M. S. Swaminathan: his contributions to science and public policy

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The role of Swaminathan in science and public policy for more than 65 years is unapproachable. His contribution to strengthen agriculture and improve food security is tremendous and more than impressive. His incisive vision on the role of science to serve societal aims is widely accepted, and leading to evergreen revolutions in many continents and countries. In this article that role of Swaminathan will be described and it will be illustrated how three main guidelines were used in his thinking, approaches and interventions: (i) Promoting basic scientific insights and understanding where physical, (bio)chemical, physiological, ecological and genetical principles and knowledge are used and integrated; (ii) Stimulating and introducing inclusive approaches where various objectives such as environmental aims, sustainable development, gender, next to productivity increases are combined and used to strengthen harmonious developments; (iii) Activating and adapting institutions, national and international, and rules and regulations such that farmers are empowered and protected and that biodiversity is protected and where possible promoted and strengthened.

All these policy issues were crucial for the functioning of Swaminathan and his impact on World Food Security, regional upgrading and local movements and sustainable development globally. The description and analysis in this article demonstrate his efforts and activities which have made the world a better place for all.

Keywords: Climate smart agriculture, inclusive thinking and inclusive approaches, production ecological principles.

Introduction

THE living legend M. S. Swaminathan (MS) is celebrating his 90th birthday this year. He has contributed more than 70 years of his life to science in service of humankind. This is an unprecedented and a very rare achievement. He jeopardized many predictions on chronic world hunger, environmental pollution and overpopulation[1] through his contributions with scientific rigour and depth. He demonstrated that basic science and the fundamentals of science pave the way to the improvement of agro-ecosystems serving multiple societal objectives, productivity, environment and social interests. He internalized all aspects of sustainable development long before the UN Report[2] 'Our Common Future' in 1987 initiated the worldwide movement for sustainable development. His slogans pro-poor, pro-environment, pro-women, pro-future generations were ahead of that mission.

His conviction based on the combination of humanistic views and scientific insights was already present in his first publication[3] of 1952. His conviction that good insight and understanding could improve policies and help solve problems of societies was the basis of his long career.

The following three main guidelines were used in this thinking, approaches and interventions.

(1) Promoting basic insights and understanding of the physical, chemical, physiological and ecological processes that determine plant and crop growth. The broadening of the scientific basis of agriculture and natural resource management has resulted in an enormous increase of productivity and a much cleaner way of producing. The production-ecological basis of agriculture has been strengthened and that has created ample opportunities for productive and sustainable ways of agriculture and in this way leading to a considerable increase in world food security.

(2) Stimulating and introducing inclusive approaches in research and implementation. More and more the awareness of effects of productivity increases when done in a not sophisticated manner present in societies. Also the consequences of change for not well-endowed members of the society, in particular women, are increasing. Swaminathan has already promoted inclusion of these objectives explicitly in policies and interventions.

(3) Activating, adapting and developing institutions that empower farmers and their organizations and multiple goals may be served. The government and non-government institutions are stimulated in their movement to policies oriented to broad societal goals. Earlier the emphasis was on activities and institutions directly related to resource utilization and management of agro-ecosystems. Then natural ecosystems and the critical relations between biodiversity conservation and broader resource conservation were addressed especially when Swaminathan played a pivotal role in IUCN. After that broadening an even wider responsibility was accepted by

