



## Can Weather Predict Crop Yield? The Power of Agrometeorology in Modern Farming

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The question of whether weather can predict crop yield is no longer a matter of speculation but a cornerstone of the interdisciplinary science known as agrometeorology. This article explores how agrometeorology, or agricultural meteorology, has transitioned from a descriptive science to a predictive and prescriptive tool essential for global food security. By integrating principles from atmospheric science, agronomy and hydrology, agrometeorology provides a holistic understanding of the soil-plant-atmosphere system. The predictive power of this field rests on quantifying biophysical interactions, such as the impact of cardinal temperatures on metabolic dynamics, the role of relative humidity in transpiration and the sensitivity of crops during critical growth stages like anthesis and grain filling. Modern advancements have revolutionized the field through "Agriculture 4.0," which leverages Internet of Things (IoT) sensor networks, high-resolution satellite remote sensing and sophisticated modeling paradigms. These paradigms include process-based mechanistic models like DSSAT and APSIM, as well as data-driven machine learning approaches like Long Short-Term Memory (LSTM) networks. Furthermore, the article examines the socio-economic implications of weather-induced yield variability, specifically focusing on its role in driving crop price volatility and market instability. Regional success stories, such as the Brazilian agricultural revolution led by Embrapa and India's National Agromet Advisory Service, illustrate the practical efficacy of these systems. As climate change intensifies weather unpredictability, the integration of real-time agrometeorological data into decision-support systems emerges as a vital strategy for building resilient farming systems capable of feeding a growing global population. By 2026, it is projected that over 70% of resilient farms will use these advanced meteorological technologies to optimize inputs and minimize risks.

**Keywords:** Agrometeorology, Precision Agriculture, Crop Modeling, Climate Resilience, Food Security, Artificial Intelligence.

### Introduction

In an era defined by rapid population growth and escalating environmental risks, the ability to predict agricultural outcomes has become a matter of global survival. Agricultural meteorology, often abbreviated as agrometeorology, stands as an indispensable tool for ensuring the resilience, sustainability and productivity of modern farming systems. It is defined as the science of meteorology at the service of agriculture, facilitating the sensible use of land, the acceleration of food production and the prevention of irreversible land degradation. Unlike general meteorology, which focuses on atmospheric physics for the

general public, agrometeorology is a biophysical science specifically tailored to the interactions within the fully coupled soil-plant-atmosphere system. As we stride into 2026, agrometeorology has moved beyond mere weather reporting to providing high-resolution, actionable intelligence for strategic and tactical decision-making. The discipline integrates meteorology and hydrology with horticulture, animal husbandry and forestry to maximize production. This integration is critical because agricultural production remains more dependent on weather and climate than almost any other human activity. By understanding how variables like temperature, precipitation and solar radiation influence crop growth, farmers can transition from calendar-based schedules to data-driven management. This article will detail the biophysical principles, technological innovations and socio-economic impacts that define the predictive power of agrometeorology in modern agriculture.

### The Biophysical Foundations of Yield Prediction

The predictive capacity of agrometeorology is grounded in the quantifiable impact of environmental variables on plant physiology. This interaction is governed by the principles of energy and mass balance, where weather factors determine the potential for biomass accumulation.

### Thermal Regulation and Metabolic Dynamics

Temperature is the primary regulator of the speed of chemical and biological reactions within a plant. Every crop species operates within a specific thermal window defined by cardinal temperatures: the minimum temperature below which growth ceases, the optimum range for maximum efficiency and the maximum temperature above which physiological damage occurs. Within the optimal range, increases in temperature generally accelerate photosynthesis, transpiration and respiration. However, a critical balance must be maintained; if temperatures rise too high, respiration may consume photosynthates faster than they are produced, leading to stunted growth. Furthermore, daily fluctuations between daytime and nighttime temperatures-known as the thermoperiod-are essential. Most plants thrive when daytime temperatures are 10° to 15°F higher than nighttime temperatures, allowing for high production during the day and reduced energy loss at night. High nighttime temperatures are increasingly recognized as a major constraint on yield, as they reduce recovery time and increase respiration losses.

