, no irrigation project can be planned and productively and economically executed. The greater the precision of long-term data on rainfall patterns and the greater the care taken in interpreting them, the higher will be the efficiency of water management projects.

Pharande and Dastane (1964) listed salient points in the practical application in the field of agriculture of data on effective rainfall as follows:

- designing irrigation projects on a sound economic basis;
- fixing cropping patterns and working out the irrigation requirements of crops;
- operating irrigation projects efficiently from year to year;
- preparing schedules of other farm operations in irrigated agriculture;
- planning cropping patterns in unirrigated or rainfed areas;
- designing drainage and land reclamation projects;
- planning soil and water conservation programs;
- interpreting field experiments accurately;
- classifying regions climatologically for agriculture.

Meteorologists can neither solve nor evaluate the problem of effective rainfall merely from tables of frequency, amount and intensity of rainfall or from physical phenomena in the atmosphere. It is a task in which several disciplines and sub-disciplines overlap. For example, in the field of agriculture, soil types, cropping patterns and social, economic and management factors all have a direct impact on the extent of effective and ineffective rainfall.ce

Because of such complexities, there is confusion in concepts, definitions and measurements and their interpretation. The nomenclature and methods of measurement need to be standardised as well as interpreted for a better understanding of effective rainfall and to convert total rainfall into effective rainfall to the maximum possible extent.

In this paper on effective rainfall, present concepts are reviewed and defined, present methods of its assessment are examined, estimating procedures for evaluation in applied fields, especially that of irrigated agriculture, are suggested and future lines of work on this subject are pinpointed.

3.6 Atmospheric Pressure

The lower atmospheric pressures experienced as altitude increases have important consequences for plant life at high altitude. At high altitudes and low atmospheric pressures the solubility of carbon dioxide and oxygen in water is reduced. Some plants show stunted growth at higher altitudes as concentrations of oxygen and carbon dioxide reach low levels. Plants with strong root systems and tough stems can live under increased wind speeds at low pressures in high-altitude areas. It is usually adequate to know the altitude at which an event takes place, but in some cases pressure variations have to be taken into account.

3.7 Wind

Wind transports heat in either sensible or latent form between lower and higher layers of the atmosphere and from lower to higher latitudes. Moderate turbulence promotes the consumption of CO_2 by crops during photosynthesis. Wind prevents frost by disrupting a temperature inversion. Wind dispersal of pollen and seeds is natural and necessary for certain agricultural crops, natural vegetation, and so on. As far as the action of wind on soil is concerned, it causes soil erosion and transport of particles and dust. Extreme winds cause mechanical damage to crops (for example, lodging or leaf damage) and forests (wind throw). Knowledge of the wind is also necessary for environmentally sensitive spray application and for the design of wind protection. For the main regional crops, it may be useful to make observations of wind profiles inside and above the crop canopies for a better understanding of exchange properties.

3.8 Humidity

Humidity is closely related to rainfall, wind and temperature. Different humidity-related parameters such as relative humidity, vapor pressure, dew point and other derived characteristics play a significant role in crop production and strongly determine the nature of crops grown in a region. Internal water potentials, transpiration and water requirements of plants are dependent on humidity. Extremely high humidity is harmful as it enhances the growth of some saprophytic and parasitic fungi, bacteria and pests, the growth of which causes extensive damage to crop plants. Extremely low humidity reduces the yield of crops.

Like temperature and for the same reasons, the humidity of the air should be measured in representative places, at different levels in the layer adjacent to the soil at principal agricultural meteorological and other category stations. The procedures for air temperature should also be followed for this weather variable, including taking measurements above and within vegetation.

Vapour Pressure Deficit, or VPD, is the difference (deficit) between the amount of moisture in the air and how much moisture the air can hold when it is saturated. Once air becomes saturated water will condense out to form clouds, dew or films of water over leaves. It is this last instance that makes VPD important for greenhouse regulation. If a film of water forms on a plant leaf it becomes far more susceptible to rot. On the other hand, as the VPD increases the plant needs to draw more water from its roots. In the case of cuttings, the plant may dry out and die. For this reason the ideal range for VPD in a greenhouse is from 0.45 kPa to 1.25 kPa, ideally sitting at around 0.85 kPa. As a general rule, most plants grow well at VPDs of between 0.8 to 0.95 kPa.

In ecology, it is the difference between the actual water vapor pressure and the saturation water vapor pressure at a particular temperature. Unlike relative humidity, vapor pressure deficit has a simple nearly straight-line relationship to the rate of evapotranspiration and other measures of evaporation.

3.9 Soil Moisture and Water Balance

In scheduling irrigation, the estimation of soil moisture content is the basic requirement. Soil moisture should be measured at all principal stations and, wherever possible, at other agrometeorological stations. Standard soil moisture observations should be made below a natural surface representative of the uncultivated regional environment. Simultaneous observations in areas devoted to principal regional crops and covering all cultural operations will show modifications introduced by agricultural processes. These soil moisture measurements are particularly useful in verifying soil moisture values estimated from meteorological measurements.

A quantitative forecast of the probability of water excess or stress for rainfed crops, and of the timing and amount of irrigation for irrigated crops, is highly useful. This kind of forecast for rainfed crops is based on correct forecasting of precipitation and evapotranspiration. The water balance approach to arrive at soil moisture excess or deficiency would require daily forecasts of rain in the first month of crop growth and on a short-period basis thereafter. Since irrigation water is applied ahead of crop water consumption for forecasts of irrigation scheduling, forecasts of evapotranspiration and likely rainfall amounts on a short-period basis will do.

An understanding of water or moisture balance is necessary to appreciate the role of various management strategies in minimizing the losses and maximizing the utilization of water, which is the most limiting factor of crop production in semi-arid tropics (SAT).

Water is essential for plant life. The important functions of water in the plant are:

Dissipate heat that is produced by the plant's metabolic activities.

Plants continually absorb water from their growth medium and evaporate part of it into the surrounding atmosphere. This is transpiration and takes place mainly through the leaves. Water loss through transpiration helps the plant dissipate heat that has accumulated as a result of metabolism and radiant energy intake.

Donate electrons through photolysis for photosynthesis.

The photosynthetic process is driven by light energy. Light functions initially to split water into protons (H+), electrons (e-), and molecular oxygen (1/2 O_2).

Light

H_20 -------------> (2 H +) + (2 e -) + (1/2 O_2)

The released electrons participate in a series of oxidation-reduction reactions that eventually drive the biochemical reactions in photosynthesis.

Dissolve minerals and organic compounds in cells.

Water is called the universal solvent, because any molecule that is polar will dissolve in it. As ions are formed, they are surrounded by the oppositely charged ions of water. In the cell, water serves as a medium through which solutes move.

Water requirements of the plants are met by the supplies from soil, which acts as reservoir for water. The amount of water held by soil depends on the inputs and losses from the system and holding capacity of the soil. Important sources of water in the field are generally rainfall and irrigation. Losses of water include surface runoff from the field, deep percolation out of root zone or drainage, evaporation from the soil surface and transpiration from the crop canopy.

