AGRICULTURAL WEATHER INDICES FOR DEVELOPING COUNTRIES

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Abstract: *The challenge of coping with natural disasters has increased as populations have increased. These challenges have been particularly acute in developing countries where both the human and economic loss can be staggering and financial resources are limited. Reducing economic vulnerability to weather events in developing countries may very well be the most critical economic development challenge of the new millennium.*

Key words: *Weather derivative, Growing Degree Days, Chilling Degree Hours, Rainfall Index, Event based indices, weather option/futures contract, weather risk management.*

As a proportion of GDP, natural disaster losses in developing countries are 20% greater than in industrial countries. The economies of many developing countries rely heavily on agriculture and agricultural success is directly tied to weather. In recent years, the international community has focused more attention on the relationship between weather disasters and poverty. Measures taken to reduce the economic impact of weather disasters can provide substantial advances in the fight against poverty. Although weather cannot be controlled, weather risk markets can be used to offset the financial impacts of adverse weather events, and possibly compensate for human suffering in developing countries.

Weather derivatives are financial contracts that can be utilized by businesses or individuals to mitigate the risk of poor or unexpected weather situations. These are also financial derivatives with a difference that the underlying asset, which could be rain, temperature, snow, wind or a combination of two or more, has no direct value to price the weather derivative, unlike other derivatives. The weather derivative contracts are tied to the weather indices and these weather indices are created by the help of the weather information provided by meteorological stations.

Like any other financial derivative contract, the weather derivative contracts can be in the form of Futures, Forwards, Options and Swaps. And, the indices on these contracts for agricultural sectors may be based on any of the following[1]:

Growing Degree Days. Growing Degree Days (GDDs) is a common index used in the agricultural sector, similar to HDDs and CDDs in the energy sector. GDDs are a measurement of the growth and development of plants (both crops

[1] Datta, B. S. (2018). Feasibility and Deterrents of Weather Derivatives-A Review in the Indian Context

and weeds) and insects during a growing season. Organisms that cannot internally regulate their own temperature are dependent on the temperature of the environment to which they are exposed. Development of an organism does not occur unless the temperature is above a minimum threshold value, known as the base temperature, and a certain amount of heat is required to for development to move from one stage to the next. The base temperature varies for different organisms and is determined through research and scientific considerations. A list of reported base temperature examples is given in Table 1[2].

Table 1: Reported Base Temperatures for GDD Computations for Crops and Insects

Base Temperature (deg Celsius) for GDD Computation	Crop/Insect Example
4.44	Wheat, Barley, Rye, Oats, Flaxseed, Lettuce, Asparagus
7.22	Sunflower, Potato
10.00	Sweet Corn, Corn, Sorghum, Rice, Soy Bean, Tomato
6.67	Corn Rootworm
8.89	Alfalfa Weevil
10.00	Black Cutworm, European Corn Borer
11.11	Green Clover worm

A GDD is calculated by the following equation:

$$\text{Daily GDD} = \max(0, (T_{average} - L)); \quad T_{average} = (T_{max} + T_{min})/2 \qquad (1)$$

where L is the baseline temperature and $T_{average}$ is the daily mean temperature, defined as the average of the daily maximum (T_{max}) and minimum (T_{min}) temperatures. If this average is greater than the threshold temperature L, the GDD accumulated for that day is the threshold temperature minus the daily average temperature. If the daily average temperature is less than the base temperature, then the GDD for that day is zero. Adding the GDD values of consecutive days gives the accumulated GDDs over a specific period.

Chilling Degree Hours. Another example of a cumulative temperature-based index is chilling degree hours or units. Although cold temperatures are often detrimental to crop production, they can also be an essential requirement for certain cultivars. For example, stone fruit trees such as peaches develop their vegetative and fruiting buds in the summer and, as winter approaches, the already developed buds go dormant in response to both shorter day lengths and

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[2] Midwestern Regional Climate Center, IL, U.S. http://mcc.sws.uiuc.edu/

cooler temperatures. This dormancy or sleeping stage protects these buds from oncoming cold weather. Once buds have entered dormancy, they will be tolerant to temperatures much below freezing and will not grow in response to mid-winter warm spells. These buds remain dormant until they have accumulated sufficient chilling units (CU) of cold weather.

