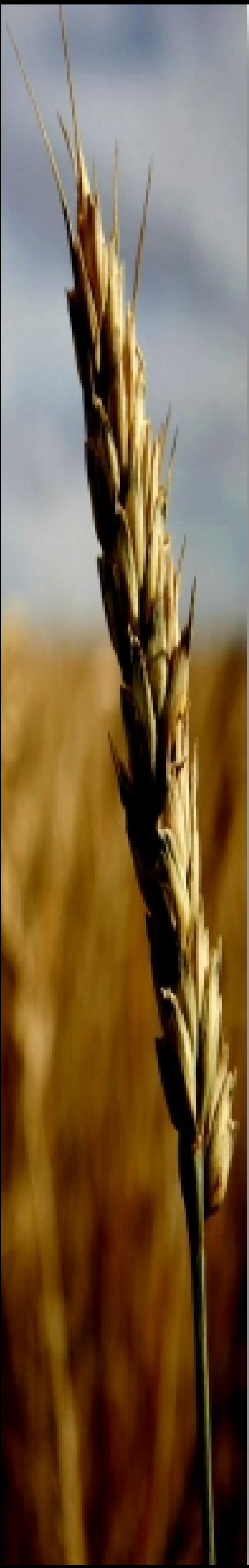
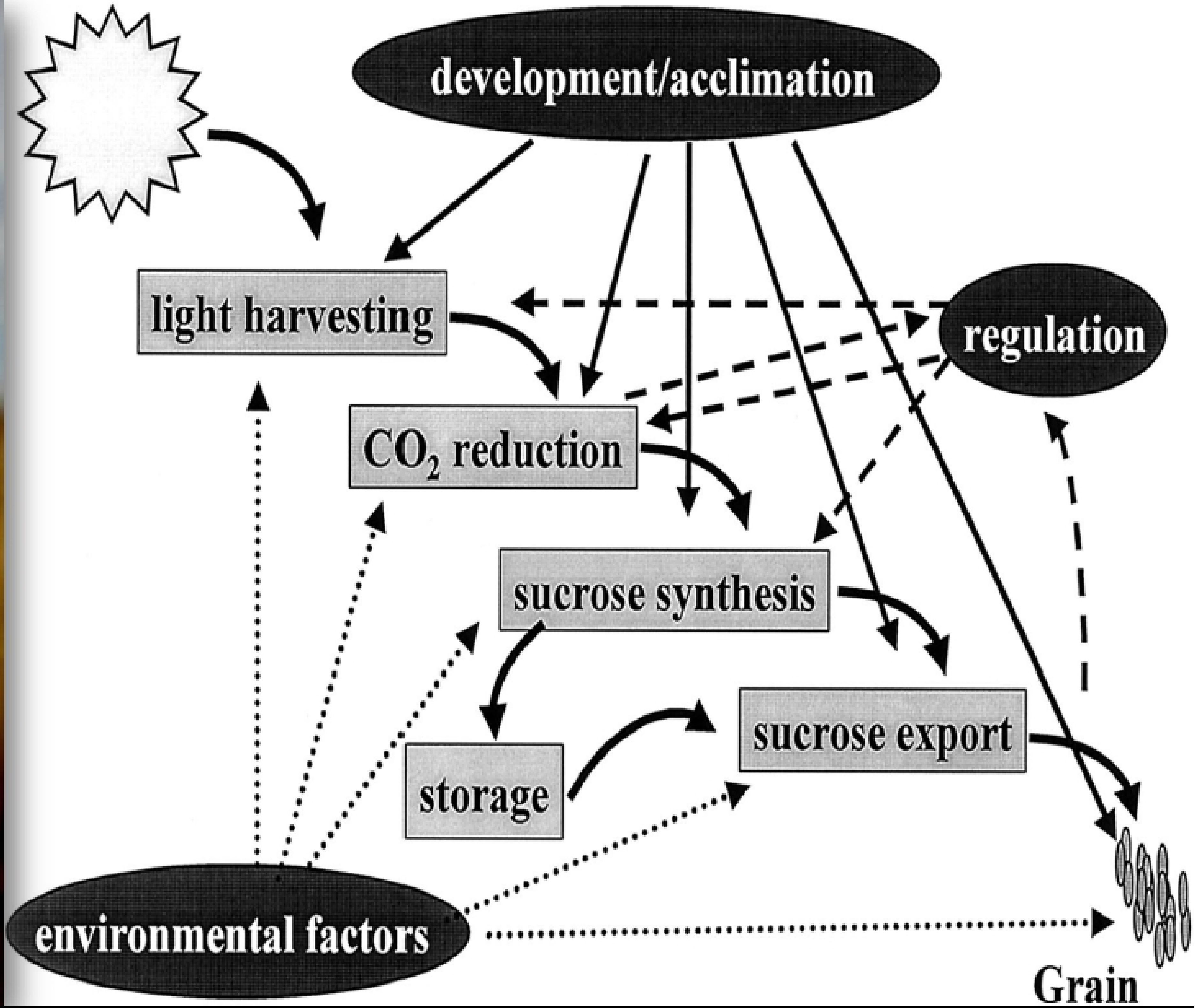
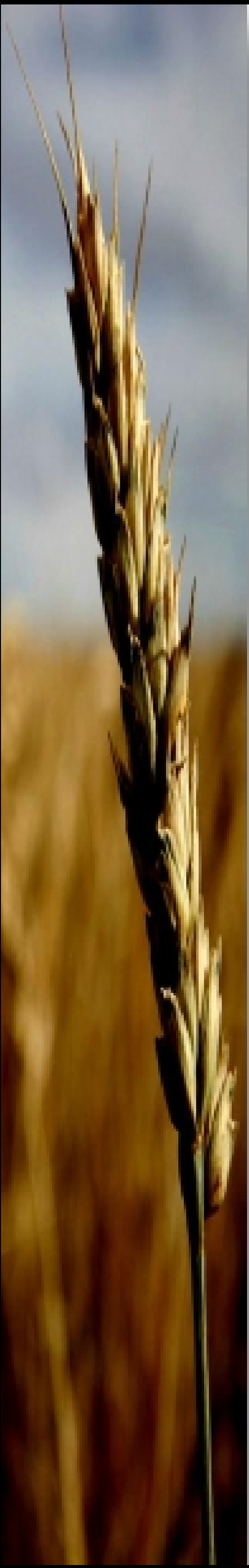
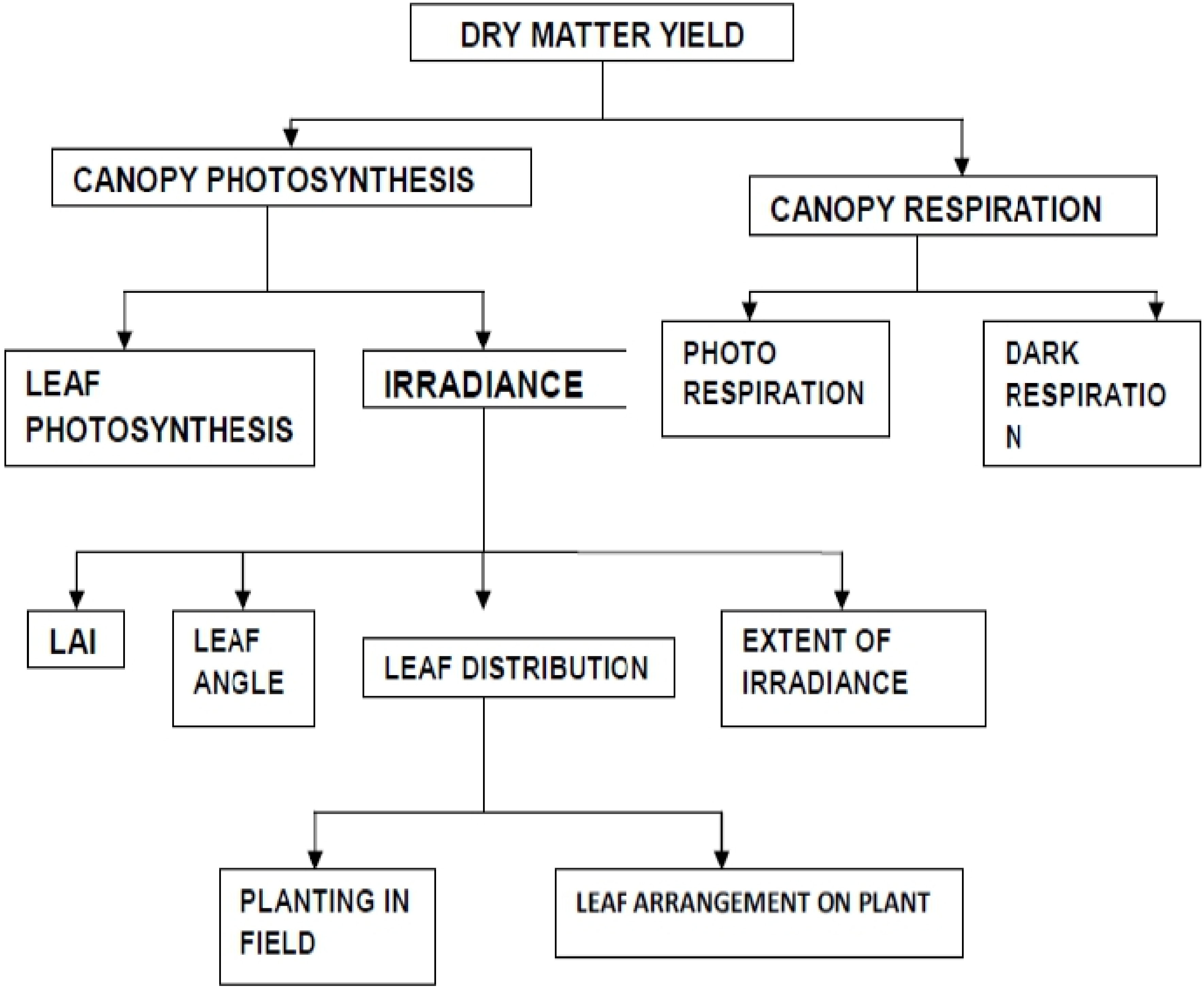
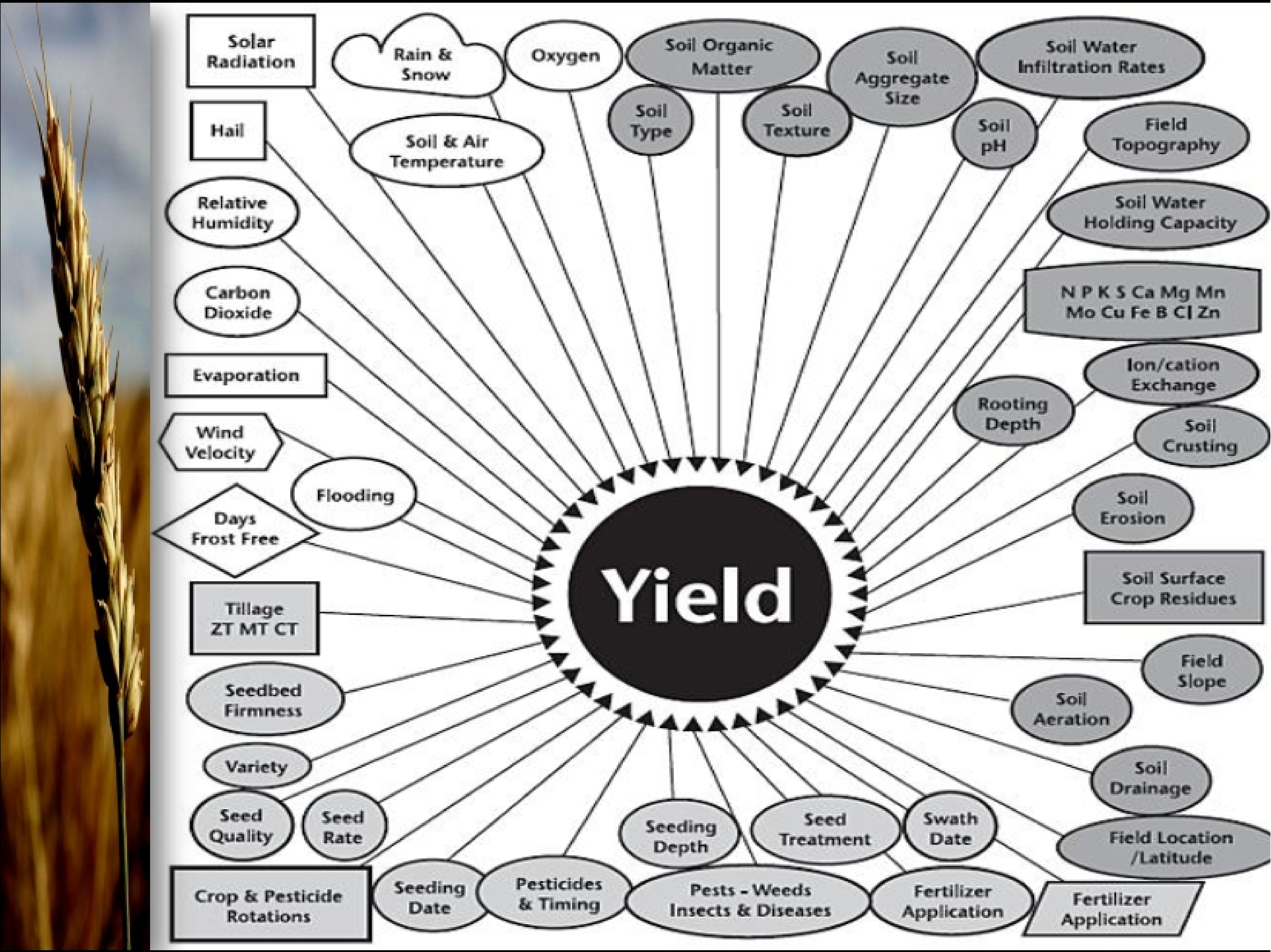
ANALYSIS OF FACTORS LIMITING CROP GROWTH AND PRODUCTIVITY- THE CONCEPT OF RATE LIMITATION




development/acclimation
light harvesting
regulation
CO_2 reduction
sucrose synthesis
sucrose export
storage
environmental factors
Grain