Soil water balance equation

Soil water balance, like a financial statement of income and expenditure, is an account of all quantities of water added, removed or stored in a given volume of soil during a given period of time. The soil water balance equation thus helps in making estimates of parameters, which influence the amount of soil water.

Using the soil water balance equation, one can identify periods of water stress/excesses which may have adverse affect on crop performance. This identification will help in adopting appropriate management practices to alleviate the constraint and increase the crop yields.
As explained earlier, the amount of water in a soil layer is determined by those factors that add water to the soil and those factors that remove water from it.

Hence the soil water balance equation in its simplest form of expression is:

Change in soil water = Inputs of water - Losses of water Addition of water to the soil:

Water is usually added to the soil in three measurable ways - precipitation (P), irrigation (I), and contribution from the ground-water table (C). The contribution from the ground water will be significant only if the ground-water table is near the surface.

So, the inputs of water can be presented as:

Water Inputs = P + I + C

Removal of water:

Water is removed from the soil through evaporation from soil surface or transpiration through plant together known as evapotranspiration (ET), and deep drainage (D). Further, a part of the rain water received at the soil surface may be lost as surface run-off(RO).
The above three factors are negative factors in the equation. The losses of water from soil can then be represented by the following equation.

Water Losses = ET + D + RO

Soil water balance
The change in the soil water content which is the difference between the water added and water withdrawn will now read:

Change in Soil water = (P + I + C) - (ET + D + RO)

Soil water refers to the amount of water held in the root zone at a given time. This amount can be measured. The change in soil water from one measurement to another depends on the contribution of components in the equation. Suppose the amount of water in the root zone at the beginning is M1 mm and at the end of a given period is M2 mm, thus the equation is expressed as

M1 - M2 = P + I + C - ET - D - RO
or
M1 + P + I + C = ET + D + RO + M2

With the help of this equation one can compute any one unknown parameter in the equation if all others are known.

The quantitative data on rainfall (P) evapotranspiration (ET), deep drainage (D) and soil moisture at a given time (M1 or M2) for different locations and for different practices are useful for selecting appropriate water-management strategies.

3.10 Leaf Wetness and Dew

Leaf wetness is produced by rainfall, dew or fog. Duration of this phenomenon can be important in order to plan different activities, such as the application of pesticides and harvesting of crops. Leaf wetness is a parameter that is scarcely recorded. Leaf wetness can result from precipitation, from dew or from guttation. Knowledge of leaf wetness duration is vital information for the protection of crops against fungi and diseases and it cannot be deduced usefully with rules of thumb such as Relative Humidity > 90 per cent. Actual monitoring has so far been carried out only in a few countries on a routine basis with specific agro-meteorological requirements in mind. Studies and recordings of leaf wetness duration (LWD) also help in developing early warning systems and plant protection, in understanding soil evaporation and in improving leaf-surface water evaporation modelling.

The weather provides liquid water not only in the form of precipitation, but also in the form of dew, which is not the same as leaf wetness but is one of its possible causes. Dew (fall) occurs in a humid atmosphere when temperature falls and wind is weak, resulting in condensation both on the vegetation and on the soil. Dew often occurs due to distillation of water from (wet) soil (dew rise). Guttation occurs on vegetation when its internal water pressure is excessive.

3.11 Evaporation and Evapotranspiration

Measurement of evaporation from free water surfaces and from the soil, and of transpiration from vegetation, remains of great importance in agricultural meteorology. Potential evapotranspiration is defined as the amount of water that evaporates from the soil–air interface and from plants when the soil is at field capacity. Actual evapotranspiration is defined as the evaporation at the soil–air interface, plus the transpiration of plants, under the existing conditions of soil moisture.

Pan evaporation is a measurement that combines or integrates the effects of several climate elements: temperature, humidity, rain fall, drought dispersion, solar radiation, and wind. Evaporation is greatest on hot, windy, dry, sunny days; and is greatly reduced when clouds block the sun and when air is cool, calm, and humid. Pan evaporation measurements enable farmers and ranchers to understand how much water their crops will need.

Forecast of evapotranspiration can be important to improve knowledge of the water status of crops. This kind of forecast is founded on the correct forecast of solar radiation, temperature, relative humidity and wind speed. For real-time use, forecast of evapotranspiration has to be founded on a forecast of pan evaporation.

4. ENSO and Monsoon Outlook

Most of the internal variability of climate in the tropics and a substantial part of mid-latitudes is related to El Niño/ Southern Oscillation (ENSO) which is a natural phenomenon. Atmospheric and oceanic conditions in the tropical Pacific vary considerably, fluctuating somewhat irregularly between the El Niño phase and the opposite La Niña phase. In the former, warm waters from the western tropical Pacific migrate eastward, and in the latter, cooling of the tropical Pacific occurs. The whole cycle can last from three to five years.

As the El Niño develops, the trade winds weaken as the warmer waters in the central and eastern Pacific occur, shifting the pattern of tropical rainstorms east. Higher than normal air pressures develop over northern Australia and Indonesia with drier conditions or drought. At the same time, lower than normal air pressures develop in the central and eastern Pacific, with excessive rains in these areas, and along the western coast of South America. Approximately reverse patterns occur during the La Niña phase of the phenomenon.

The main global impacts that El Niño events cause are above-average global temperature anomalies. Since the mid-1970s El Niño events have been more frequent, and in each subsequent event, global temperature anomalies have been higher.

Low atmospheric pressure tends to occur over warm water and high pressure occurs over cold water, in part because of deep convection over the warm water. El Niño episodes are defined as sustained warming of the central and eastern tropical Pacific Ocean. The relationship between El Niño and the Indian monsoon rainfall is expected to be useful in forecasting large-scale anomalies in the monsoon over Indian sub-continent. Generally drier conditions are experienced in South Asia during El Niño year. Due to that, the onset of monsoon is delayed during El Niño year. So, prediction of ENSO is vital for Nepal’s agriculture as it depends mainly in rainfall during summer monsoon. And, also drought-like or flood-like climate can be predicted.

5. Drought

Drought is a climatic hazard that occurs in almost every region of the world. It causes physical suffering, economic losses, and degradation of the environment. A drought is a creeping phenomenon, and it is very difficult to determine when a dry spell becomes a drought or when a severe drought becomes an exceptional drought. It is slower and less dramatic than other natural disasters, but its effects are long lasting and widespread. The cost and misery suffered from a drought are more than those resulting from typhoons, earthquakes, and all other sudden climatic hazards. A drought results in less water in the soil, streams, and reservoirs, less water for livestock and wildlife, and poor crops and pastures. A chain of indirect effects follows which may include depressed farm income, closure of farm-supporting industries, and reduced hydroelectric power.

