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The need to study and manage variation in agro-ecosystems

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Abstract

Variation within agro-ecosystems is a universal but complex phenomenon which is present in each of the factors that determine the agro-ecosystem, i.e. the environment, genetic resources and management. Agrodiversity is defined as the variation resulting from the interaction between these factors. This variation manifests itself in many different forms, at different scales and levels of aggregation. Examples show that poor management of agrodiversity in high and low external input agriculture reduces output, output stability, resource-use efficiency and the production potential of the natural resource base. A better understanding of agrodiversity is required to improve its management. Also, analysis of variation in agro-ecosystems requires other approaches in research to be further developed in order to characterise, measure, and understand relevant variation.

Keywords: agricultural research, agrodiversity, agro-ecosystem, genetic diversity, resource-use efficiency, sustainability, variation management

Introduction

Variation within agro-ecosystems is a normal phenomenon. It occurs as a result of environmental variation and agricultural activity itself. There are many sources of variation and variation is present in many different characteristics and forms. Moreover, variation manifests itself at many different scales and system levels. Temporal and spatial variations are for example present in mineral distribution in the rhizosphere (Caldwell & Percy, 1994), in yields within and between fields (Goland, 1993; Kessler, 1994), in execution and timing of cultivation practices, and in farming styles (Richards, 1985; Van der Ploeg, 1990; De Steenhuijsen Piters, 1995).

Hitherto, variation in agricultural production and in research is considered a disturbing factor (De Steenhuijsen Piters, 1995). In high external input agriculture, technology is usually directed towards increasing production, at the same time aiming at standardisation of the produce. Technology development usually advances through further intensification, i.e. increasing production by increasing input levels (Francis & Youngberg, 1990; De Wit, 1994), while eliminating some forms of variation and not considering other forms. Variation in low external input agriculture is more prominent and recognised by farmers and researchers (Richards, 1985; Brush, 1986; Dennis, 1987; Zimmerer, 1991b). In contrast to high-input systems, variation in low-input systems is often considered a characteristic that can be utilised to diversify production and to reduce risks. Sustainability of both types of agro-ecosystems is under pressure (Edwards, 1990; Francis & Youngberg, 1990).

This paper is an effort to relate sustainability with the way variation in the different agro-ecosystems is managed. It illustrates the presence of different forms of variation in agro-ecosystems, at different scales and levels of aggregation. The resulting total variation is embodied in the concept of agrodiversity. Finally, implications of agrodiversity for sustainable agricultural management and for agricultural research are discussed.

Concepts

Agro-ecosystems are considered as ecological systems with an agricultural component, characterised by withdrawal of products and the use of external inputs. An agro-ecosystem is for example a plant, a crop, a farming system or a land use system (Stomph *et al.*, 1994). The total of agro-ecosystems forms a hierarchical structure: each agro-ecosystem is an aggregation of lower-order systems and is at the same time with other systems aggregated into a higher-order system. For example, a crop system is an aggregation of plant, pathogen and soil systems, and together with other crop and animal systems it is aggregated into a farming system.

An arable agro-ecosystem is determined by four factors: plant genetic resources (G_p), the abiotic and the biotic environments (E_{abio} and E_{bio}), and management practices (M). Plant genetic resources (G_p) refer to genetic information in plant material that is being used for agricultural production, including crops, trees, grassland vegetations, semi-domesticated and wild plants. For an analysis of primary production, animal resources are included in E_{bio}. M represents the human factor that modifies, utilises and combines the available resources, in order to achieve production and management goals. M includes decisions and activities of land users such as farmers, foresters, cattle ranchers at the field and farm levels, while at higher levels it includes those of policy makers and governments. This human manipulation of factors and processes strongly infuences the system, thereby limiting the validity of purely ecological principles.

We call the variation resulting from the interaction between the factors that determine the agro-ecosystems, 'agrodiversity'. As a consequence of the hierarchical structure of the total of agro-ecosystems, agrodiversity is a multi-scale concept which expresses itself at different levels of aggregation (De Steenhuijsen Piters, 1995). For example, the different ways in which land is used for agricultural production is a form of agrodiversity and yield variations are an expression of agrodiversity.