DRY MATTER YIELD
CANOPY PHOTOSYNTHESIS
CANOPY RESPIRATION
LEAF PHOTOSYNTHESIS
IRRADIANCE
PHOTO RESPIRATION
DARK RESPIRATIO N
LAI
LEAF ANGLE
LEAF DISTRIBUTION
EXTENT OF IRRADIANCE
PLANTING IN FIELD
LEAF ARRANGEMENT ON PLANT


Solar Radiation
Rain & Snow
Oxygen
Soil Organic Matter
Soil Aggregate Size
Soil Water Infiltration Rates
Hail
Soil & Air Temperature
Soil Type
Soil Texture
Soil pH
Field Topography
Relative Humidity
Soil Water Holding Capacity
Carbon Dioxide
N P K S Ca Mg Mn Mo Cu Fe B Cl Zn
Evaporation
Ion/cation Exchange
Rooting Depth
Wind Velocity
Soil Crusting
Flooding
Days Frost Free
Soil Erosion
Yield
Soil Surface Crop Residues
Tillage ZT MT CT
Field Slope
Seedbed Firmness
Soil Aeration
Variety
Soil Drainage
Seed Quality
Seed Rate
Seeding Depth
Seed Treatment
Swath Date
Field Location /Latitude
Crop & Pesticide Rotations
Seeding Date
Pesticides & Timing
Pests - Weeds Insects & Diseases
Fertilizer Application
Fertilizer Application

Liebig : Law of the minimum

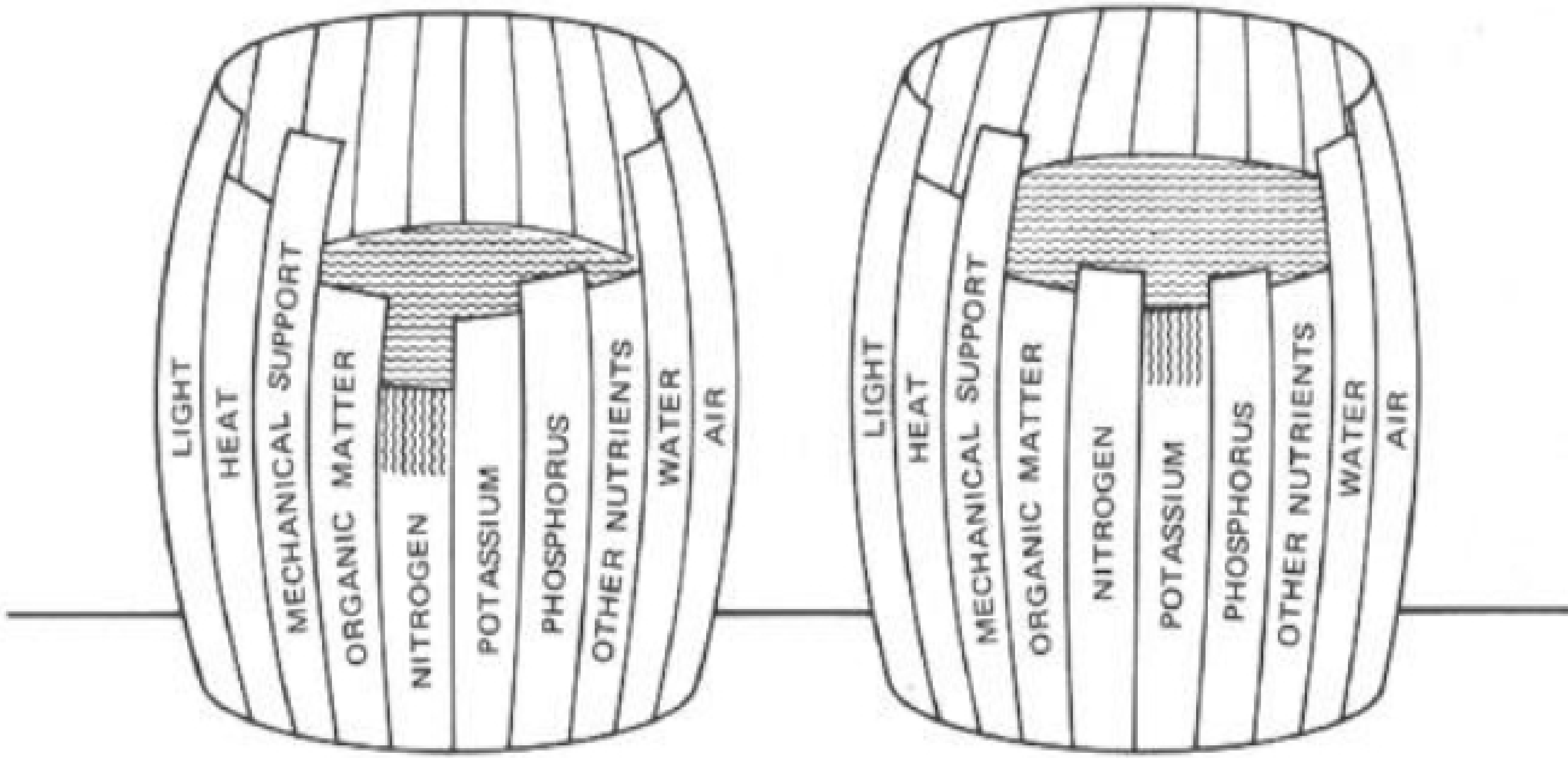
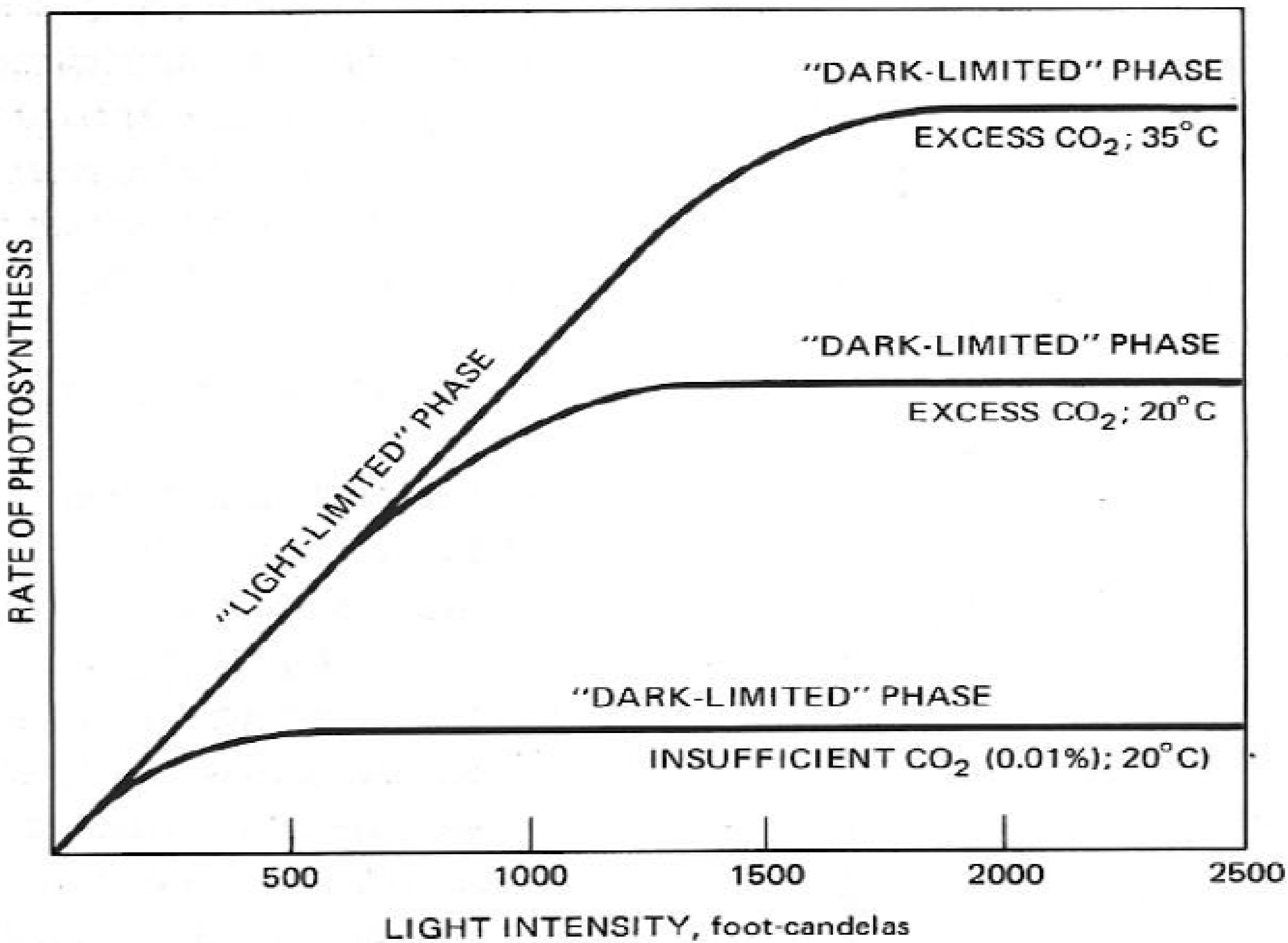
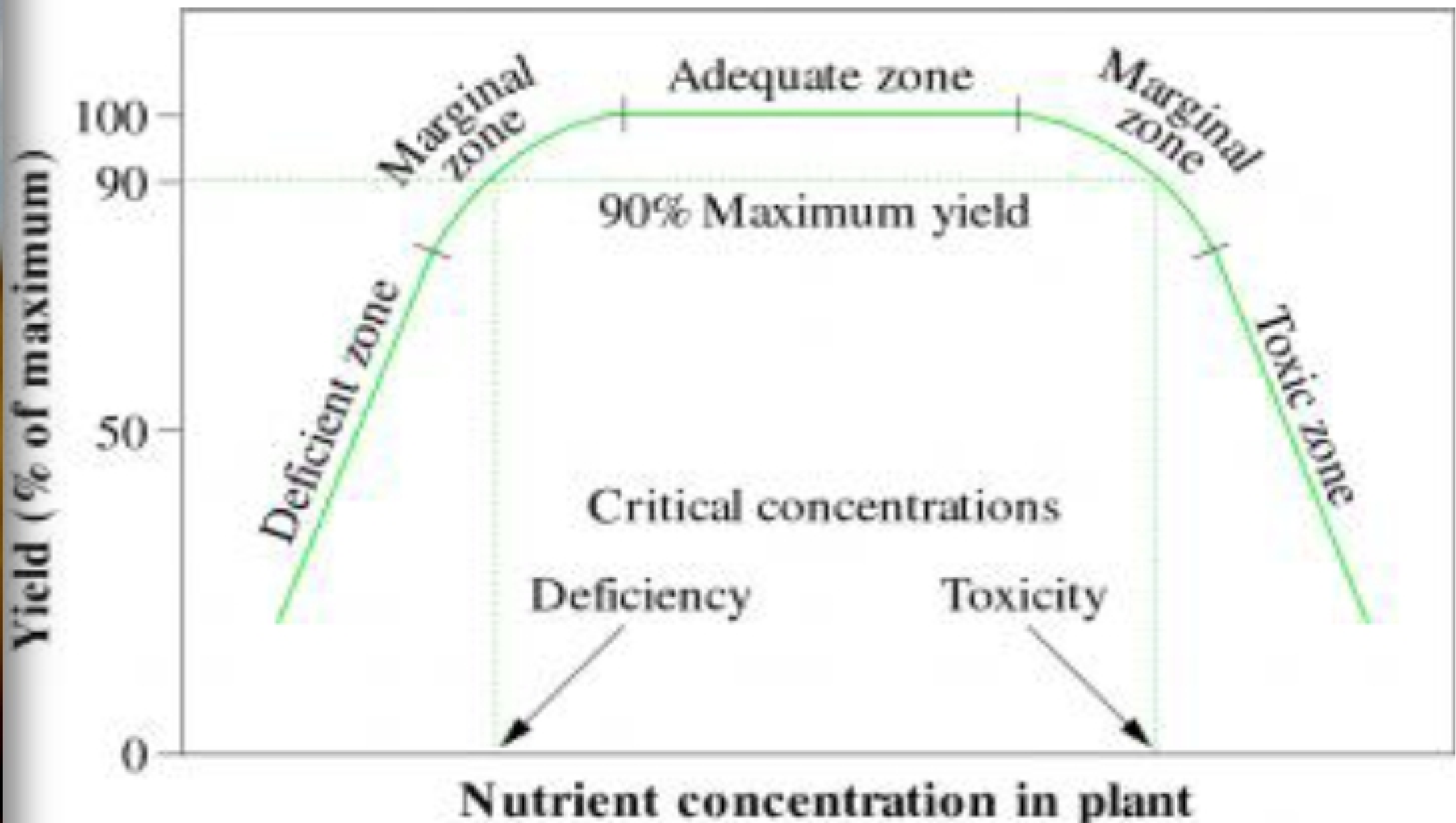


FIGURE 2:1. An illustration of the principle of limiting factors. The level of water in the barrels above represents the level of crop production. (*Left*) Nitrogen is represented as being the factor that is most limiting. Even though the other elements are present in more adequate amounts, crop production can be no higher than that allowed by the nitrogen. When nitrogen is added (*right*) the level of crop production is raised until it is controlled by the next most limiting factor, in this case, potassium.

