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RESEARCH METHODOLOGY TO QUANTIFY AND UNDERSTAND THE MODIFICATION OF THE ENERGY FLUX AT SOIL/ATMOSPHERE INTERFACES

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INTRODUCTION

Before dealing with this colloquium's subject in soil surface physics, the context in which energy flux modifications will be treated is reviewed.Already for several decades, but recently more severely, we are urged as agricultural physicists to increasingly apply our skills to obtain operational knowledge for solving actual third world agricultural problems. And more and more are we requested to do this for modes of agricultural production where traditional techniques are suspected to be (on the brink of) loosing the battle with external pressures. In low-input agriculture this may be population pressure but it may also be due to other pressing conditions which are consequences of deteriorating national economies and/or devastating national policies with respect to agricultural production (Weiss and Stigter, 1985).

EXTERNAL CRITERIA

Whatever the reasons are, subsistence and small cash-crop farmers should be increasingly our target groups, if we want to contribute to agricultural development. This is particularly true in Africa but still also applies to not negligible parts of Asian and Latin-American agriculture. This is not the place to tackle actual problems of agricultural extension services or of the organization of a dialogue between participating farmers and field research scientists. We should be aware that these problems exist and have to be taken into account (Stigter and Weiss, 1985). But we have to mention here the experience of the last 10 to 20 years that proposed improvements which appeal to small farmers must meet the following conditions:

1.low economical and/or subsistence security risk;
2.certain familiarities with respect to known techniques;
3.not violating empirically known and proven ecological constraints;
4.not violating labour requirement and availability aspects.

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One may call the taking into account of such problems and factors the application of <u>external</u> criteria for meaningful research with respect to low-input agriculture. By meeting these external criteria better we will have more chances to meet the needs of our target groups in our research approach.

INTERNAL CRITERIA

Fig.1 (Stigter,1982) deals with the research methodology in environmental physics in a way from which we can derive some <u>internal</u> criteria for tackling agricultural physics problems.The most important ones of these are high quality implementation of the following:

1.guesses at basic processes involved;
2.choice and effectuation of observations and accurate measurements;
3.use of pertinent statistics and parameter identification;
4.interdisciplinary approach, including biophysics;
5.use of selected applied mathematics;
6.choice of operational quantitative relations;
7.synthesis of derived cause and effect relationships in understanding the actual processes determined to be involved in the problems under consideration;
8.derivation of actual manipulations/modifications needed to solve (part of) the problems under the conditions set by the external criteria;
9.writing, with extension officers and participating farmers, of draft operational advisories on such management required;
10.validation of advisories with extension people and farmers.

If these internal criteria are met, a well working positive feed-back system as shown in fig.2 (Stigter,1982) may be expected to exist, where we distinguish agricultural physics research related to education, infrastructure, and, indirectly and directly, production in agriculture.

ENERGY FLUXES, BALANCES AND CONVERSIONS

One may distinguish ten basic energy fluxes in ecosystems:

1.absorbed solar radiation;
2.absorbed far infra red thermal (long wave) radiation;
3.emitted far infra red thermal (long wave) radiation;
4.sensible heat in forced and free convection;
5.sensible heat in conduction;

6.latent heat in evaporation, condensation, freezing and melting;
7.conversions implied in photosynthesis and respiration;
8.conversions implied in decomposition and burning;
9.conversions implied in wind energy and in movements of its constituents;
10.conversions implied in water energy (rain,hail,run-off,flood).

In a long-term thermal energy balance of a not-burning ecosystem volume or at a not-burning ecosystem interface, normally only the first six fluxes play quantitatively a role of importance. From this thermal point of view the other four are mainly of interest, quantitatively, under some short term or other special conditions. Their main significance lies in the biological consequences of the implied conversions and their control function over other energy fluxes (comp. also Miller,1981).An energy flux description in a bare surface heat balance, taken from Stigter (1984), is given in Appendix 1 for completeness.