An agro-ecosystem is sustainable when the ecologically, economically and socially defined production objectives can be met now and in the future. In this paper, a production is sustainable when output, output stability and resource-use efficiency are maximised, while maintaining or improving the (production) potential of the natural resource base.

The output of an agro-ecosystem is a function of G_p, E_{abio}, E_{bio} and M. Stability of the output is considered a function of the variation in these same four factors. Output and output stability can be expressed in different dimensions and at different scales and system levels (Marten, 1988), such as kg per ha per season, capital value per crop, energy output or income per farming system per year, kg biomass per unit of water. The efficiency with which a particular input is used for production is expressed in the resource-use efficiency.

Environmental variation

The perception that the environment in an agro-ecosystem represents a 'condition' for crop growth and development is misleading: the environment shows complex temporal and spatial variation, e.g. variation within and over seasons, within and over fields and farming systems. For conceptual reasons, we distinguish abiotic and biotic environments, although in practice they cannot be studied separately because of their strong interaction.

Abiotic environmental variation. Variation in the abiotic environment (E_{abio}) is present in topography, chemical and physical soil parameters and climate. Important factors in the topography are variation in altitude and slope gradient and orientation. The climatic variation in rainfall, light intensity and quality, temperature, humidity and wind is to a large extent unpredictable and uncontrollable, depending on the period over which values are averaged.

Distribution of chemical and physical soil parameters, such as water and nutrients, shows important three-dimensional variation, which changes in time (Van Noordwijk & Wadman, 1992; Brouwer *et al.*, 1993; Stark, 1994; Sylla, 1994; Kooistra & Van Noordwijk, 1995). Even in apparently homogeneous agricultural fields in The Netherlands, variation is considerable (Van Noordwijk & Wadman, 1992). Variation in the soil is the result of interacting processes occurring at different levels and scales.

Biotic environmental variation. The biotic environment is part of the total biodiversity in agro-ecosystems and forms an important source of variation, as is evident from the information related to IPM (Andow, 1983; Altieri, 1987; Bird *et al.*, 1990). The different organisms that form the biotic environment show genetic, spatial and temporal variation, and strongly interact. Spatial variation in growth limiting factors of the biotic environment is for example found in the form of patchy distribution of weeds, soil-borne fungi, nematodes and other micro- and meso-flora and -fauna (Seinhorst, 1982; Storey, 1982; Mortensen *et al.*, 1993; Schans, 1993). The variation in biotic environments also includes variation in benificial organisms, such as *Rhizobium*, mycorrhiza, springtails, earthworms, ants (Witkamp & Ausmus, 1976; Andersen *et al.*, 1981; Lootsma, 1994).

Interactions between abiotic and biotic environments. The different forms of variation in E_{abio} and E_{bio} interact. Climate strongly influences all other forms of variation. Climatic variation influences abiotic soil factors (structure, soil erosion and mineralisation) and biotic ones (of pests, diseases, weeds, and other organisms). Variation in abiotic soil conditions, such as nutrient concentrations and pH, influences the presence, activity and distribution of soil flora and fauna (Swift, 1976).

A crucial source of variation in soil organic matter, nutrient distribution and composition, is the activity of organisms, plants being one of them (Matus, 1994). Plant root activity increases variation in chemical, physical and biological soil fertility through absorption of nutrients during the growing season (Barber, 1984), nitrogen fixation by *Rhizobium*, influence on spatial and temporal distribution of microsclerotia (Mol & Van Riessen, 1994), and the production of root exudates (Norton, 1991). Plants also interact with nutrient concentrations in the soil through litterfall and redistribution of precipitation as a result of their canopy structure (Carlisle *et al.*, 1966; 1967; Sharma & Tongway, 1973; Kessler, 1994). Deposition of urine and dung by grazing cattle also contributes to the variation of minerals and organic matter in the soil (Lotero *et al.*, 1966).

