SECTION 5

The Effects of Variations in Mean Temperature and Frost Risk

5.1. Aims

Villagers identify frost as one of the major hazards in the Ecuadorian highlands (*see* Section 3), and a considerable area is uncultivated owing to excessive frost risk or excessively low temperatures. This section explores the vulnerability of traditional agriculture to possible variations in mean temperature and frost risk. After an initial discussion of farmer adaptation to frost, meteorological records are analyzed to determine the patterns of fluctuation of frost risk and mean temperature. A plausible scenario of increased seasonal frost risk will be defined and used to determine areas potentially at risk in Chimborazo Province.

5.2. Previous Studies

Biogeographers have long been intrigued by the altitudinal zonation of crops and vegetation in tropical mountains. Each crop and plant species has an observed upper limit to its distribution, although there are disagreements on the precise climatic factors responsible for setting the upper limit of tree growth. Troll (1968) felt that the critical factor was risk of nocturnal frost. Walter (1973) emphasized soil temperature; and Ellenberg (1979), low effective radiation. The Holdridge (1967) system of ecological classification places emphasis on mean annual temperature. All of these factors are, of course, closely correlated with elevation. Frost risk and radiation are also affected by topographic position, while soil temperatures are related to soil properties.

Local correlations of altitude with crop distributions are so striking that studies of Andean agriculture are usually couched in an altitudinal framework (Brush, 1977; Gade, 1967; Guillet, 1983; Mayer, 1979). The notion of "verticality" which provided the framework for much ethnography and ethnohistory in the 1970s, explicitly assumed that the most significant agricultural problems and opportunities in the Andean environment were posed by factors associated with altitude. It was assumed that Andean farmers strive to maximize access to

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ecological, altitudinal zones (Brush, 1977; Masuda *et al.*, 1985; Murra, 1972; for a critique of this position *see* Sanchez, 1976).

Gade (1967) makes a useful distinction between the effective and absolute limits of cultivation in the Andes. The effective limit is the upper limit of the "agricultural region continuously enclosed by fields", e.g., of the region where people are critically dependent on their harvests. In the Vilcanota Valley of Peru, this limit was where hardy crops yielded "satisfactorily" in at least 60% of the years. Above this effective limit, one finds scattered fields of agro-pastoralists not critically dependent on good harvests. These fields are found up to the "absolute limit" of cultivation, which in this valley was 420 meters higher than the effective limit.

There has been only limited attention given to fluctuations in the upper limit of cultivation. Fossil cultivation ridges may exist up to 4300 m elevation in the Vilcanota Valley of Peru; this is above the current effective limit of cultivation but below the current absolute limit (Gade, 1967). At the Lauricocha Plain and environs (3950–4000 m) in Peru, farmers stated that cultivation was very risky 30–40 years ago due to frost, but satisfactory in the early 1970s. Nearby walled parcels of land suggest that the upper limit of cultivation was even higher – about 4100 m – during the Early Intermediate Period (200 BC – 700 AD) (Cardich, 1975). Gondard and Lopez (1983) noted that abandoned terraces or semi-terraces in northern highland Ecuador are found at higher elevations that the currently observed upper limit of cultivation. Abandoned field ridges were found in flats at 3150 m, higher than the current limit of cultivation in flats.

These studies are difficult to evaluate because, first, we do not know whether the apparent shifts in upper limit of cultivation were due to changes in social factors (effective limit) or climatic factors (absolute or effective limit) and, secondly, the changes may have been due to use/abandonment of frost management technology (e.g., walls, ridges, etc.).

Little work has been done on the geography of frost hazard in the Andes. Lauer (1982) has demonstrated patterns of frost hazard as a function of relief in Bolivia, but the strongly seasonal temperature regime there is very different from the equatorial temperature pattern in Ecuador.

5.3. Data Sources

In this study we will rely for the most part on data collected by national meteorological stations in order to estimate patterns of temperature and frost risk. Monthly temperature data (means, absolute minima, etc.) for a limited number of highland Ecuadorian meteorological stations are available in the INAMHI (Instituto Nacional de Meteorologia e Hidrologia) *Meteorological Annuals* (*Anuarios Meteorologicos*), available as of this writing for the years 1959 to 1981. More recent data are available on computer printouts or on the original station report cards on file at INAMHI. The data have been subjected to limited quality checks. Meteorological stations were visited in the mid-1970s, and the state of the instruments, the location and the reliability of the observers were noted (PRONAREG-ORSTOM, 1976, 1977a). Partially corrected data are