i) woody vegetation large proportion in upper layers
ii) grassland vegetation more uniform distribution

4. CARBON STORAGE IN THE CUBIC METER SOIL PEDON

The objective of this study has been to derive the pattern of meter depth calculation of carbon and nitrogen storage from as wide a range of sites, ecosystem complexes, life zones, and natural soil types as possible. The data are presented in the Appendix of this report. Each data record has an identifying profile number, a country or state locational code, latitude and longitude of the site (with elevation where available), carbon and nitrogen content per cubic meter pedon, bibliographical source, Holdridge climatic class, ecosystem type, and parent material category.

Although the data presented in the Appendix are for carbon storage through the cubic meter storage pedon, it is well known, and our detailed data show, that for most soils there is a greater concentration of carbon in the surface horizons, and a lower concentration with depth. Distribution of carbon with depth is well approximated by a log-log relation between cumulative carbon storage to a given depth. Cumulative carbon storage to a soil depth such as 20 cm may be as much as 50% of the total meter depth storage. Examples of these proportions are shown for a selected set of soil profiles from different parts of the world (Fig. 4.1). Areas with woody vegetation tend to have a large proportion of carbon storage in the upper layers of the soil. However, in grassland areas, there is a more uniform distribution

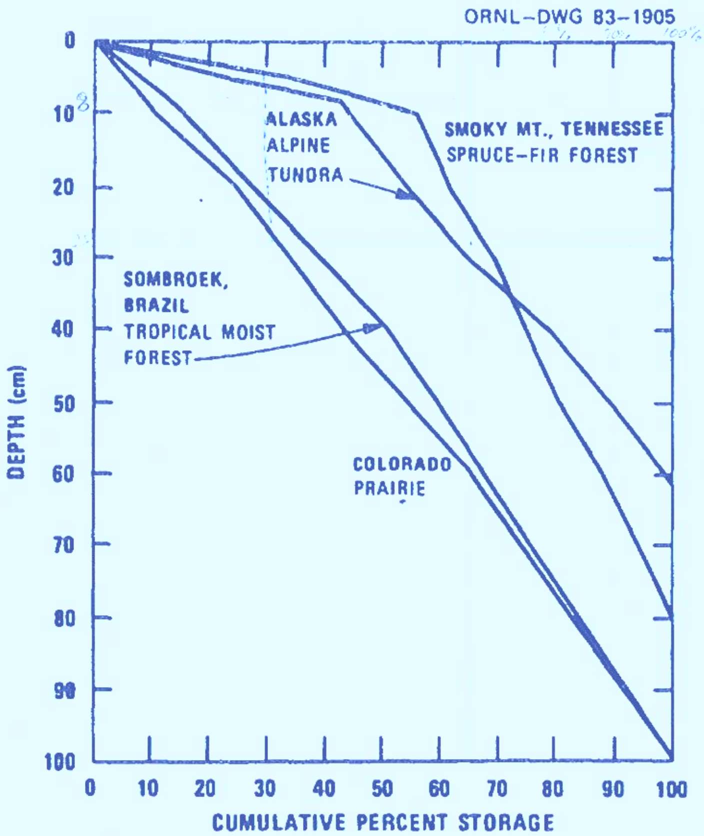

Fig. 4.1. Cumulative carbon storage as a function of depth for four ecosystems.

of carbon through the soil profile. These types of relationships are relevant to determination of the effects of various types of disturbance on soil carbon storage.

The meter depth data offer the opportunity to explore the relationship of soil nutrient storage and major soil-forming variables. In this section we present analyses of carbon and nitrogen storage in relation to latitude, climate, ecosystem, and parent material.