The economic cost may include losses from crop, dairy, livestock, fishery, and timber production. Economic development, recreational business, and manufacturing are slowed, unemployment increases, and prices of essential commodities soar. Social costs of a drought may encompass food shortages, malnutrition, conflict between water users, water and garbage sanitation problems, increased poverty, decreased living standards and reduced quality of life, social unrest, and population migration from rural areas to urban centers.

According to a WMO definition, “drought is a sustained, extended deficiency in precipitation.” Operational definitions of drought vary from place to place and are crucial to identify the beginning and intensity of drought. There are three main types of drought;

1. Meteorological drought is an expression of rainfall departure from normal over some period of time. Meteorological drought definitions are usually region specific and are based on a thorough understanding of the climatology of the region.

2. Agricultural drought occurs when there is not enough soil moisture to meet the needs of crops at a particular time.

3. Hydrological drought refers to deficiencies in surface and subsurface water supplies. It is measured as stream flow and as lake, reservoir, and groundwater levels.

5.1 Meteorological Indicators of Drought

Drought conditions are basically due to a deficit of water supply in time and/or space. The deficit may be in precipitation, stream flow, or accumulated water in storage reservoirs, ground aquifers, and soil moisture reserves. In describing a drought situation, it is important to understand its duration, spatial extent, severity, initiation, and termination. Depending on the areal extent, a drought can be referred to as a point drought, small-area drought, or a continental drought. The point and small-area drought frequency are very high but are not major sources of concern at the national scale, unless they continue for a prolonged period. When the areal extent of the drought assumes a wide dimension, its assessment and mitigation measures become state and national concerns.

Over time, a number of drought assessment methods have been proposed. Some methods are based on qualitative observations, some on scientific criteria, and others on actual field surveys. However, to date, no comprehensive assessment method is available that has universal appeal. Different countries use different criteria to define and assess the drought situation. It is beyond the scope of this report to enumerate each and every indicator of drought that has been proposed and referred to in the literature. Some of these are very simple and old but still widely used. Others are more comprehensive, having sound scientific bases and holding good promise for application.

The percent of normal precipitation is one of the simplest measurements of drought for a location. It is calculated by dividing actual precipitation by the normal (considered to be a 30 or more years mean) and multiplying by 100. The percent of normal is calculated for a variety of time scales. Usually the time scales range from a single month, to a group of months representing a particular season, to an annual climatic year.

Analyses using the percent of normal are very effective when used for a single region or a single season. However, it is also easily misunderstood and gives different indications of conditions depending on the location and season.

One of the disadvantages of using the percent of normal precipitation is that the mean, or average, precipitation is often not the same as the median precipitation, which is the value exceeded by 50 percent of the precipitation occurrences in a long-term climatic record, largely because precipitation on monthly or seasonal scales does not have a normal distribution. Use of the percent of normal comparison implies a normal distribution in which the mean and median are considered to be the same. Because of the variety in precipitation records over time and locations, there is no way to determine the frequency of the departures from normal. Therefore, the rarity of an occurring drought is not known and cannot be compared to a different location.

The India Meteorological Department defines drought on the basis of rainfall deficiency during the southwest monsoon season on the basis of the percent of normal rainfall (Murty and Takeuchi, 1996). It employs two measures, the first describing rainfall conditions and the second representing drought severity. Rainfall conditions (based on the average rainfall of the last 70 to 100 years) are described as rainfall thresholds, with rainfall expressed on a weekly or monthly basis.

Standardize Precipitation Index:

Deficit of rainfall over a period of time at a certain location could lead to various degrees of drought conditions, affecting water resources, agriculture and socio-economic activities. Since rainfall varies significantly among different regions, the concept of drought may differ from places to places. As such, for more effective assessment of the drought phenomena, the World Meteorological Organization (WMO) recommends adopting the Standardized Precipitation Index (SPI) to monitor the severity of drought events.

In simple terms, SPI is a normalized index representing the probability of occurrence of an observed rainfall amount when compared with the rainfall climatology at a certain geographical location over a long-term reference period. Negative SPI values represent rainfall deficit, whereas positive SPI values indicate rainfall surplus. Intensity of drought event can be classified according to the magnitude of negative SPI values such that the larger the negative SPI values are, the more serious the event would be. For example, negative SPI values greater than 2 are often classified as extremely dry conditions.

Moreover, SPI enables rainfall conditions to be quantified over different time scales (e.g. 3-, 6-,12-, or 24-month rainfall), facilitating the analyses of drought impact on various water resource needs. For example, SPI-3 measures rainfall conditions over a 3-month period, the anomalies of which impact mostly on soil water conditions and agricultural produce; while SPI-24 measures rainfall conditions over two years, as prolonged droughts can give rise to shortfalls in groundwater, stream flow, and fresh water storage in reservoirs.

An advantage in using SPI is that only rainfall data are needed for its computation. SPI can also be compared across regions of different climatic zones.

McKee and others (1993) used the classification system shown in the SPI value table below (Table 1) to define drought intensities resulting from the SPI. They also defined the criteria for a drought event for any of the timescales. A drought event occurs any time the SPI is continuously negative and reaches an intensity of -1.0 or less. The event ends when the SPI becomes positive. Each drought event, therefore, has a duration defined by its beginning and end, and an intensity for each month that the event continues. The positive sum of the SPI for all the months within a drought event can be termed the drought's "magnitude".

Table 1 SPI Values

2.0+	extremely wet
1.5 to 1.99	very wet
1.0 to 1.49	moderately wet
-.99 to .99	near normal
-1.0 to -1.49	moderately dry
-1.5 to -1.99	severely dry
-2 and less	extremely dry

Based on an analysis of stations across Colorado in the United States, McKee determined that the SPI indicates mild drought 24% of the time, moderate drought 9.2% of the time, severe drought 4.4% of the time and extreme drought 2.3% of the time (McKee and others, 1993). Because the SPI is standardized, these percentages are expected from a normal distribution of the SPI. The 2.3% of SPI values within the "extreme drought" category is a percentage that is typically expected for an "extreme" event. In contrast, the Palmer Drought Severity Index reaches its "extreme" category more than 10% of the time across portions of the central Great Plains in the United States. This standardization allows the SPI to determine the rarity of a current drought (Table 2), as well as the probability of the precipitation necessary to end it (McKee and others, 1993). It also allows the user to confidently compare historical and current droughts between different climatic and geographic locations when assessing how rare, or frequent, a given drought event is.

Table 2 Probability of Recurrence

SPI	Category	Number of times in 100 years	Severity of Events
0 to -0.99	Mild dryness	33	1 in 3 yrs.
-1.00 to -1.49	Moderate dryness	10	1 in 10 yrs.
-1.5 to -1.99	Severe dryness	5	1 in 20 yrs.
< -2.0	Extreme dryness	2.5	1 in 50 yrs.

