Production factors in the tropics[1]

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Summary

Annual crop plants accumulate the greater part of their ultimate dry weight in a relatively small part of their life period, *i.e.* when there is a closed green crop surface and when the plants are still in the vegetative stage.

Annual crop plants, of which the life period can be regulated by the photoperiod, show that optimal (fruit) yields can be obtained with life periods of 5 to 7 months, dependent on species, variety and environmental conditions.

Under comparable weather conditions the total radiation received by annual crops during their growing season may be 1,5 × as high in the temperate zone as in the tropics.
Soil and temperature conditions in the temperate zone compare favourably with those in the tropics. This applies in particular to arable farming where bare soil is exposed to direct sunlight several times per year.

The usually rapid depletion of the soil as a result of arable farming in the tropics often necessitates farming systems such as shifting cultivation, relatively long fallow periods or the annual planting with *paddy rice* (*i.e.* the temporary flooding of the soil).

Over long periods highest actual and potential yields in the tropics can be obtained with perennial crops such as *cacao* and *oilpalm*, *i.e.* under conditions which resemble to some extent those in forests, with soils permanently protected against insolation and erosion, and regularly supplied with organic matter.

1. Introduction

In this paper an attempt is made to compare some of the main agricultural production factors in the tropics with those in the temperate zone. It does not present an extensive analysis nor goes into much detail. It deals mainly with some items which hitherto have often been overlooked, and, in accordance with the principal subject of this course, most attention is paid to the influence of light on crop production.

2. Developmental stages and photosynthesis

2.1. Light

The effects of light on a green plant are manifold, but the following classification can be made:

[1] Lecture held at the course "Fundamentals of dry-matter production and distribution" organized by the Royal Netherlands Society for Agricultural Sciences, Wageningen, 9th January, 1962.

Light

- Photo-energy processes
  - *photosynthesis*
- Photo-stimulus processes
  - Movement processes
    - *nastic movements*
    - *movements of orientation*
    - *tropisms*
    - *tactic movements*
  - Formative processes
    - *stem elongation*
    - *leaf expansion*
    - *pigment formation*
    - *pubescence*
    - *flowering in photoperiodically sensitive plants*
    - *formation of protochlorophyll*
    - *anthocyanin formation*
    - *etc.*

Generally speaking it can be said that for optimal photosynthesis a high light intensity is required, whereas in many cases photo-stimulus processes can be accomplished with very low light intensities (cf. WASSINK, 1954).
Formative processes are often determined by the relative length of light and dark periods to which the plants are exposed, a phenomenon which is commonly designated by the term photoperiodism.