When enough chilling accumulates, the buds are ready to grow in response to warm temperatures. As long as there have been enough CUs the flower and leaf buds develop normally. If the buds do not receive sufficient chilling temperatures during winter to completely release dormancy, trees will develop one or more of the physiological symptoms associated with insufficient chilling:

1) delayed foliation,

2) reduced fruit set and increased buttoning and,

3) reduced fruit quality.[3]

There are various models used to define and calculate chilling degree units which could be used an index for a weather risk management strategy. The three most common models are:

a) the number of hours during the winter period where the temperature is below 7.2 degrees Celsius;

b) the number of hours where the temperature is between 0 and 7.2 degrees Celsius and;

c) a model that associates varying chill units according to the actual hourly temperature, known as the Utah model[4].

The first two models are simple and define a chilling unit as one hour below or between certain temperatures. The Utah method is more complex because it introduces the concept of relative chilling effectiveness and negative chilling accumulation. Average monthly temperature can also be used to estimate accumulated chilling units.

Event Based Indices. However, crop damage can also be the result of specific or critical temperature events that can be detrimental to yield or quality. For instance, freezing conditions were reported to have caused more than $600 million in damage to the U.S. citrus crop in a single week of December 1998, with $300 million occurring in Tulare County, California, alone[5]. Critical temperatures causing crop damage may vary depending on the length of time that temperatures remain below freezing as well as the variety, health and development stage of a plant.

For example, winter wheat yields at harvest depend to a great extent on how well the plants survive the winter hibernation period. Winterkill events cause damage and death of the plants' tillering node. With little or no snow plants begin

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[3] Byrne, D. H. and T. Bacon, "Chilling Accumulation: its Importance and Estimation", Dept. Of Horticultural Sciences, Texas A&M University, College Station, TX 77843-2133

[4] Byrne, D. H. and T. Bacon, "Chilling Accumulation: its Importance and Estimation", Dept. Of Horticultural Sciences, Texas A&M University, College Station, TX 77843-2133

[5] "Freeze Risk to Citrus Crops", GuaranteedWeather Case Study, www.guaranteedweather.com

to die when the daily minimum air temperature drops below –16 deg C. A crop can be completely lost if this happens for four days in a row or in the minimum temperature drops below –21 deg C [6].

Table 2: Critical Temperatures that Result in Freeze Damage to Crops [7]

Critical Temperature for Freeze Damage	Crop Example
0 to -1 deg Celsius	Strawberries and Raspberries (blossom and fruit), Tomatoes, Cucumbers, Melons, Peppers, Squash and Pumpkin (plants), Beans, Tobacco
-1 to -2 deg Celsius	Potatoes, Corn, Apples and Plums (blossom), Pears and Cherries (blossom and fruit), Beans
-2 to -4 deg Celsius	Apples (fruit and buds), Blueberries, Alfalfa, Pears

Snow cover considerably improves conditions of winter wheat hibernation, as the difference between air and soil temperature increases from 0.5 to 1.1°C per centimeter of snow cover. A winterkill index, based on days where the daily minimum temperature is less than -16 deg Celsius, could therefore be used by a farmer to obtain protection against such crop failure risk. For instance, a farmer could enter into a contract where the recovery is the full value of the crop, as expected under normal weather conditions, if the recorded daily minimum air temperature is less than -16 deg Celsius for four or more consecutive days at any time during the winter period, November to March.

Excessive heat can also damage crop production and quality and can be a lot more difficult to control than freezing temperatures. For example, significant losses in winter wheat harvest are very likely when daily maximum air temperatures exceed +30°C (at the height of 2 m) at critical shaping and ripening stages of winter wheat kernels in late spring and early summer.

Precipitation, either rainfall or snowfall, can also be vital to crop growth and development. In the example above it was clear that a snowfall has a critical role in protecting hibernating crops from the damaging effects of low air temperatures. However, rainfall variability is often the most critical factor in agriculture. It is the second most popular weather index to trade.