6. Pests and Agrometeorological Indicators

Weather is the most important factor that determines the geographical distribution and periodic abundance of crop insect pests and parasites of animals. Weather controls the development rate, survival, fitness, and level of activity of individual insects; the phenology, distribution, size, and continuity of insect populations; migration and their establishment; and the initiation of insect outbreaks (Drake and Farrow, 1988). Weather influence can be immediate, cumulative, direct, indirect, time lagged, exported, or imported. Indirect effects arise through host quality and parasite populations. A time-lagged influence is one that occurs at a later stage as a consequence of both past and current weather. Imported/exported influences arise because insects are highly mobile, and outbreaks may be initiated by windborne migrations (Drake, 1994).

Among the weather elements, temperature, humidity, and wind play the major roles in insect life. Other elements of lesser importance are solar radiation and photoperiod. In interpreting the role of weather in an insect’s life, we must remember that all weather elements are interrelated, so the role played by any individual element is not simple to understand and explain.

Agrometeorological risks in the farming sector include the temporal and spatial variability of rainfall, temperature, evaporation and, in climate change scenarios, atmospheric carbon dioxide levels. While such factors may impact directly on plant growth and development they can also exert an important indirect effect by influencing the life cycles of plant diseases and pests. In addition they may have a profound influence on attempts to control such pests, as is seen when an unexpected rainfall event causes dilution or early hydrolysis of a surface pesticide, or when hail damage opens the way for mould, bacterial or insect attack. Integrated pest management (IPM) must take into account such risks if crop damage is to be minimized. The implications of agrometeorological risk studies offer not only local perspectives on IPM but also provide information for improved crop profitability, natural resource usage and agricultural sustainability in other countries, where a critical relationship between crop success, regional food security and human survival may exist.

Global climate change will inevitably present a challenge to those engaged in agroclimatic risk modelling in the interests of Integrated Pest Management (IPM). Agribusiness units most at risk are likely to be those already stressed as a result of factors such as land degradation, salinization and ecological change. Local economic setting must also be taken into account when estimating possible impacts. In countries with a low level of agricultural industrialization, many units may be based on low capital investment resulting in short-term land use policies, while in industrialized countries units may exist at the other extreme, having overcapitalized on items such as dedicated irrigation systems, slow-growing cultivars and on-site processing facilities. Units at both ends of this capitalization spectrum may, however, be economically marginal in terms of climate change, with increased reliance on state subsidy, off-farm income, or secondary industry support. Such situations do not offer much leeway for farming sustainability through IPM in areas where climate change may be accompanied by increased disease occurrence or pest invasion.

7.. Review of Gaps in Agrometeorological Indicators in Nepal

7.1 Department of Hydrology and Meteorology

The principal information base for describing the climate of Nepal, its variability, and its long-term trends is provided by the Department of Hydrology and Meteorology (DHM) which has a mandate from Government of Nepal to monitor all the hydrological and meteorological activities in Nepal. The scope of work includes the monitoring of river hydrology, climate, agrometeorology, sediment, air quality, water quality, limnology, snow hydrology, glaciology, and wind and solar energy. General and aviation weather forecasts are the regular services provided by DHM.

As a member of the World Meteorological Organization (WMO), DHM contributes to the global exchange of meteorological data on a regular basis. DHM actively participates in the programs of relevant international organizations, such as, the UNESCO's International Hydrological Program (IHP) and WMO's Operational Hydrology Program (OHP). In the past, DHM has hosted several regional and international workshops, symposia, seminars and meetings on different aspects of meteorology, hydrology, sediment, water quality and snow hydrology. The department is also a focal point for the Intergovernmental Panel on Climate Change (IPCC) and for the meteorological activities of the South Asian Association for Regional Co-operation (SAARC). The International Civil Aviation Organization (ICAO) has recognized DHM as an authority to provide meteorological services for international flights.

Short-term weather and daily weather forecasts for Kathmandu and forecast for mountaineering expedition are made available through the media, including newspapers, radio, television, and the World Wide Web (www.mfd.gov.np). The Director General heads DHM. The present Organizational Chart has four divisions headed by Deputy Director Generals: Hydrology Division, Climatology Division, Meteorological Forecasting Division and Meteorological Network Division. Hydrology Division has five major sections: Hydrological Network Section, Flood Forecasting Section, Snow, Water Quality and Environment Section, Hydrological Data Management Section and Technical Relation and Arrangement Section. Similarly, the sections under the Climatology Division include: Climatology Section, Agro-meteorology Section, Instruments Section and Meteorological Data Management Section. The Meteorological Forecasting Division has three main units: the Communication Unit, Aviation Unit, and General Weather Forecast Unit. Meteorological Network Division is primarily responsible for operation and maintenance of nationwide meteorological stations network. It has the three regional offices and the Planning and Network Section at central office.

Existing Observational Network of DHM

Manual Stations

Type of Stations	Number of Stations
a. Precipitation stations	173
b. Climatic Stations	72
c. Agro-meteorological Stations	21
d. Synoptic	9
e. Aero-synoptic Stations	7
f. Hydrometric stations	154
g. sediment stations	20

Automatic Surface Observation systems

Type of Stations	No. of Stations
1. Automatic weather stations near real time data (Air temp, R.H. , Precipitation, atm. Pressure, wind speed and direction, solar radiation)	14 stations
2. Automatic stations near real time data (air temp, R.H. Rainfall)	7 stations
3. Automatic rainfall stations near real time (Data transmission is through GPRS, CDMA system in every 10-30 minute depending on site)	51 stations
4. Automatic weather stations offline	7 stations
5. Automatic real time river gauge stations	31 stations

Besides that FY-2D Data Receiving and Processing station installed on 18th Dec 2007 and Digital Meteorological Data Dissemination (DMDD) system to receive INSAT imageries, meteorological data and products installed in 2010. DHM has been collecting Hydro-meteorological information through different medium like by post, SDMA wireless technology (www.easy-q.com/mfd/), e-link to receive global data, fax, telephone and email.And, such data are disseminating through publication, digital data, websites (www.dhm.gov.np ; www.mfd.gov.np), Data exchange through e-links server, Radio & F.M., Television, Newspaper, and via phone (Toll free no. 1618070733333) mfd upon request. Moreover, DHm is issuing weekly and monthly bulletin. Weather Forecast and Research (WRF) model has been using to forecast for 3 days

DHM Agro-met Data Gaps:

There are about 21agrometeorological stations(see annex 3) under DHM network in Kanchanpur, Banke, Mustang, Nawalparasi, Rupandehi, Gorkha, Kaski, Tanahu, Chitawan, Bara, Nuwakot, Lalitpur, Dolakha, Siraha, Dhankuta, Sunsari, Ilam and Jhapa which gives observations on Precipitation (mm), Temperature (°C), Soil Temperature (0, 5 cms, 10 cms, 20 cms, 30 cms, 50 cms), wind speed and direction (2 m to 10 m), Sunshine duration (hrs.) and Evaporation (mm/day).

Most of the manual stations historical data have been digitized but some of parameters like soil temperature (0, 5 cms, 10 cms, 20 cms, 30 cms, 50 cms), Wind speed and direction (2 m to 10 m), Sunshine duration (hrs.) and Evaporation (mm/day) have to be digitized as the continuity of the record of the such parameters may be broken with missing data.

