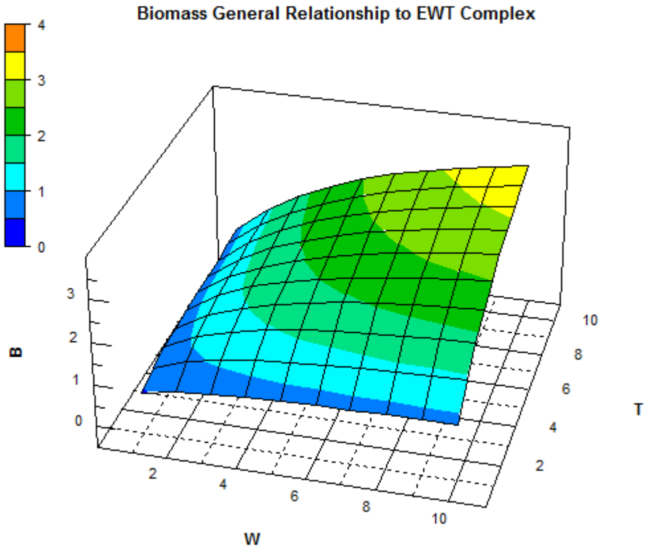
SUSTAINABLE DEVELOPMENT GOALS

Locational-State Theory
&
Crop Production Systems

Hector W. McNeill

SEEL



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Introduction

Since 1983 SEEL and now The George Boole Foundation Limited has been associated with the development of agricultural information systems linked to decision analysis and production optimization.

With climate change and the state of agricultural project design, the George Boole Foundation organized the Decision Analysis Initiative in 2010. This ran in two phases until 2020. This was concerned with transforming theory based on practical observation and experience in agricultural project design, management and evaluation back into useful tools and techniques for the design and management of sustainable agricultural projects. The Open Quality Standards Initiative (OQSI) was formed to manage a review of agricultural production systems design procedures and to specify a due diligence design and management system. This resulted in designs and implementations of the necessary tools to practitioners charged with project design and management.

The results were the OQSI due diligence design procedures and the implementation of the SDGToolkit a cloud-based agricultural project design and portfolio system. As a result of advanced developed in programming techniques during the course of this work SEEL is currently completing a lower-cost implementation known as mutec.cloud Agricultural Project.

To date SDGToolkit and mutec.cloud Agricultural Project are the only systems to have implemented all of the OQSI recommendations.

One of the important developments has been to build into a project management system a leaning system structure to create a dynamic process where any variations in expectations established during the design phases can be managed in real time during the project setup and operational phases. Under climate change this has become an essential requirement.

This publication describes Locational-State Theory (LST), an essential component of decision analysis procedures necessary for sustainable agricultural project design and management. LST was developed almost exclusively by SEEL. It is an important underlying component of the OQSI development and the SDGToolkit and mutec.cloud Agricultural project service designs.

Climate change has thrown up a major challenge for agriculture and food production requiring a logical and efficient response. Along with advanced farm typological work and the Data Reference Model approach developed at SEEL, we believe LST will become an increasingly vital component in the technical, economic and financial appraisal of agricultural production systems and projects. It is also an essential component of the decision analysis to identify appropriate agricultural policies to provide the right incentives to secure effective developments in the face of climate change.

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Locational-State Theory & Crop Production Systems

The Locational State Theory homepage, website states that,

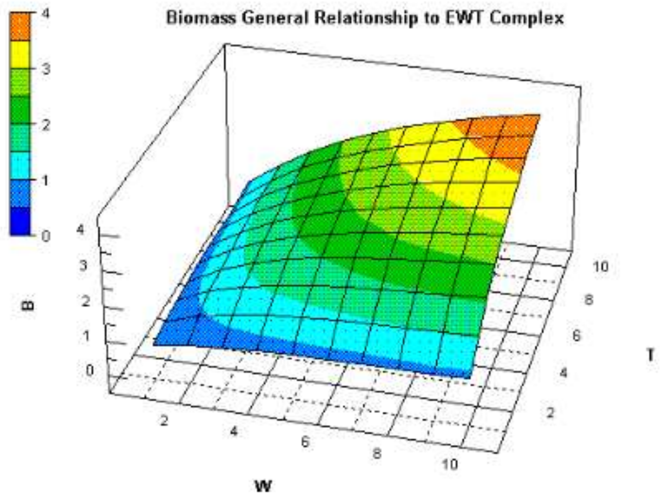
"The components of Location-State Theory are not particularly original but it pulls together already existing knowledge from a wide range of disciplines and the output of countless practitioners, into a single system. It provides a model that integrates the interactions of human, social, economic, financial, technological, environmental, ecosystem, climatic and sustainability factors. The particular focus on the significance of the space-time dimension to important relationships can contribute to a better identification of options of significance in solving pressing practical problems facing the human population…."