Deficit Rainfall and Drought. Meteorological drought is usually defined

[6] Private Communication: Adamenko, T., *"Agroclimatic Conditions and Assessment of Weather Risks for Growing Winter Wheat in Kherson Oblast",* July 2004, Ukrainian Hydrometeorological Centre, Kiev.

[7] Ministry of Agriculture and Food, Ontario, Canada http://www.gov.on.ca/OMAFRA/english/crops/facts/85-116.htm

in terms of deviations of precipitation from normal levels and the duration of dry periods in a region. Agricultural drought refers to situations in which moisture in the soil is no longer sufficient to meet the needs of crop growing in an area due to insufficient rainfall. Crops, particularly rain-fed crops, often have a minimum overall threshold of cumulative rainfall for successful and healthy plant development. For example, sugar beet can consume up to 560 mm of water during the growing season, depending on plant density, soils, climate and weather conditions[8]. Crops, such as spring wheat, require at least 350mm-400mm of rain for reliable yields[9]; for dry-land corn farming 450-500mm or more is required for high yields during the growing season[10].

These water requirements must be met by natural rainfall, stored soil moisture from precipitation prior to the growing season or from supplemental irrigation. A deficit of rainfall therefore below these levels, in the absence of irrigation, can cause plant moisture stress that affects development and consequently reduces yields.

General indices, such as the Palmer Drought Severity Index (PDSI)[11], have also become widely used drought assessment tools; the U.S. federal government and many U.S. state governments rely on the PDSI to trigger drought relief programs. The PDSI is based on more than just rainfall and uses temperature, latitude, available water holding capacity of the soil as well as precipitation to infer the supply and demand of the soil moisture at a location on a weekly basis throughout a growing season. The value of the PDSI is reflective of the how the soil moisture, excess or deficit, compares with normal conditions. Such an index could be used as a general indicator of the severity of weather and therefore growing conditions of the local area.

Excess Rainfall. Excessive moisture conditions, however, can also retard growth and affect the yield and quality of a harvest. Excess precipitation can cause flooding and water-logging of the soil, which can restrict oxygen supply to root systems, reduce nutrient uptake, lead to nitrate leaching and an increase in the incidence of plant disease and pests[12]. The effects are worse when combined with warmer than average temperatures which encourage pest development; warm water also contains less dissolved oxygen than cold water. Precipitation can impact the time and effectiveness of farming operations such as sowing, land preparation and pesticide and fertilizer applications. Excessive rainfall at harvest time can also delay harvest and/or spoil standing crops. Daily

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[8]Eftha, A., "Irrigation Management of Sugar Beets", Agriculture, Food and Rural Development, Government of Alberta

[9] "Agriculture Industry Study", Weather Risk Management Association, www.wrma.org

[10] Neild, R. E. and J. E. Newman, "Growing Season Characteristics and Requirements of the Corn Belt", Purdue University, http://www.ces.purdue.edu/extmedia/NCH/NCH-40.html

[11] Palmer, W. C., 1965, "Meteorological Drought", Office of Climatology of the U.S. Weather Bureau.

[12] "Agriculture Industry Study", Weather Risk Management Association, www.wrma.org

rainfall amounts in excess of 4 mm[13] can make harvesting impossible – a grower could purchase weather protection for such an event(s) that would cover the associated financial cost of a harvest delay. There are also wind and hybrid weather derivatives.

Once the index has been identified and calibrated, the next step is to structure a contract that pays when the specified adverse weather occurs in order to perform a hedging or risk smoothing function for an agricultural grower or producer. The structure of weather derivatives are based on a standard derivative structure, which includes; swaps, puts, collars, straddles, strangles, and the calls.

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[13] Private Communication: Adamenko, T., *“Agroclimatic Conditions and Assessment of Weather Risks for Growing Winter Wheat in Kherson Oblast”,* July 2004, Ukrainian Hydrometeorological Centre, Kiev.