Reduction of Risk by Diversity

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A Theoretical Basis for Age-old Farming Systems

Many agricultural scientists trained in temperate regions are surprised by the diversity of crops and crop varieties found in tropical farming systems, not yet made uniform by a 'green revolution' approach. Understanding the background of this diversity is a prerequisite for a balanced, evolutionary approach to agriculture, based on both traditional farmers' wisdom and modern scientific possibilities.

The AGRISK Project

In the AGRISK-project of the Universities of Ouagadougou and Groningen the risks of food shortages on the Mossi plateau in Burkina Faso are analyzed from social, economic and agricultural points of view. Based on rainfall statistics the expected food grain production on district level is compared with demand for food, which follows from population density. The necessity of maintaining food reserves can then be quantified. Also the possibilities can be evaluated of using surplus grain of one region in a good year to supplement production of a neighboring region where rainfall and thus production were not adequate in that year.
The difference in rainfall between regions in one year are considerable and a substantial spreading of risk occurs if food transport and trade between regions functions effectively. Still, total grain production on the Mossi plateau almost certainly falls behind the requirements in the coming years and measures to increase production are necessary. If possible, measures taken to increase the average production should not increase the variability between years. 'Green revolution' techniques of replacing the existing cultivar diversity by one or two high yielding varieties and of a higher use of chemical inputs have to be carefully evaluated and probably modified.
In the agricultural part of the AGRISK-project the risks involved in food grain production on a farm level are studied and we think a new criterion was found for understanding the role of diversity in risk reduction.

Betting on more horses

Popular wisdom tells us that 'betting on more than one horse reduces the risks', but it does not tell us on how many and on which horses we have to bet. Confronted with the possibly 40 recognizable lines or varieties of Sorghum found on some farms in the Savannah region one wonders about their function in this context. To a certain extent different varieties are grown for different purposes (food or beer) or because of a special taste; to a certain extent they are grown on different parts of the farm, because their genetic constitution matches with a particular soil or location.
Still, a considerable number of varieties is grown on the same location and their grain can be used for the same purpose. Their function may be that relatively good years of one variety coincide with relatively bad years of another and thus the total production is stabilized.
Part of the risks involved may come from insect or disease attack, with difference in susceptibility to particular diseases or insects between the varieties. Another part may come from variability in the water regime, affecting the length of the growing season and the chances of drought halfway the growing season.

We have chosen this latter aspect for further study, so we concentrate on varieties grown on the same location and analyze the risks which are the consequence of variation in rainfall regime affecting both the water and nitrogen balance of the soil.

Niche concept applied to crops

In ecology the niche concept helps to understand the diversity found in natural ecosystems; species which differ in the environmental factor which determine their abundance are said to occupy different niches and will generally be able to coexist. In many cases niche differences will be a result of a dependence on different environmental resources.
For plants, uptake of water and nutrients from different layers of soil is a clear example of a niche difference which leads to stable coexistence in nature. Similar niche differences between crops form a criterion whether or not an agronomic advantage can be expected from mixed cropping. Being regulated by different predators or diseases is also a form of niche differentiation and similarly leads to a criterion for reducing risks in mixed cropping patterns. The niche concept can thus be used in a qualitative sense to judge whether adding a new crop (cultivar) or a new way of growing crops to the farm will be advantageous or not.

From elementary statistics it follows that the standard deviation of the total yield of a combination of two crops does not only depend on the standard

	average	st.dev.	m20
soil water storage	+	-	+
rooting depth	+ +	-	+ +
N-fertilization	+ +	+	0
flowering time	opt.	0	opt.

Table 1. The effect of changes in soil-crop parameters on grain production, calculated with 30 years rainfall data of Bobo Diolasso; st.dev. = standard deviation, m20 = expected minimum production in 95% of years; + + = strongly increasing; + = increasing; 0 = no effect; - = decreasing; opt. = shows optimum curve.

	average	st.dev.	m20
d210 monoculture	4691	1810	1723
d250 monoculture	3204	1555	654
0.3*d250 + 0.7*d210	4182	1330	2001

Table 2. Probability distribution of yields of two Sorghum cultivars flowering at different dates (d120 = day 210, d250 = day 250) and of a 30/70% combination of the two, calculated with 30 years rainfall data of Bobo Diolasso; st.dev. = standard deviation, m20 = expected minimum production in 95% of years; all yields are total above ground biomass in kg/ha (grain yields will be roughly half this value).

deviation of the yields of the two crops separately, but also on the correlation between the yields of the two crops measured over a representative number of years. In fact, the standard deviation of the total yield can be zero if the two crops show a complete negative correlation, i.e. good years of one crop always coincide with bad years of the other and vice-versa. A farming practice found in Southern Sudan may come close to this complete negative correlation between the two components: a mixture of sorghum and rice is grown on soils which in some years are flooded (so the sorghum crop fails and the rice produces grain) and in other years remain dry (so only the sorghum produces grain).
Negative correlations are not required, however, to construct crop combinations which are meaningful for risk reduction. The standard deviation of the yield of a two component system is smaller than that of each of the monocultures if the correlation coefficient of the yields of the two components is less than the ratio of the smallest and highest single-crop standard deviation. In other words, the sorghum/rice example is an extreme case of stabilization of yields by mixed cropping, but much more subtle differences between crop (varieties) leading to a partial, but positive correlation of their yields can still be meaningful for risk reduction. A partial correlation of the yields of two crops in a variable environment is an indication of a partial niche difference between the crops. If we know the yields of different crops over a period of years which reflects the environmental variability, we can now test the risk reduction obtained.