8. Recommendations for developing Agrometeorological Indicators in Nepal

Agrometeorological parameters are important for the growth of the plant. For optimum crop growth, specific climatic conditions are required. Agrometeorology thus becomes relevant to crop production because it is concerned with the interactions between meteorological and hydrological factors on the one hand and agriculture, in the widest sense including horticulture, animal husbandry, and forestry, on the other (Figure 1). Its objective is to discover and define such effects and to apply knowledge of the atmosphere to practical agricultural use. The field of interest of an agrometeorologist extends from the soil surface layer to the depth down to which tree roots penetrate. In the atmosphere he or she is interested in the air layer near the ground in which crops and higher organisms grow and animals live, to the highest levels in the atmosphere through which the transport of seeds, spores, pollen, and insects may take place. As new research uncovers the se crets of meteorological phenomena, there is increasing interest in remote sensing and interactions between oceans and the atmosphere in shaping seasonal conditions.

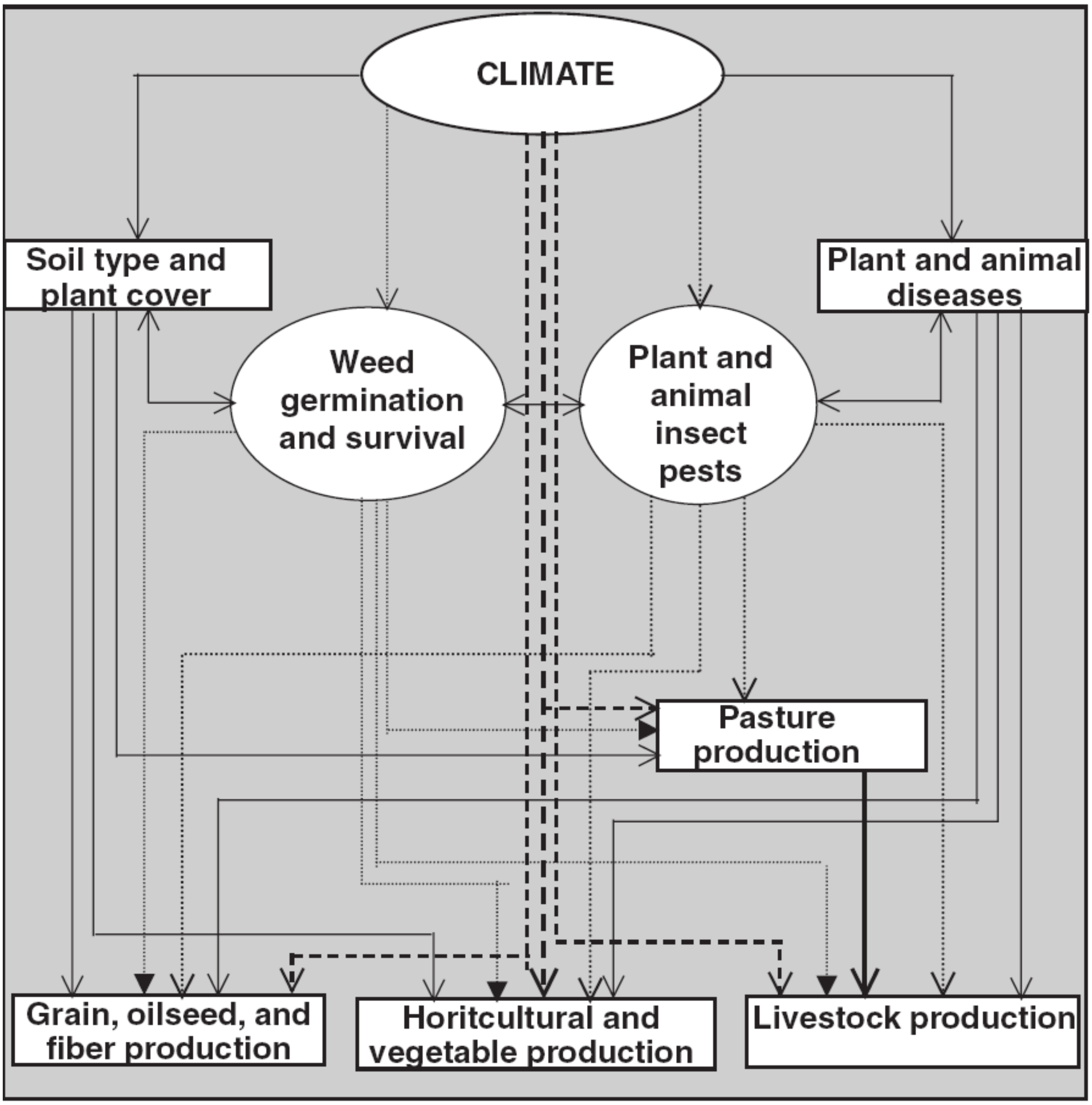

Figure 1Climate and Agricultural Production(adapted)

For the agromet advisories following climate information should be tailored from available DHM data;

- *Weather synopsis*: This is the description of locations and movements of low pressure systems, high pressure systems, upper air troughs, fronts, and associated weather with these systems. This information is derived from synoptic observations, prognostic charts, and visible and infrared imageries from meteorological satellites. For seasonal forecasts the inferences are drawn from historical data, ENSO(SOI values) and phases, and other relevant tele-connections.
- *Interpretation of weather on crops*: Interpretation of weather conditions on crops takes into account the impact of weather on germination, growth rate, freeze protection, and irrigation demand. The cumulative effect of weather encountered and anticipated is used to determine dates of harvest, duration of harvest, and quality and storage capabilities of grains, fruits, and vegetables.
- *Interpretation of weather on farm operations*: Interpretation of weather on farm operations takes into account the drying rate of soil, evaporation losses, effect of heat, cold, and wind on applications of chemicals and fertilizers, and the drying rate of curing, wetting, and rewetting grains and hay.
- *Interpretation of weather on livestock*: Various combinations of heat and moisture in the atmosphere cause comfort or discomfort to animals. Indices are available that express the combined effects of temperature and humidity on animals. The indices provide indications of heat stress, cold stress, shelter requirements, and the effect of weather on meat, milk, and egg production. These indices are used to give timely warnings of anticipated weather dangerous to the health and safety of livestock.
- *Interpretation of weather for crop pests and diseases*: A close relationship exists between many animal and plant diseases, insect pests, and weather. The incidence of these diseases and pests is forecast in the light of accumulated and anticipated weather. Simulation, synoptic, and statistical techniques are used for forecasts which pertain to the probable development, intensity, spatial and temporal spread, or suppression of diseases.