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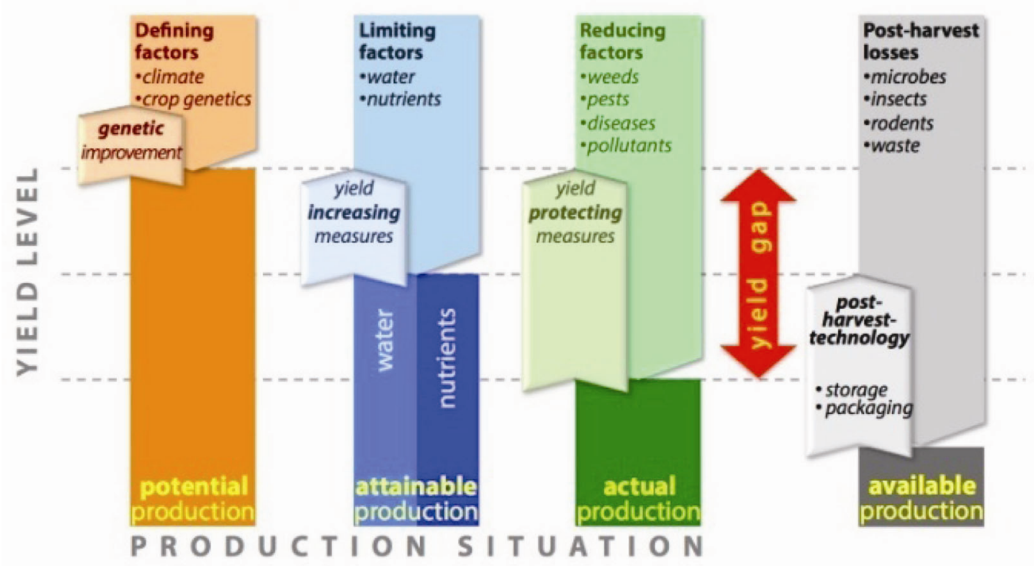

Figure 1. Principles of theoretical production ecology.

leading Pugwash, the bottom-up movement of scientists and policymakers contributing to peace and mutual understanding of societies and political structures from a very different background.

Basic sciences and ecological principles of production

In terrestrial and aquatic ecosystems, the way production takes place may be characterized by production levels and the influences of various factors[4]. In agro-ecosystems, four levels of primary production may be characterized such as potential, the attainable, the actual level and the available production (Figure 1).

The potential production level is dictated by the growth and yield defining factors such as the environmental conditions, temperature and incoming radiation. The genetical traits of a crop concern the physiological, phenological, optical and geometrical characteristics. The physiological characteristics concern with the photosynthetic traits. They include the photochemical traits, the biochemical traits such as the primary photosynthesis process and the synthesis of proteins, lipids, structural carbohydrates, lignin and other plant products with the primary product of the photosynthesis glucose as a starting point. The combination of glucose also delivers the energy needed to synthesize ATP (adenosine-tri-phosphate), the energy carrier within the plant.

The geometrical characteristics concern with the geometric position of the leaves that determine the interception of the incoming radiation. The basic processes of these characteristics are described by C. T. de Wit in his classical essay on photosynthesis[5]. He explains how depending on the place on earth, erectophyle or planophyle positions of the leaves with respect to the incoming radiation are more or less attractive for total light interception. This determines the absorption of light and the photochemical process that explains how many energy-rich components as ATP can be synthesized.

The energy-rich components are needed for the basic photosynthesis process resulting in the binding of CO_2 and H_2O with glucose as a product[6]. Glucose is used for the synthesis of the structural compounds proteins, carbohydrates, lignin and fats. All the biochemical processes involved are well known and quantitatively documented. These processes are rather conservative and as well in the photochemical as in the synthesis of structural compounds the variation is very limited. The C_3 and C_4 photosynthesis are basically the same, only a pre-step in the C_4 photosynthesis such that the direct contact of O_2 with RuBisCO is absent which eliminates a substantial effect of photorespiration[7]. The photosynthetic capacity is therefore higher and the water use efficiency substantially better. This is an advantage for C_4 plants, such as corn. The major crops have a C_3 photosynthesis.

The possibilities to influence the basic physiological processes through different genetic traits are very limited.

The efforts for a C_4 rice plant were started some 20 years ago, initiated in IRRI when Swaminathan was the Director General[8]. The physiological processes that determine the allocation of photosynthesis compounds to stem or root may however be influenced by the availability of water and nutrients and the physiological response. That process may be affected by genetic traits. In fact, the short straw varieties of wheat and rice that laid the basis for the green revolution were developed by Borlaug and Swaminathan in the early seventies and earlier already in wheat in the fifties in Germany. This was a major step in increasing the harvest index, which is pivotal for the increase in yield in the small grains.

