# Domestic Agriculture Sector in the Post - Green Revolution Era: Science and Research Gap

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Sri Lanka is one of the earliest countries to produce new improved varieties through hybridization during the green revolution and adopted the breeding method such as mutation breeding. However, Sri Lanka has been lagging in exploiting science for technology development in agriculture in the recent past. Sri Lanka still cultivates varieties that were developed or introduced in its early adoption up to today and in some instances, it is the only promising variety grown for years.

At the beginning of the '90s, Vietnam rice yield exceeded the Sri Lankan rice yield. Rice varietal development in the 1990s in Sri Lanka and later couldn't push the yield potential that was acquired by outstanding varieties such as Bg 94-1 developed in the 1970s. Rice varietal development in the 1990s and later mainly focussed on breeding varieties against pests and abiotic stresses. Soybean variety PB 1 is cultivated now for 40 years. Dambulu Red selection, a local selection of Pusa red emerged as a promising cultivar of big onion after 30 years of its cultivation. Granola is the only promising variety cultivated in potato farming. 'Mauritius' is the widely cultivated pineapple variety for known years. Agricultural research in the last few decades has not made breakthroughs in technology generation except the introduction of MICH HY 1, late but promising chilli hybrid superior to imported hybrids developed in 2015. It is the main breakthrough in varietal technology development in the recent past.

This paper addresses the historical purview of agricultural research in Sri Lanka to show that there exists a research gap and science gap (Evenson 2000)[1] and that Sri Lanka has drifted from its innovation path due to internal and external factors that influenced the ecosystem of agricultural research. This review is supported from the main writings of Adam Pain (Pain, 1986) who analysed the agricultural research ecosystem in Sri Lanka up to 80's exemplifying vital and competent research organization and programme Sri Lanka had during the 50s' to '80s. Literature citing green revolution (Cummings, 1970; Davies, 2003; Patel, 2013) about its origin, its spread to Asia and the establishment of CGIAR institutes and the development assistance are taken for discussion to understand the influence of external factors on national agricultural research

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[1] Evenson defines the research gap as the difference between research potential yields and best practice yields. Research potential yield is the hypothetical best practice yield that would be expected to be attained as a result of a successful applied research program directed toward the particular crop. Science gap exists between science potential and research potential yields. The science potential yield is also a hypothetical yield and it is the research potential yield attainable if new scientific discoveries (e.g., in biotechnology) are made and utilized in an applied research program.

programs of the country. The recent varietal development in neighbouring countries in Asia is next discussed. Adaptation to changing development paradigm in these countries, particularly the private sector taking up in breeding programs, collaboration with international development assistance partners, and multinational engagement in agriculture is discussed.

The history of the world's agricultural development elucidates that even the least developed countries had established agricultural research institutes of some form or the other by the mid-20th century (Wickramasinghe et al, 2020). The seeds of agricultural research had been laid in Sri Lanka in as early as 1822 at the Royal Botanic Garden at Peradeniya in the form of botanic investigations of indigenous plant varieties with possible commercial potentials. Department of Agriculture was set up in 1912, but the early activities and focus of the Department reflected the economic crop bias of the Botanical Gardens. Initial research was underway in collection and selection of improved rice varieties and during the 1920s, many selections were made that were subsequently to be used as parents for some of the most important rice varieties to come out of the Batalagoda rice breeding programme in the 1960s and 1970. The period before Independence most of the research work was on laying the basic approach to the fundamentally sound fertilizer recommendations based on soil types. An experimental station had been based at Maha Illuppalama (MI) since the twenties concentrating particularly on cotton research.

When the contemporary new agriculture technology /varietal development in Sri Lanka during the green revolution is studied, it is evident that Sri Lankan agricultural research offers evidence of a vital and competent research organization and programme. The country followed or some time led the concurrent development in agricultural research outside Sri Lanka. Unlike many other ex-colonies, the process of localization of the colonial bureaucracy took place long before Independence in Sri Lanka and DOA had a trained and experienced professional cadre. Director of Agriculture, E. Rodrigo, whose experience in 1938 of Indian research on dryland agriculture was to lead him to encourage a more systematic enquiry into the resource base of Sri Lanka's dry zone.