From the explanation in this Appendix it shows that growing plants and other organisms within, at and above the soil surface passively modify themselves their microclimates or ecoclimates near the soil/atmosphere interface, by modifying existing and creating new energy exchanges and balances.It is also clear (comp. Stigter,1984) that man is doing that actively, whether deliberately or not, as soon as he is practising agriculture. And the same is true in any other outdoor activity such as building activities, land reclamation, deforestation etc. If such activities take place on a large scale not only the microclimate changes but also the mesoclimate and sometimes even the macroclimate.

If the agriculturist delibarately modifies the microclimatological conditions close to his soil, crops or animals we talk about <u>management</u>, in the sense of judicious use of obtained skills on a large scale and frequently, and <u>manipulation</u>, in the same sense but on a smaller scale and for a shorter period.What is true for thermal energy cum radiation exchanges and balances (Stigter,1985) is also true for the listed energy conversions. By management and manipulation, benefits of such conversions are optimized and risks are minimized.

<u>EXAMPLES OF ENERGY FLUX MODIFICATIONS IN TRADITIONAL FARMING</u>

Traditional farmers have a location-specific knowledge of their soil plots.They are very much aware of their heterogeneities and apply such knowledge and skills in their husbandry decisions (Allan,1965). In such low-input agriculture, these small farmers have developed empirically many ways in which they modify energy fluxes for optimizing or protecting their soils and plants, as their means of production, and their yields. Evidence has been collected which points into the direction of even an indigenous empirical awareness of the existence of related terms of energy balances(Stigter,1985). Given the external criteria as discussed earlier in this paper,proposals for improvements will only make sense after a thorough quantification and understanding of such traditional modification techniques.

For illustration of the potential of this approach we use a catalogization of examples of such traditional techniques as earlier developed by the author (Stigter, 1983;1985)and reprinted in Appendix 2. The first 15 classes in that catalogization deal with manipulation of the first three basic energy fluxes. The next 16 classes with the next three energy fluxes. Manipulation of photosynthesis and respiration is related to radiation manipulation of the first group of examples and plant respiration manipulation mainly to drying (senescence) in the field of growth(D.1.1;J.1.1), as examples of CO_2 manipulation in the open are not known. Respiration of products such as fruits and grain, which is a self accelerating process, is manipulated in drying and storage practices including protection for ripening purposes. It should be noted in this respect that underground storage forms an up till recently scientifically neglected traditionally managed soil/inner atmosphere interface (Stigter,1985). Where decomposition is slow, its place in maintaining equilibrium in steady state ecosystems may be taken by wildfire to give way to new solar energy fixing into biological energy (biomass), but fire has also long been a major tool in human systems. Early humans in East Africa were among the first to appropriate this energy conversion mechanism in a diversity of microenvironments at or near the soil surface (Miller,1981). Finally the 12 classes of category III in Appendix 2 deal with the last two energy fluxes. In the discussion below examples have been selected that pertain to soil surface energy fluxes.

Modification of wind, rain (drops and water) and hail kinetic energy

Protecting the soil with dead or living vegetation from mechanical impact is well known to be the most effective modification of such energy conversion impacts. Accidentally observed soil compaction potential of Kenyan hail storms (Stigter et al., 1984) appears to confirm this in observed differences between bare and covered soil. Maximum vertical kinetic energy is of the order of 5 Wm^{-2} (cited by Miller, 1981). Rain drop and water erosion by splash and overland run off respectively are functions of rainfall acceptance, aggregate stability and soil erodibility, detachability and transportability (Lal, 1979). In both cases potential energy conversion into kinetic energy is not at a high rate as such but in a form capable of doing mechanical work (Miller, 1981), leading to damaging action. Prevention of such conversions, having them taking place in steps, each reducin the damage more than proportional to below threshold values, or absorbing the damaging energy in an alternative non-damaging way is well developed in some traditional agriculture. Research on such subjects in general has got reasonable to fair attention (Lal, 1979) but traditional systems do merit more attention.