What is Locational-State Theory?

The groundwork into Locational-State Theory (LST) was initiated in 1968 by Hector McNeill while a Fellow of the Food Research Institute (FRI) at Stanford University and a TA in a systems engineering course at the School of Engineering. At the FRI this work led to a three-dimensional agricultural economics production model that brought together the main factors of production into a single function. In the Engineering School work the interest was related the natural resources factors contributing to the productivity of agricultural production. It was soon realised that these factors vary according to location defined by latitude, longitude and altitude. The main factors being, temperature, water accessibility and soil conditions (texture) and fertility.

In both cases, economic and biometric, the same form of production function was applied and the resulting crop production response surface generated from various combinations of temperature (T), water accessibility (W) and fertility (E) are shown below. This production response surface is a signature of the genetic potential of a crop ; it is genotype specific.

Temperature & Water range is 1-10; Edaphic is fixed at 20; The surface plot is Biomass



McNeill, H.W., *"Biomass production according to EWT complex item values"*, 2000, SEEL.

Based on: McNeill, H.W., 3D Development Model, TP, Food Research Institute, Stanford University, 1968 and McNeill & Jino, *"Simulation of 3D Development Model"*, CNAE, 1969.

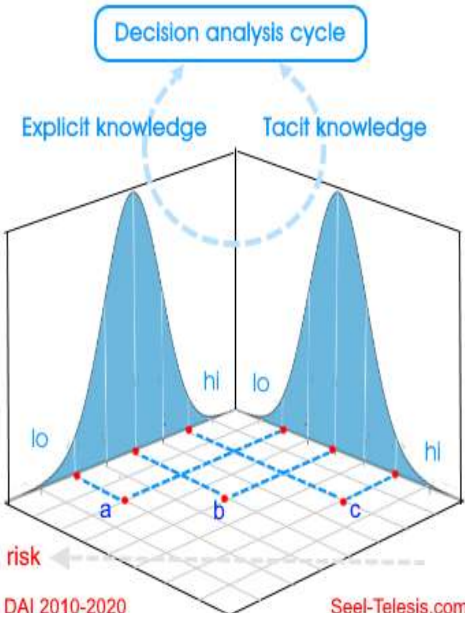
It is self-evident that for rain fed agricultural production which accounts for more than 96% of the world's crop areas, that the main variables of the state of temperature, water and natural fertility all depend upon geographic location and therefore can be referred to as locational-state variables. The locational dimension relates both to geographic location as well as location in the time dimension. This is associated with the states of these variables over the crop production cycles during each year as well as seasonal year to year variations in these locational-state variables.

From a method to a theory

Although strongly linked to agriculture and natural resources systems the term “Locational-State Theory” only appeared as “Locational-State” in 1986 as a method to improve the specification of information requirements for decision analysis and to transmit requests for and receive data over a global network. This arose as a result of the development of life-long learning and innovation systems concepts where precise data and decision analysis combine to better orientate personal, business and government decisions. Locational-State “tagged” all data elements with the locational-state specifications.

The original multi-factor production function was applied to the general economy in the context of development economics as a means of tracing the impacts of changes in factors on economic performance. This same formula applies to natural resource-based ecosystems and agricultural crop and by extension animal production. The “learning systems” development work concentrated on the human condition and the LS concept was found to be applicable to the process of learning or accumulation of facts and cause and effect relationships (explicit knowledge) and the development of human capabilities (tacit knowledge). Both of these major components of human ability rest on the accumulated history of each individual and their specific accumulated locational states when different information was accessed and events took place in their lifetimes. In terms of recording locational-state information the notion of an Accumulog was identified in 1986 as an immutable record a decade before blockchain appeared. The Accumulog in essence records the advance in learning and innovation in what today is referred to as the “process method” which is an ISO Standard 9000 (see right).