Biotic and abiotic variation frequently limit crop production (Boyer, 1982). These limitations or stresses (pests, diseases, weeds, harmful animals, frost, drought, heat, salinity, Al and Fe toxicity, acidity, wind, hail, and waterlogging) are highly heterogeneous in time and space (Ceccarelli, 1994; Parlevliet, 1994). Data on the frequency, timing, intensity and duration of each of the stresses, as well as the variation in their specific combinations within and between fields and over seasons or years are mostly not available and principally limited to the use of meteorological data (Virmani *et al.*, 1980; Ceccarelli *et al.*, 1987; Belay & Struik, 1993). Data on stresses in soil conditions are hardly available. As a consequence, it is difficult to quantify effects of environmental variation and to study their interactions with other factors determining the agro-ecosystem and their impact at higher system levels.

Crop genetic diversity

Crop genetic diversity refers to genetic variation within a plant, between plants of a species, and between species. This means that genetic variation is present in different forms. A plant can be genetically homogeneous or heterogeneous at a particular locus, a crop can consist of different genotypes of one or more cultivars, and even of one or more (sub)species, such as in the case of native potato fields in the Andes (Brush *et al.*, 1981). A field can be a monocropping system or a multiple cropping system. A farming system and higher land use units usually contain various fields with various crops, in combination with other agricultural activities. Cultivar or crop rotation, and land-use sequences represent genetic variation in time.

Crop genetic resources are principally the *product* of a complex interaction over time between the abiotic and biotic environments, and farmers' handling and selection of the material (Harlan, 1992). This interaction involves introgression from wild and weedy relatives, hybridisation with other cultivars, mutations, and natural and human selection pressure. The results of this evolutionary process are materials or 'landraces' which are well adapted to the local abiotic and biotic environmental variation (e.g. Collins, 1914; Curtis, 1968; Richards, 1985; Benzing, 1989; Weltzien & Fischbeck, 1990). Landraces are often genetically heterogeneous populations: the genetic variation within landraces is supposed to be a consequence of the variation in environmental conditions under which the material evolved (Harlan, 1992; Hardon & de Boef, 1993).

Because genetic variation has the potential to adapt to environmental variation, it also may be considered a *tool* in agricultural production. Genetic variation within and between crops often favour production stability in time and space through a suppression of pests, diseases and weeds (Altieri & Liebman, 1986; Barrett *et al.*, 1990). The direct relation between genetic variation and abiotic stress has received less attention. Stabilisation of yield levels over seasons and over fields through genetic variation is probably associated with large variation between genotypes in contribution to the total yield. Crop diversity at the field level can also increase production (expressed as Land Equivalent Ratio or farm income) and use efficiency of other resources such as solar energy, water and labour (Lynam *et al.*, 1986; Trenbath, 1986; Stinner & Blair, 1990). Also for the level of the farming system, it is demonstrated that crop diversity can increase and stabilise total output (Lynam *et al.*, 1986; Barrett *et al.*, 1990). Furthermore, at the farm and regional levels, diversity in agricultural commodities is likely to affect prices and income resulting in a dampening of the market fluctuations (Anderson *et al.*, 1987). At the regional level, the effect of crop diversity on stability is reflected in the output of different types of land use and land cover patterns.

Variation due to management by farmers and other land users

Management (M) by farmers and other land users involves a wide range of decisions and activities, influencing crop genetic diversity, the (variation in) abiotic and biotic environments and their interactions in many different ways, and at different system levels. He or she influences crop diversity by deciding on the crops and cultivars to plant, and on crop sequences to follow. This indirectly influences the micro-climate and the biotic environment (Doran & Werner, 1990; Liebman & Janke, 1990; Struik & Scholte, 1992). The crop determines groundcover, which in turn influences soil conditions and erosion. Fertilisation (dosis and the type), soil tillage, mulching, irrigation, etc., are farmers' practices which more directly affect variation of abiotic and biotic environmental factors and their interaction, for example by preventing erosion and changing microclimate (Bird *et al.*, 1990; Doran & Werner, 1990). Management practices which correct for environmental variation are for example irrigation (correcting variation in rainfall distribution), and mulching (correcting temperature fluctuations). Blanket applications of fertilizers and biocides reduce the consequences of environmental variation on yield by 'overruling'.