In fact, Swaminathan started work in potato where the harvest index was much higher, 0.8, due to the absence of the need to maintain a support system for the potato. That is different in small grains where the traditional varieties could reach a harvest index of 0.35 and the modern short straw varieties have a harvest index of 0.54. With the same total biomass the grain yields are therefore considerably higher. Moreover, due to yield-increasing measures such as adequate plant nutrition and water management, the total growth and biomass increased considerably. The net result was a discontinuity in productivity rise in these two crops. In the fifties of the last century that discontinuity in wheat yields was seen in Europe and the USA and in the seventies in rice in Asia and Latin America. Yield increased from 8 to 15 kg ha^{-1} $year^{-1}$ to levels between 80 and 150 kg ha^{-1} $year^{-1}$. Therefore the incremental increase was in a discontinuous mode substantially higher than before. The major reason for this discontinuity was the synergism between various disciplines, breeding delivered the short straw varieties with a higher harvest index, fine-tuned irrigation resulted in the decrease of water shortage, plant nutrition and soil fertility resulted in the elimination of nutrient shortage during part or the whole growing season and crop protection resulted in a considerable reduction in growth and yield reduction due to pests and diseases.

The role of breeding as the engine behind the green revolution is in many cases overestimated, but not by Swaminathan. He made it clear that the combination of disciplines was needed and laid the basis for the substantial increase of crop productivity.

The role of the growth and yield-defining factors was visible in the physiological traits, photosynthesis, allocation of assimilates, respiration and ageing. These effects are clearly accepted and adopted. The role of scientists under the leadership of Swaminathan was to consider the possibilities of changes in these physiological traits, especially changes in allocation and ageing were impressive.

The other growth and yield-defining factors, geometrical, optical, phenological characteristics may be affected by breeding and agronomic measures. Breeding for more erectophyle crops, especially in small grains such as rice, is possible and was one of the major characteristics that changed in the earlier IR varieties, IR8, IR36, etc. It influences the absorption of light and results in a higher photochemical reaction. Similar effects are attained by changing the optical characteristics of crops. Through better plant nutrition, the optical characteristics are affected, more dark green leaves, and a longer life for the flag leaves and the chaff resulting in a higher net photosynthesis.

The fertilization around flowering is important to gain that effect. The net photosynthesis increases per day, but more important is the longer life of the leaves effecting total productivity.

The physiological, geometrical and optical traits may be affected by new varieties, resulting in higher growth and yield, but the biggest effect is due to the allocation of assimilates, harvest index and the phenology of the crop. The phenology of the crops may be considerably affected by genetic changes.

Phenological changes in rice have resulted in the possibility of three harvests per year, in wheat the extended grain filling period was a result of phenological change.