Figure 4.2 shows average carbon and nitrogen storage and carbon-nitrogen ratio along with 95% confidence intervals ranging from the equator to 75° north or south latitude. The means and confidence intervals for each latitude are computed from samples within that latitude band and from the surrounding eight degree bands, four on either side. The general trend with latitude shows a peak in carbon and nitrogen storage in the tropics (0° to 25°), a minimum in the subtropic dry latitudes (25° to 30°), a second peak in the high latitudes (50° to 60°), and finally low amounts in the highest latitude (>65°) where soils are immature. Hypothetically, these peaks are related to excess of carbon additions over losses typical of tropical and cool regions due to interactions of productivity and decomposition rates with environmental factors such as temperature, aeration, and fertility. Differences in

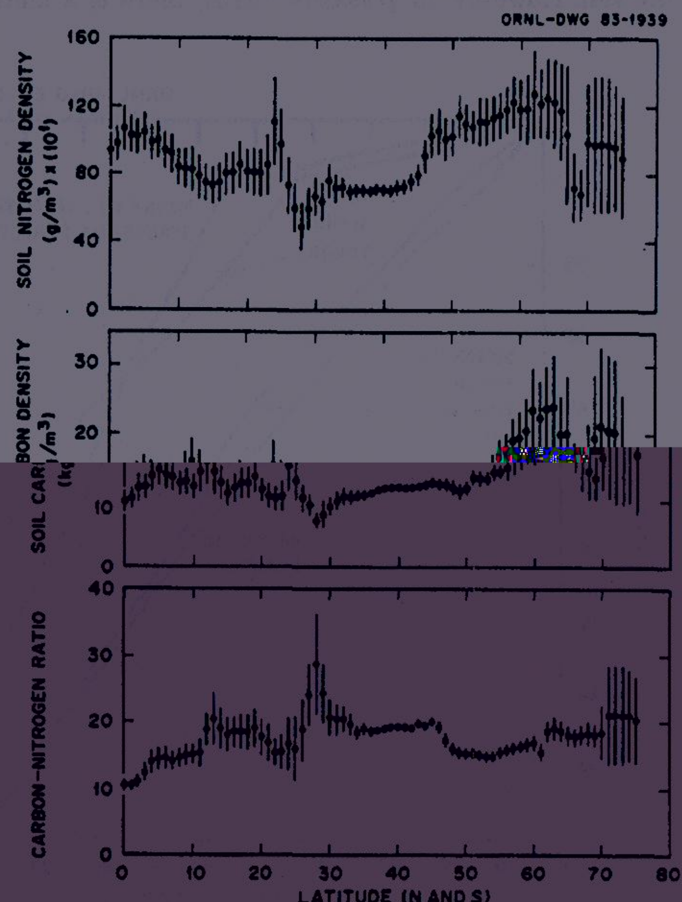

Fig. 4.2. Nine-degree running average of mineral soil nitrogen, carbon content, and C:N ratio. Means are represented by solid dots and vertical lines indicate 95% confidence intervals.

the size of the 95% confidence intervals in Fig. 4.2 is largely due to the number of samples in each class.

Organizing the soil profile data of the less disturbed soils on a climatic basis according to the Holdridge (1947) Life-Zone Classification System, we observe a strong relationship between climate and soil carbon density (Post et al. 1982). The contours of soil carbon density displayed in Fig. 4.3 reflect the balance of input and loss of carbon imposed by climate. Soil carbon density increases from left to right due to greater organic matter production with higher annual precipitation. This effect is clearest in the tropics where temperature does not limit productivity. The effect of temperature is greater than that of precipitation so that soil carbon density increases (Fig. 4.3) with decreasing biotemperature for any particular annual precipitation. Organic matter production decreases with temperature, but low temperatures limit soil organic matter decomposition.

