Need for a dialectical approach in agricultural research for sustainable growth*

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In order to meet the target of National Agricultural Policy (NAP) to produce a growth that is sustainable technologically, environmentally and economically, it is suggested that a dialectical approach in agricultural research need be explored. The history of dialectics and related developments on systems theory, cybernetics, and science of complexity is described and dialectical principles enunciated. The approach is discussed in relation to the current methodology of agricultural research that is unidirectional from input factors to the output. Experimentation with model plant organism Arabidopsis thaliana is a possible way to study the dialectical relationship in the context of gene manipulation at the molecular level. Simulation of plant processes on computers so as to include plant–environment interactions can help in understanding the feedback and feed-forward mechanisms of grain production process. An appropriate sustainable growth strategy should take into account, on quantitative basis, the environmental effect of crop production process as well as the feedback from the quality of environmental resources to crop productivity. These seem to be novel problems needing a multidisciplinary approach and a coordinated effort by plant breeders, agronomists, soil scientists, microbiologists, computer scientists and statisticians.

The National Agricultural Policy (NAP) announced recently envisages, among other things, a *growth that is sustainable technologically, environmentally and economically*. This means development and adoption of technologies that would meet short-term requirements while maintaining the ability to meet long-term needs. The country's natural resources, i.e. land, water and genetic endowment are to be used in a manner that is environment-friendly, economically viable and meets the concerns of the society. In this context, it is important to note that the green revolution strategy involved, given the dwarf varieties of wheat and rice, searching for levels of inputs that would give high yields ignoring the irreversible losses in the form of soil erosion and loss of pest resistance. The dwarf varieties put more of their energy into grains instead of the vegetative parts of the plant, that no doubt increases the yield but also makes it easier for weeds to outgrow them, making the herbicide treatment necessary. Their reduced root growth makes the plant more sensitive to shortage of water. So while the age-old problem of 'lodging of plants' with tall Indian varieties was solved with the advent of dwarf varieties, it created simultaneously problems for soil health and ecosystem due to the mandatory application of high-nitrogen fertilizer, irrigation and pest management. The strategy became environment non-friendly and led to an ecologically unstable system. The problem before agricultural researchers is whether we can develop a technology that can have the positive aspects of increased yields minus the negative ones noticed in the green revolution strategy. Is it possible? Apparently, this requires giving a fresh look at the grain production process itself, particularly at the fundamental level, to see how it affects the environment in terms of the soil health and the ecosystem surrounding the plants, in addition to being affected by it. It is only when we are able to understand the feedback and feed-forward mechanisms of such a process that we can discover ways and means to incorporate sustainability in agricultural production.

In order to understand this issue, we have to reconsider the methodology of agricultural research that is mostly based on the principle of *reductionism*, in which a complex system is broken down into its constituents in a hierarchical manner till we get to the fundamental units whose behaviour is studied to explain the phenomenon at the next upper level. This principle, taken from the basic sciences of physics, chemistry, mathematics, etc., has no doubt given over the past two centuries remarkable success in scientists' endeavour to understand nature. But it is now being questioned[1]. It can be the best strategy only when the interaction with the environment is negligible. An alternative to this approach is that of *dialectics*, in which the relationship between the plant and its environment consisting of soil, water, air, sunshine, etc. as well as other neighbouring plants, is required to be exploited along with their interaction effects[2,3].

Historical background

Friedrich Hegel, a German philosopher, believed that the *thought* process moves in a three-beat rhythm that he called 'dialectic'. It begins with an idea – a thesis – then proceeds to develop into its opposite, the antithesis; after that the mind sees the relatedness of thesis and antithesis and weaves them together into a synthesis. This synthesis, in turn, becomes another thesis, and the dialectic continues. It is a way of explaining the world faced with a set of opposing, dichotomic and contradictory processes. In fact, dialectics is only another way of saying 'thinking correctly'.

That the so-called reductionist concepts do not always apply in the real world was also realized by Ludwig von Bertalanffy in early 1920s, who gave an *organismic* conception in biology, somewhat similar to dialectics. The problems of order, organization, wholeness, etc. that are absent in the reductionist

*Dedicated to the memory of Prof. S. K. Sinha, former Director of IARI, New Delhi and presented during the NAAS Workshop on 'Agricultural Policy: Redesigning R&D to Achieve the Objectives', held on 10–11 April 2002 at New Delhi.

approach became central in a *general system theory* proposed by him[4]. In a system, different parts of it interrelate with each other to produce a complex picture that needs to be structurally modelled to give a meaningful analysis of the system. At the same time, *Cybernetics*, as the science of control and communication in animals and machines, was invented by Wiener[5], that involved similar concepts akin to dialectics and used computers, information and self-regulating machines.