The way Swaminathan was capable of bringing all these genetic aspects together was rewarding. His earlier work in the fifties was on potato, a major crop for the European and American populations, laid the basis for his work for the majority of the world population in Asia. The high harvest index in potato, more than 0.8 as support, is not needed contrary to small grains, enables a very high productivity. The very high water use efficiency and the possibility to harvest part of the growth and yield before the completion of the growing season makes it a very attractive food crop. The role of potato in world food security during the last decades has increased considerably and is also based on the genetic analysis of potato by Swaminathan. His Ph D thesis was partly based on his work in Wageningen where the genetic analysis of potato was studied. After his Ph D in England (Cambridge), Swaminathan moved to Wisconsin, the homeland of potato growing in the USA. His contributions to the better understanding of genetic traits that define the growth and yield are impressive. Growth and yield-defining factors are pivotal for the attainment of potential yields. However, the circumstances are never optimal and therefore the yields attained are much less than the potential. The limitations due to absence of sufficient plant nutrition and water will result in an obtainable yield which is below the potential[9]. In many cases the absence of these yield-increasing components results in substantially lower yields, often less than 50% of the potential. Adequate measures include use of irrigation and inorganic fertilizers. In the majority of agricultural land irrigation, sometimes supplementary may remove yield limitation due to water shortage. In young alluvial soils, where the most well-endowed soils are found, the availability of sufficient plant nutrients is not a problem. However, in many cases, especially in semi-arid regions, soil fertility problem results in a situation where the best form of irrigation is fertilization. For example, in the Sahelian regions and in many places in West Asia and North Africa such limitations are more profound than water shortage as such. Irrigation may in such circumstances lead to a stronger exhaustion of already poor soils and therefore rather poor yields. The systems approach propagated by Swaminathan may help identify limiting factors in the growing cycle and take adequate measures to overcome their negative effects. His commitment to a programme, where systems approaches in rice research were promoted, was started in IRRI in the early eighties with strong involvement of Wageningen University. All disciplines then fall in place: soil fertilization by a combination of bringing a good structure and texture with sufficient organic material and the increased mineral content by the use of inorganic fertilizers. This combination in a sophisticated manner is a typical example of ecological literacy as proposed and promoted by Swaminathan for an evergreen revolution. Overuse of fertilizers or overestimation of the role of organic matters is then absent.

Fine-tuning to context, circumstances and social and environmental possibilities is needed and possible. It requires good understanding of the basic physical and chemical processes and its operationalization at field level. Experience and expertise enriched with adequate knowledge may help to create an optimal set of growth and yield-increasing measures. As in many cases such a balance in interventions and inputs is absent and the consequences in terms of suboptimal use of inputs and negative side effects may occur. This is the major reason for environmental pollution and for example a substantial contribution to greenhouse gas (GHG) emission by agriculture. The studies of such effects have shown that the suboptimal use of inputs has created a tremendous effect on GHG emissions. For example in suboptimal livestock systems, it is shown that 'livestock's long shadow' is causing enormous GHG emission in terms of CH_4 and NO_x emissions[10]. Adequate measures in land use, treating manure, sophisticated stables and adapted diets will reduce such effects considerably. Modern high productive livestock systems scarcely contribute to GHG emission and may even be a net consumer of GHGs such as CO_2. The same holds for high productive paddy rice systems, seen as the major contributor to the emission of CH_4 through the anaerobic processes occurring in irrigated rice systems. Counterintuitively it is demonstrated that high productive systems with precision agriculture and fine-tuned production ecological measures result in much less GHG emission. The explanation for that effect is the way the root systems in such high productive systems function. Surpluses in carbon are absent as the activity of the growth needs it and anaerobic processes resulting in CH_4 emission are substantially decreased.

These examples in various farming systems may be seen as climate smart agriculture. The climate smart agriculture is nowadays accepted and adopted as a way to contribute to the reduction of GHG emission by agriculture. Contrary to many preconceived ideas or ideologically motivated opinions, the climate smart agriculture is not back to the past with low productive systems where suboptimal growth and yields dominate but a way forward based on good production-ecological insights and implementation of best ecological means. In well-endowed soils the high productive systems reach the highest efficiency of external inputs and the lowest GHG emissions, in marginal lands with less endowed conditions low productive systems are best in their contribution to efficiency and GHG emission. Contrary to general belief, it is therefore needed to make best use of well-endowed land and good conditions and make limited use of poor land and treat them in a much less production-dominated way. Other objectives, such as social and landscape aims, may be approached in these conditions.

Such insights have immediate effects on the attainable yields and may contribute to productivity increase, reduction in GHG emission and reduction in negative environmental side effects such as overuse of external inputs. This may also result in more empowerment of farming communities as use of inputs is optimized. A win (productivity), win (climate smart), win (less environmental pollution), win (empowered farmers with efficient and effective farming methods) situation may be promoted. This is the basis for the evergreen revolution. But there is more.