9. Need for Digitization of Agricultural Information and Data for use in Agrometeorological Advisories

The Government of Nepal has accorded top priority to agricultural development in every five-year plan period. So, the governmental and non-governmental bodies has been collecting important basic data on agricultural structures (such as: information on number of farms and their distribution by size, land tenure and land use, data on all crops and livestock species, information on crop patterns, use of pesticides and fertilizers, irrigation practices, employment in agriculture, etc.) for planning development of agriculture. In case of crop data of Nepal from 1961/62 to 1996/97, one should know all those data were previously collected and published either by the Ministry of Agriculture and Department of Food and Marketing Services. Since 1992, the responsibility of collecting crop data was transferred to the Central Bureau of Statistics, National Planning Commission. In addition to the above decision, there is also important point to note that Agricultural Statistics of Nepal from 1974/75 to 1991/92 was revised by National Planning Commission Secretariat during May, 1994 and it has been mentioned that estimated agricultural cropped area and production were changed significantly due to the recent availability of information from cadastral survey and land resources mapping survey.

The following is the list the major agricultural censuses, surveys, and administrative records currently and/or frequently conducted in the country:

- Censuses: National Sample Census of Agriculture (NSCA)
- Surveys: Crop and Livestock Survey (CLS)
- MOAD Administrative Records
- NARC research/survey Records

Usefulness of Historical Data for Digitization

Following information/data has to be digitized for the following reasons;

I. Long term preservation of documents
II. Orderly archiving of documents
III. Easy and customized access to information
IV. Easy information dissemination through images, text, CD-ROMs, internet, intranet and extranets

More precisely, digitization offers the following potential benefits:

The ability for more than one person to access agricultural related data at once:

Users can concurrently access the same data. A company or organization does not need to acquire and keep several copies of one data/information.

Access from anywhere at any time:

Apart from access while users can do from different locations, different devices , anytime.The physical documentation usually has a schedule of access, but the business world (and the public goes along) knows no timetables or regions, making business and operations throughout the week, especially when SMEs (Strengthening, Monitoring and Evaluation) start internationalize and presence in several markets at once (you do not have to be in the same time zone).

The ability to transmit data/information within a structured workflow to facilitate:

The process of transferring hard copies of data/information can be really expensive, in time and physical material (ink, paper).

The elimination of hybrid systems (paper and digital) that can confuse users who want access to the entire history of a case:

When we change environments when speaking of the same compendium of information, we will inevitably lose some information along the way. There will be some updated documents in digital paper that are obsolete, and in many cases it will be difficult to know which is the latest version of the document or set of documents in question. Furthermore, as indicated from the norm, tracking (history) to the evolution of the document will be really difficult to do, since the document may be digital in some versions, and on paper in a specific location for other versions.

The ability to reuse existing resources limited by its format, such as large maps or materials stored on microfilm or magnetic tape:

Of course, the physical resources are limited, both the size of printing as to the cost of storing. Store large volumes of maps, etc paper documents has an associated cost huge in itself, not only by the slow search or access difficulties, but simply because the square meter of land is expensive, and populate it with data in the form of paper does not seem the best investments perform.

Hence the benefits of using other methods like the "cloud".

Obtaining a copy protected and safe:

A backup of a paper document requires either alone scanning of the document or use a capture process to perform a physical reproduction (with paper waste, electricity and associated with printing ink). The backup in an encrypted environment is performed in most cases in a matter of less than one second.

The potential reduction in physical storage space:

After digitization we do not need large room for documents and storage can be done in hard disk, compatible discs etc. easily.

The ability to increase the productivity of the organization:

Document capture systems that support document scanning reported drastic reductions of manual labor, or what is the same, release team task as identifying documents, archiving according to their type and extraction information contained in the documents. Between 60 and 90% of the costs of such tasks are entirely avoidable using support advanced capture system.

So, as the data are available easily and at any time, making agromet advisory will be also easy and can be prepared and issued as per needed.

10. Conclusions

Agrometeorological parameters is part of a continuum that begins with scientific knowledge and understanding and ends with the evaluation of the information. In order to address weather/climate risks and uncertainties, climate change and variability, drought and other climate-related extremes on agricultural productivity, a number of agrometeorological indicators need to be generated. In addition, prediction of ENSO and Monsoon onset would help the agriculture sector in Nepal.

The generation and digitization of available historical information/data helps from research to decision making process.

11. Recommendation

The recommendation for fulfilling gaps;

1. There are 21 agromet stations of DHM but some do not fulfill the criteria of agromet station so instruments should be upgraded.
2. 21 agromet stations are not sufficient for the country so more agromet stations should be installed.
3. Manual stations are of old model so as far as possible there should be more automatic weather stations with agromet station criteria.
4. Since all information and data are not easily accessible, from researcher to decision makers' level so all available historical data should be digitized to compatible format.

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Annexes:

Annex1: Role of weather/climate indicators in making key decisions in the agriculture sector

Agricultural Sector	Key Decision	Importance of weather and climate indicators	Required Climate/weather indicators
Management (Land, Financial etc.)	Buying new property	Debt taken in unfavorable weather conditions can make repayment difficult.	Historical records of rainfall, wind, temperature, and frosts Buy only if climate is favorable for the enterprise.
	Investment in new machinery	Purchase/hire of high-cost machinery requires good weather for maximum income to ensure easy repayments.	Seasonal climate outlook (ENSO, Monsoon)
	Seasonal planning	Warmer weather conditions may cause crops to mature early.	Excessively wet season requires planning for control of weeds, insect pests, and diseases.
	Managing labor and equipment	Labor and machinery will not be efficiently deployed under an extreme combination of high temperature and high humidity or low temperature and strong winds. A combination of temperatures of 30°C and above, coupled with 70 percent or higher relative humidity, causes discomfort for humans. *Wind chill*: Wind chill stress on the human body occurs when temperatures are very low and strong winds are blowing. The convective heat loss from the body becomes painfully extreme. Exposure to wind chill in wet clothing is most dangerous.	Short-range weather forecast
	Marketing produce	Potential profit changes with production and quality estimates/information.	Regional, national, and worldwide weather forecasts
Cropping	What crop(s) to plant	Select a crop that makes the best use of the climate	Probabilities of rainfall and abnormalities in temperature
	Variety of crop to plant	Most crop species have a number of varieties available that vary in their length of growing season or resistance to heat, cold, frost, waterlogging, or disease.	Seasonal climate outlook (ENSO, Monsoon)
	When to plant a crop	Most crop seeds cannot germinate below 4.5 C during the winter season and below 10 C during the summer season. Follow-up rainfall may make the paddock too wet to plant or more rainfall may be needed to allow the crop to establish. Even a light rainfall after the crop has been sown adversely affects the germination rate through crust formation.	Extended weather forecast; probability of follow-up rainfall in short term
	Optimum depth at which seed should be sown to achieve an optimal rate of seed emergence	Under extremely dry weather, soil moisture will deplete at a fast rate because of high evaporation. Hence, upper soil profiles will dry rapidly, resulting in inadequate moisture for the seed to germinate. The second limiting factor will be extremely high temperature in the shallower depths of the soil, and the seed planted at shallow depth will be roasted or the emerging seedlings will be burnt.	Extended weather forecast
	Fertilizing	Fertilizing with nitrogen can increase crop yield potential but only if there is sufficient rainfall.	Seasonal climate outlook (Monsoon, ENSO)
	Fertilizer application	Temperature, rainfall, and wind speeds determine the efficiency of fertilizer application Wind speed greater than 15 km/hour does not allow the finely particle fertilizer to hit the ground at the right place. The spread is uneven and a substantial amount is blown away from the target and wasted as drift.	Short-range weather forecast of temperature, wind, and rainfall
	Disease control	Many crop diseases are affected by weather As an example, yellow spot in wheat can become prevalent in wet years, causing reduced production.	Seasonal climate outlook (ENSO, Monsoon)
	Insect control	Many insect pests become a problem in only particular seasonal conditions. *Heliothis* in the caterpillar stage is an example. *Heliothis* moth can move in on storm fronts.	Seasonal climate outlook (ENSO, Monsoon); extended and short-range weather forecast of rain, wind, and temperature
	Weed control	Wetter years or wetter than average seasons may cause an increase in the number of crop weeds.	Seasonal climate outlook (ENSO, Monsoon) and extended weather forecast of rain, wind, and temperature