Stigter (1985 b) has given the following description of wind protection of soils."The single major reason for windbreak use around the world is to control soil blow and its consequences. Soil erosion is a cumulative effect by flying particles getting kinetic energy from horizontal wind close to the surface. Travelling up and down in wind gust eddies, soil particles pass their momentum in meeting and liberating other particles not yet air borne. Managing living and dead vegetative cover is the most effctive and practical method for controlling wind erosion. Roughness of the surface then diminishes soil erosion in two ways. It firstly reduces the horizontal wind speed, and in this way surface and form drag on the soil and the flying particles. Secondly the roughness elements catch the air borne particles not yet redeposited, making them harmless as erosion agents. In most cases traditional farmers are only aware of wind speed reducing effects but they exploit this sometimes skillfully. Tanzanian farmers in some areas use soil ridges on flat land for this purpose. They also leave untilled land strips with tall grass or other natural vegetation as wind breaks to this end.(.......)They also learned that an area is sheltered by growing or leaving natural vegetation single or in patches throughout the field. This is also done against erosion in Tanzania.

We did not meet an equivalent in Africa of the surprising example of Zuni Indians improving conditions of eroded soil by setting out rows of low sagebrush on worn out or barren fields to induce deposition of fresh sand and dust. Traditionally also cover crops were used widely in Africa as they were known to be surprisingly effective in controlling soil blowing."

The last three examples are typically fit for physics research that has not been tackled elsewhere because they are typical traditional practices almost without equivalents in todays agriculture in the developed world. The same applies to some traditional agroforestry cropping systems where wind protection is incorporated (Fig.3). What is worse is that quantification of such systems is hampered by lack of appropriate measuring techniques, which will have to be developed for these purposes. So a study of traditional methods shows that research lacunae exist on which agricultural physics research in developing countries may concentrate, using the methodology outlined earlier in this paper.

Modyfying the surface energy balance

Modification of the soil surface energy balances

$$R_{net}(1+2+3) + H(4) + F(5) + E(6) = 0$$

takes place by changing exposure of surfaces to the atmosphere or modifying directly their original properties to change the environmental impact on these surfaces (Stigter, 1985c)(Numbers in the equation refer to the list of basic energy fluxes above). Tillage and ridging are typical examples of the latter and shading and mulching (excluding tillage as mulch formation) of the former. As tillage and mulching are more commonly treated in reviews (e.g. Voorhees et al., 1981) and will also be discussed in an other paper at this cooloquium (Stigter, 1985 d) we finalize this paper by a closer look at ridging and shading.

The most curious examples in ridge perfection are those reported by Allan (1965) and Stigter (1982 b) and called "Mitombela" in Tanzania's Iringa region. These hand hoe constructed ridges can reach a height of between 1 and 3 m (towards a meter in Allan's cases from elsewhere in Africa) and create a small scale topoclimatology. In Tanzania in first instance cassava, a subsistence root crop not very demanding in moisture or nutrients, is grown in the ridges. Because of better drainage and increased evaporation the ridge tops and upper sides are relatively dry. Evaporation E is increased because at least part of the day (depending on their direction) the angle with the solar rays increases R_{net}. Moreover the evaporating surface is enlarged and the soil may be expected to be appreciably warmer at the sun lit side(s), because of this absorption and changed thermal properties. Rainwater collects in the furrows. Other crops found to be grown in the ridge system are groundnuts, sunflower, millet and peas.

Quantitatively again not much is known on these mound constructions which at first sight appear a tremendous waste of human energy. A thorough quantification using known long-term measuring techniques of absorbed solar and/or net radiation, spatial temperature patterns and moisture conditions in "Mitombela" and other mounds, of different height and as a function of direction and spacing practiced, would give an answer on the question of actual benefits of such constructions, demonstrate their efficiency and bring forward recommendations for their use in other regions.