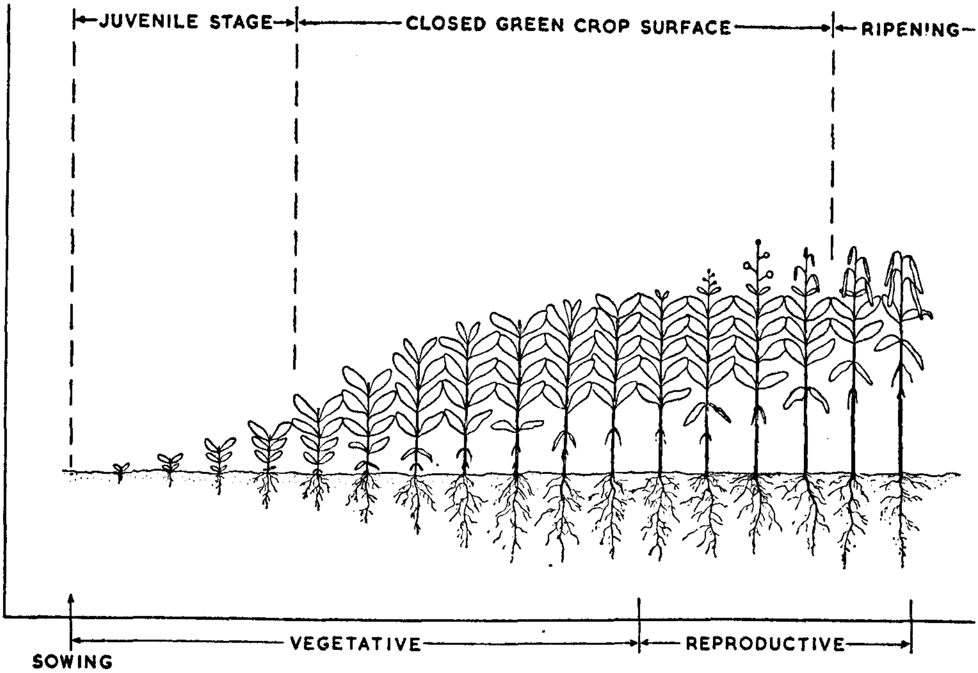
2.2. Developmental stages

Photoperiodism as such will not be discussed here since it is the subject of WELLENSIEK's paper in this symposium. However, one aspect of photoperiodism will be taken into consideration, *viz.* the control of the vegetative period of some tropical crop plants with the help of weak supplementary irradiation. With this method it is possible to vary the vegetative period of a variety and, at the same time, to maintain the same daily radiation in all treatments. The implications of this possibility in respect of photosynthetic output can probably be demonstrated best with the aid of a simple schematic figure in which the various development stages of an (imaginary) annual crop plant with a terminal inflorescence are presented.
With regard to FIG. 1 the following remarks can be made. From germination onwards a juvenile stage can be distinguished in which the plants do not yet cover the soil. Thereafter one can speak of a closed green crop surface, and finally, a stage in which the leaves die off during the ripening of the fruits.

2.3. Net assimilation

It may be assumed that the net assimilation rate is highest in the juvenile stage before the planting becomes closed. The data presented by ALBERDA in this symposium, concerning the dry-weight measurements of periodic harvesting of grass after cutting, point at the same phenomenon. In addition, this has been clearly demonstrated in an experiment with the periodic harvesting of *rice* plants, in which total leaf surface and dry-weight increase were measured in plants of different ages and with different spacings (BEST, 1956).
When the net assimilation per unit of soil surface is considered, a maximum value is reached after the planting has become closed and all direct sunlight is intercepted

FIG. 1. Schematic presentation of the developmental stages of an (imaginary) annual crop plant with a terminal inflorescence



by the leaves. If we look at FIG. 1, it appears that in this period part of the reproductive phase is also included. However, in the reproductive phase the respiration can reach a high value and consequently the net assimilation will be reduced. A striking increase in respiration during flowering has been established in several experiments, whereas GAASTRA (personal communication) found that the dissimilation of growing fruits can be very high. Since the net assimilation is determined by the gross assimilation minus the respiration of the whole plant, it will be clear that in general the photosynthetic output will be highest when there is a closed green crop surface and when the plants are still in the vegetative stage. GAASTRA (1958) actually established that during this period, comprising about 40 % of the total life cycle of an annual plant, 80 % of the ultimate dry weight of the plant was accumulated.

3. The life period optimal for fruit yield

In theory one would expect that the longer the stage of maximum net assimilation per unit of soil surface lasts, the higher the total dry-matter production will be, and the more fruits or other parts the plants will be able to produce. Some data support this view. For example, the best late maturing varieties of a crop normally outyield the best early maturing varieties.

In this respect the tropics might seem to have an advantage over the temperate zone, for in the tropics the duration of the vegetation period is not limited by temperature and varieties with very long vegetative periods could be used which would yield very well. This is incorrect, however. There are many other factors which come into play, of which the larger part may probably be taken together under the heading senility of the plant. In the following two examples (fruit) yield was studied as a function of the vegetation period. *Rice*, the most important cereal in the tropics, and *soybean*, one of the most important tropical pulses, have been investigated. In both studies a variety sensitive to the photoperiod was used and variations in the duration of the vegetation period were obtained with the help of weak supplementary irradiation, maintaining at the same time a similar amount of daylight per 24 h in all treatments.