	Harvesting	Rainy spell delays/prevents harvest and creates problems in transport and storage of harvested grain. Rainfall at crop maturity reduces grain quality and increases grain moisture.	Extended weather forecast of rain, wind, and temperature
Sugarcane	Replant or retain old ratoon	New plantings culminate in poor stands and stunted growth in dry seasons.	Seasonal climate outlook (ENSO, Monsoon)
	Determining harvesting and crushing schedules	Rainfall reduces the commercial cane sugar content (CSC) and hinders transport of cane from paddocks.	Extended and short-range weather forecasts
	Trash blanket	Trash on ground in dry weather will preserve moisture.	Seasonal climate outlook (ENSO, Monsoon)
	When to burn cane prior to harvest.	Weather affects the effectiveness and safety of using fire as a tool for cleaning cane.	Extended and short-range weather forecasts of temperature, relative humidity, and rain
Horticulture	Site selection	Climate records can determine if the area is suitable for particular crops.	Historical records of rainfall, wind, humidity, temperature, and frosts
	Crop selection	Most crops have specific climatic and water requirements. ***Low temperatures***: Number, duration, and severity significantly influence plant growth and product quality. For example, lettuce heads are affected by several light frosts in a row. ***High temperatures***: Heat wave conditions and high night temperatures markedly affect crop quality. ***Rainfall:*** In many horticultural areas, if irrigation water is not limiting, rain can cause damage and an increase in disease prevalence for most crops.	Historical records of rainfall, wind strength, humidity, and frost; number of frosts/year, likely dates of first and last frosts of the season
Water/ Irrigation	Location and size of water storage	Climatic expectations determine the size and location of surface water storage to satisfy water needs.	Seasonal climate outlook (ENSO, Monsoon) ; historical records of rainfall, evaporation, and stream flow
	Water allocations	Weather will determine if storage or water source is replenished.	Seasonal climate outlook (ENSO, Monsoon)
	Stock water	Hot dry weather increases stock water intake and increases evaporation from the stored water.	Seasonal climate outlook (ENSO, Monsoon); extended weather forecast
	Planning irrigation schedules—amount of water and time of application of water	Evaporation affects crop water requirements. Rain after irrigation causes lodging, crop damage, and erosion. At high wind speed, water flow and spread is adversely affected and its efficiency is reduced.	Extended weather forecast

Agricultural Activities	**Key Decision**	**Importance of weather and climate indicators**	**Required Climate/weather indicators**
Crop Spraying	When to spray crops for Weeds, Pests, and Diseases (ground applications)	Temperature above 30°C results in significant loss of highly volatile chemicals through evaporation. ***Wind direction***: Wrong wind direction can result in chemicals on non target area/object. ***Wind speed***: At higher wind speeds the chemical does not hit the right target, there is a big loss of chemicals through drift, and there is the danger of air, water, and soil pollution. ***Humidity***: Under extremely dry conditions, the water carrier may evaporate completely or leave a very fine dust of solid chemical. Under humid conditions, evaporation may not take place but the droplets may drift for several hundred meters downward.	Short-range weather forecast of wind direction and speed, relative humidity, temperature, and rainfall for the localized area Anemometer Whirling psychrometer in the field
	Spray and Dust (Aerial Applications)	Poor visibility, either due to low clouds or fog, and strong wind speed are the two most important weather factors that adversely affect aerial spray operations. Low cloud ceiling and visibility are two great risks for aircraft flying. At high wind speed, dust and spray will miss much of the target area and result in heavy drifting and pollution. Dew will dilute the chemical and decrease its effectiveness. At extremely high temperatures, a considerable amount of liquid chemical evaporates either in the air above the plant canopy or just after falling on the target.	Short-range weather forecasts of visibility, wind direction and speed, relative humidity, temperature, and rainfall for the localized area Anemometer Whirling psychomotor in the field

Agricultural Activities	Key Decision	Importance of weather and climate indicators	Required Climate/weather indicators
Grazing/Pastures	Optimum Stocking Rates	Climate determines the type and amount of grass and herbage growth.	Historical climatic records; seasonal climate outlook (ENSO, Monsoon)
	The number of stock to carry during the dry season	Weather determines how much stock feed will be available.	Seasonal climate outlook (ENSO, Monsoon)
	Burning Pasture for Weed Control	Weather affects the effectiveness and safety of using fire as a tool. In the longer term, burning before a dry period may mean a shortfall in feed supplies.	Short-range weather forecast of temperature, relative humidity, and rain; seasonal climate outlook (ENSO, Monsoon)
	Fire Breaks	Weather can affect the severity of the fire season leading up to fire occurrences.	Short-range weather forecast; seasonal climate outlook(ENSO, Monsoon)
	Feeding and Supplements	Dry periods result in little or no plant growth.	Seasonal climate outlook (ENSO, Monsoon)
	Weed Control	Rainfall and temperature determine the intensity of weed infestation.	Short-range weather forecast
	Pasture Improvement	Pasture improvement is a costly program, and the aim is to maximize establishment of pasture. Ideal climatic conditions are required for pasture improvement.	Historical climate records; seasonal climate outlook (ENSO, Monsoon)
Haymaking	When to cut hay	If hay becomes wet or takes a long period of time to dry it loses nutrition.	Extended weather forecast for local areas
	Drying rate of soil/straw/hay	On average, under normal weather conditions, temperature contributes 80 % toward evaporation, and wind and saturation deficit another 20 %t. When any or all three forces are working abnormally, evaporation or evapotranspiration increases proportionally.	Extended forecast of temperature, wind, and evaporative loss of water from soil, plants, and water bodies
	Silage or hay	If there is a likelihood of rain and hay needs to be cut, the hay can be made into silage 24 hours after it is cut. Silage has, however, less cash value, as it is difficult to handle.	Extended forecast for local areas
	When to bale (store)	High-quality hay must be baled with some moisture content, usually at night after dew has fallen.	Short-range weather forecast; likely dew point temperature
	Marketing	Hay prices are usually low in good seasons and high in poor seasons.	Seasonal climate outlook (ENSO, Monsoon)