Blackman : Concept of limiting factors

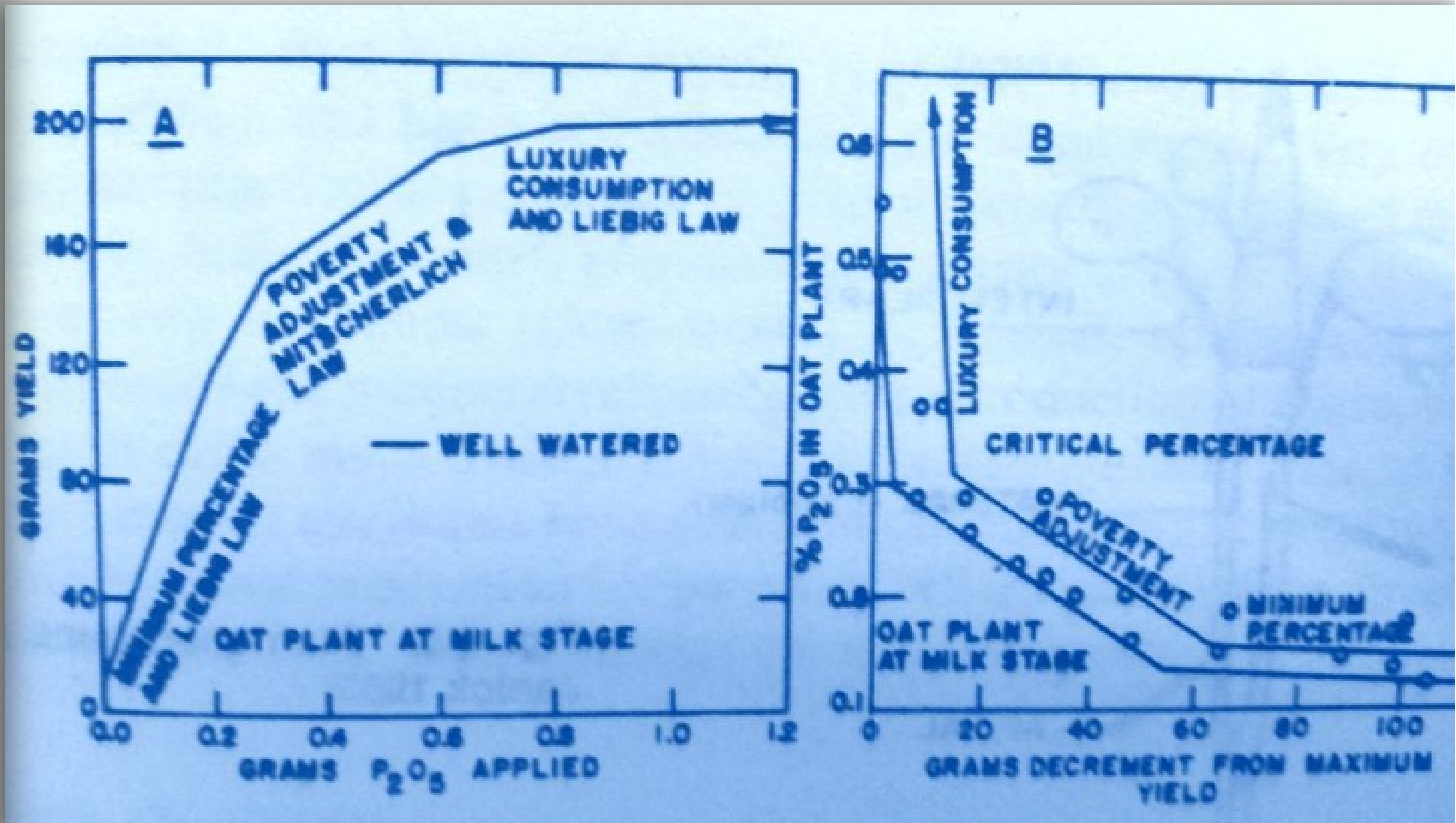


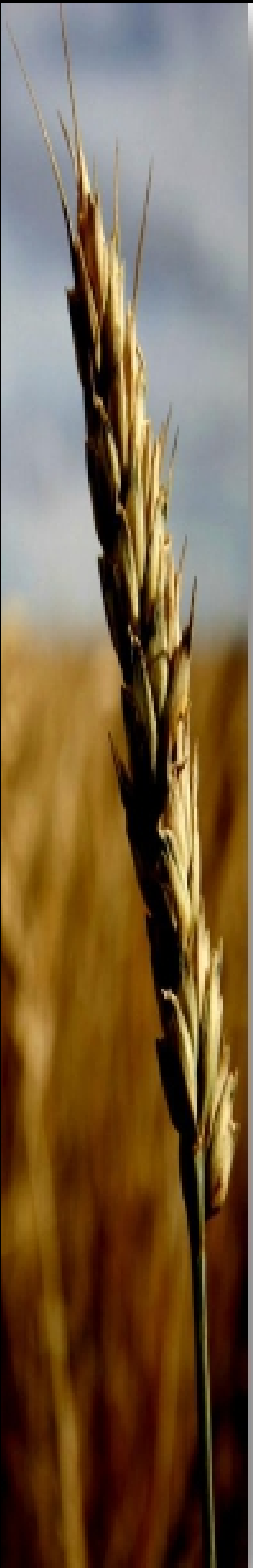
Mitscherlich : Law of Diminishing Returns



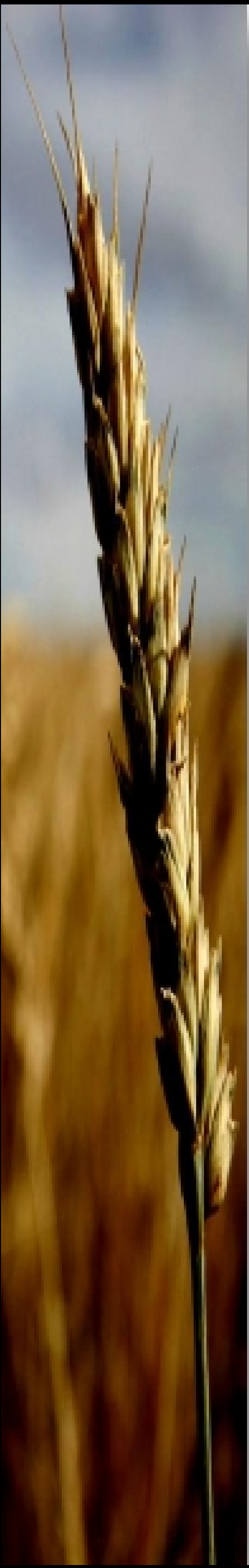
- Baule Units

Macy : Critical Percentages





Why these are only theories and not accepted as laws?

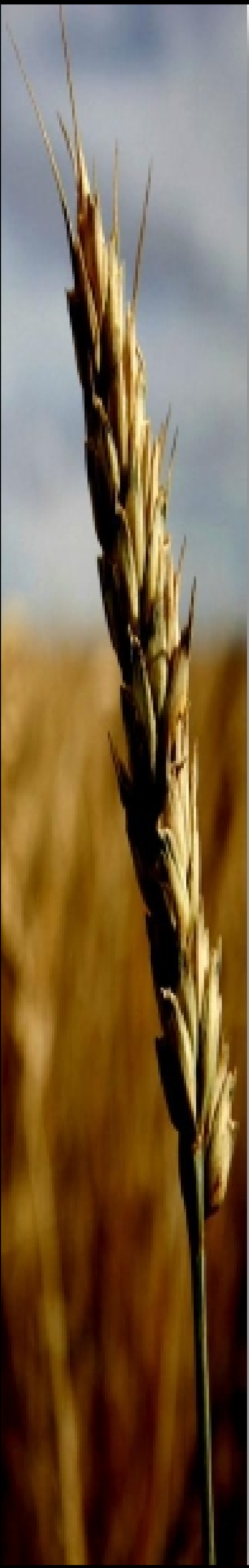


Yield limitation by water :

$$Y = Q_w \times A \times \varepsilon_w \times H$$

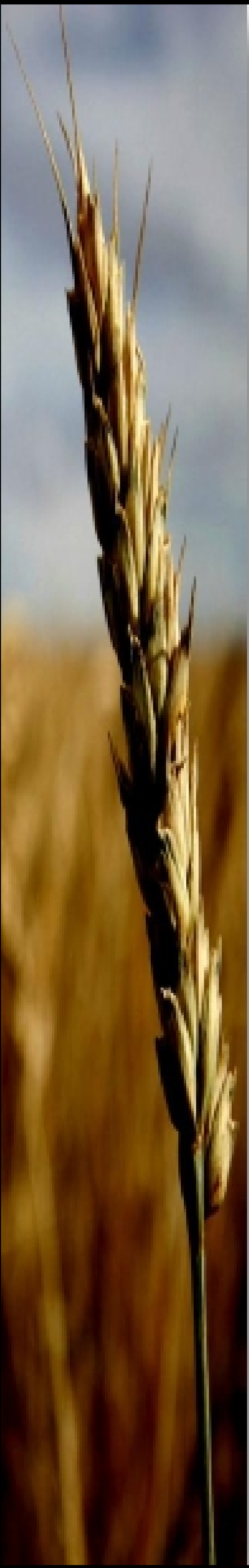
-Crop biomass is linearly related to cumulative transpiration.