The advocacy of dialectics in biology was, however, put forward much later at the Bressanone Conference held in 1981, where it was shown that the current status of biological theory can be better explained by a dialectical approach than otherwise. This subsequently resulted in a publication, *Dialectical Biologist*, by Levins and Lewontin[6]. More recently, a related new science of *complexity* is emerging at the cutting edge of different sciences, particularly biological sciences. This is the study of the behaviour of macroscopic collections of such units that are endowed with the potential to evolve in time. Their interactions led to coherent collective phenomenon – the *emergent* properties – visible only at higher levels than those of the individual units. This science concentrates on the *whole* rather than the individual parts of the system, unlike dialectical approach but like systems approach, that offers a means for transcending the materialistic limitations of reductionism[7].

Dialectical principles

Let us look into the concepts of *part* and *whole* of a given system. In the Cartesian reductionist perspective, the whole consists of a natural set of units or parts that are homogeneous within themselves. The dialectical perspective on the contrary looks at the whole as a relation of *heterogeneous* parts that have no prior existence as parts. What constitutes the part is defined by the whole under consideration. Parts acquire properties by virtue of being the parts of a particular whole – properties they do not have in isolation or as parts of another whole. At the same time, as soon as the parts acquire properties by being together, they impart to the whole new properties, that are in turn reflected in changes in the parts, and so on. Parts and wholes therefore evolve as a consequence of their relationship, and the relationship itself evolves. Things that follow such properties are called *dialectical*. They can occur at the micro- as well as macro-level. In the reductionist approach when there is no interaction amongst parts, the whole is just the sum of its parts; but when interactions exist, as in the systems approach, the whole can be more than the sum of its parts. In dialectics, *emergent* properties of parts come into existence in the interaction that makes the whole. There is interpenetration of parts and wholes due to the interchangeability of subject and object, of cause and effect. Because parts recreate each other by interacting and are created by the wholes of which they are parts, *change* is a characteristic of all systems and all aspects of all systems in the dialectical framework. It means dynamism in that the system is always in motion. Subject becomes object, cause becomes effect, and the systems develop, destroying the conditions that gave rise to them. The development of the system over time seems therefore to be the consequence of opposing forces and opposing motions.

The appearance of opposing forces in dialectical principles is in fact based on the concept of *contradiction* inherent in the meaning of dialectics. Things change because of action of the opposing forces on them, and things remain what they are because of the temporary balance of opposing forces. The opposing forces are seen as contradictory in the sense that each taken separately would have opposite effects, and their joint action may be different from the result of either acting alone. But in the dialectical framework, these forces are part of the self-regulation and development of the object that is regarded as a network of positive and negative feedbacks that are basically *cybernetic* concepts. The negative feedbacks are more common, wherein a particular state of the system is self-negating – an increase in something initiates a process that leads to its decrease – as, for instance, in the control of blood sugar in humans. Such feedbacks characterize self-regulation – *homeostasis* – and are prerequisites for stability. But systems also contain less numerous positive feedbacks that lead to instability. The stability or persistence of a system depends on a particular balance of positive and negative feedbacks.

Dialectical approach in agricultural research

This requires, first of all, identifying the system to be studied. At the micro-level in the production process, the plant is both the subject and object of growth. It both, makes and is made by the environment provided by soil, water, fertilizer, etc. and thus acts in its own growth. This is unlike the traditional view, wherein the plant's growth is caused by the inputs given, and the reciprocal phenomenon of the reaction of the environment in response to plant itself is ignored. We examine this approach in relation to plant biotechnological research, computer simulation of plant process, and experimentation on plant breeding and agronomic practices.

Plant biotechnological investigations at the molecular level

Rapid advances are being made in plant biotechnological methods worldwide through the new science of *genomics*, along with their commercial exploitation by producing genetically modified organisms (GMOs) for food. It seems possible now to manipulate the genome of a given plant to modify its function and its development in such a way so as to suit the given production system environment, thereby paving the way to enhance the vertical productivity in agriculture without environmental degradation. These developments sound very impressive, but in a dialectical sense they still miss the point by ignoring the feedback mechanisms that might operate on the environment of the system by increased productivity of the plant. This aspect can be investigated by experimenting with a model plant organism like *Arabidopsis thaliana*, a small mustard self-pollinating species related to many food plants like rice, wheat, maize, sorghum, millets, etc., whose entire genome, a highly compact one consisting of about 130 Mb with little interspersed repetitive DNA, has been sequenced.