### The Hydrological Cycle and Relative Humidity

Water is the medium for most biochemical reactions and is responsible for maintaining turgor pressure, which provides the physical force for cell expansion and root movement through the soil. Relative humidity (RH) directly influences plant water relations and indirectly affects photosynthesis and pollination. Low RH increases the vapor pressure deficit, driving higher transpiration and potential water stress, while very high RH can increase the heat load on the plant and foster environments conducive to fungal pathogens like potato and tea blight.

### Solar Radiation and Photoperiodic Control

Solar radiation provides the energy for photosynthesis and developmental signals through day length, or photoperiodism. Plants are categorized as short-day, long-day, or day-neutral based on their flowering response to uninterrupted periods of darkness. For example, long-day plants like beets and spinach form flowers only when day length exceeds 12 hours, while short-day plants like chrysanthemums require longer nights.

**Table 1: Influence of Meteorological Factors on Crop Physiology**

Meteorological Factor	Direct Physiological Effect	Indirect Agronomic Impact
Temperature	Metabolic rate and phenological timing	Pest/disease cycles and nutrient release
Precipitation	Turgor maintenance and nutrient transport	Soil erosion and chemical leaching

Meteorological Factor	Direct Physiological Effect	Indirect Agronomic Impact
Relative Humidity	Transpiration and stomatal control	Fungal spore germination and pollination
Solar Radiation	Energy for Photosynthesis	Soil solarization and weed management
Soil Temperature	Root growth and nutrient uptake	Microbial metabolism and seeding success

### Physiological Sensitivity Across Growth Stages

The vulnerability of crops to weather fluctuations is not uniform; instead, agrometeorology identifies specific "moisture-sensitive" or "critical periods" where stress causes disproportionate yield losses.

#### Germination and Reproductive Stages

The initial phase of the crop cycle depends heavily on soil temperature and moisture, as deficits here lead to poor crop stands. However, the reproductive stage is often the most sensitive to extremes. In cereals like rice and wheat, water deficit or heat stress during anthesis can cause flower abortion and reduce pollen viability. In pulses, stress during pod filling reduces seed number and weight. Cotton is highly sensitive between 45 and 60 days after sowing, where stress triggers square and boll drop due to hormonal imbalances.

#### Grain Filling and Ripening

During the grain-filling stage, high temperatures accelerate development but shorten the duration of the filling period. Research indicates that for every 1°C increase in mean temperature, yield can be reduced by up to 4% due to this acceleration. Water stress during ripening results in reduced "test weight" or seed size. Interestingly, moderate water stress in certain fruit crops like apples and peaches can improve quality by increasing soluble sugar content and fruit color.

### Analytical Paradigms in Yield Prediction Modeling

To transform meteorological data into reliable forecasts, scientists use three primary modeling architectures: process-based, data-driven and hybrid systems.

#### Process-Based Mechanistic Models

Process-based models (PBMs), such as DSSAT (Decision Support System for Agrotechnology Transfer) and APSIM (Agricultural Production Systems Simulator), use mathematical representations of biological and physical principles to simulate interactions within the agroecosystem. These models typically operate at daily time steps and are driven by meteorological inputs, simulating processes like carbon assimilation, biomass partitioning and soil-water dynamics. PBMs are prized for their mechanistic transparency, allowing researchers to trace model behavior back to specific physiological processes.

#### Data-Driven and Hybrid Approaches

In contrast, data-driven models do not explicitly represent biological processes but instead infer relationships directly from historical records, meteorological time series and remote sensing observations. Algorithms such as Random Forest (RF) and Long Short-Term Memory (LSTM) networks are increasingly used because they can capture complex, non-linear patterns that PBMs might miss. For example, machine learning models have been shown to explain up to 93% of observed yield variability in certain regional assessments.

The current frontier lies in hybrid models that combine the explanatory power of PBMs with the flexibility of machine learning. Hybrid frameworks often involve using PBMs to generate synthetic data for training machine learning models or assimilating real-time remote sensing data into mechanistic frameworks to correct model parameters.

#### Modern Technological Infrastructure: Agriculture 4.0

The integration of advanced monitoring technologies has transformed agrometeorology into a high-resolution, real-time science often referred to as "Precision Agrometeorology".