- Efficiency of water supply → Photosynthetic efficiency → Partitioning of assimilates



Acquisition of Water :

- Q_w is determined by environmental factors.
- A varies considerably among species, varieties.
- Root soil inter phase



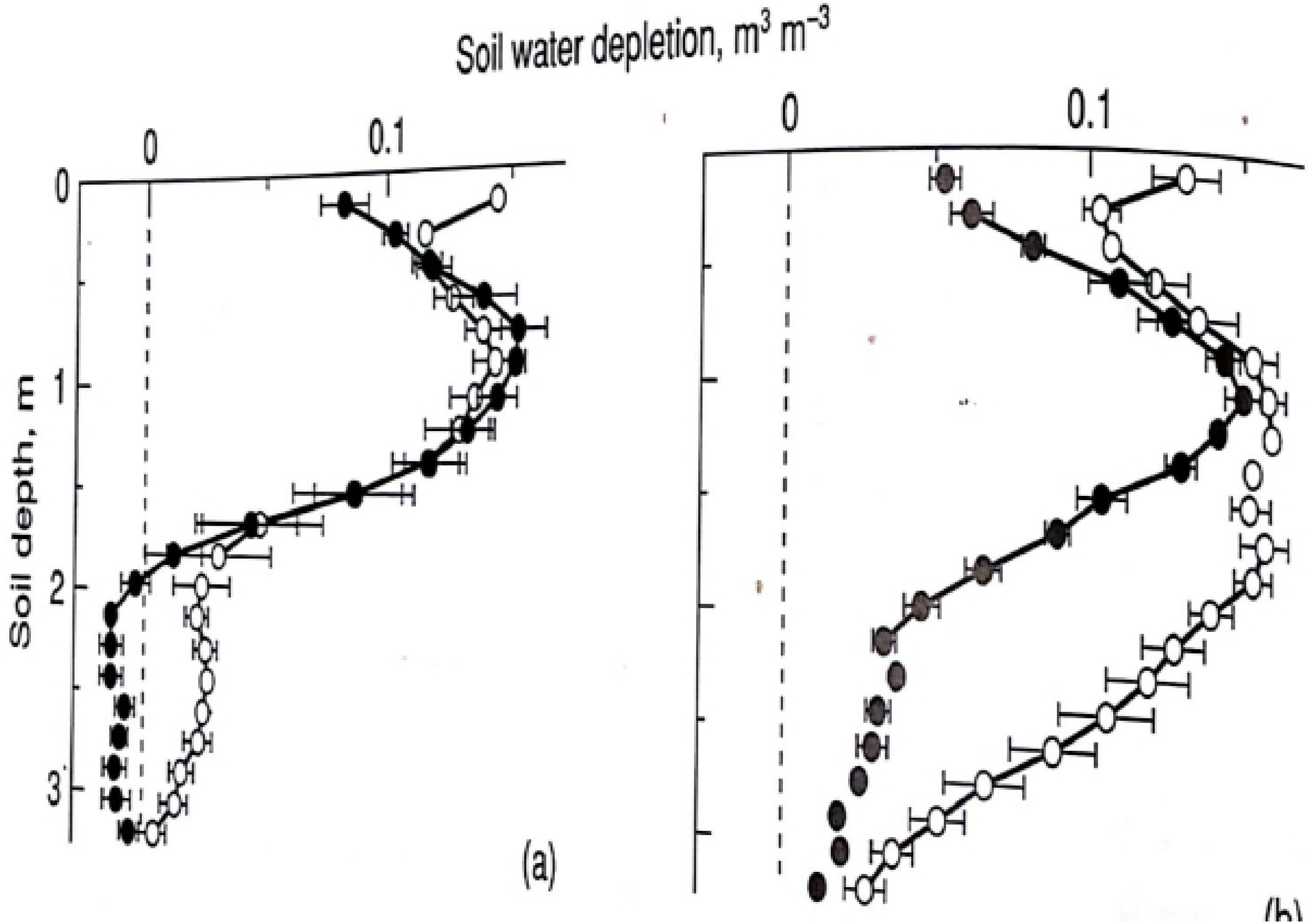
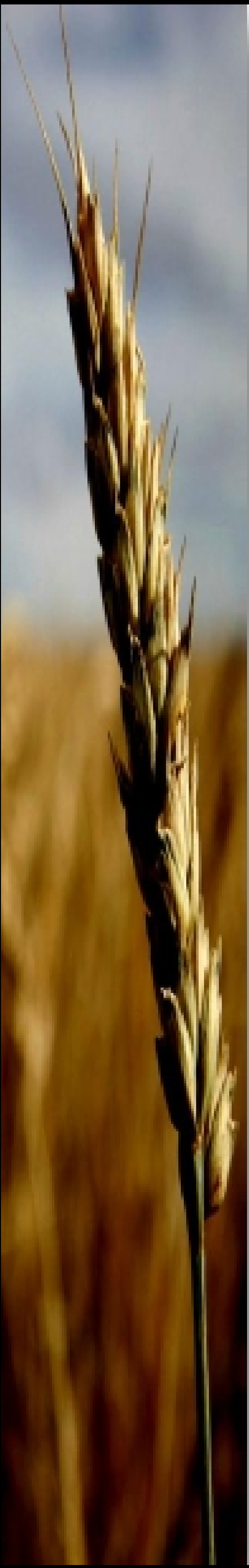


Fig: Soil water depletion by sunflower (open circles) and grain sorghum (closed) grown in semi arid zone of Kansas. (Stone et al., 2002)



Carbon costs of vigorous root systems:

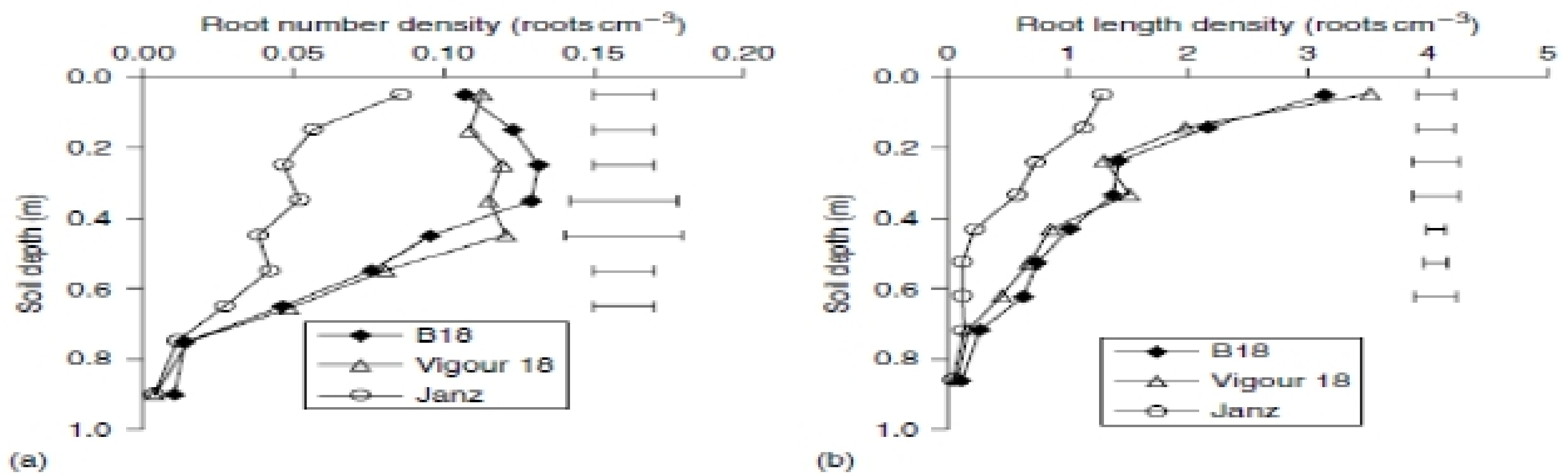


FIGURE 1

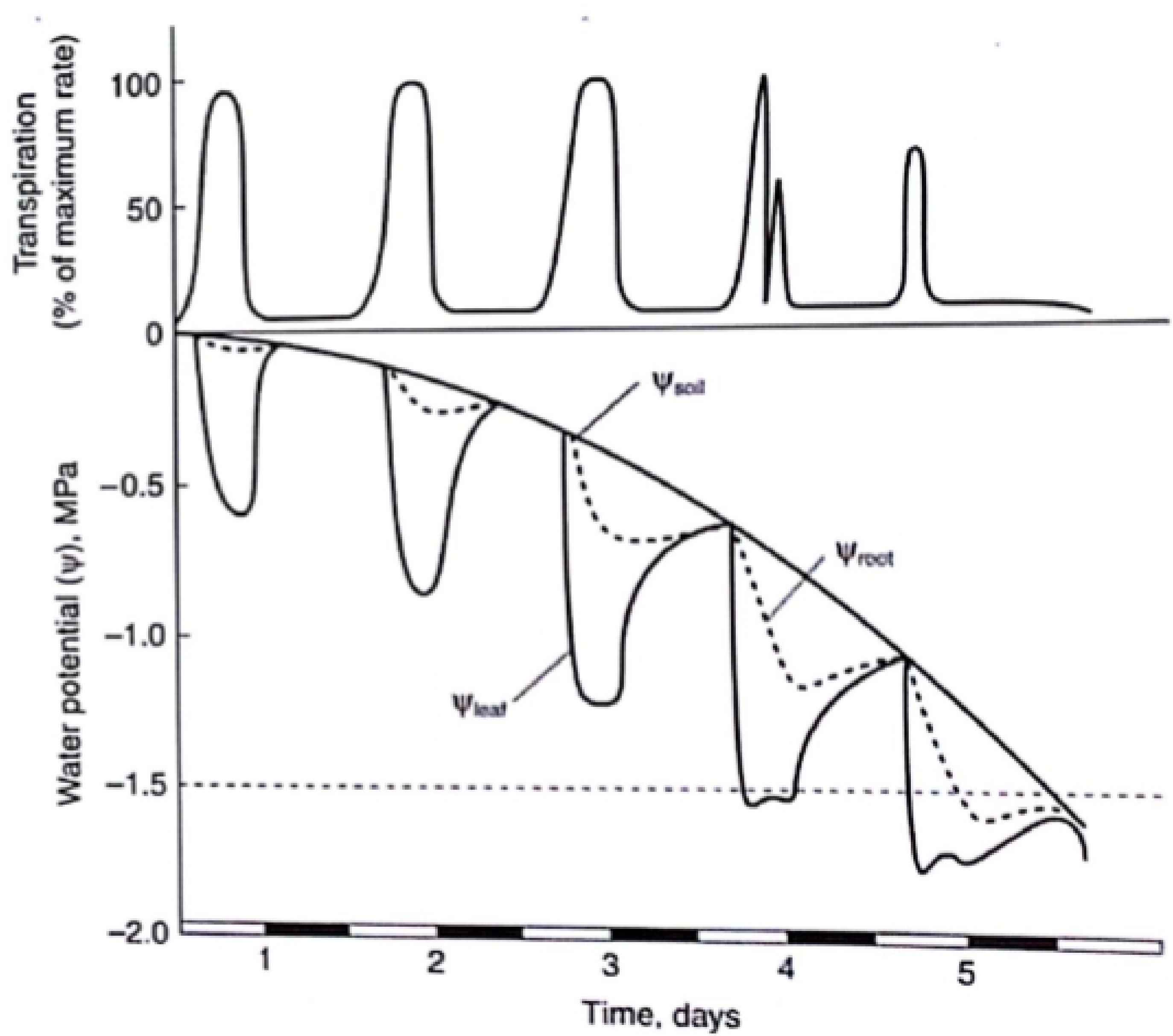
(a) Root number density and (b) root length density down the soil profile of the non-vigorous wheat cultivar Janz and the vigorous wheat breeding lines Vigour 18 and B18. Measurements were made at the beginning of stem elongation (Z31) on plants grown in specialised glass-windowed growth root boxes. The horizontal bars represent the l.s.d. (P = 0.05). (Source: Liao et al., 2006.)

Table 2 Distribution of Photosynthetically Fixed Carbon in the Shoot and Roots of the Vigorous Wheat Breeding Lines Vigour 18 and B18 and the Non-Vigorous Wheat Cultivar Janz at the Beginning of Stem Elongation (Z31)

Genotypes	Photosynthetically Fixed Carbon (g m^{-2})			Root/total Carbon (%)
	Shoot	Root	Total	
B18	17.8	8.01	25.8	31.0
Vigour 18	19.1	7.70	26.8	28.8
Janz	11.8	4.83	16.6	29.0
l.s.d. ($P = 0.05$)	2.1	0.02	3.1	3.1

Values are the absolute amounts of carbon derived from feeding the canopies with $^{13}CO_2$ for 24h at the end of stem elongation. Source: Palta (unpublished).