Decision analysis



The Process Approach

The process approach is commonly applied in the development of most systems involving the combination of human and technical components. The evolution of innovation and its impacts are recorded in time-based locational-state data

Decision analysis models

The relationships to economic inputs or natural conditions to a process output, meet with a response which at first rises in proportion to input and then the response levels decline. This is the typical production curve exhibiting diminishing marginal returns to the input of any factor. Each axis of the multi-factor production function has this characteristic for any economic or natural system input response. This is why it was realised that Location-state as a method was in based on a general theory of such relationships. All precise models need to combine estimates of the combined impact of the current state of explicit and tacit knowledge to build or improve production processes and Locational-State Theory has an important role in advancing the state of this important procedure.

Relevant measurements in biometric relationships in agriculture

The relationships of bioclimatic to agricultural production are measured on the basis of agrobiometry. Agrobiometry is the application of statistics and mathematical logic to the analysis of the biological and environmental phenomena and agricultural production and rural communities as part of an ecosystem. Statistics is concerned with collecting representative data on phenomena and the presentation of analytical descriptions of the information collected. Mathematical logic is the deductive design and logic applied to factual information and existing knowledge of relationships to determine the probability of events and uncertainties upon which to base decisions

Agricultural production

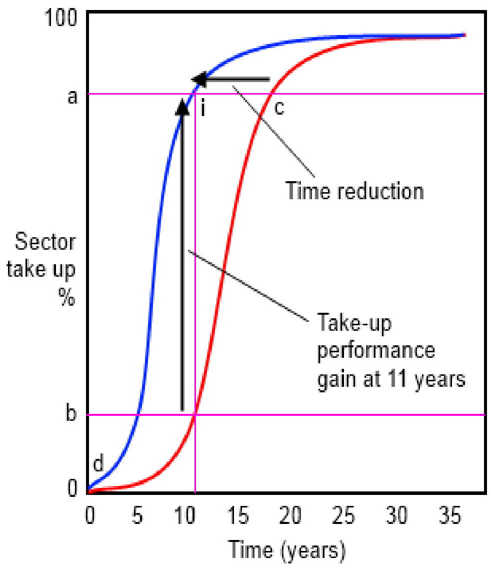
In 1962 Kenneth Arrow, the American Economist, published a paper entitled "The Economic Implications of Learning by Doing" (The review of Economic Studies, Vol 29, No 3, June 1962, pp. 155-173). In this paper he explained, based on empirical evidence that the main generator of economic development is learning resulting in beneficial change as a result of practical changes in the way things are done, or, as a result of innovation.

This has been recognized over many generations and the process of agricultural development has been based on the developments of a range of new technologies and techniques which have been disseminated across geographic space largely through agricultural extension activities. Although there is a significant intellectual investment in the development of new technologies and techniques the practical impact in terms of increased production and economic growth depends upon the rate of diffusion not so much information but rather the take up and practical implementation of the new techniques.

The take up and application of new techniques varies according to the status of the farms involved. Small lower income farms require practical guidance with combined demonstrations of the techniques required, preferably under farm conditions through "farmer's field demonstrations" where farmers are provided with the opportunity to actually carry out a technique in practice. This process is of vital importance to acquaint the farmer with "what is involved" to implement a new technique and to judge for themselves the relative ease on implementation and the risks involved. This type of exposure provides farmers with more confidence to make use of the technique and initiate a process of learning by doing and the accumulation of competence in its execution (tacit knowledge).

Therefore, the impact of take up depends upon the process of acquisition of capability in carrying out the appropriate tasks associated with a new technology and technique. As a farmer descends the learning curve in the application of the new technology and technique the efficiency of the task

The impact of rate of diffusion of a new technology on production and economic growth