A final example is that of shading. Again shading by an individual tree is difficult to quantify because of the sun's diurnal path and moving tree parts. Studying the tree/soil interface intensively at the shade edges and determining an area around the stem where average solar radiation values may be used might be a permissable approach. That we don't know is due to the fact that "it seems that insufficient attention has been devoted to the controlled transformation of the radiation climate. (......). Most of the techniques used to date are based on traditional and emperical knowledge rather than on physical theory." (Fuchs, 1972). Improvement in this situation was recorded on some aspects in the seventies (Blad and Lemeur, 1979). From the review just quoted it followed that for an array of trees or plants the problem of the interaction between canopy geometry and the radiation climate was also largely unsolved. This remains true and becomes even worse for sparsely vegetated (low density planting), row crop and intercrop conditions (Stigter, 1984 b). So again much remains to be done in the tropics (Stigter, 1984 c). Shading of the soil surface is under these latter conditions also more complicated

but under a closed more regular canopy its average can be determined reasonably well.

When shading diminishes the exposure to solar radiation in daytime it equally diminishes the loss of net long wave radiation at night. Conditions of a rather conservative cloudiness or averages over a longer time keep the diurnal temperature shape a sine wave, which is anyway especially valid in the tropics, with only a different amplitude. This allows mathematically an identical treatment of soil temperature fluctuations modification in cases of soil albedo modification and shade modification (such as in cases of grass mulches or regular canopies). This has resulted in a generalized theory for such cases which has been confirmed by experimental data from Kenya and Tanzania (Stigter et al., 1984, 1984 b, 1984 c, 1984 d; Othieno et. al., 1985). We will deal with the physics and mathematics of these cases in the second paper to be delivered in this colloquium (Stigter, 1985 d) and we will show there that this may lead to quantitative advise for farmer practices in what we have called advisories (Stigter, 1984 d).

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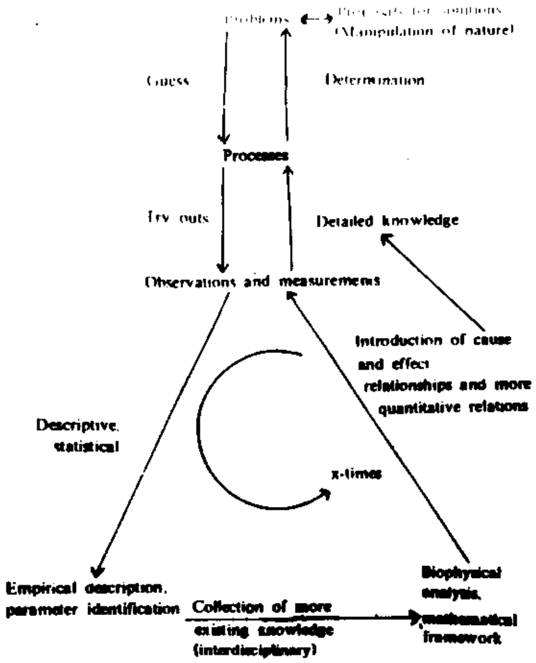

Fig. 1: Schematic Outline of Methodology of Problem Oriented Research in Environmental Physics.

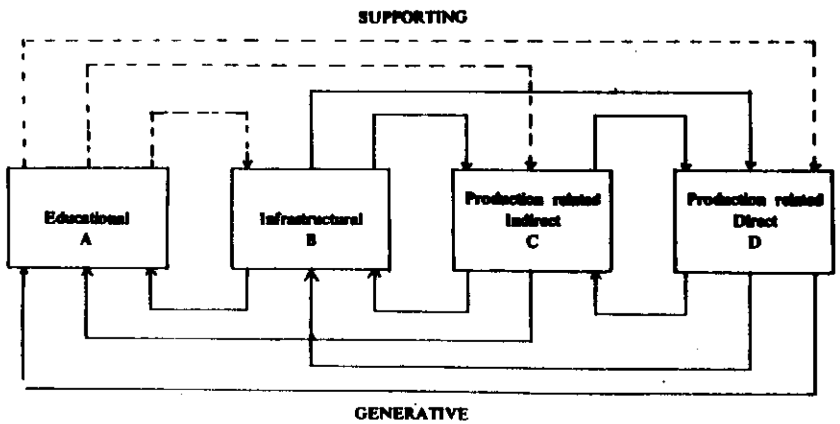

Fig. 2. Positive feedback system between different research types disti guished in the text. Dotted lines indicate an indirect supporting.