Ecological principles of production show that the actual yield is a result of yield-defining, yield-limiting and yield-reducing factors. The two concern with the influence of pests, diseases and weeds. They affect the actual yields. Pests and diseases are common and seen as nearly inevitable. However, detailed analysis shows that the majority of yield reduction is due to mismanagement resulting in upsurge of pests and diseases. Too rich crops, too early application of pesticides or too much neglecting the ecological processes that determine the self-reliance of production systems may result in considerable reduction of growth and yield. Crops made resistant to pests and diseases will lose that resistance rather soon as the race between resistance breeding and the upsurge of new non-resistant strains through mutations, is a race without finish. That race is never won. It will and should continue but strongly supported by the possibilities of biological control. The majority of pests and diseases are suppressed to a level that is acceptable when biological control mechanisms are fully used. In fact, after a period of too much reliance on use of pesticides we are now approaching a way to develop best ecological means even further.

A risk accepting attitude for the short term day-to-day management of crops may be much more risk adverse in terms of promoting a more robust and less volatile systems than when the risk averse attitude for the short term is adopted resulting in too rapid use of pesticides, and too much reliance on crop protecting measures. A more ecological advanced approach is less risk adverse for the short term, but relies on the resilience of ecological systems of production, which is for the long-term much better and therefore risk adverse. Advanced crop protection systems monitor, supervise and act only when there is no other possibility, primarily with biological control measures, but ultimately with selective use of pesticides.

This approach is characteristic for the evergreen revolution promoted by Swaminathan. It requires much more ecological knowledge, extensive experience with biological systems, understanding of ethological, ecological, physiological and evolutionary processes.

The simple fact that it works is demonstrated in closed systems such as in greenhouses where biological control dominates and scarcely any pesticide is used. Also, open field systems such as fruit orchards and many other systems have adopted this approach. The bond between biologists who develop the ecologically advanced systems and the farmers community has to be very strong, to empower the latter in their confidence and trust that they can manage and control the living system and are not surprised by disasters they could prevent.

Farmer field schools promoted by Swaminathan in the early seventies have demonstrated that empowered farmers with good understanding of the ecological systems and with sufficient access to the means of control have resulted in the precision agriculture and best ecological means that characterize the evergreen revolution.

The actual yields may then be not too different from the attainable yield and thus losses are very limited. However, the available yield in many cases is substantially lower than the actual yield as a result of postharvest losses. In many places around the world, these losses are very high due to consumer behaviour, dumping food and leftovers, and inappropriate storage facilities. This may then lead to economic and food security problems. Therefore consumer behaviour in the West and adequate storage facilities in the developing world should be improved to eliminate losses. There is ample opportunity for a sustainable decrease of postharvest losses, be it through adaptation in behaviour or by technical measures tuned to the specific possibilities and interests of the various parties in the food production and consumption chain[11]. Swaminathan's mission pro-poor, pro-environment, pro-women and children is a beacon for the development of agro-ecosystems that contribute to food and nutrition security, and empower farmers and their organizations.

Inclusive thinking and inclusive approaches

During his long journey in science and its application, Swaminathan always demonstrated how inclusive thinking might lead to self-confident, civilized and respected people and communities[12]. As a young scientist working in genetics and plant breeding, he demonstrated his skills of bringing environmental issues, social issues and morality to the table of the pure and applied scientists. His attitude and his way of working where doubts were absent and a clear compass was present was not only convincing but removed any objection before a controversy could appear. This attitude and the way of working where inclusion of various aspects was done, was present all the time. It was present in his role as an active scientist in the fifties and sixties, in his role as an administrator in the seventies and eighties and his role as an opinion leader and a policy maker. He made things work and never met any resistance.