Basic understanding of plant process using computer simulation

The life of a plant, like any other life form, starting from germination of seed till it withers out, is a complex phenomenon involving a collection of processes, such as metabolism, reproduction or formation of a protein. It is analogous to sub-routines in software programming, that are with little programs encoded on a data tape called the DNA. A relatively small number of regulatory genes switch on and off like a series of computer commands, that transform a single fertilized egg cell into an adult plant with a large number of highly specialized cells performing different functions. The fundamental mechanism of plant development can therefore be modelled on a high-speed computer. Due to the availability of increased computer power and advanced graphic workstations, one can model and simulate progressively more complex and more interesting phenomena on computers. The basic understanding about the plant process on computers, without going to the laboratory or field, can be enhanced by extending it to include plant–environment interactions as required in the dialectical method.

Experimentation on plant breeding and agronomic practices

It is now well recognized that to ensure sustained and enhanced crop productivity, agronomic practices of using different sources of plant nutrients, pesticides, crop rotations, variety selection and production record analysis need to be integrated in a meaningful way. This has resulted in the concept of what is known as *Integrated Crop Management* (ICM) system in which the inputs are optimized at the micro-level relative to yield, profitability and environmental impact. A well-developed ICM system utilizes a system of *Best Management Practices* (BMPs) to achieve the most profitable and environmentally sound yield level, known as *Maximum Economic Yield* (MEY) that would be somewhat *lower* than the maximum potential yield for the given soil–crop–climate system. A component of ICM is *Integrated Nutrient Management* (INM), wherein the use of chemical, organic and microbiological sources of plant nutrients is integrated to maintain and improve soil health for sustained crop productivity on a long-term basis. Another component is *Integrated Pest Management* (IPM) to help improve pest management programmes by determining exactly when pesticide applications are necessary. The choice of intensive cropping system is also an important factor in the ICM. The cropping systems research seeks the technology that will increase the crop production by growing two or more crops in succession within a year, with the minimum of soil deterioration. All components of the system, viz. the physical and biological inputs, including technology, capital, labour and management required for growing a set of crops on a plot during the year as well as their relationship with the environment are required to be considered in this system. However, such agronomic technology usually developed at the experimental stations does not transfer easily to farmers' fields due to non-availability of inputs and sociological constraints. The technology has therefore to be investigated in the farmers' fields – usually called *on farm adaptive research* – so that emerging recommendations have practical applicability and use. This requires statistical skills in planning the investigation in a specific recommendation domain, characterized by relatively homogeneous farming systems associated with similar agro-climatic conditions, as well as collection, analysis and interpretation of the resulting experimental data. Narain and Bapat[8] discussed such a methodology in relation to cropping systems research and illustrated its usefulness in relation to experiments conducted under the All-India Coordinated Agronomic Research Project of the ICAR.

Apart from farming systems research, we have also what is known as *Farming Systems Research and Extension* (FSR&E) approach in which the whole farm of a given household is treated as a system with interdependent components under the control of the members of the household, and their interactions with the physical, biological and socioeconomic factors not under the control of the household[9]. Intimate interaction between the scientists and extension personnel is insured by undertaking technology development for identifying appropriate genotypes and agronomic practices for the given region, using statistically sound experimental designs, on operational-scale plots in farmers' fields. This is in sharp contrast to the usual approach in which scientists hand over a package of breeding and agronomic practices developed on research stations to extension personnel.

Recently, the systems approach discussed above has become more visible in intensive irrigated rice–wheat (R–W) systems practised by the farmers in the Indo-Gangetic Plains due to the efforts of Rice–Wheat Consortium (RWC) set up in 1994, and convened by CIMMYT as one of the Eco-regional Programmes of the CIGAR. The Consortium has been operating farmer participatory research programmes in system ecology perspective, with major involvement of NARS, IARCs and advanced research institutions. Focusing on resource conserving technologies (RCTs) such as surface seeding and zero-tillage in wheat and raised bed-planting system in rice, wheat and other crops as well as site-specific nutrient management (SSNM) in rice–rice and R–W systems, it has been possible to enhance production and productivity of the R–W systems at reduced cost in addition to providing food security, poverty reduction and environmental quality through reduced burning of crop residues[10].