Diffusion of technology

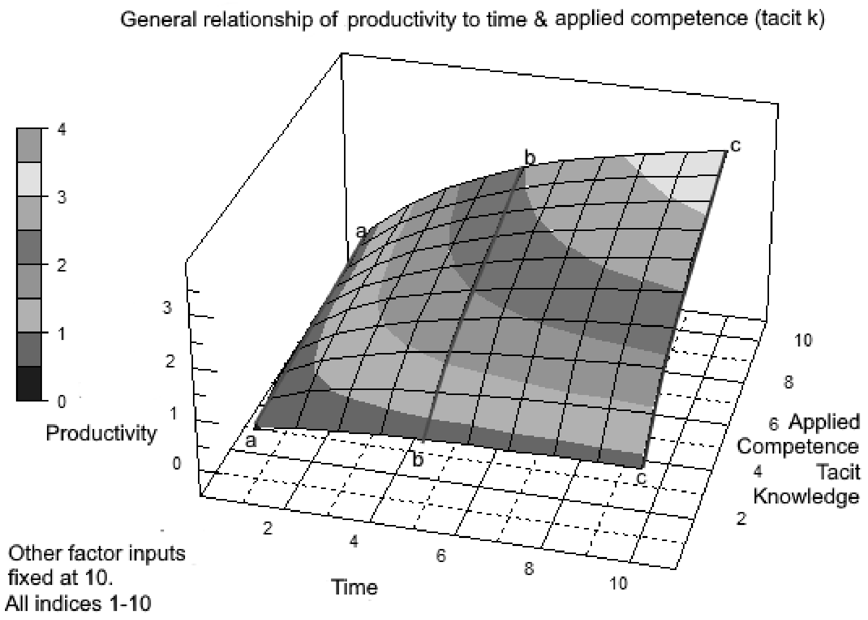
By reducing the time of take up and application of a new technology from reaching an adoption of 85% in 18 years to an adoption rate of 85% within 11 years results in a gain in take up from 70% within just 11 years instead of 18 years.

Assuming a crop area is 100,000 ha and the change in technology raises productivity from an average of 2,700 kg./ha to 5,000 kg./ha.

The gain in production will be 0.85 x 100,000 x (5,000-2,700) = 195,500 tonnes.

If the previous Gross Margin was £270/ha. and the new GM is £500/ha. the gain in profits would be £19.55 million execution rises involving less time, less mistakes and waste and a general decline in unit costs. As a result, productivity rises following LST laws as illustrated in the MFPF (Multi-factor production function) model (see below).

The management of operations requires an understanding of the impact of several factors on crops yields and unit costs of output.


General relationship of productivity to time & applied competence (tacit k)

Other factor inputs fixed at 10.
All indices 1-10

The quality of advice

The foundation of good advice is an ethic based on the evaluation of reliable evidence to identify what works and does not work within a full understanding of the environment within which agricultural activities are performed. In this context the use of complete data sets upon which to base the knowledge used to provide advice is essential. An important consideration in identifying the core data set required to improve the understanding of crop yields is an understanding of locational state displacements. This refers to the separation of data collection on farms being subject to either time location or geographic location displacements or separations.

Time displacement

By way of example of time displacement of data collected, the Diagrams 1, 2 and 3, on the nest page, show the differences in a fixed range of fertilizer applications to separate plots and the yield of barley, repeated over 5 years (1986 to 1990). Each diagram shows the results of the production response curve to fertilizer inputs.

In 1989 the yield was very low attaining a maximum yield of just 2.25 tonnes/ha. In three separate years of 1986, 1987 and 1990, the yield response curves were similar attaining a maximum yield of 4.5 tonnes/ha. In 1989 the yield reached 7 tonnes/ha. The only data collected each year was the fertilizer inputs and the corresponding yields. Therefore, based on the data set it was not possible to explain the significance differences between the data sets. On the other hand, the correlations between fertilizer inputs and yields were high in every year.

Diagram 4 combines these separated graphs to show the very significant yield differences obtained by the "same fertilizer treatments”.

The reasons for the very significant differences in yield responses were the results of the impact of locational state factors in the form of the available water and ambient temperatures. In the year 1989 there was a late spring with low temperatures, inadequate rainfall during the growth period and a damp harvest period. In the years 1986, 1987 and 1990 the rainfall and temperature profiles were "normal" and the yields were close to what was considered to be average production. In 1989 the spring was early, with adequate rainfall during the growth period and a good temperature regime and dry period for harvest.