Usually risk reduction by diversity means that the production obtained in bad years (specified for a certain probability of occurrence) is higher, but that the average production decreases. Which extent of risk reduction is desirable, then depends on social and economic consideration, e.g. the price of grain on the market in bad and in average years. All these relations can be formulated and quantified. The main conclusion is that risk reduction on farm level does not follow directly from choosing components with a low variability themselves, but also from the partial correlation and thus niche differences between the components. For a farmer one or two observations of a different response of two crops to weather fluctuations may be sufficient indications of a partial correlation, to decide to maintain both crops on the farm, provided their average yields do not differ too much.

Simulation model

A problem in applying the criterion of partial correlation is, that yield data for different varieties which cover a sufficiently large number of years are rarely available. An alternative is formed by using a simulation model which describes the water and nitrogen balance of the soil under the influence of rainfall and which describes crop growth on a day-to-day basis. By running the model for actual rainfall data for a period of thirty years the average production and its variation can be estimated. First of all the effects of modifying single factors on average yield and yield-variability can be studied. For a model which we use in the AGRISK-project as a first approximation for sorghum production some results are found in table 1.
If the nitrogen level is increased, the average yield will increase, but the variability of yields will increase as well and the minimum production in 95% of the years will stay the same. In years of a small positive or even negative fertilizer effect the economic effect of using fertilizers is clearly negative.

If rooting depth could be increased, e.g. by choosing a different variety or maintaining a good soil structure, the yield increase will be accompanied by reduction of risks. An increase in the water storage capacity, e.g. by an increased organic matter content of the soil, will act in the same way. For the length of the crop's growth cycle, which in the model is represented by the date of flowering, an optimum curve is found: crops with a short cycle and crops with a long cycle give a lower average yield than intermediate cycle crops, with little effect on the variability.

Crop combinations

The length of the crop's growth cycle provides an example of 'niche differentiation'. The correlation between calculated yields of short and long cycle crops is low, so combinations of the two can lead to risk reduction Table 2 illustrates that a long-cycle cultivar, flowering at 'Julian' day 250 has a rather low average production and as a monoculture carries considerable risk. In all selection and plant breeding work such a variety would probably be discarded. Still, because of its low correlation with yields of short-cycle crops, the long cycle crop is valuable for risk reduction on the farm level. A combination of short and long cycle crops has a lower average yield then the short-cycle monoculture, but shows better yield stability and shows higher minimum-yields. Combinations may be favorable by spreading labour requirements at harvest time as well. The crop combinations do not have to be used in a mixed cropping pattern to show this risk reduction effect. In fact mixed cropping may be undesirable in certain combinations where water 'saved' by one variety for later use, would be used too early by another variety. Growing such varieties in different parts of a field is then preferable.

Conclusions

The theoretical framework for judging the role of diversity in risk reduction is still in development, but hopefully it may already help to reverse the current trend of diversity-reduction where risk-reduction is required. Yield stabilization often leads to different agronomic choices than yield maximization. The niche concept can help to extrapolate crop information and plant breeding work to the real world of the farm. Risk-reduction, diversity, complexity and long-term stability are all dynamic key elements in the survival of many resource-poor farmers and herders. Research to make these elements more understandable does not only legitimize the indigenous knowledge of farmers and herders, it also enables adapting new research methodologies to cope to a certain degree with the agricultural complexities in which farmers survive.

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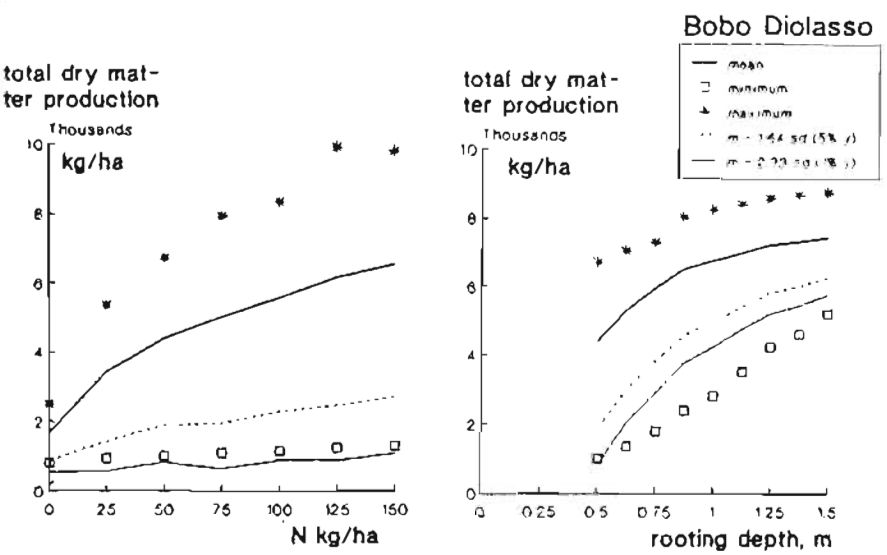

Model calculations of Sorghum yields using longterm rainfall data of Bobo Diolasso, Burkina Faso. Clearly can be seen that if Nitrogen fertilizer is used the average yield increases, but in bad years no extra yield is obtained to cover fertilizer costs. If rooting depth can be increased for instance by waterharvesting or mulching higher and more stable yields will be obtained.