→ **Variation in A can also be caused by differences in the ability of roots to extract water per unit of soil.**



Capacity of osmotic adjustment:

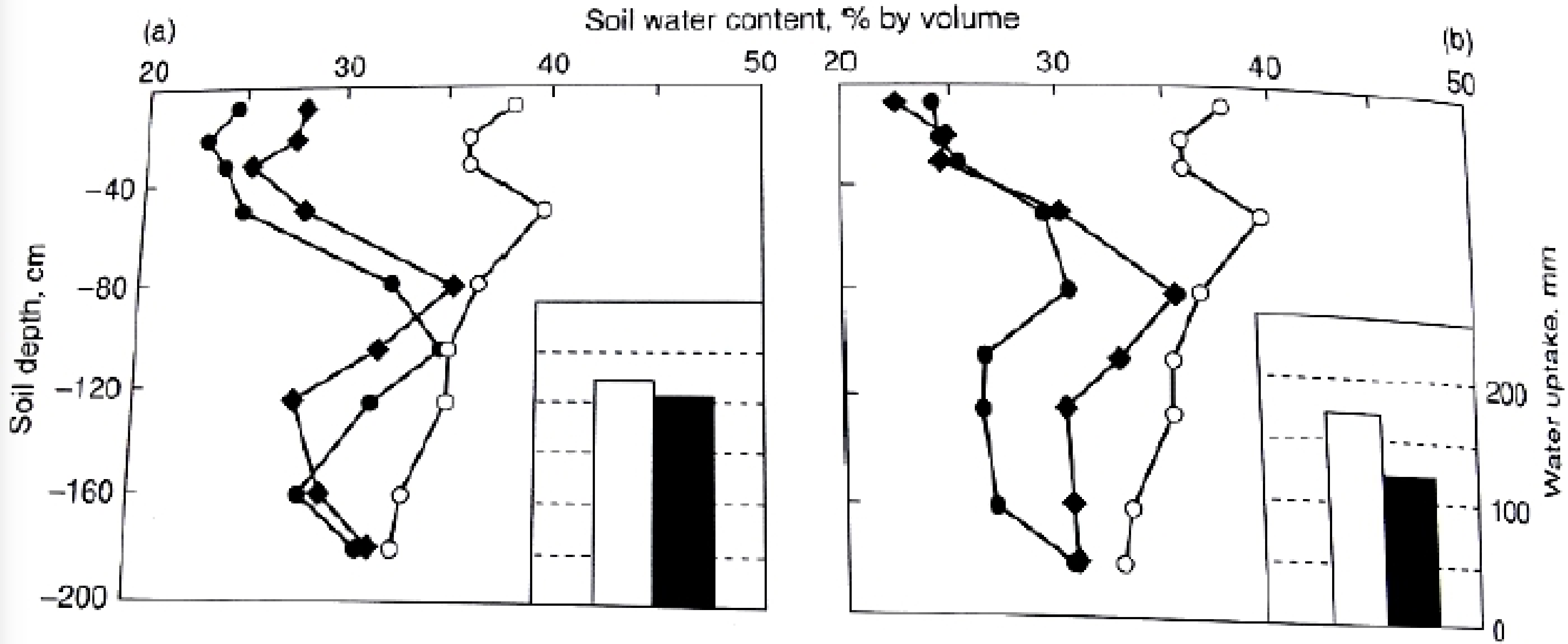
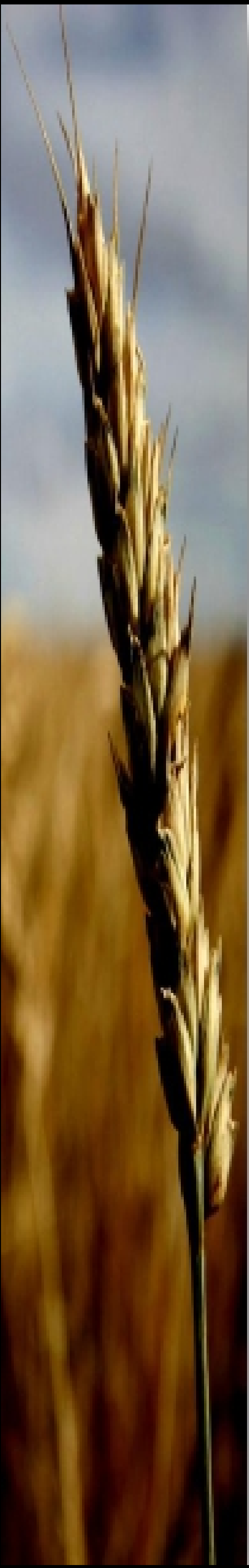
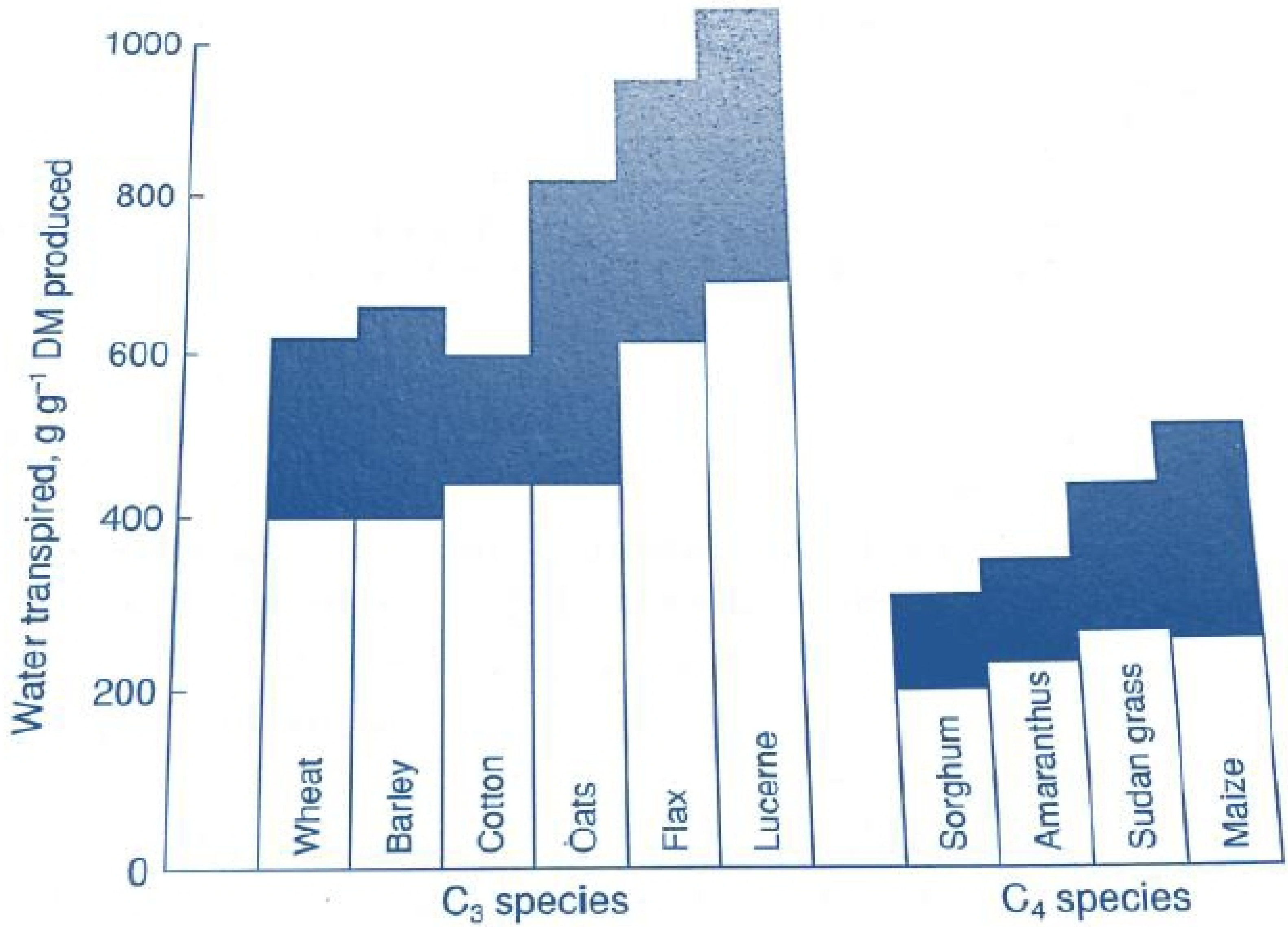


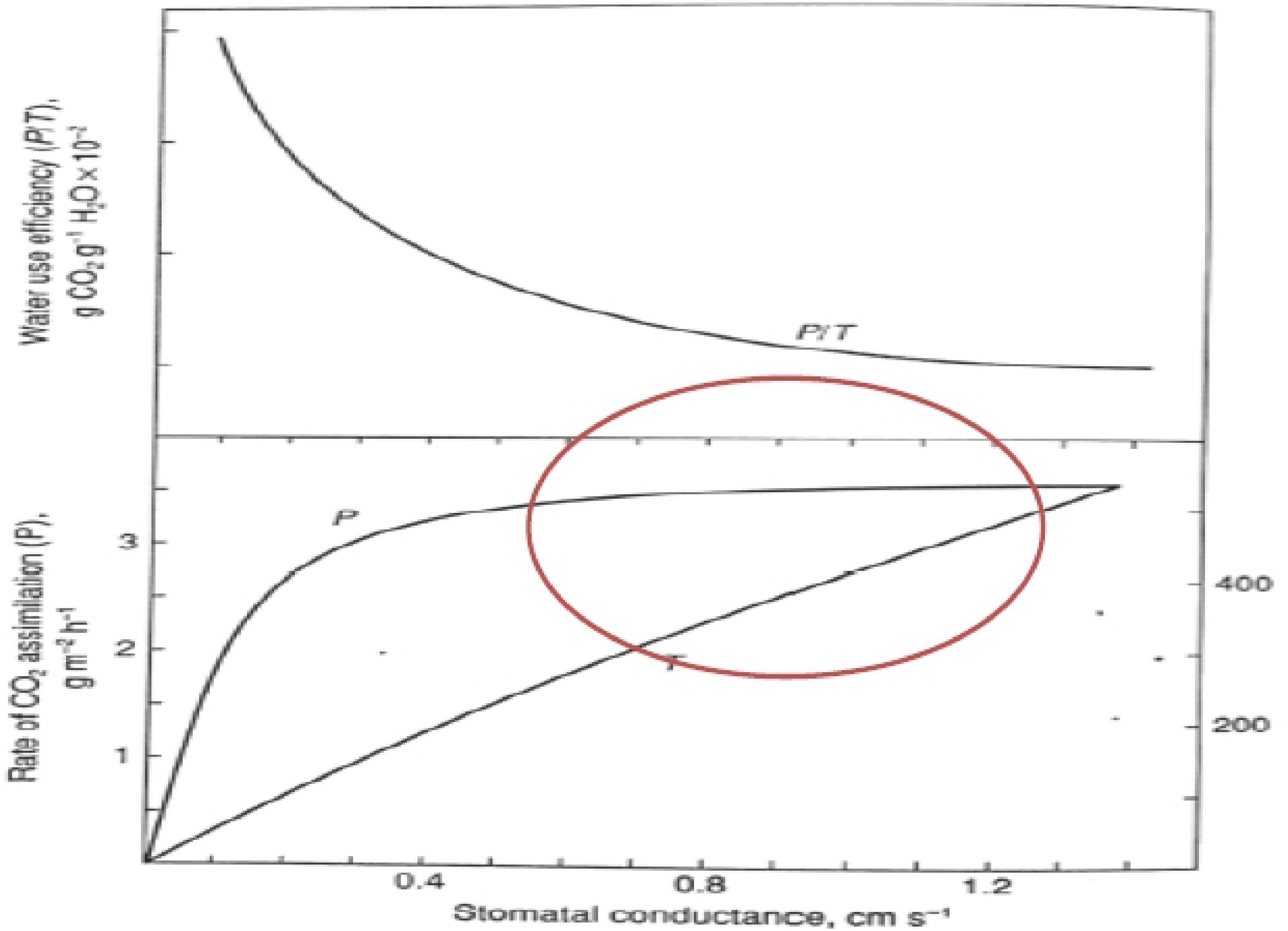
Fig: Soil water extraction at 30 DAS after anthesis by maize crops.
Closed circle LP125R, Closed diamond LMO017
A- Irrigation B – Drought condition
Open circles- Soil water content at the start of crop growth
Histograms show total water uptake by LP125R (white) and LMO17(black)

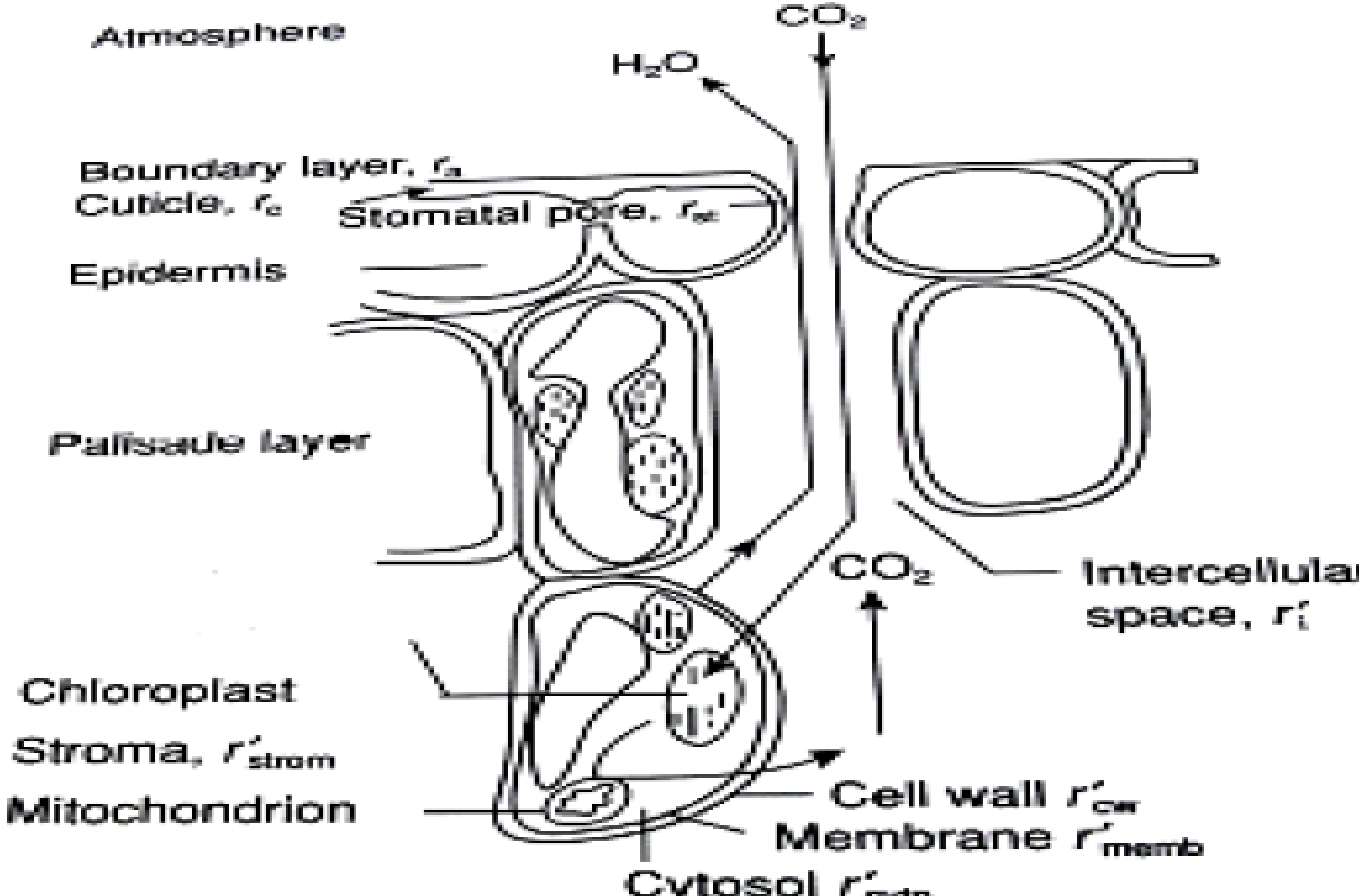


Water Use Efficiency :