Agricultural Activities	Key Decision	Importance of weather and climate indicators	Required Climate/weather indicators
Sheep and Wool	When to shear	Choose a time of year to shear when newly shorn sheep are not subject to extreme weather changes.	Climate history; seasonal climate Outlook (Monsoon, ENSO)
	When to muster for shearing	Rapid temperature changes can cause sheep losses after shearing. Wet sheep cannot be shorn; early warning of rain may allow more sheep to be put under cover.	Rainfall and temperature forecasts; sheep weather alerts
	Lamb Wind Chill	Low temperatures below 15 C, coupled with rain and strong winds, cause hypothermia in lambs.	Short-range weather forecast of temperature, wind, and rainfall/ snowfall
	Supplementary Feeding	Lack of rain may necessitate early feeding of costly supplements to maintain growth and minimize production losses.	Seasonal climate outlook (ENSO, Monsoon)
	Fly Control Treatment	Warm humid weather increases incidence of sheep becoming struck/infested with flies.	Seasonal climate outlook (ENSO, Monsoon); extended weather forecast of prolonged periods of wet weather
	Footrot .	Wet conditions favor spread of footrot in sheep.	Seasonal climate outlook (ENSO, Monsoon); short range weather forecast
	Parasite Control	Wet conditions allow an increase in the level of internal parasites.	Seasonal climate outlook (ENSO, Monsoon)
Cattle	Mustering	Wet conditions often make cattle handling difficult. In some cases it is not possible to truck stock after rain due to wet roads.	Short-range and extended weather forecasts
	Restocking	After drought, producers often buy stock to take advantage of extra paddock feed.	Seasonal climate outlook (ENSO, Monsoon)
	Weaning	Calves may need to be weaned from mothers earlier if there is a dry period and then sold or fed.	Seasonal climate outlook (ENSO, Monsoon)
	Parasite control	In wet conditions internal worms are more likely to increase in numbers.	Seasonal climate outlook (ENSO, Monsoon)
	Animal feed requirements	Animals need greater than normal feed to maintain thermal balance in cold and chilly weather, whereas they eat less under hot and humid weather.	Extended weather forecast of temperature, rain, and wind
Poultry	Heat stress mitigation	There is a rapid increase in death rate of the broilers of less than two months age when the temperature exceeds 30 °C in a crowded poultry house. Mortality is high during heat wave conditions.	Short-range and extended weather forecasts of temperature, rain, and wind
Dairy	Heat stress mitigation	Hot weather causes heat stress in dairy cattle that results in a decrease in milk production.	Short-range and extended weather forecasts of temperature, rain, and wind
Pigs	Heat stress mitigation	Hot weather conditions cause heat stress to pigs that results in significant loss in body weight.	Short-range and extended weather forecasts of temperature, rain, and wind

Annex 2: Weather Forecasts for Agriculture: Accuracy, Usefulness and Main Limitations

Type of weather forecast	**Accuracy***	**Usefulness**		**Main limitations**
		Real	***Potential***	
Nowcasting (NC) :*A description of currentWeather variables and Description of forecast Weather variables for 0–2 hours*	Very high	Very low	Low	Unsuitability of broadcasting system; insufficientflexibility of agricultural technology
Very short-range Forecast (VSRF): *Description of weather variables for up to 12 hours*	Very high	Low	Moderate	Unsuitability of broadcasting system; insufficientflexibility of agricultural technology; farmersdo not know how to make the most use of available forecasts
Short-range weather forecast (SRF): *Descriptionof weathervariables formore than 12hours and upto 72 hours*	High	Moderate	High	Further adaptation of forecasts to farmers'requirements is needed; farmers do not knowhow to make the most use of available forecasts
Medium-range weather forecast (MRF): *A relatively complete set of variablescan be produced*	High or moderate until 5 days; lower thereafter	High	Very high	Further adaptation of forecasts to farmers'requirements is needed; farmers do not knowhow to make the most use of available forecasts
Long-range forecast (LRF): *From 12–30 days up to two years*	Very low	High in warning of delays in arrival of weather systems. Very low Otherwise	Poor	Reliability (The reliability of LRF is higher for the tropics than for mid-latitudes. This is because tropical areas have a moderate amount of predictable signal, whereas in the mid-latitudes random weather fluctuations are usually larger than the predictable component of the weather.)

**Subjective judgment of a weather forecaster working at mid-latitudes. The judgment refers to cloud coverage, air temperature and precipitation occurrence.*

(Reference Source: WMO-No. 134)

Annex 3: Details of Agrometeorological Stations in Nepal

S.N.	Station Name	Index No.	Lat."N"	Long."E"	Elev."m"	Est.Date	District
1	Mahendra Nagar	0105	29 0 02'	80 0 13'	176	Feb.71	Kanchanpur
2	Khajura	0409	28 0 06'	81 0 34'	190	Jan. 68	Banke
3	Sikta	0419	28 0 02'	82 0 47'	195	May-78	Banke
4	Thakmarpha	0406	28 0 45'	83 0 42'	2566	Dec. '66	Mustang
5	Dumkauli	0706	27 0 41'	84 0 13'	154	Jan. 74	Nawalparasi
6	Bhairahawa(Agri.)	0707	27 0 32'	83 0 28'	120	Jan. 68	Rupandehi
7	Gorkha	0809	28 0 00'	84 0 37'	1097	Nov. 71	Gorkha
8	Malepatan	0811	28 0 07'	84 0 07'	856	Apr. 66	Kaski
9	Lumle	0814	28 0 18'	83 0 48'	1740	Nov. 69	Kaski
10	Khairenitar	0815	28 0 02'	84 0 06'	500	Jul. 74	Tanahu
11	Rampur	0902	27 0 37'	84 0 25'	256	Jan. 67	Chitawan
12	Parwanipur	0911	27 0 04'	84 0 58'	115	Jan. 67	Bara
13	Kakani	1007	27 0 48'	85 0 15'	2064	Dec. 71	Nuwakot
14	Khumaltar	1029	27 0 40'	85 0 20'	1350	May-67	Lalitpur
15	Jiri	1103	27 0 38'	86 0 14'	2003	Sep. 65	Dolakha
16	Kabhre	1124	27 0 38'	86 0 08'	1755	May.07	Dolakha
17	Lahan	1215	26 0 44'	86 0 26'	138	Jan. 72	Siraha
18	Pakhribas	1304	27 0 03'	87 0 17'	1680		Dhankuta
19	Tarahara	1320	26 0 42'	87 0 16'	200	Jul. 68	Sunsari
20	Ilam	1407	26 0 55'	87 0 54'	1300	Jun. 66	Ilam
21	Gaide	1421	26 0 35'	87 0 54'	143	Feb. 84	Jhapa