The combined influence of temperature and precipitation is clarified by the third (upper left) axis of the Holdridge diagram (Fig. 4.3), the ratio of potential evapotranspiration (PET) to annual precipitation. When this ratio is less than 1.0, rainfall exceeds potential evapotranspiration and vice versa. All the life zones bordering the unit PET ratio line have soil carbon densities of around 10 $kg \cdot m^{-3}$, except in the warm temperate and subtropical belts. There a strong seasonality

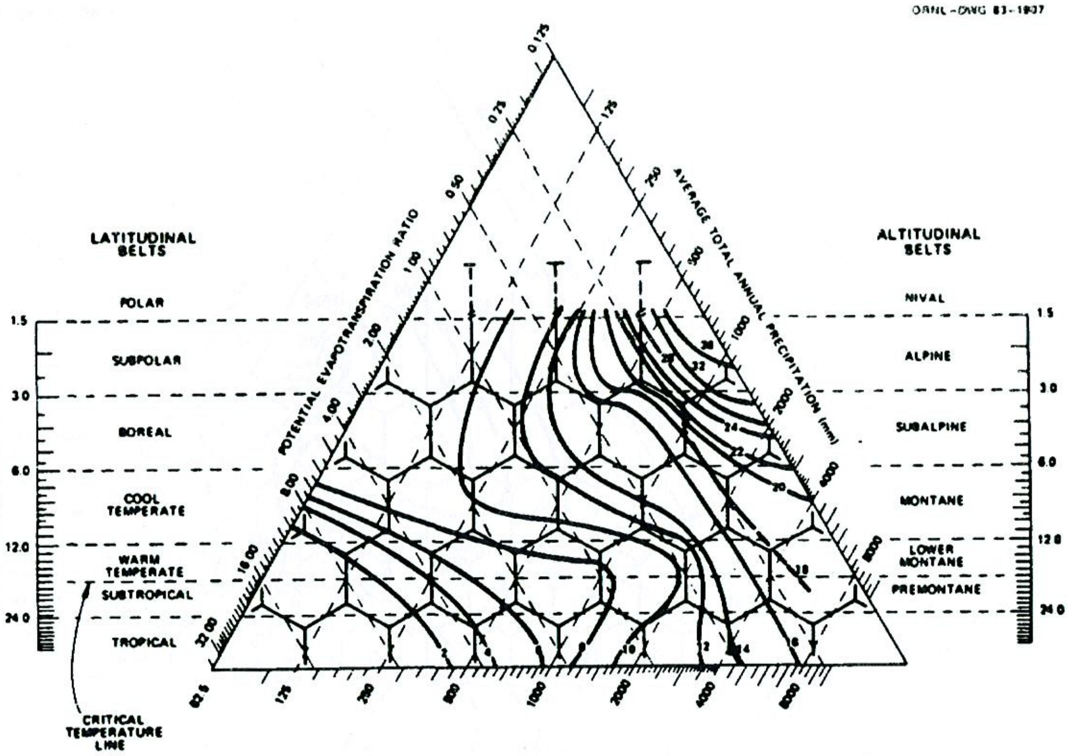

Fig. 4.3. Soil organic carbon (kg per surface cubic meter). Dark curves represent isolines of soil carbon density on the Holdridge life zone chart (see Holdridge 1947).

commonly limits production, but decomposition conditions are favorable for most of the year. This introduces an area of low soil carbon density in the life zones of this part of the diagram. Perpendicular to this line, soil carbon density uniformly increases as the PET ratio decreases, indicating not only increased vegetative productivity with humidity but possible inhibition of soil organic matter decomposition in waterlogged soils of the superhumid life zones. Conversely, as the ratio of PET to precipitation increases, soil carbon density decreases.

Soil nitrogen has a broadly similar climatic pattern to carbon when displayed on the Holdridge life zone diagram (Fig. 4.4). This results in a fairly uniform trend in soil carbon-nitrogen ratios (Fig. 4.5). In arid regions the carbon-nitrogen ratio is low and increases with increasing humidity, particularly with decreasing temperatures. Carbon data are further summarized by continents in Table 4.1.