At the beginning of the green revolution, his conviction and approach were accepted and adopted by the policy-makers and the leaders at local, regional and national levels. He made it clear that environmental objectives and aims are not hindering or limiting agricultural progress, but seen as a challenge to develop more resilient and inclusive production systems. His thinking was based on the insight that synergism can be promoted and attained when various aspects are internalized and used. Environmental aims are in that case not a liability, but an asset for the production systems. Social issues and especially gender issues are not an hindrance in the progress of such production systems, but an accelerator in their acceptance.

This thinking may also help us understand the strong support for the evergreen revolution. It is a step in an historical development of agriculture during the last decades. The increase in productivity in agriculture was during many ages only incremental. Due to changes in the way agriculture was organized and insight in soil fertility and traditional breeding methods increase took place with 5–8 kg ha^{-1} $year^{-1}$. This was visible at many places where agriculture played an important role. At the beginning of the 20th century, it became possible to enrich soils by making use of inorganic fertilizers and that was the start of an acceleration of productivity. The possibility of protecting plants against pests and diseases with pesticides was another basic component of productivity rise and the improved water management accelerated the productivity in major staple crops considerably in the industrialized world and also at other places. The chemical revolution in agriculture started after the World War II. This had dramatic effects on the growth and yields of crops. It enabled the green revolutions, discontinuities in productivity rise in the western world in the fifties and in Asia and Latin America in the seventies. The yield increase reached levels of 80 to 150 kg ha^{-1} $year^{-1}$. The combination of knowledge and insight from different disciplines, plant breeding, soil fertility, and plant nutrition, water management and irrigation and crop protection caused productive synergisms. The yield increases were due to better harvest indices as a result of new varieties, more biomass through better water availability and plant nutrition, longer active assimilation of leaves due to better crop protection[13]. The results of that increase of productivity per ha have supported food security and safeguarded many hectares for other purposes such as maintaining biodiversity.

The support in the chemical revolution in agriculture in the fifties was enormous. The optimism that productivity could be increased and chemical warfare was adequate was widely spread. However, early warnings against this development were already given in the fifties and sixties. Swaminathan was one of them. At many places the warnings were ignored and the dependence on fertilizers and pesticides was increasing. The need to promote other ways of crop improvement and yield increase was felt in many biological and agricultural circles. Yield-increasing measures by removing limitations and yield-protecting measures through sophisticated methods were more and more developed. The adoption of new more harmonious methods of yield increase and yield protection was stimulated by farmers field schools. Already in the early seventies Swaminathan promoted those approaches that were extended during the last decades.

In 1983 Swaminathan organized an International dialogue on New Technologies: Reaching the unreached – III Ecotechnology and Rural Employment at Chennai. It was then he proposed that technologies should marry ecology, so that technologies become harmonious with ecology. He went on to blend frontier technologies (space technology, biotechnology, nuclear and modern information communication technologies) with traditional knowledge and ecological prudence of the tribal and rural communities, particularly of the women of these communities and provide pro-nature, pro-poor, pro-women and pro-livelihood orientation to the technology development and dissemination in the rural areas. Federico Mayor the then DG of UNESCO was impressed with Swaminathan's concept of mainstreaming ecology in technology development and dissemination with the result that in 1993, the UNESCO created a Chair in Ecotechnology for M. S. Swaminathan. Mayor also gave an endowment grant for the chair. Later the UNESCO conferred the Mahatma Gandhi Prize on Swaminathan. This illustrates the way Swaminathan came with a systems approach long before the concept became more fashionable as in the 21st century.