Farmers' management decisions are always taken in an agro-ecological and a socio-economical context. Management at higher system levels involves policy decisions, which may directly or indirectly influence farmers' management practices, such as the adoption of improved cultivars, the stimulation to grow export crops, the use of irrigation and the combination of other inputs (Van der Ploeg, 1990). Variation in the socio-economical resources and farmers' decision criteria such as their attitude towards risk, may lead to variation in farming styles, including variation in cultivation practices, crop and cultivar diversity, with important consequences for variation in the agro-ecosystem (Sandoval, 1991; Zimmerer, 1991a; Long & Van der Ploeg, 1994; De Steenhuijsen Piters, 1995). As a consequence, economic conditions or policy decisions do not necessarily affect farmers' management practices uniformly (Van der Ploeg, 1994).

Agrodiversity and sustainability

As a consequence of the variation in the factors that determine the agro-ecosystem, there is variation in their interaction and in the resulting agrodiversity. Variation in output is an important expression of agrodiversity; it is the result of variation in E, G and M.

Because of the hierarchical structure of the agro-ecosystems, variation in management (M) is both part of the agrodiversity, as well as the factor that manages agrodiversity. Examples of situations in which inadequate management of agrodiversity reduces sustainability can be found both in high-input and low-input agriculture. However, the character of the problems related with management of agrodiversity in the two systems is contrasting.

High-external input agriculture. Technology development in agriculture has advanced mostly through increasing external input levels. This way of intensification has generally increased (biomass) production per unit of land and uniformity of the produce. While increasing production, in many cases this intensification has reduced output stability and resource-use efficiency, and has enhanced an over-exploitation of the natural resource base, thereby reducing the sustainability of agro-ecosystems (Edwards, 1990). There are many examples of situations in which this type of intensification reduced sustainability because it was associated with elimination of growth limitations and controlling yield-reducing factors, resulting in uniformization of environment and reduction of genetic variation (De Wit, 1994; Solbrig, 1994), and overlooking or ignoring other sources of variation.

Some of those examples show negative effects of reducing variation in the abiotic environment. For instance, high levels of applications of chemical fertiliser create more uniform nutrient distributions within the field by overruling existing variation, but can reduce use efficiency of nitrogen and other resources because it ignores the existing variation in nutrient availability in space and time (Mulla, 1993). Furthermore, Van Noordwijk & Wadman (1992) showed that ignoring variation in nitrogen availability in the soil leads to fertiliser applications which are higher than what is ecologically acceptable. At such levels of fertilisation, nitrate or toxic compounds leach into the ground water and reach unacceptable concentrations in the produce. Irrigation corrects for variation in rainfall, but in combination with increasing other external inputs, they can result in over-exploitation of the natural resource base: ground-water levels decrease because more water is used than is naturally supplemented and soil fertility is depleted. Furthermore, in many situations this has lead to salinity problems.

Control of biotic environmental variation (through application of biocides) has multiple negative effects on the biotic and abiotic environment. In many situations, application of biocides has lead to environmental degradation through ground-water pollution (Marks & Ward, 1993). Weed control may increase soil erosion because weeds can serve as a living mulch. The application of biocides has negative effects on organisms which are directly or indirectly benificial for crop growth (Altieri, 1987; Edwards, 1990). Negative effects of biocides on natural enemies of pests and diseases further increase the need for biocides. For example, controlling the variation in pressure of nematodes by preventive applications of granulates, reduces the population of springtails (*Collembola*), antagonists of Rhizoctonia (Hofman, 1988). Fungicides negatively affect mycorrhiza which increase phosphorus absorption by their host plants (Sukarno *et al.*, 1993).