Diagram 1

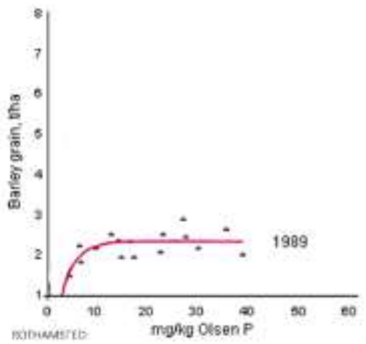


Diagram 2

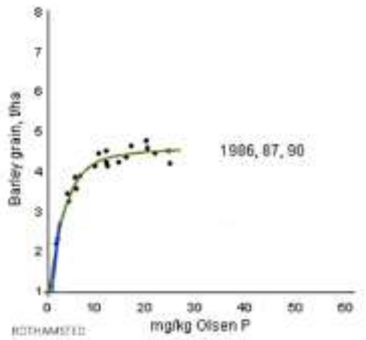


Diagram 3

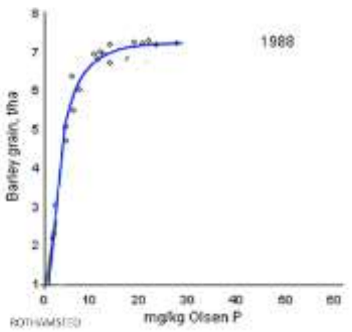
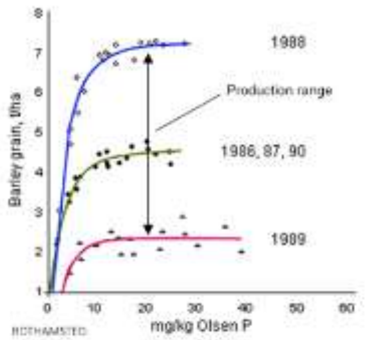


Diagram 4



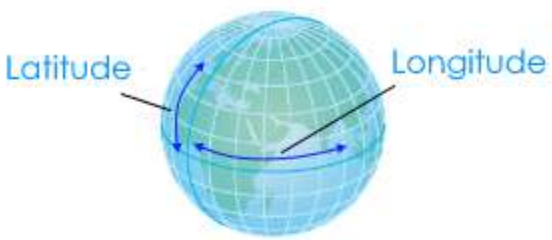
From an incomplete to a more complete data set

It is therefore evident that in order to be able to explain with more precision the variations in yield, the rainfall and temperature regimes should have also been collected as critical determinants and this would have produced a more complete data set to enable a more precise explanation of the reasons for the significant yield variations.

Relevant locational state relationships

Mention was made in this example of temperature regimes and rainfall regimes. These are explored further to trace the specific nature of these impacts on crop yields.

Geographic location displacement



Temperature impacts

Yields rise with rises in temperature linked to the fact that chemical reactions speed up with rises in temperature. For crops there is a range of temperatures over which this affects plant growth, being over the 10^{o}C to 35^{o}C range, as shown in Diagram 5 below comparing biomass production and different temperature regimes which would be within that range. Temperatures also vary with altitude by approximately 0.6^{o}C for each difference of 100 metres between locations. The temperature falls as the terrain altitude increases and the temperature rises by the same amount as the terrain altitude falls in altitude. This why data sets that related to production but collected from farms distributed across terrains with significant differences in altitude possess quite different values, just as in the case of year-to-year separations of data collections in the previous examples. Therefore, the temperature regime biomass relationship can be represented as in the case of Diagram 6 as the effect of altitude on biomass production.