The inclusive approach where more objectives and aims had to be served than only yield increase became a key in all developments of the work of Swaminathan in India and abroad. His influence on the development of best ecological means instead of yield maximization or traditional agronomic improvement is very strong. Best ecological means make use of the best biological knowledge and experience and is based on good understanding of agro-ecosystems and the way they may be optimized. In the way societies operate the concepts of best economical means and best technical means are widely accepted and adopted. The latter makes use of the best of technical know-how and principles, but that is not always economically feasible. Therefore both concepts are used next to each other. Environmentalists promote the use of best technical means and presume that economies have to adapt or make use of these technical advancements. Environmental policy has made enormous progress through the use of these concepts. Similar possibilities have been developed, used and implemented in agriculture. Land use, technical possibilities, use of inputs etc. are considered in the concept of Best Ecological Means instead of best technical means by using these insights. The individual crop or field is then used and managed in the context of the farming systems most widely defined. That implies the use of methods of precision farming and integrated pest and disease management, but also the involvement of farmers and their families in an advanced way. Swaminathan introduced these concepts, methodologies and approaches at many places comprising the ultimate users, the farmers and their families, the knowledge institutions and the enabling and empowering local, regional and national authorities[14]. His approach was in this way unifying and had therefore a tremendous impact in terms of productivity rise, environmental effects such as better management of resources and an emancipating effect on local communities.

This is typical for an inclusive approach where liabilities are translated and amended in such a way that they may be seen as assets. The too narrow and focussed approach may result in better yields, but side effects are neglected. It was a major problem during the chemical revolution in agriculture in the fifties and sixties. The approach developed and advocated by Swaminathan is not suffering from that blinker mentality. He proposed in his work in India as the engine behind the green revolution already had a much broader approach. He advocated this as Director General of IRRI and made it an explicit objective and trademark of the M.S. Swaminathan Foundation. This inclusive way of working and use of best ecological means is a major characteristic of Sustainable Development and Food and Nutrition Security.

Swaminathan's plea for the battle against hidden and chronic hunger was promoting this inclusive approach. Globally the approach is fully accepted, but adoption is not yet complete in some regions. The dramatic increase in global food security demonstrates that there is ample reason for optimism.

Public policy

The impact of science is limited when the implementation of new concepts and ideas is not successful. In the fifties Swaminathan was convinced that he had a role to play in the strengthening of the scientific insights and achievements in practical activities. His skills in genomics were immediately applicable in the tuning and focussing of plant breeding. In potato research, he used these skills extensively which resulted in the first steps to hybrids in potato. His decision to go back to India early in the fifties after a scientific programme in Wageningen University and a Ph D from Cambridge University and a post doc position in Wisconsin was based on the conviction that he had to contribute to agricultural development in India. Food security for the rapid growing Indian population was the aim. This required appropriate research, but even more importantly, the right policy to get scientific insights adopted and used in various interventions.

This paved the way for the green revolution in rice and wheat in India. The short straw varieties developed by Norman Borlaug were immediately used in programmes in India under the leadership of Swaminathan[15]. He was instrumental in the development of new varieties and their implementation making use of the appropriate agronomic measures. In his role at that time as leader of the Indian Council for Agricultural Research (ICAR), Swaminathan was responsible for the adoption and promotion of new technologies. He took crucial decision to have demonstration fields with the mainstream farmers. The adoption of new varieties and technologies with the support of the government policy was successful due to this decision. The basis of appropriate public policy was crucial for the rapid adoption of new technologies and varieties and maintaining the momentum. The role of Swaminathan was pivotal in this process. His role in International Rice Research Institute was strengthening the scientific activities, initiating new partnerships and importantly, building up critical mass in agricultural research in general and more specifically in rice research.

National programmes and national institutes were created in many Asian countries and policies to make better use of research-driven productivity rise in agriculture. Policy in this case is more than legislation, but especially the right decisions for subsidies or non-subsidies in inputs or guaranteed prices, and last but not the least capacity building. The critical role of an experienced policymaker was the reason for success of these programmes in China, the Philippines, Vietnam, Kampuchea and Laos. The role of a policymaker is also an obligation to the society.

The experience in policy making and scientific leadership made Swaminathan a very appropriate person to lead the FAO council. His role there was again very important as he was successful in bringing the debate on a higher level; dialogues took place and, importantly the policy on gene banks and maintaining the genetic traits *in vitro* and *in vivo*, was adopted. This is critical for future generations and in that way Swaminathan was well positioned to create unanimous decisions and a clear policy in various fields, especially in the field of food and nutrition and in the field of biodiversity and genetic policies. The Codex Alimentaris and the regulations on gene banks and biodiversity were initiated or approved under his leadership. More recently, he was successful in including farmers rights and property rights for breeders based on breeder's rights in India. All these activities were close to the core competence of Swaminathan.