Table 4.2 summarizes soil carbon storage by major ecosystem group, approximately matching the legend elements of the world map of Olson and Watts (1982) and described in Olson et al. (1983). Almost all ecosystems dominated by trees have soil carbon densities ranging from 10 to 20 $kg \cdot m^{-3}$. This includes most seasonally dry tropical forests. Where these intergrade and alternate with savannas, the mean soil organic carbon density (excluding charcoal) drops to 6 $kg \cdot m^{-3}$ and even lower for thorn or succulent woods and scrub (2.1 $kg \cdot m^{-3}$). Mediterranean-type vegeta-

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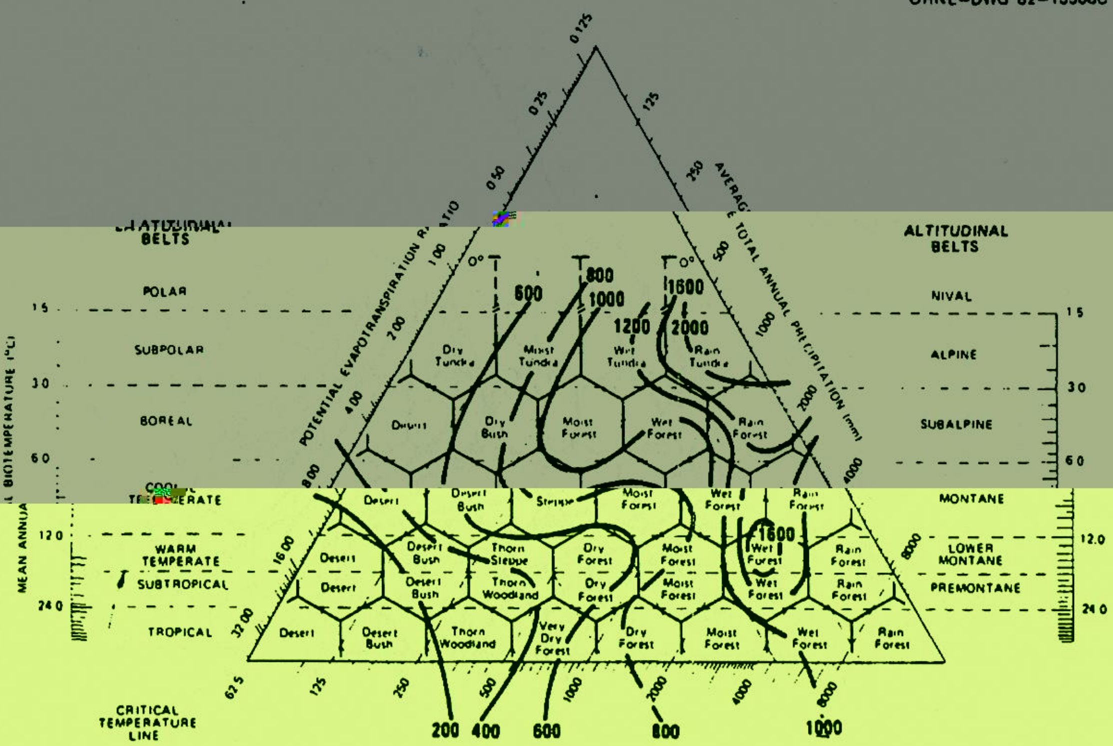

Fig. 4.4. Soil nitrogen (g per surface cubic meter). Dark curves represent isolines of soil nitrogen density on the Holdridge life zone chart.