Reduction of genetic variation provides other examples of negative effects of reducing agrodiversity on sustainability. Reduced crop diversity and modified cultivation practices can be associated with soil erosion in some cases. The change from multiple to monocropping systems and the replacement of broadcast-sowing by line-sowing provides a less protective canopy cover and makes the soil more vulnerable to wind and water erosion (Barrett *et al.*, 1990). Incomplete crop-ground cover also increases weed infestation (Rao, 1986) and the pressure of some pests such as aphids (Heathcote, 1970). Decrease of genetic variation in agro-ecosystems, in time and space increases pests and disease problems (Anonymous, 1972; Altieri & Liebman, 1986; Bird *et al.*, 1990), thereby reducing the output stability and further increasing the need for biocides. Problems with particular crop-adapted weeds have also increased with narrower rotations. Replacing genetically heterogeneous crops by a smaller number of genetically uniform crops has narrowed the genetic base in agro-ecosystems and increases chances of losing genetic resources, which reduces the potential for future genetic improvement (Harlan, 1992).

At higher levels of aggregation, negative effects on sustainability are found as a result of a reduction of landscape diversity (Barrett *et al.*, 1990; Vos & Fresco, 1994). The removal of trees, hedgerows and other microenvironments in land consolidation and development programmes has strongly reduced the diversity of the biotic environment in agro-ecosystems and has disturbed balances between yield reducing pathogens, insects and their natural enemies (Altieri, 1987; Barrett *et al.*, 1990).

Environmental variation and its interactions with crop growth cannot be completely controlled. For example, coefficients of variation as high as 10-15 % are still reported for fertiliser distribution in controlled experiments (Bouma & Finke, 1993), whereas coefficients of variation of individual plant dry weight in maize in controlled conditions range from 30 to 50 % (Deinum & Struik, 1980). Furthermore, variation is unescapable because macro-climatic variation is erratic and largely independent and uncontrollable. Moreover, correction of environmental variation often generates or reveals variation in other factors, sometimes at other system levels. For example, mechanised sowing reduces variation in planting depth and planting distance, but creates new variation through the effect of the (weight of the) machinery on soil structure, which influences a range of physical soil parameters and processes. Windbrakes reduce environmental variation in time, but increase variation within the field. Also terracing modifies the environment and its variation on a hill-side. Irrigation reduces variation in water availability for a field within and between years, but may increase the variation between farmers, because some may get more or more reliable water supply than others (Marten, 1988).

Also the improvement of production practices and research reveals sources of variation which were formerly overlooked, considered irrelevant or unmanagable. For example, within field variation of soil fertility is such a type of variation which has become relevant since technology has developed equipment capable of handling smaller scales of variation, enabling site-specific crop management (Borgelt, 1993; Tyler, 1993).

Low-external input agriculture. In low-input agricultural systems, resource availability is generally limited and the control over the environment is less than in high-input systems. Typically, low-input agriculture in developing countries is practiced in environments where variation cannot be eliminated, simply because it is too large and overruling or reducing variation would imply inefficient resource use. Therefore, technology development in these agro-ecosystems usually cannot proceed through increasing external input levels, but advances by more complete and more efficient utilisation of the (scarcely) available resources, or by entire change of the agro-ecosystem (e.g. replacement of shifting cultivation by permanent farming). Although some farmers appear to optimally utilise their available resources, there are reasons to believe that in many situations this utilisation is not maximised, resulting in sub-optimal output, output stability and resource-use efficiency.

One of the strategies to deal with the different types of environmental variation in agro-ecosystems is to adapt the choice of the crop or cultivar to the growing conditions. This is (still) done by many farmers in strongly heterogeneous environments: they typically use a large number of crops and genetically heterogeneous landraces or landrace mixtures (Stoop *et al.*, 1982; Clawson, 1985; Richards, 1985; Brush, 1986). Optimising resource utilisation may also mean that for planting the best spots have to be selected, i.e. spots which are richer in nutrients, have more organic matter or a more favourable water supply (Richards, 1985; Chambers, 1990).