The same approach based on authority, convincing arguments and commitment to sustainable development was very effective during Swaminathan's period as president of IUCN. The support for nature conservation increased and the polarization between agriculturalists and nature conservationists disappeared and common goals and common ambitions were attained a typical example of the possibilities of inclusion based on conviction, understanding and respect. That was his trademark which also was demonstrated during his presidency of Pugwash. That important movement of scientists oriented to peace and justice was one of the bridges between East and West during the cold war in the fifties. The scientists were convinced that open communication channels would help depolarize political and ideological gaps. They succeeded in strengthening mutual understanding and maintaining stable relations. When Swaminathan was asked to chair that important movement, he succeeded in broadening the agenda, making it clear that management of natural resources and water for nature and agriculture are vital components. Therefore his plea and approach was adopted and became a new revitalizing activity of Pugwash.

Concluding remarks

The above illustrates the pivotal position of Swaminathan has had in many places. His role in science was clearly described and illustrated. His interest in the basic principles of biology and physical and chemical processes, and his knowledge and experience in genetics were the basis of his role as a leader in science.

He laid the basis for a productive and clean agriculture, increased the biological knowledge and was a typical representative of the New Biology. That biology is different from the traditional biology where description and categorization are typical and science for science sake dominates. In the New Biology, the connection with the fields in which biological understanding and insight is needed, dominates. For example in the field of health and nutrition, or in the field of production ecology and also in the field of development, or in neurosciences, biologists play a role different from that of classical biologist. Swaminathan exemplifies New Biology.

In his work Swaminathan may be characterized by his typical approach. He was and is undogmatic and strongly convinced of his mission leading to more food security and nutrition security. This requires enlightenment and a socio-liberal attitude. His belief in democracy and in the power of arguments and conviction stimulated dialogue and discussion, which create mutual respect and understanding and in fact also consensus.

Swaminathan's slogans, pro-poor, pro-environment, pro-women, and his plea for an evergreen revolution are stimulating. The power of his one-liners is very strong and very instrumental as they are based on idealism, conviction and internalized and honest opinions. The living legend has been active in all domains that complement sustainable development: food security, water use and saving, natural resource conservation and management, maintaining biodiversity and finally energy use. This does not mean a caring or conserving attitude in all domains. Such an attitude is not possible in all domains because of conflicts that may occur. Therefore productive, efficient and effective agriculture to attain food security, water saving and recycling and upcycling of natural resources and safeguarding hectares for biodiversity and agro-ecosystems that guarantee agro-related biodiversity.

Energy supply making use of solar, direct and indirect, is possible, but biofuel and bio-energy cannot be combined with the aims of other domains. Swaminathan made this clear in many of his lectures and reports. The promotion of inclusive thinking was demonstrated in all his positions and responsibilities. Various components come together in a synergistic manner and are therefore more than a technical exercise. His attitude and his successes with concrete and practical examples illustrate how inclusive thinking will bring the various disciplines together to bridge the gap between aggregation levels and make more stable and robust solutions for problems possible. That way of thinking was already demonstrated by Swaminathan before the concept was introduced.

His role in the public domain and in public policy was always oriented towards harmony, mutual respect and on that basis a very clear and aim orientation. He exemplifies the crucial role leading scientists may play in society and in public policy. He was outspoken, but never with disrespect and therefore completely respected and accepted. His leadership in organizations such as IRRI, IUCN, Pugwash, FAO, HLPE, CFS and many others shows his global orientation, but he never forgot his crucial role in India where he played a pivotal role in Agricultural Sciences, Policy and as a society leader.

It is an honour and privilege to have had the opportunity to work with him for more than thirty-five years and have enjoyed his warmth and friendship during such a long period.

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