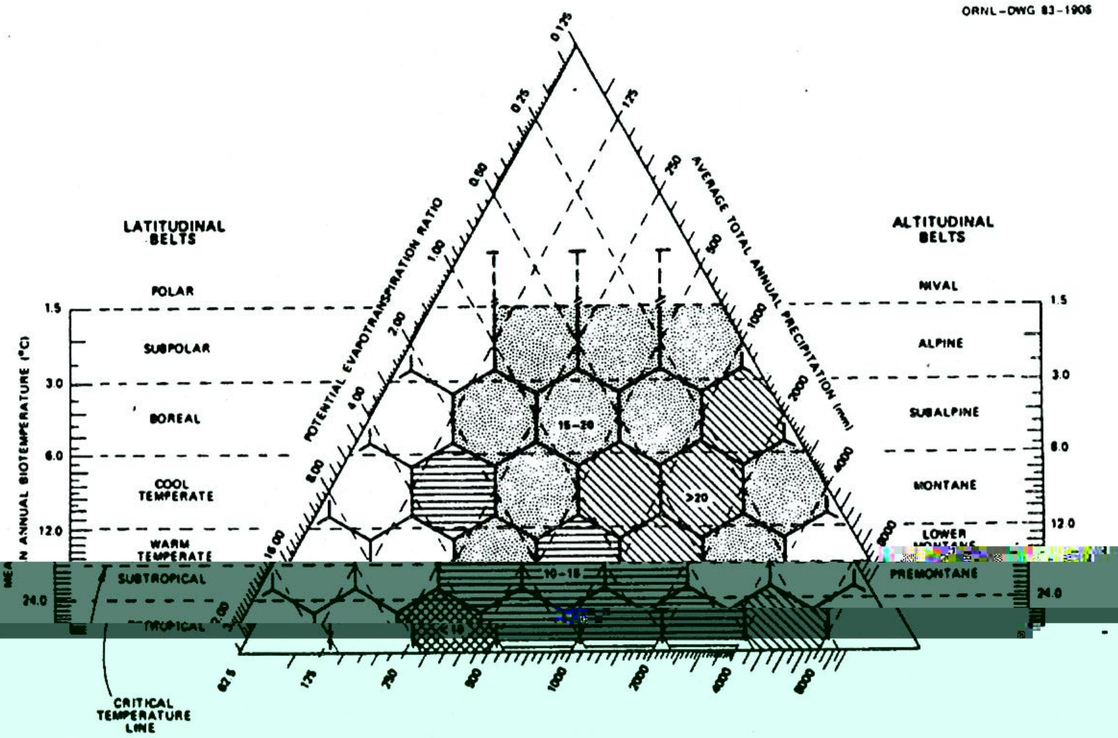

Fig. 4.5. Carbon:nitrogen ratio. Shading pattern indicates range of mean carbon-nitrogen ratios for life zones. Those life zones for which we have no data are left blank.

tion averages 7.5 ± 6.7 $kg \cdot m^{-3}$. Other kinds of sparse woodland and shrubland average between 7 and 13 $kg \cdot m^{-3}$.

Tundra samples (including many boggy areas, commonly over permafrost) have a higher carbon density (18.1 $kg \cdot m^{-3}$). At the other extreme, the few samples for warm to hot deserts average 2.5 $kg \cdot m^{-3}$, while cooler deserts and semideserts have slightly higher values (6.0 $kg \cdot m^{-3}$).

Special wetland and coastal ecosystems have soils with very high carbon densities. Five samples identified as bog represent one extreme with an average of 177 $kg \cdot m^{-3}$. Still high but less extreme ecosystems (23.4 $kg \cdot m^{-3}$) are marshes and swamps with some shrub or tree growth interspersed. Not only wetlands but some other soils may be modified by the conditions of various environments in shoreland complexes. To date, such soils have not been drawn separately from the larger groups with which they have closest affinity.

Ecosystems that are most affected by human activities, omitted from the Holdridge life zone analysis, are summarized separately here. These include second-growth woods and field mosaics that clearly have been influenced by histories of disturbance and recovery as well as those ecosystems subject to permanent conversion such as grazing and crop land and residential, commercial, and artificial park lands. Those derived from forested ecosystems and cool grasslands average between 10 and 15 $kg \cdot m^{-3}$. Those derived from warm grasslands have slightly lower soil carbon densities (8.7 $kg \cdot m^{-3}$).