Sometimes, it may be necessary to increase within-field variation to maximise output, output stability or resource-use efficiency. For example, when resource availability is strongly limited, applying water or fertiliser selectively to the best spots in the field (termite heaps), to the best fields or to the most profitable crops may be most productive (De Schlippe, 1956; Fresco, 1986; Ceccarelli, 1994). In the 'citemene' system of shifting cultivation, branches and leaves of trees are collected and burned to selectively increase soil fertility (Nye & Greenland, 1960). At the landscape level, variation in soil fertility is increased by corralling animals directly on the field, thereby concentrating to an arable field the nutrients and organic matter from a wider area (Powell & Williams, 1993).

While agrodiversity in these agro-ecosystems is something that has to be dealt with, it also has a positive value which should be optimised: agrodiversity offers opportunities to stabilise field and farm production, i.e to reduce risks. Fields with different soil types and micro-climate provide an opportunity to diversify output and increase output stability (Van Noordwijk & Van Andel, 1988; Brouwer *et al.*, 1993; Goland, 1993). Chambers (1990) points out that micro-environments such as home-gardens, alluvial pans, silt traps and river banks represent niches that often produce crucial output in seasons with adverse conditions. These micro-environments have long been overlooked as a result of the dispersal and the differences between farmers and researchers in scales of observation and the priorities in research. Genetic variation within and between crops can be used to increase buffering against environmental variation (Brush, 1986) and it offers possibilities to diversify food and marketable produce. Genetic variation may also be used to optimise the use of household labour by distributing labour demands for planting, weeding and harvesting more evenly over time (Altieri & Merrick, 1987). Maintaining genetic variation within the farming systems may be valuable for adaptation to future changes, as is recognised by some farmers (Dennis, 1987; Benzing, 1989).

Since resource availability is more capricious in strongly heterogeneous environments, appropriate management of agrodiversity may be more crucial for maximum output, output stability and resource-use efficiency in such conditions than in less heterogeneous environments. However, agricultural technology development in the less heterogeneous and more developed areas may have underestimated the presence and importance of variation and thereby also forgone important benefits in the utilisation of resources. For both situations, there is a need to prove that better management of agrodiversity can increase sustainability of production and reduce degradation of the (production) potential of the natural resource base.

Researching and managing agrodiversity

Rethinking the performance of agro-ecological systems shows us that, inevitably, variation is present in each of the factors that shape the systems and that in general, variation within and between agro-ecosystems and its complexity are underperceived. Since there is evidence that 'mis'-management of that variation can seriously affect the sustainability of agricultural production, there is an urgent need for the design of variation management that can increase output, output stability and resource-use efficiency in combination with the maintenance of the natural resource base. Research on variation in agro-ecosystems is needed to understand variation and to design practices of sustainable management of agrodiversity.

Understanding variation. Variation is a complex phenomenon. Considering the relation between interactions and the different levels of aggregation, the phenomenon of agrodiversity is even more complex.

Relations in agro-ecosystems are scale specific (Fresco, 1995). This means that the assessment and relevance of variation is a function of the system level and scale resolution or 'grain'.

Because variation changes with the level of aggregation, sometimes other levels have to be studied to understand observed variation. For example, variation in relations between stocking rate, fodder production, fodder purchase and milk production per cow on dairy farms in The Netherlands can only be understood when considering differences in 'styles' of farm management (Van der Ploeg, 1994).

Uniformity may be the result of dampening the variation present at a lower system level. For example, variations in maize yields of 30–120 % at the plant or field level result in variations of the world maize production of 4 % (De Steenhuysen Piters, 1995). Dry matter concentration in potato tubers, an important characteristic for the processing industry, varies considerably between plants or single stems, parts of the field, and fields (A.J. Veerman, pers.comm.). Variation between tubers of one plant, however, explains approximately 80 % of the total variation between tubers of an entire field. In contrast, relatively small variation in different factors may result in considerable variation at a higher level of aggregation. Van der Ploeg (1994) demonstrated that a 'chain' of small relative differences in technical relations resulted in strongly varying effects of increasing stocking rate on the production per cow when considering various 'styles' of farm management.