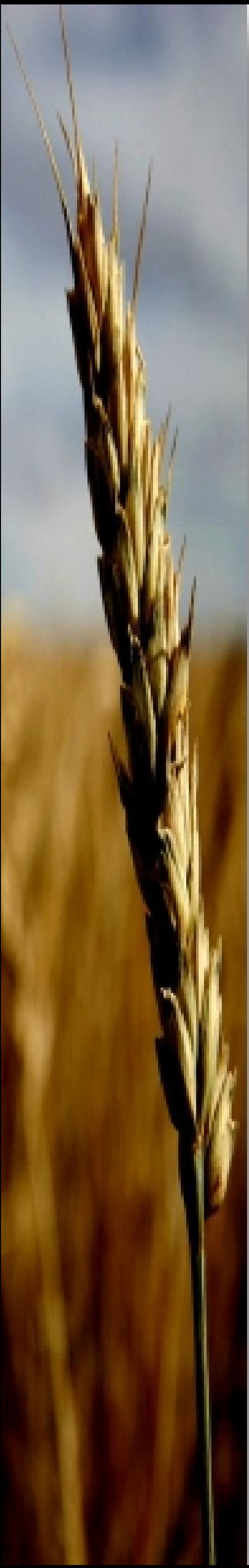


Model response of water loss, CO2 assimilation and water use efficiency to changes in the conductance of the stomata of a C_3 leaf.





Atmosphere
CO_2
H_2O
Boundary layer, r_a
Cuticle, r_c
Stomatal pore, r_{st}
Epidermis
Palisade layer
CO_2
Intercellular space, r_i
Chloroplast
Stroma, r'_{strom}
Mitochondrion
Cell wall r'_{cw}
Membrane r'_{memb}
Cytosol r'_{cyto}



Potential for improving ε_w within species ?

Variety	Year of introduction	Days to maturity	Yield (kg ha^{-1})		HI	Transpiration to maturity (mm)	Transpiration efficiency (kg biomass mm^{-1})
			Biomass	Grain			
Purple Straw	1860s	167	4824	1162	0.25	122	39.5
Nabawa	1915	159	4794	1342	0.28	129	37.2
Bencubbin	1929	159	5326	1619	0.30	119	44.7
Gamenya	1960	154	4781	1674	0.35	107	44.9
Tincurrin	1978	148	5264	1870	0.36	121	43.7
Miling	1979	159	5286	1826	0.34	122	43.5
Gutha	1982	148	5266	1888	0.36	114	46.1
Kulin	1986	148	5122	1892	0.37	119	43.2

HI, harvest index.

Fig. : Yield and water use of spring wheat varieties growing in Mediterranean climate in W. Australia

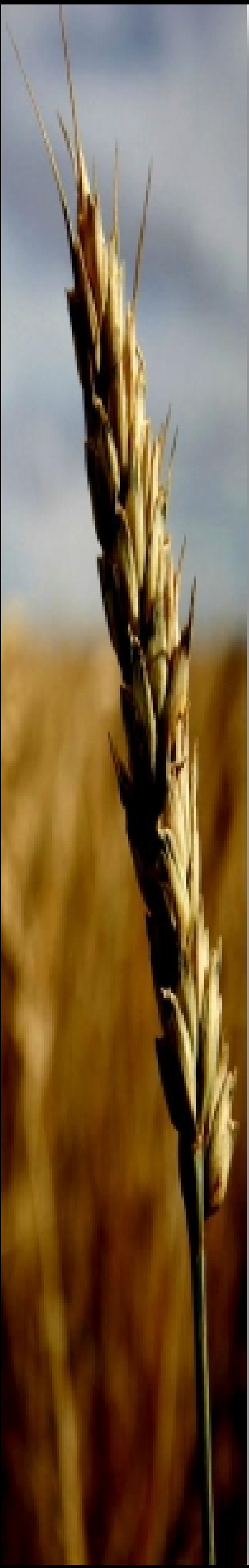
Additional issues:

→A and ε_W both are highly dependent on stomatal physiology.

→ Crop Phenology

→ Anthesis and silking interval of maize

→Breeding for intermittent drought is more challenging than for terminal drought.



Limitation by nitrogen supply :

$$Y = Q_N \times A \times \varepsilon_N \times H$$

Where

Q_N is the total quantity of nitrogen potentially available to the crop over the growing season,

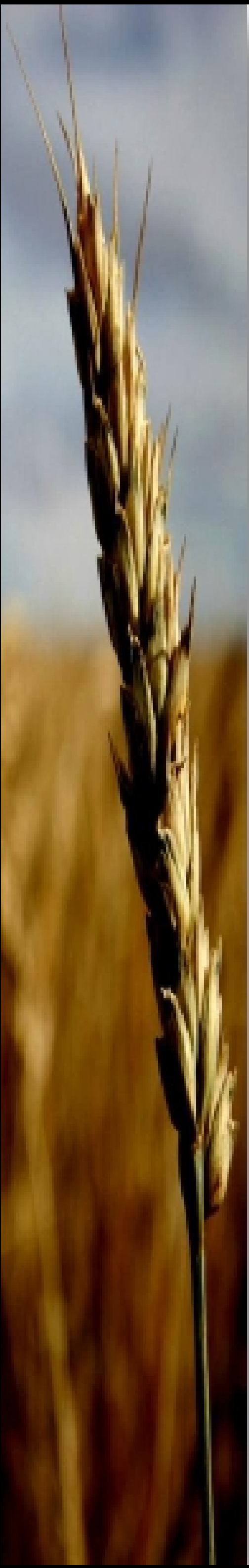
A is the fraction of Q_N that is taken up by the crop,

$Q_N A$ is the total quantity of nitrogen taken up the crop,

ε_N is the overall photosynthetic efficiency of the crop in terms of the total plan dry matter produced per unit of nitrogen taken up (NUE)

H is the harvest index

Important difference b/w water and nitrogen limitation ?



Q_N :

Determined solely by environmental and management factors.

Ex.:

- Nitrate and ammonium content at sowing
- Contribution from mineralisation
- Fertilizer application
- Soil temp, moisture, microbial activity before and during the growing seasons, crop history

→ A depends upon the distribution of roots.

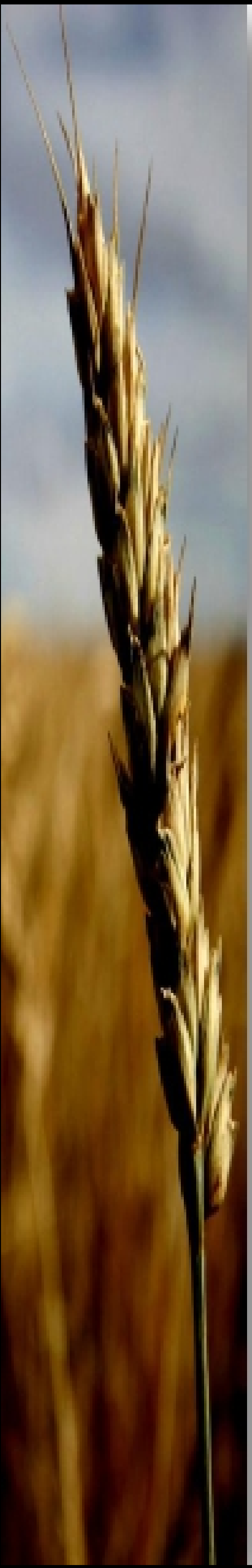
Product of mineralisation of SOM is ammonium ion