In FIGS. 2 and 3 the yield of grain (beans) and the total dry matter produced by the rice and soybean varieties have been plotted on the ordinate against the duration of the vegetation period on the abscissa. The graphs show clearly that for seed production there are certain optimum vegetation periods which are not correlated with the maximum dry-matter production. It may be mentioned here that the shape of the curves can be influenced by the soil fertility and especially by increasing the supply of nitrogen to the plant.

The experimental results obtained so far indicate that the optimum life period for the yield of cereals and pulses never exceeds a period of about seven months, which is approximately in accordance with the growing season in the temperate zone.

In the tropics it has actually been established that yield is not only reduced by planting in a season which causes the plants to flower very early, but also by planting in a season which causes very late flowering. CHANDRARATNA (1948) reported, for instance, that highly sensitive *rice* varieties in Ceylon with a "normal" vegeta-

FIG. 2. Effect of duration of the vegetative period on grain and straw yield in rice. Duration of vegetative periods regulated by photoperiodic treatments, the daily amount of photosynthetic light being similar in all treatments

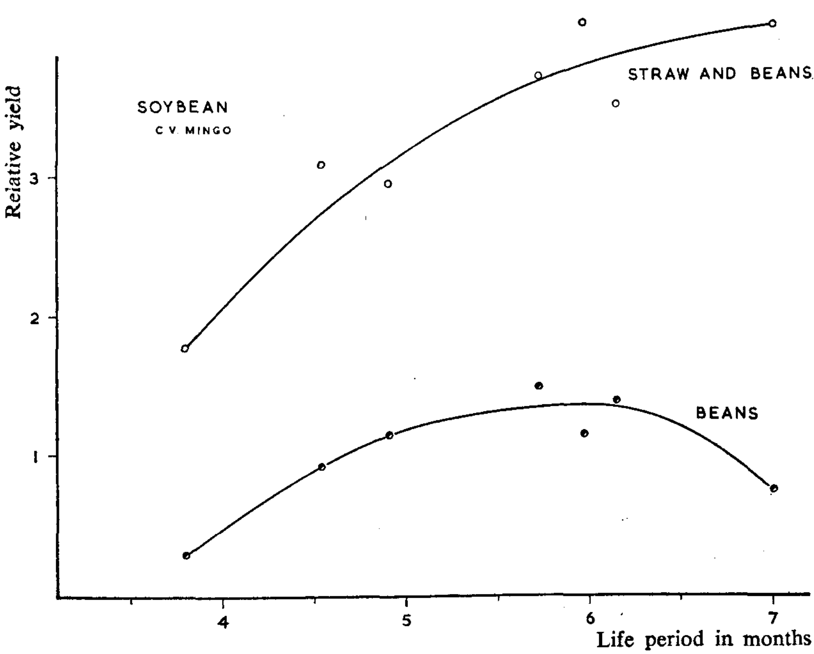
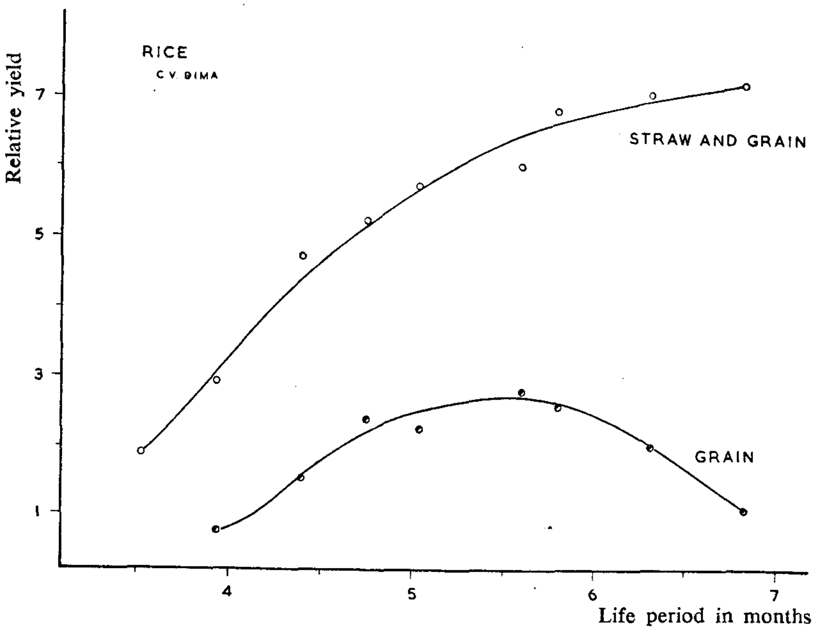