Green Revolution is a set of research technology transfer initiatives occurring between 1950 and the late 1960s that increased agricultural production worldwide, beginning most markedly in the late 1960s (Hazell, 2009). The initiatives resulted in the adoption of new technologies, including high-yielding varieties (HYVs) of cereals, especially dwarf wheat and rice. It was associated with chemical fertilizers, agrochemicals, and controlled water-supply (usually involving irrigation) and newer methods of cultivation, including mechanization. All of these together were seen as a 'package of practices' to supersede 'traditional' technology and to be adopted as a whole (Farmer, 1986).

In early 1941, the seeds of green revolution were planted, when the Rockefeller Foundation sent a team to survey Mexican agriculture. In 1943, the Mexican government founded the International Maize and Wheat Improvement Center (CIMMYT), which became a base for international agricultural research. The government also created the Mexican Agricultural

Program (MAP) to be the lead organization in raising productivity. Mexican Agricultural Program (MAP), to which in 1944 a young biologist named Norman Borlaug was hired.

Discovery of dwarfing genes in the Norin wheat variety by Japanese scientists provided the technological breakthrough for wheat when agricultural researchers sought to reconstruct the architecture of the plant to overcome physical limitations to higher yields. It was brought to the U.S. in 1946. Norman Borlaug's research work in Mexico produced 'miracle wheat' as early as 1954 and released several dwarf spring varieties (to which the photo-period insensitivity factor was added) in their Mexican program. In 1961 the dwarf winter variety Gaines was released in Washington State. These varieties were spread by the Rockefeller and Ford foundations through the world, in the 1950s and 1960s. Rice was added to the menu, with the help of the US government toward the end 1960s. In 1970, Norman Borlaug won the Nobel Peace Prize, soon after which the Green Revolution can be said to have come to an end.

By the early 1950s, it was felt that further progress by pure line selections as a means of enhancing yield potential of rice varieties in Sri Lanka was not possible, partly because of the narrow genetic base of the indigenous Sri Lankan varieties. Pure line selections had shown only a 10% yield increase over the unimproved varieties. Already by 1920, the Japanese had exhausted the potential for pure line selections as a strategy for improvement of rice and were embarking on their hybridization programme. International Rice Commission was also of the view that Indica rice varieties, the type grown in Sri Lanka and elsewhere in monsoonal Asia lacked the yield potential of the japonica varieties and an international Indica—Japonica hybridization programme was developed by the IRC to transfer the yield potential from japonica to the Indica varieties. The problems of sterility in these crosses were however such that Dr Chandraratne, chief botanist at the time, rejected this as an approach for Sri Lanka to follow and the subsequent Sri Lankan programme was to concentrate on hybridization within the Indica group.

Dr M. F. Chandraratne, Chief Botanist in the 1950s and later to become Director of Agriculture did some important early work on techniques of breeding and photoperiodism in rice; he was later to write a major textbook on rice breeding.' Sri Lankan scientists have made important contributions in the recognition of biotypes of the pathogenic bacteria and in the development of techniques for the in vitro culture of gall midge, a major rice pest.

The early 1950s saw an important phase of importation and introduction of many Indica varieties from all over Asia and their testing and incorporation into the breeding programme, which was centred initially at M.I. but by 1952 had established itself at Bathalagoda, in the intermediate zone near Kurunegala. Fernando records that 726 varieties had been imported since 1948 although few were to make much direct impact on cultivators' fields. However, Sri Lanka was one of the earliest of national programmes to produce new hybrid varieties and in 1957 the H4 variety was released with other H varieties, these have come to be known as the Old Improved varieties [OlV). It had been recognized early on in the breeding programme that environmental variation both within the wet and dry zones defined a requirement for different age classes of rice. The most important age group in terms of the acreage that it occupied was the 4-41/2 month group. H4, bred from an improved local variety and an imported Indonesian one, was of this age group and was probably the most successful of the OIV in that in some areas it came to occupy near to 60% of the rice lands, by its wide adaptability to different environmental conditions. From 1957 onwards several other H varieties were released although none were to achieve the success of H4.

In 1960, IRRI was set up as an independent, nonprofit, research and educational institute by the Ford and Rockefeller foundations with support from the Philippine government. One of the very justifications for the setting up of such international research institutes was that national research programme was seen to lack sufficient strength and organization to be able to respond to the urgent needs of food production. The primary role of the International Centres was to support and develop national research programmes both through training and the provision of new plant varieties and technologies and that the building up of local research capability in developing countries. The first Sri Lankan collaborative venture with IRRI was taken place at the same time in 1960. In 1969 Sri Lanka and IRRI renewed the program and included technology transfer activities. From 1960 to date the International Rice Gene bank holds in trust 2,027 types of rice varieties from Sri Lanka (Waidyanatha, 2014).