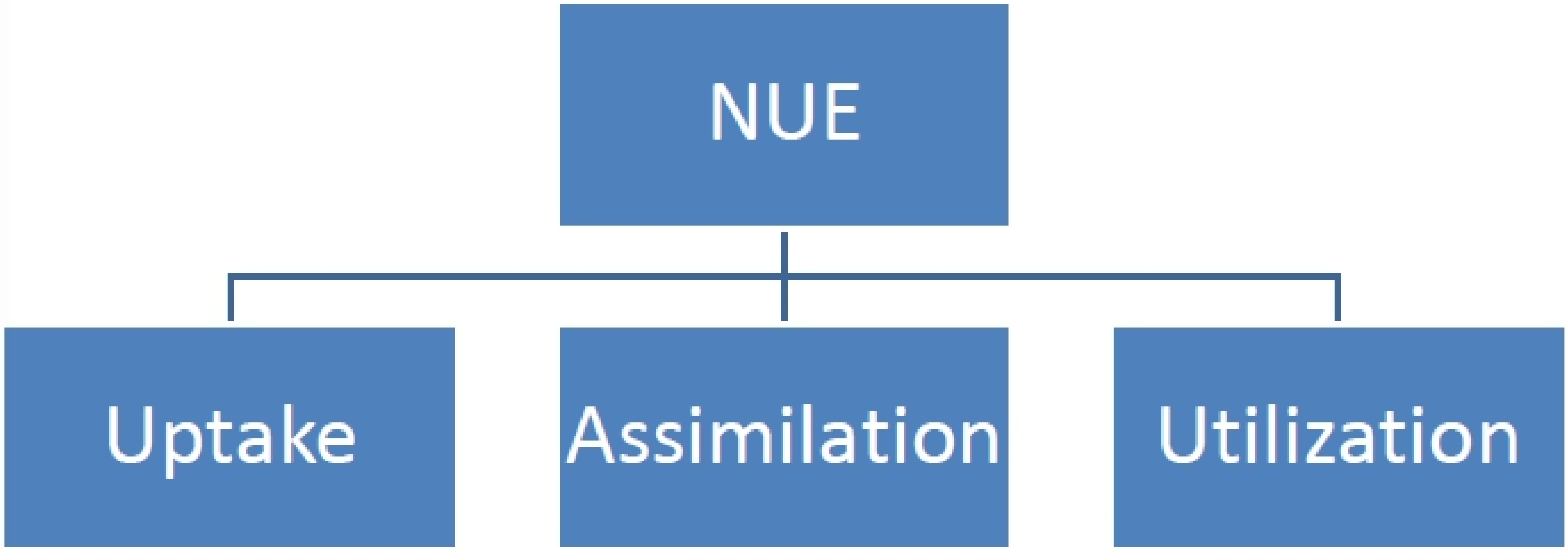
↓

Ammonium ion rapidly transformed into nitrate

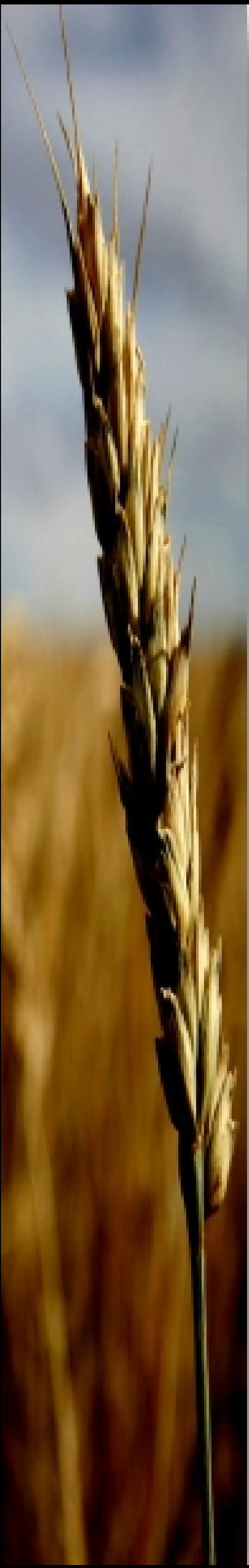
↓

Nitrate ions do not move more than a few mm

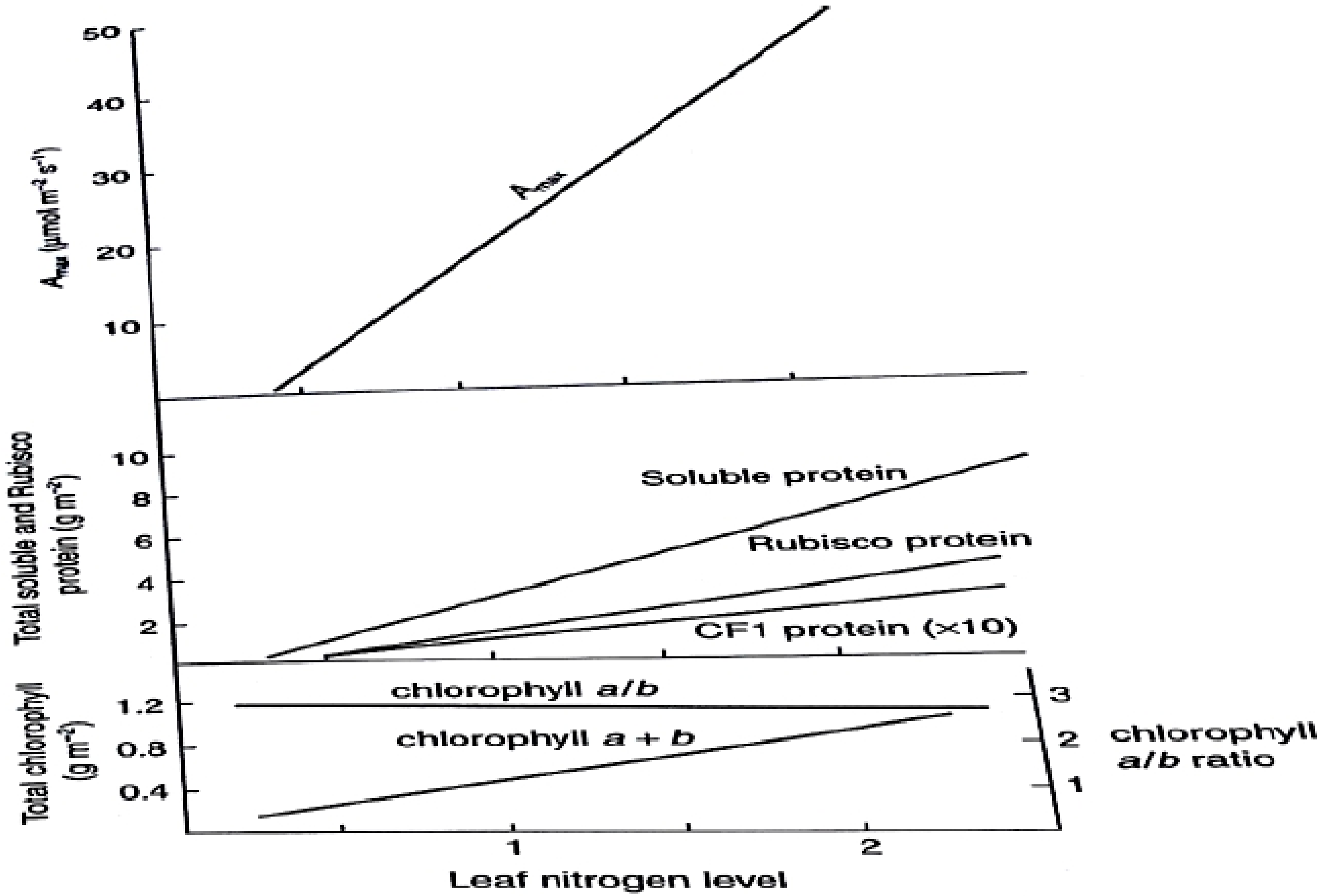


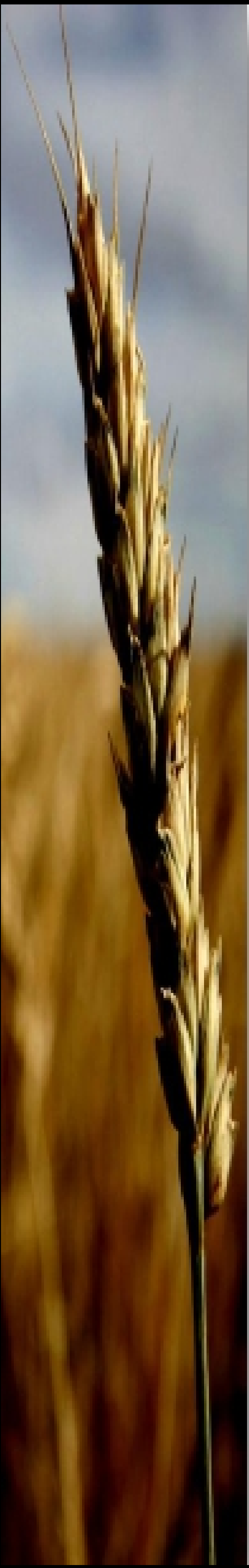


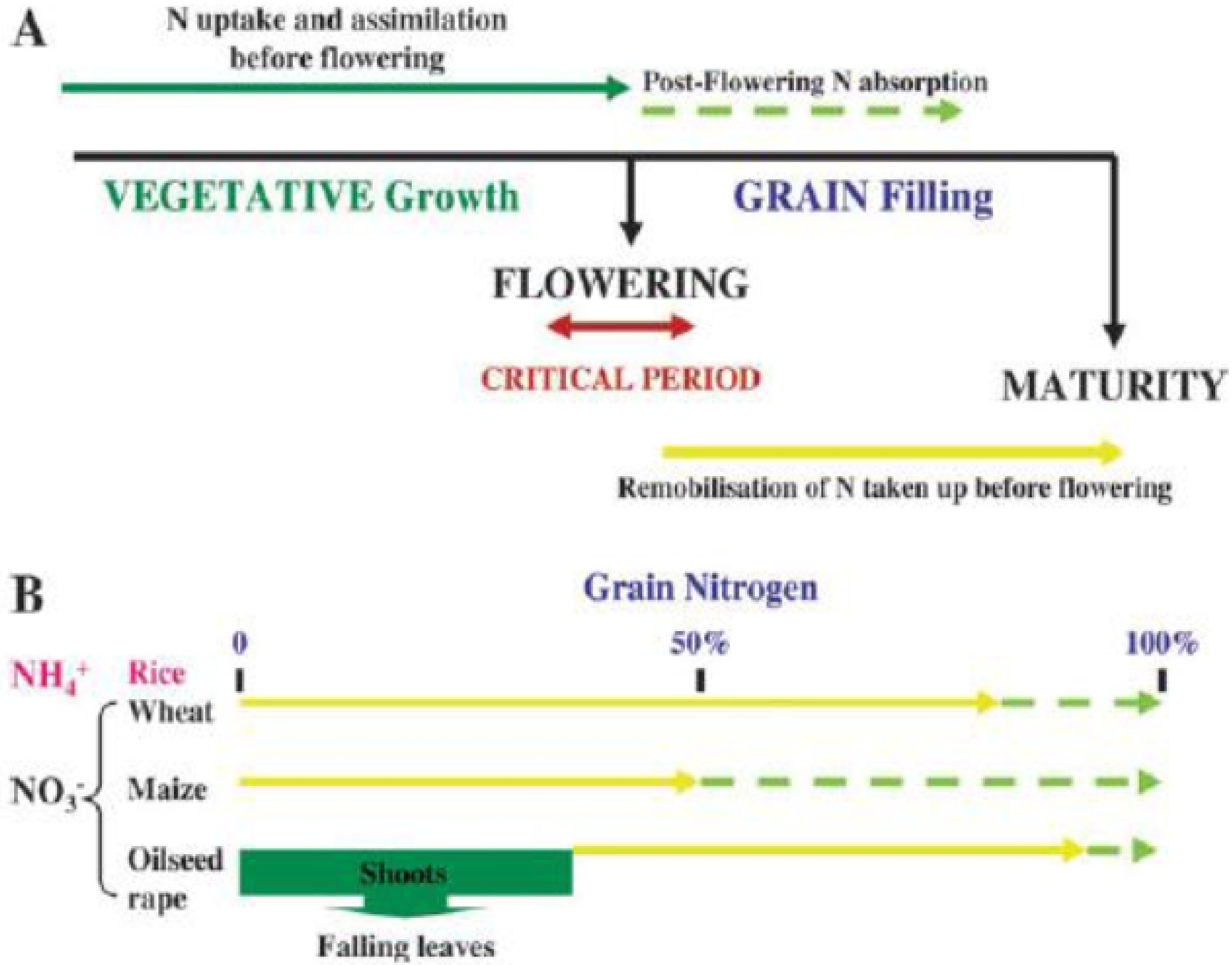
Research interpretation of NUE is complicated by spectrum of definitions.



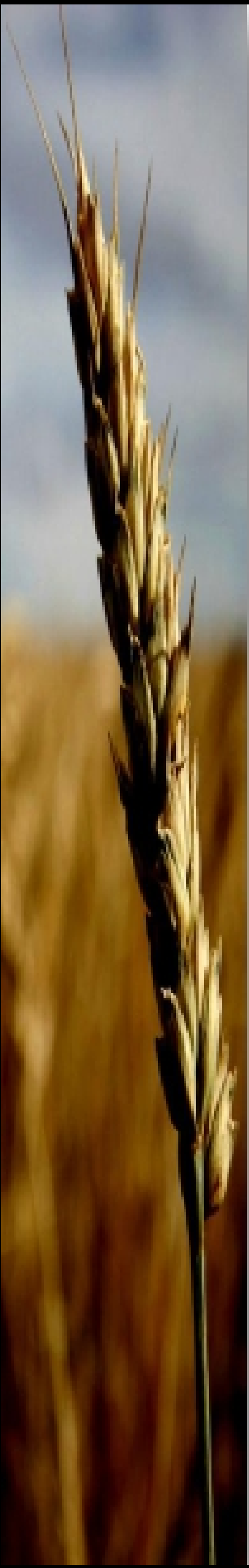
→ Leaf N content is related with Rubisco and photosynthesis







A
N uptake and assimilation before flowering
Post-Flowering N absorption
VEGETATIVE Growth
GRAIN Filling
FLOWERING
CRITICAL PERIOD
MATURITY
Remobilisation of N taken up before flowering
B
Grain Nitrogen
0
50%
100%
NH_4^+
Rice
Wheat
NO_3^-
Maize
Oilseed rape
Shoots
Falling leaves



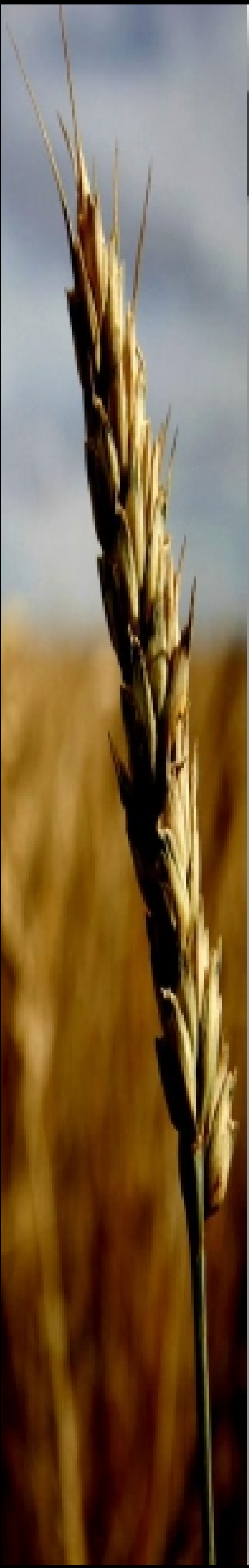
In summary, NUE depends upon:

→The proportion of N allocated to Rubisco

→The distribution of Rubisco within the canopy

→ the longevity of Rubisco/functional leaves

Only last one made a significant contribution to crop improvement through the introduction of stay green characters.



Achieving higher yield where N supply is limiting:

→N influences crop yield by affecting canopy expansion, longevity of organ and survival

→Biomass is dependent upon how much N absorbed, how much leaf area constructed per unit of N taken up.

→ Optimising yield at lower levels of fertility.