Diagram 5

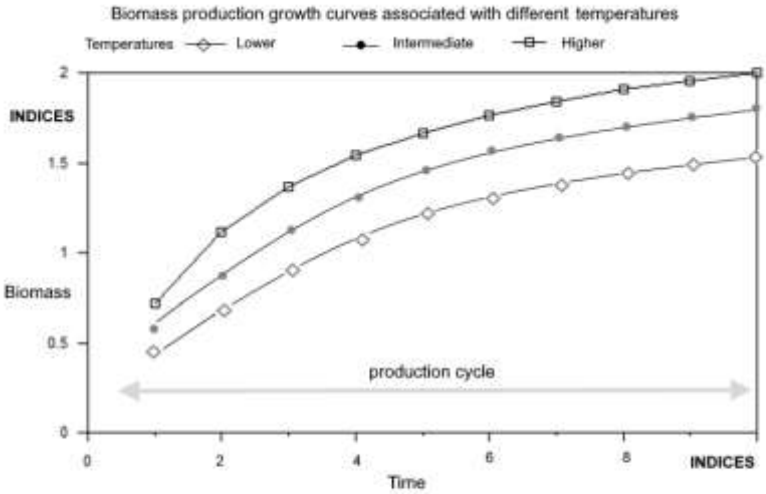
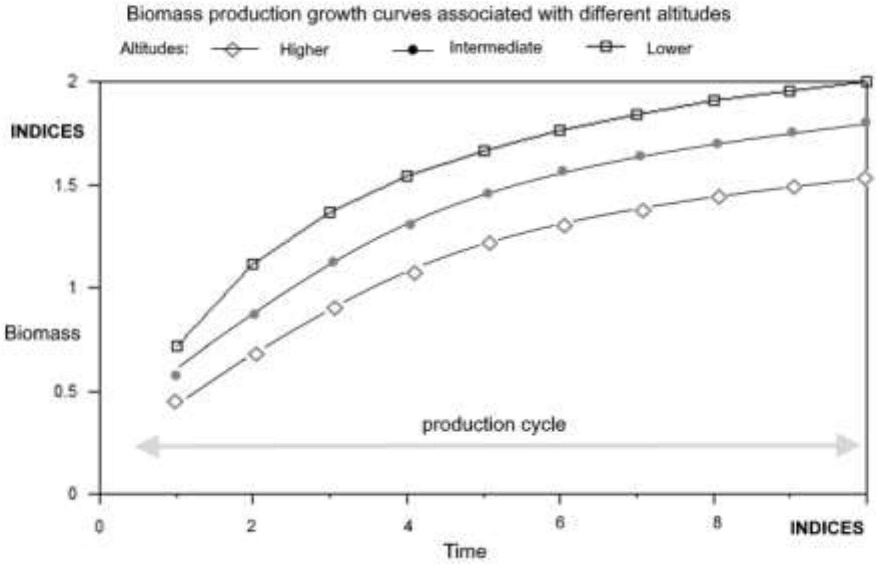
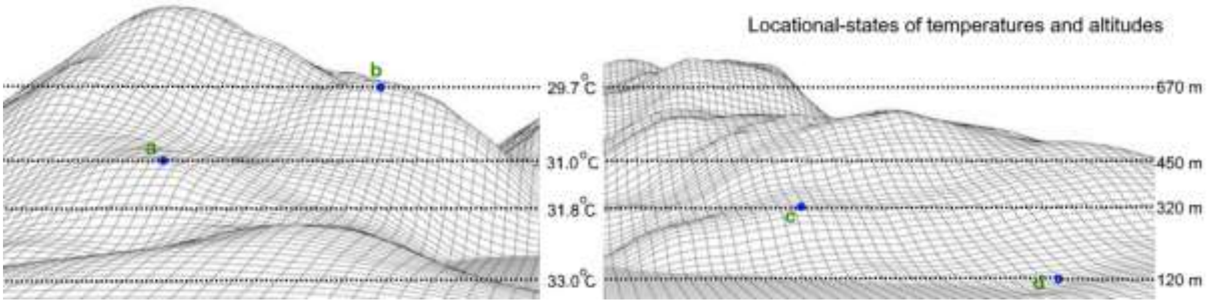