Fig.3: *Food production for a healthy nation.*

APPENDIX 1

For bare surfaces absorption of solar radiation is determined by albedo, that is reflection of solar radiation, transmission and surface geometry. The latter determines the angle with the solar rays at any moment. For every part of such a surface the law of conservation of energy holds. The absorbed solar radiation energy is used up (exchanged) as follows:

- latent heat of evaporation. This is determined by the moisture available, the temperature of the surface, the humidity of the air and the power of air movement to carry away the vapour from the surface. For water surfaces moisture is limitless, but part of the radiation is transmitted by the water, which contributes to reduction of the surface temperature. For a wet soil surface again the equilibrium temperature at any moment is important for evaporation and this temperature may be higher than in the case of a water surface. As soon as the surface starts to have spots which are dry, the soil itself becomes an additional limiting factor to evaporation.

- sensible heat. This is determined again by the surface temperature which itself is a resultant of the energy balance as a whole, including all the other terms. It is of course determined by the air temperature and the wind speed as well. Hot air over an evaporating surface may even make sensible heat flowing to instead of from the surface and in both cases air movement influences the exchange rate.

- net long wave radiation. This is determined by the surface temperature and for clear skies by humidity and temperature of the air, largely in the first 100 m. When clouds cover the sky (even only partially) they become of very much influence on long wave radiation exchange.

- conducted heat. This is determined by the thermal properties of the matter under the bare surface (soil water having a high and soil air having a low conductivity) and again the surface temperature.

As soon as anything grows on or stands over the bare surface, clearly the whole energy balance is upset. Every exchange at the original surface is modified and new exchanges and energy balances are occurring at any new surface that absorbs solar radiation. Moreover, these exchanges are influencing each other in a complicated way. Finally a "closed" vegetation such as a forest, a fully grown maize crop or a covering grass, and even a herd of zebu, will have created a climate of its own where at any level, to some extend also above its top, there is an influence of what happens elsewhere within this array of living objects (Stigter, 1982 c; 1984).

APPENDIX 2

CATALOGIZATION OF EXAMPLES OF MANIPULATION OF MICROCLIMATE

I. Manipulatiuon of radiation (15 classes) by (A,B,C,D)

A	Shading	1. using natural means.		
		2. using mulch (artificial).		
		3. using artificial means other than mulch.		
B	Increase) or)of surface Decrease)	(1. reflectivity)	by	i. use of colour or other surface change.
				ii. use of geometry change.
		(2. absorption)		iii. use of stony structures.
C	Cover for radiation loss at night	1. using natural means.		
		2. using mulch (artificial).		
		3. using artificial means other than mulch.		
D	Using solar radiation for	1. field drying.....		i. in the field of growth
				ii. elsewhere before storage.
		2. keeping products dry in storage		

II. Manipulation of heat and/or moisture flow (16 classes) by (E,F,G,H,I,J,K)

E (Non)Tillage

F Mulching
- 1. by natural means.
- 2. by artificial means.

G
- 1. Using wind breaks.
- 2. Using other shelter (storage)

H Protection for ripening purposes

I Influencing flow processes by changing conditions at or on the surface

J Using air warmed by
- 1. solar radiation)) for
- 2. other means)
  - i. field drying in the field of growth.
  - ii. field drying elsewhere before storage.
  - iii. keeping products dry (and pest free) in storage.

K
- 1. Increase of)
- 2. Use of) natural dew fall.
- 3. Protection against)

III. Manipulation of mechanical impact of wind, rain and/or hail (12 classes) by (L,M,O,P,Q)

L Change of
- 1. direction))) of wind and air flow by
- 2. speed)
  - i. wind breaks.
  - ii. other shelter.

M Planting in lower places or pits or where deep rooting is possible

N Improving soil conditions by natural deposits

O Protection from soil erosion by
- 1. wind.
- 2. rain and hail.

P Protection of crops and produce against impact by
- 1. rain.
- 2. hail.
- 3. wind.

Q Use of wind for winnowing

IV. Two general examples (R,S)

R Fitting cropping periods to the seasons

S Making use of superhuman intervention