Developing lodging resistant varieties then became the major challenge for the rice breeders, but fortunately, a new plant type created in Taiwan around 1960, exemplified by Taichung (Native 1) paved the way. It had short sturdy lodging resistant stems and short, upright, narrow leaves which could efficiently capture sunlight. The International Rice Research Institute based in the Philippines, experimenting with the new plant type developed the variety IR 8. However, both IR 8 and Taichung Native 1 failed to perform in Sri Lanka due to several reasons. Consequently, a major interdisciplinary rice improvement programme was launched to breed short-statured lodging resistant and fertilizer responsive varieties which were also resistant to diseases. Bacterial leaf blight (BLB) by then had turned out to be a major disease both here and elsewhere in Asia. A series of new improved varieties NIVs such as Bg 11-11 (4.5 month variety) and Bg 34-6 (3.5 month variety) were released with the requisite attributes and yield potential of 7 t/ha. A major breakthrough was the development of Bg34-8 with a yield potential of 7 t/ha which became immensely popular, replacing the traditional variety Pachchaperumal with an average yield of only 2-3 t/ha. Over the years, more and more NIVs began to emerge, a major one being BG 94-1, a 3.5 month variety, which was able to replace even the existing 4 and 4.5 month varieties because of the higher yield potential and the ability to cultivate in both Maha and Yala seasons (Waidyanatha, 2014).

Through the Rice Research Project from 1977 to 1984, USAID assisted the Department of Agriculture to further develop and accelerate the utilization of improved varieties of rice and develop new cropping technology. The project funded technical assistance in production and research technology, education and training, and commodities for equipping production research farms. Five new varieties of rice were developed and released as a direct result of the Rice Research Project. New varieties were developed for resistance to pests and diseases, and adaptation to the climate and geographic characteristics of different areas (USAID, 2006).

Adam Pain argues that Sri Lankan agricultural research in the '60s to '80s offers evidence of a vital and competent research organization and programme. Concerning the production of improved techniques and plant varieties and adaptable techniques and varieties, Sri Lanka's record had been impressive. The Ceylon Daily News on 5 August 1982 reported that 'the International Rice Research Institute has selected two varieties of paddy from Sri Lanka, BG 367-4 and BG 367-7 as the best high yield varieties in South East Asia and Africa.

Since then the establishment of DOA in 1912, DOA's research service has grown into a countrywide network of 18 research institutes and centres spread around the country. The country embarked on rice varietal development program in the first of its agenda.

However varietal development bringing yield leaps Sri Lanka experienced parallel to the green revolution period was not observed in the recent past until the introduction of chilli hybrid in 2015. Yield increases observed in the last three decades largely brought about through input intensification particularly water and fertilizer, quality seed production programs and for weedicide application in later years. Rice varietal improvements were mainly against pest and disease attacks.

Although Sri Lanka was stagnating in its yield frontiers, neighbouring countries such as India, Bangladesh, and Vietnam recorded significant yield increases owing to the exploitation of science developments in particularly exploiting hybrid vigor, use of modern biotechnology in their varietal development programs.

Adoption of hybrid technology in Vietnam made Vietnam paddy yield to surpass the Sri Lankan paddy yield since the beginning of '90s. Due to the high prominence, Viet Nam placed on their Hybrid rice research program which began in 1983, Vietnam was able to bring in more land under Hybrid rice varieties that were released for commercial cultivation. Hybrids, the first generation progeny of genetically distinct and different parents, exhibit increased vigor and yield through heterosis. Hybrids are most commonly exploited among outcrossing commercial crops. Viet Nam Hybrid rice research began in 1983 intending to evaluate CMS lines, identifying respective maintainer and restorer lines, improving F1 seed production, and evaluating hybrid rice varieties developed in China and by IRRI. In the late 1980s, the Vietnamese national hybrid rice programme was placed under the leadership of the Minister of Agriculture and Rural Development. In addition to two FAO TCP projects, the government has provided a budget of about US$300 000 annually. Hybrid rice varieties were released for commercial cultivation. The area planted to hybrid rice increased from about 11 000 ha in 1992 to about 102 000 ha in 1996. F1 seed production increased from about 302 kg/ha in 1992 to about 1 751 kg/ha in 1996 (Tran et al, 1998). By 2010, the cultivation area of hybrid rice in Vietnam reached 600,000 ha while seed production covers an area of 1,500 – 1,700 ha with an average yield of 2 tones/ha providing a self-supporting of approx. 20% of the total seed demand. Vietnam is further improving the development of Hybrid combinations by solving the problems in relation to science technology for the mass production of quality rice as a rice exporting country. Expansion of private companies, joint venture and cooperation with other countries in the region, encouragement of foreign organisations and individuals in breeding investment & rice hybrid production are prioritized in Vietnam (Hoan et al, 2014).