### The Internet of Things (IoT) and Sensors

Modern farms are increasingly equipped with networks of IoT sensors that collect fine-scale data on microclimates. These include soil moisture probes, ambient weather stations and leaf wetness sensors. These devices relay data via low-power networks like LoRaWAN to cloud platforms where AI models generate real-time advisories. For instance, a system might issue a "Frost Alert" to trigger the deployment of frost fans or sprinklers when temperatures drop below crop tolerance.

### Satellite Remote Sensing and Big Data

Satellite-based monitoring provides an expansive view of field conditions through multispectral and hyperspectral imagery. Indices such as the Normalized Difference Vegetation Index (NDVI) and Leaf Area Index (LAI) allow for the detection of crop stress before it becomes visible to the naked eye. Innovative platforms now leverage AI to process massive multi-source data streams from satellites, drones and field sensors into farm-specific actionable insights.

**Table 2: Projected Impact of Agrometeorological Technologies (2025-2026)**

Technology / Tool	Core Function	Projected Yield Increase
AI-Powered Weather Forecasting	Predictive analytics for weather and disease risk	18 - 30%
IoT-Connected Soil Sensors	Real-time soil moisture and nutrient monitoring	14 - 25%
Satellite Crop Health Monitoring	Biomass, NDVI and moisture insights	10 - 18%
Satellite Rainfall Monitoring	Precipitation and drought tracking	10 - 20%
Remote Weather Stations	Localized frost and microclimate warnings	8 - 15%
Digital Fleet Management	Resource and logistics optimization	5 - 11%

### Socio-Economic Implications and Market Volatility

The ability of weather to predict crop yield has profound implications for global markets and food prices. Fluctuations in temperature and precipitation lead to unexpected shortages or surpluses, directly influencing market volatility.

#### Weather and Price Volatility

A case study of soybean and brinjal in India highlights how meteorological factors impact different crop types. Soybean, an export-oriented oilseed, shows significant price volatility tied to monsoon patterns and global disruptions, whereas brinjal, a domestic vegetable grown year-round, exhibits less drastic spikes. Research using EGARCH (Exponential Generalized Autoregressive Conditional Heteroskedasticity) models has shown that soybean price volatility is causally linked to meteorological variables at a three-month lag, consistent with the crop's sowing-to-harvest cycle.

#### Economic Returns of Agromet Services

The investment in agrometeorological services yields high economic returns. In India, Agromet Advisory Services (AAS) have been shown to decrease cultivation costs by up to 25% and increase net returns by up to 83%. In Bangladesh, forecast-based financing has reduced asset losses for flood-affected households by 27%. Globally, it is estimated that the benefits of hydro-meteorological systems outweigh costs by a ratio of 80 to 1.

#### Ethical Governance and Global Collaboration

As agrometeorology becomes more data-intensive, challenges regarding data ownership and equity arise. Farmers often express concern that data regarding their soil health and yields could be used against them by large agribusinesses or mismanaged by third parties. Furthermore, there is a significant power asymmetry between individual smallholders and large biotech firms that aggregate proprietary data.

Institutional frameworks led by the World Meteorological Organization (WMO) and the Food and Agriculture Organization (FAO) are crucial in addressing these issues. The WMO Agricultural Meteorology Programme (AGMP) supports member nations in delivering meteorological services that improve production while conserving natural resources. Initiatives such as "Early Warnings for All" and the promotion of open-source data schemas are essential for ensuring that these transformative technologies benefit both large commercial enterprises and smallholder farmers alike.

## Conclusion

The evidence presented demonstrates that weather is the most significant predictor of crop yield and agrometeorology is the essential toolbox for harnessing that predictive power. By understanding the biophysical limits of crops and deploying a sophisticated technological infrastructure-ranging from LEO nanosatellites to deep learning architectures-modern farming can now anticipate stress and adapt proactively. The shift from Agriculture 1.0 to Agriculture 4.0 has enabled yield prediction improvements of up to 30% through precise weather forecasting tools. The future of agrometeorology lies in "closing the loop" between data acquisition and automated field response. As climate change continues to drive unpredictable weather patterns, the ability to translate atmospheric variability into precise management strategies will define the stability of global food systems. Ultimately, the power of agrometeorology lies not just in its ability to predict the weather, but in its capacity to predict the harvest and provide the wisdom to manage it for a sustainable future.

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