These efforts, particularly the FRS&E and RWC, come quite close to the dialectical method in that the feedback between farmers and scientists is taken care of. However, the methodology of *on farm research* remains the same as practised at the experimental stations. The biological relationship exploited is still unidirectional – from input factors to output. The strategy for sustainable growth in crop production, however, depends on understanding how the plant production system influences and is influenced by the environmental system. In intensive cropping systems, plant growth extracts nutrients from the soil that adversely affects its health. If the health status of the soil is to be preserved at some desired level for future use, the production process gets constrained in that the production would become less than what it would be, if we ignore the effect of increased production on the characteristics of the soil. We have therefore to determine by how much the production gets lowered in maintaining the soil status. At the same time when soils deteriorate, as a feedback, the plant productivity goes down. We have then to determine by how much the soil erosion is to be prevented to maintain the productivity at the same level. In other words, an appropriate sustainable growth strategy should take into account, on quantitative basis, the environmental effect of crop production process as well as the feedback from the quality of environmental resources to crop productivity.

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SCIENTIFIC CORRESPONDENCE

‘Holes’ on erythrocyte membrane and its roughness contour imaged by atomic force microscopy and lateral force microscopy

Atomic Force Microscopy (AFM) is a powerful, recent technique which has been largely applied in the field of material sciences, but less so in the biological realm[1–5].

The first AFM image of erythrocytes was reported to reveal a large number of closely-packed nanometer size particles[6]. This has been further studied recently[7]. Another work[8] deals with the action of drugs on human erythrocytes, which opens up new horizons in the medical field.

We report here the presence of depressions or pits on the human erythrocyte membrane and the varying roughness, as revealed by the change of friction, of different areas of the erythrocyte with the help of Lateral Force Microscope (LFM) technique.

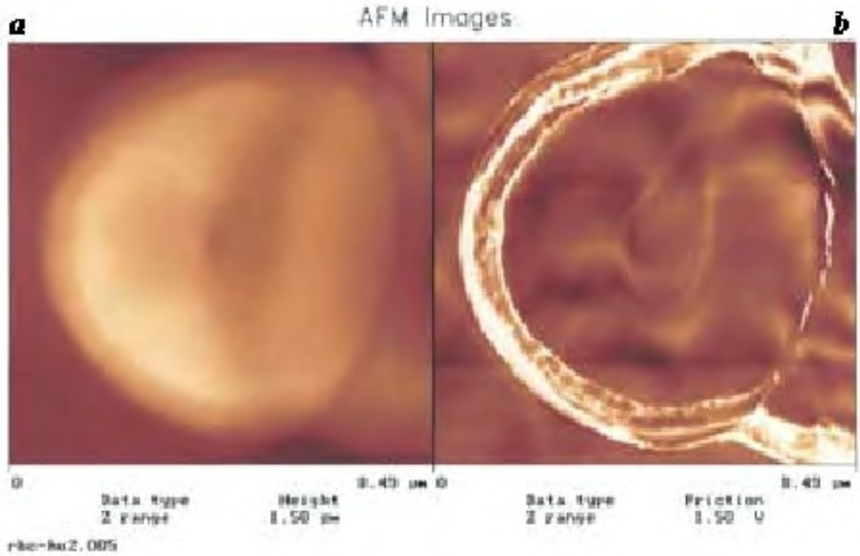

Figure 1 ***a***. AFM of erythrocyte image at lower magnification shows that normal shape has been retained after air-drying on a glass slide. White areas indicate highest regions and darker areas, lower regions; ***b***, LFM image of the same erythrocyte shows the roughness contour. White areas indicate the highest roughness, darker areas are smoother.

The AFM was a Digital Instruments Nanoscope, ESPM system. The cantilever was 100 µm, wide-legged tripod type. Imaging was effected in the contact mode in air after drawing blood (from a healthy subject) on a glass slide and air-drying.

Figure 1 *a* shows that this procedure maintains the normal shape of erythrocytes as evident in natural or near-natural conditions. Figure 1 *b* shows the ‘roughness contour’ of the erythrocyte shown in Figure 1 *a*. For this, LFM, i.e. using the horizontal component of the force has been utilized. This force reveals the variable friction (due to varying roughness) on the erythrocyte surface. Here the white portions show the roughest parts of the membrane and the darker (reddish) parts, the smoother region. This erythrocyte has of course been subjected to ‘unnatural’ stress/strain forces during air-drying, but interestingly, the whole circular rim is the roughest (with an inner, smoother band) and there is a sudden transition beyond this rim.

Figure 2, at higher magnification, reveals between the ‘closely packed particles of nanometer size’ at least nine