FIG. 3. Effect of duration of the vegetative period on yield of beans and straw in soybeans. Duration of vegetative periods regulated by photoperiodic treatments, the daily amount of photosynthetic light being similar in all treatments



tion period of 5 to 6 months, may extend their life period to more than a year when planted in the wrong season, causing an almost complete loss of yield. Similar considerations apply to some varieties of *sesame* and *cotton,* and probably also to other crop plants of which highly sensitive varieties are grown.

4. Productions in the tropics and the temperate zone

With a comparable duration of the vegetative period the tropics seem to be at a disadvantage in respect of the potential photosynthesis since the number of daylight hours per 24 h is markedly smaller than in the temperate zone in summer. In fact distribution of days with favourable light conditions largely determines the average daily radiation during much of the summer period. However, in the tropics sufficient water to grow crops is often available only in the wet monsoon, a season with a low daily radiation in many regions of the wet tropics. Under such conditions a comparison of the average daily radiation in the tropics and the temperate zone shows that the temperate zone is at an advantage, while the distribution of the light per 24 h is also frequently better in the temperate zone than in the tropics. Calculated according to DE WIT's method, the ratio of tropical to temperate average daily radiation is found to be approximately 1 : 1,5. This ratio applies also when a sunny growth season in the tropics is compared with, for instance, the sunny summer conditions in the Po valley (Italy) or Suecca (Spain).

From these considerations it can be said that in respect of the light factor the potential production of annual crop plants is often about one and a half times as high in the temperate zone as in the tropics. The actual yields vary much more, however. For example, *rice* is one of the few crops which are grown in both equatorial and temperate zones. The average yields of this crop vary in the tropics round the equator from 1,1 to 1,8 tons/ha, whereas in Spain and Italy they are 4 to 5 times as high. Naturally there are, apart from light, many different factors which are responsible for this phenomenon, but results from experimental stations in the equatorial tropics show yield maxima in the order of 5 tons/ha against 12,5 tons/ha in the Bologna, Italy. Varietal differences, etc. contribute to such differences, but there also other factors which come into play. For example: long days cause a relatively more vigorous root development than short days. Plants with an extensive root system normally have a better water supply than plants with a comparatively small root system. This may affect transport of carbohydrates and mineral nutrients in the plant, it may affect photosynthesis via the diffusion resistanse of the CO_2-transport, etc.

Another important factor is the influence of temperature on the distribution of dry matter in the plant. For some tropical crop plants the equable high temperatures in many tropical regions are in fact unfavourable. With *rice,* for instance, the total grain weight is higher when the grain develops and ripens under conditions of gradually declining temperatures, such as occurs in autumn. This can be explained by the transport of carbohydrates to the grains. With high temperatures this transport is rapid, but lasts for a short period only. Senescence of leaves sets in early and at very high temperatures renewed tillering occurs and depletes the plants of much carbohydrate and mineral nutrients. With low temperatures the transport of carbohydrates and minerals towards the grain is slow but lasts long. Senescence of leaves occurs late and the ripening period of the grains is prolonged, which results in a higher grain weight than under high temperature conditions.