Diagram 6

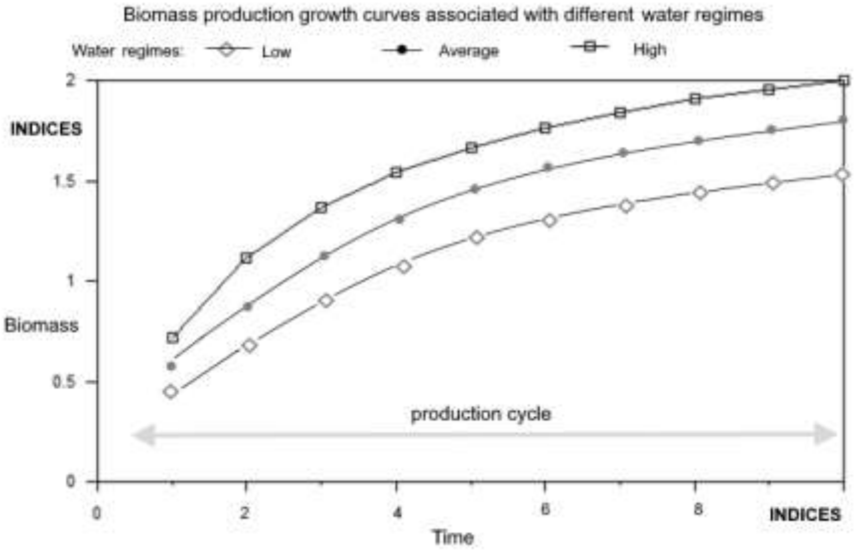




Water availability

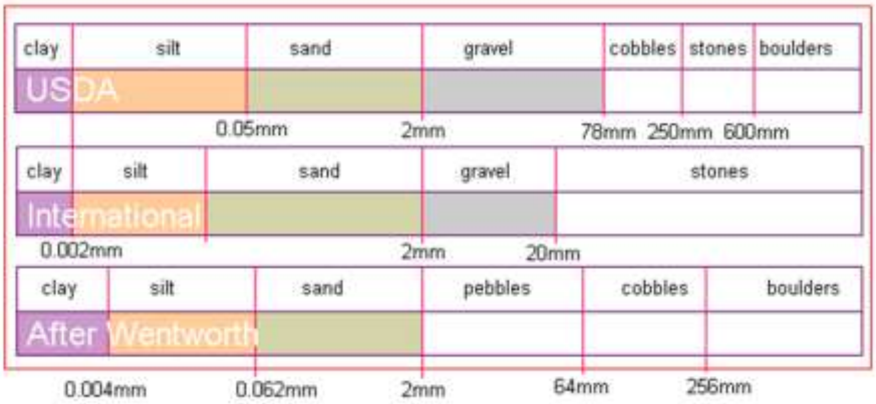
The general relationship of biomass production to availability of water is shown in Diagram 7.

Diagram 7



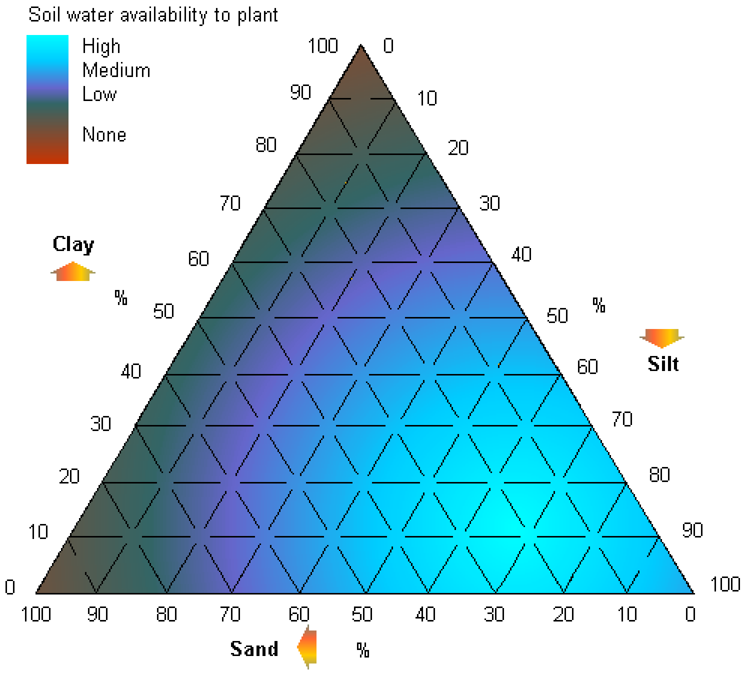
Although in most rain fed agriculture, the source of water is rainfall, the actual availability of water to crops varies with other locational-state factors. The availability of water to plant roots is determined by the degree of surface run off of rainwater, the degree of percolation into the soil, the texture of the soil, the evapotranspiration during the year leaving a new balance of water held known as the water deficit. Evapotranspiration is determined by the temperature regime during the year. Also, the availability of the water to the plant roots is also related to the soil water holding capacity.

Soil texture is measured by the proportions of different sized particles making up the soil and classed as clay, silt and sand. There are several classifications as shown below.



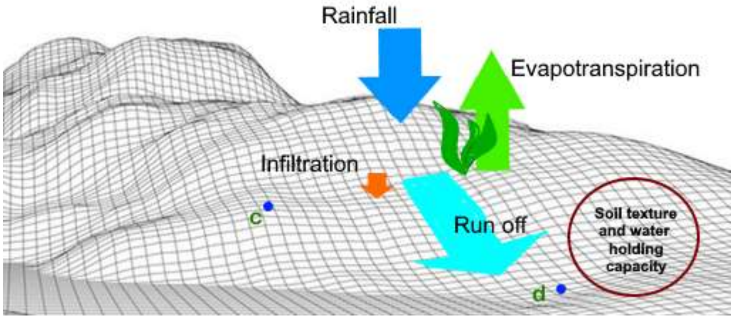
The effect of particle size on water availability to plants is related to the capillary action of water with the specific surface of small particles having a greater attraction that larger particles. Sand, as a coarse particle size has very little capillary action and water tends to drain away under gravity. Clay being made up of very fine particles has a string capillary action and when the water content declines the capillary action creates an attraction or "tension" that exceeds the ability of plant roots to absorb water. As an intermediate particle size silt has a lower capillary tension but sufficient to prevent much of the water from draining away under gravity and thereby facilitating plant root access to the water available in the soil even under drying conditions.