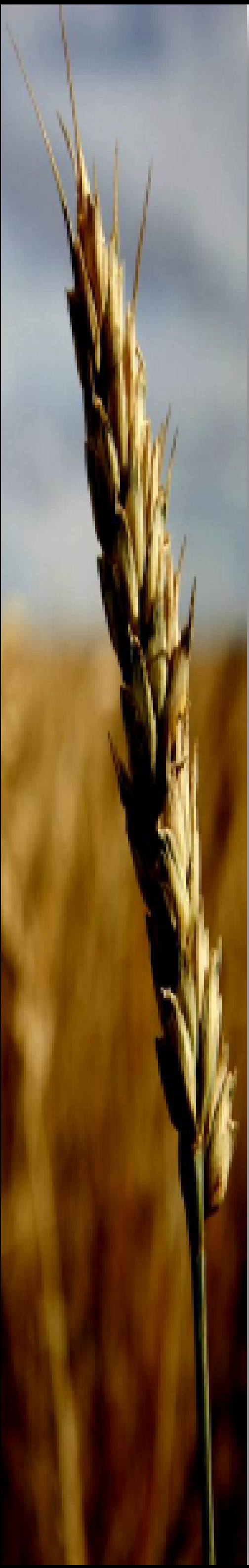
→ Yield stability (Degree of plasticity)

Case Study: Breeding for higher NUE in Mexican Maize

(Lafitte and Edmeades, 1994)

		C_0	C_1	C_2	C_3
Grain yield t ha^{-1}	Low N	2.62	2.65	2.80	2.81 *
	High N	5.76	5.86	5.12	6.13 ***
Biomass yield t ha^{-1}	Low N	7.33	7.23	7.80	7.56 *
	High N	12.78	13.09	13.70	13.52 **
Harvest index	Low N	0.36	0.37	0.36	0.37
	High N	0.45	0.45	0.45	0.45
Grains per ear	Low N	207	207	209	211 ns
	High N	349	358	368	372 **
Anthesis–silking interval, days	Low N	2.6	3.3	2.9	0.5
	High N	0.6	0.9	0.9	0.6
Total N at maturity g m^{-2}	Low N	5.3	5.1	5.4	5.3 ns
	High N	14.8	14.4	15.2	15.0 ns
Grain N %	Low N	1.14	1.13	1.10	1.10 ns
	High N	1.62	1.53	1.55	1.55 **
Grain N from mobilisation %	Low N	43	48	44	49 ns
	High N	42	48	45	49 ns

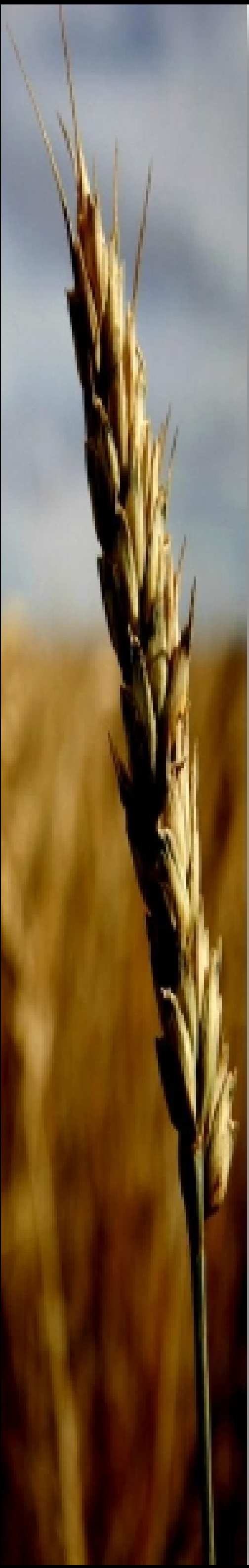
* No change in $Q_N A$ or H but in ε_N



Achieving higher yield : resource capture and assimilate partitioning

→ Crop biomass production depends upon resource capture rather than resource utilisation.

Intensive cultivation	:	Amount of PAR intercepted
Water limitation	:	Quantity of water transpired
Nitrogen limitation	:	Nitrogen uptake is important



Solar energy absorption

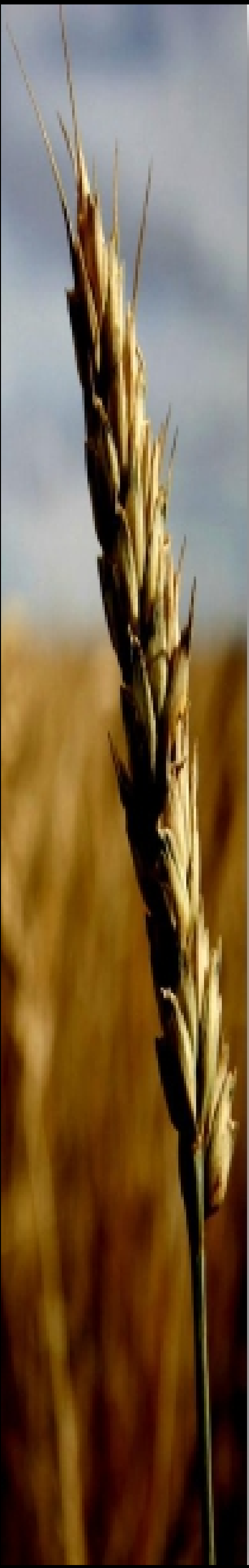
Uniform distribution

Utilization of solar energy

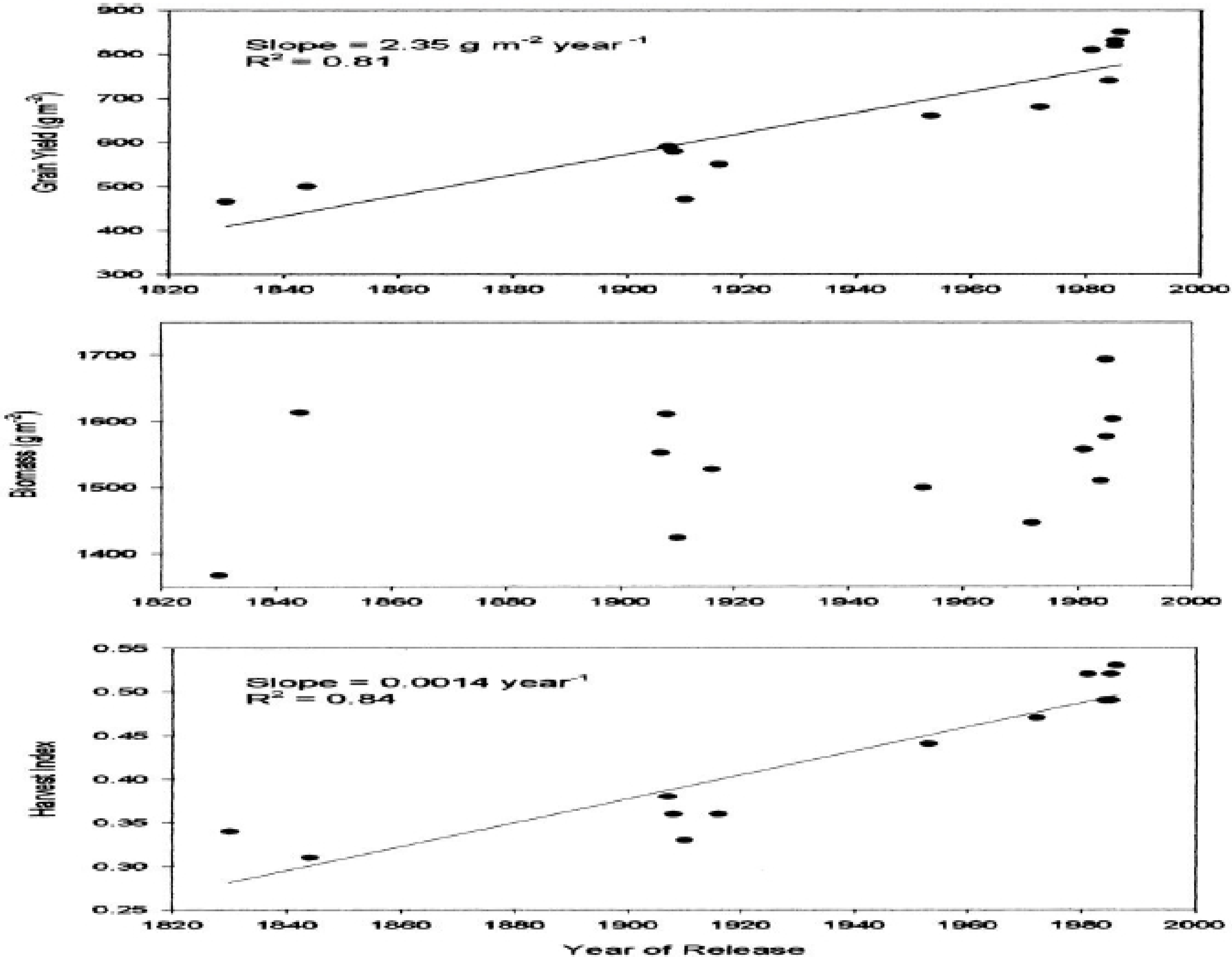
Photosynthesis i.e. CO_2 assimilation

Maximizing solar energy utilization

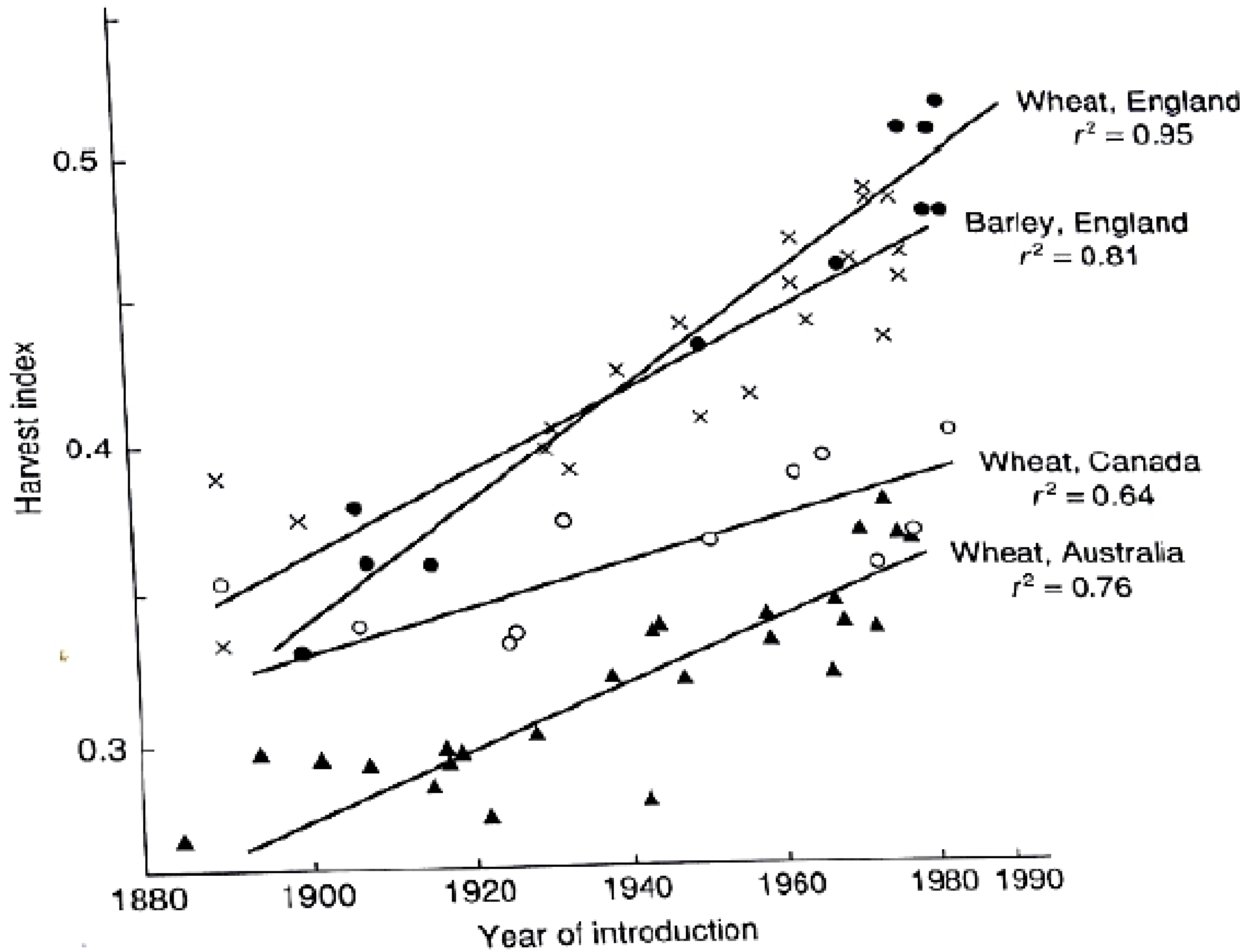
(Optimum N application, planting densities, sowing dates and plant protection)



The relation between grain yield, above-ground biomass, harvest index and year of release of wheat cultivars released in the UK since 1820.



Relationship between HI and date of introduction of wheat varieties in England, Canada and Australia and of barley in England.



* All varieties were grown under the same conditions.

Thank You