Finally the soil must be considered. Soil conditions in the temperate zone are, from an agricultural point of view, often much more favourable than in the tropics. Frost during the fallow period in winter improves the structure of the soil, whereas the low winter temperatures conserve soil organic matter. In the tropics fallow periods of about half a year are also often necessary, mostly as a result of seasonal drought conditions, but the destruction of organic matter is very rapid when the soil is exposed to direct sunlight. As a result, a very low content of organic matter, nitrogen, etc. is common in most tropical soils used for the cultivation of annual crops. To maintain a reasonable level of yield this necessitates in most cases either the use of one or another system of shifting cultivation, long fallow periods or, with a dense rural population, the annual planting of paddy rice and the concomitant flooding of the soil with irrigation water during part of the year.

5. Yields of perennials in the tropics

In the preceding section a fairly pessimistic view was presented of the tropics: not only are the actual productions of a number of annual crop plants lower than in the temperate zone, but potential productions show the same trend. However, the tropics also have more favourable aspects. When sufficient water is available, crops can be grown all the year round. In this respect favourable results are not so much to be expected from a frequent succession of crops, whereby a rapid depletion of the soil is likely, as from crops with a long vegetation period. A very good example is *sugar cane*, a crop with a growth period of usually 12 to 18 months, resulting in a relatively long period with a closed green crop surface. Production of fresh weights of leaves and stems can indeed be impressive, *viz.* in favourable cases 260 tons/ha in 12 months, against 120 tons/ha for sugar beets in 7 months. With sugar beet a closed green crop surface exists for 4½ months with sugar cane for 9 months. Sugar production averages 12 tons/ha for beets compared with 21 tons/ha for cane with these top yields.

Another example of crop plants which can intercept the sunlight to a maximum extent over long periods are the perennials such as *cacao* and *oilpalm*. Published figures of the dry-matter increase per ha are unfortunately not available, but yield figures of oil palm may be as high as 4 tons of oil/ha from 12 year old trees. This is a production level which cannot be reached with any system of annual oil crops over long periods.

6. Discussion

In early years little or no attention was paid to the light as a specific production factor in tropical agriculture. In literature published before the second world war the suggestion was, for instance, only rarely made that the differences in daily radiation at different latitudes could have an influence on the yield of crop plants.

In the post-war period an ever increasing interest in the light factor has become apparent. This broad interest has, in addition to advantages, also some disadvantages. For in some cases the importance of light has been one-sidedly stressed, thereby overlooking the relative importance of this factor with regard to other production factors. The increased interest in light has also lead, however, to some fundamental research on the role of light in tropical crop production. With a number of perennial crops, such as *coffee, cacao,* and *tea* it appeared, for instance, that, although the planting of these crops under shade trees is common, the abscence of shade may increase the production provided water supply and mineral nutrition are optimal. In particular these last points should be kept in mind. In many tropical regions an optimal water supply may be difficult to accomplish. In addition, it should be kept in mind that the shade used in the cultivation of the above mentioned crops is often of less importance for the crop plants than for the protection of the soil against insolation. In practice the last factor may be of more importance than the first one.

REFERENCES

BEST, R. 1956 Unpublished report.

CHANDRARATNA, M. F. 1948 The effect of day length on heading time in rice. *Trop. Agric. Ceylon. 104,* 130—140.

GAASTRA, P. 1958 Light energy conversion in field crops in comparison with the photosynthetic efficiency under laboratory conditions. *Meded. Landb.hogesch. Wageningen. 58* (4) 1—12.

WASSINK, E. C. 1954 Remarks on energy relations in photobiological processes. *Proc. 1st Intern. Photobiol. Congr. Amsterdam.* Biol. Sect. V, 307—322.

WIT, C. T. DE 1958 Transpiration and Crop Yields. *Versl. Landbouwk. Onderz.* No. 64.6, 88 pp.