Characterising and measuring. Since variation in agro-ecosystems has hardly been investigated in a systematic way, appropriate tools and methods have to be further developed, in order to qualify and quantify the variation (and its causes). Such tools and methodologies also involve alternative approaches in statistics, such as geostatistics (Stein, 1991; Robertson & Gross, 1994; Sylla, 1994), risk-analysis (Rossing, 1993; Van Noordwijk et al., 1994) and multivariate techniques. Study of agrodiversity at different levels of aggregation requires a different, comprehensive approach of characterisation and measurement (De Steenhuijsen Piters, 1995).

Management of agrodiversity. Once assessed, variation can be ignored or dealt with. The possibilities and strategies to manage variation depend very much on the predictability of the variation. Different strategies to manage predictable variation are possible. 'Elimination' of variation through overruling or reducing variation is often practiced in high external input agriculture. 'Overruling' is a strategy in which expression of (underlying) variation is reduced. For example, applying large amounts of fertilisers reduces fluctuations of yield due to natural variation in mineralisation. This may not to be a sustainable strategy in many situations because it increases the loss of nutrients from the system. 'Reduction' of heterogeneity in soil structure can improve germination and root growth, and thereby crop production (J.E. Parlevliet, pers.comm.). However, while reduction of variation may eliminate the limitation of the factor addressed, variation due to other factors may become limiting and new forms of variation may be created. 'Reduction' of genetic variation is used to eliminate variation in crop stands, whereas the limitation due to pests and diseases remains similar or even increases. Sowing is mechanised to avoid variation in planting depth and to achieve uniform crop stand. However, variation in crop stand due to soil compaction is generated and the advantage of variation in planting depth in relation with the variation in fertility and rainfall may be largely foregone.

Strategies that 'match' variation may yield benefits in relation to resource-use efficiency and output (stability), in combination with diminished degradation of natural resource base. 'Matching' agrodiversity can be achieved through adaptation (with genetic variation within and between crops), through modification (mulching, terracing) or correction of variation (irrigation, position-fertiliser application). 'Increasing' variation may be pursued in resource poor environments. 'Maintenance' or conservation of variation in crop genetic resources is for example pursued to maintain the capacity to adapt to future changes (Simmonds, 1979). This strategy of conservation also aims to protect landscapes and relative undisturbed ecosystems (Vos & Fresco, 1994). Sustainable management of agrodiversity will probably require a blend of eliminating, matching and increasing agrodiversity. In general, these strategies, rather than aiming at elimination of variation, will distinguish undesirable and desirable variation. The desirable abiotic environmental variation may be 'matched', while desirable biotic variation can be a valuable tool in 'matching' which needs to be maintained.

Since variation may be a function of differences at other, lower levels of aggregation, manipulation of the variation is possibly achieved by tools operating at a level different from the one at which the relevant variation manifests itself. For example, to reduce environmental pollution at a regional level, policy measures may have to be directed at reducing pesticide use at the level of crops or fields.

Conclusion

In conclusion, occurrence and importance of variation in agro-ecosystems need more recognition. Variation in agro-ecosystems is not a newly recognised phenomenon, but the management of that variation is becoming increasingly important in the view of the growing population of the world: maximising production efficiency of available resources while maintaining their production potential is crucial for the sustainability of agro-ecosystems.

As for now, our understanding of that variation is limited. Systematic study of variation is expected to increase this understanding and to lead to the design of a more efficient and productive management of variation in agro-ecosystems, at different levels of aggregation, while not further degrading the natural resource base.

A further development of the concept of agrodiversity may be useful in structuring the research on variation and its impact at different levels of aggregation.

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