These general relationships influence the water holding capacity of the soil and the overall availability of water is indicated in the diagram below by the lighter blue areas in the "soil triangle"

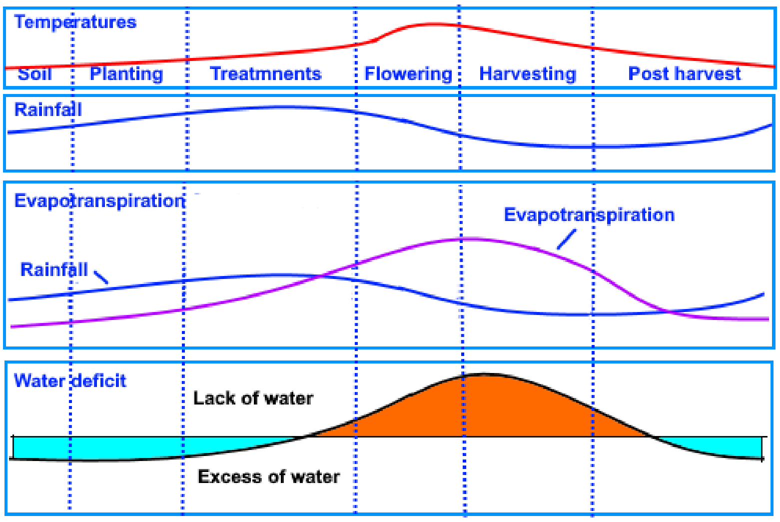


Water deficit

The actual amount of water available to plants is measured by the soil "water deficit". This can be calculated by deducting the run off, evapotranspiration and drainage of water volumes from the water delivered through rainfall measured in mm. The rates of evapotranspiration are related to leaf area indices, temperature and wind speed.



Useful meteorological records in calculating water deficit.



Significance of these facts to statistical analysis

Temperature as well as altitude and soil texture are all important elements in explaining the level of a crops yield. Therefore, these determinants should be included where possible as a way to stratify analysis by applying a typology to farms according to their location. If these elements are not included along with meteorological records used to calculate the water deficit the precision of analysis is correspondingly lowered and it is more difficult to provide useful advice to farmers on their farm plans.

The relationship of these issues to agroecological zoning

Agroecological zoning (AEZ) is a system of land classifications used to assess agrobioclimatic conditions to determine its suitability for different crops. AEZ is based on long term climatic trends whereas what has been reviewed above is the short-term dynamics of agrobioclimatic variance both over time and distance. The significance of these differences are reviewed in the sections entitled "***Climate change***" and "***Sustainability***".

The relevance of LST and decision analysis to the whole range of food production systems

In board terms the range of crop production systems can be divided into:

- Rain fed
- Intensive production
- Protected and irrigated
- Closed systems such as hydroponics

Rain fed systems

Most of the world's agriculture is dependent upon the natural conditions and locational-state variable reviewed in this paper as the local temperature, water and fertility regimes. Where there are deficits fertilizer might be added as well as water to make up these gaps in order to raise yields.

Intensive production

Intensive production involves higher inputs of fertilizer, traction and implements, energy and water to align yield expectations with the required levels of inputs. However, in terms of sustainability and carbon footprints such systems will need to undergo modifications.

Protected and irrigated

Protected agriculture includes greenhouses, shading and other devices to gain more control over temperatures and protection from wind and excessive insolation,

Closed systems such as hydroponics

The most effective control over locational-state variables of temperature, water and fertility include the different types of close hydroponic systems which possess the ability to recycle water, moderate or control temperatures and to control fertility to map over the genotypic potential of each crop grown. Under such conditions the locational-state variables are less dependent upon the natural "outside" conditions of a location but become directly related to the genetic potential of the crop being produced.

Locational-State Genotypic Sequencing

With rises in temperatures with climate change caused by rising greenhouse gas emissions there will be a decline in accessibility to water resulting from increase evapotranspiration. This will result in declining yields. Under traditional systems there are a range of commonly growth crops that have been valued locally because they perform well under the specific bioclimatic conditions of a location. Therefore, there exist in the field a range if genotypes that demonstrate varying degrees of tolerance to temperatures and water deficits in relation to yields obtained. Because temperatures are rising the typical average locational state variable for any given location are changing. Locational-State Genotypic Sequencing is a procedure whereby the varieties grown in a location are substituted over time by varieties known to be more drought and temperature resistant. This has the benefit of helping stabilize yields over time while seasonal variance will continue and has the added advantage on larger projects of lowering the risks to cash flow.