Breeding programs on obtaining the hybrid vigour in Sri Lanka is still not a perfect technology. RRDI released the hybrid variety Bg 407-H in 2015 which has a 10 % yield increase compared to high yielding OPVs. However hybrid seed production has limitation due to low F1 yields in seed production. This is how when China first developed their hybrid seeds which they overcame later. FAO, in collaboration with IRRI, Japanese scientists, the China National Hybrid Rice Research and Development Centre (CNHRRDC) and other selected national research centres, initiated its global hybrid rice programme in 1986 to expedite the widespread use of hybrid rice technologies outside China. Sri Lanka's hybrid rice research programme started in the 1980s and by late '90s evaluation of promising CMS lines introduced from IRRI and other countries and the transfer of cytoplasmic male sterility from IRRI-developed lines to Sri Lankan lines had started. Constraints such as lack of high performing germplasms, separate hybrid unit are some drawbacks for hybrid technology practices in Sri Lanka. When rice breeding research in Sri Lanka is compared with the world, there is a huge gap between technological advancements in the breeding program although hybrid technology has the highest economics returns (Personal Communications).

Countries in the region have exploited the heterosis/hybrid vigour of chilli, maize and other cross-pollinated crops about many decades ago.

Bangladesh Agricultural Research Institute (BARI) began a programme in mid-1990 to develop its own maize hybrids in collaboration with international partners, particularly CIMMYT. During the 2000s many seed companies in Bangladesh, including Bangladesh Rural Advancement Committee (BRAC), imported and marketed hybrid maize seed from Pacific Seeds in Thailand. BARI released its first maize hybrid (BARI Hybrid Bhutta 1) in 2001. Two further maize Hybrids, BARI hybrid Bhutta 3 (released in 2002) and BARI Hybrid Bhutta 5 have become very popular since they can produce up to 10-11 t/ha of grain under optimum conditions. This was comparable with or better than imported commercial hybrids, such as Pacific-11., BARI has so for released six other maize hybrids with complete management technology packages. Also, Bangladeshi farmers cultivate Syngenta hybrids such as Sunshine, Monsanto hybrids such as Pinnacle, 900 m Gold, 981 apart from pacific varieties (Pandey, 2017).

Bangladesh has also produced several hybrid potato varieties for commercial cultivation.

In 1998 Sri Lanka initiated a program to meet the requirement of developing hybrids locally by introducing inbred lines released by the International Maize and Wheat Improvement Center (CIMMYT) in Mexico, and Thailand, to develop hybrid maize varieties locally. The maize is given as the priority crop under other field crops in research and development programs at Field Crops Research and Development Institute of DOA. The several OPVs and hybrids were developed in the country in collaboration with CIMMYT during last 40 years. The initial program was solely dependent upon exotic inbred lines in which over 160 different hybrids were developed between them, which were evaluated for yield and other desirable grain characters. Simultaneously a program was launched to develop inbred lines locally after deliberate selection of source materials, to give rise to high heterotic progenies. Although farmers are demanding hybrid maize seeds and 95% of maize area is under hybrid maize, 95% of the total hybrid seed requirement is met by imported high yielding hybrids.

India has the highest genetic variability for chilli and has been able to bring in 25 % of its chilli area with F1 hybrids. Currently, commercially local types (including landraces), open-pollinated improved varieties and hybrid cultivars are being grown in the country. Fifty per cent chilli growing area is under local varieties, 25% of the area is under improved OP varieties and the remaining 25% area in under chilli F1 hybrids (Reddy, 2016). Stable maintainers and high GCA restorers are developed in hot chillies and Paprika's at Sarpan Agri Horticultural Research Centre, Dharwad, Karnataka, India and is in use since 1996-97. Sarpan has developed 42 F1 hybrids using CGMS technology and released for the market for commercial use (Gaddagimath 2016).

First local chilli hybrid, MICH HY 1 developed by the Department of Agriculture was released in the year 2015 with the green chilli yield potential of 32t/ha. The country has a very high genetic variability. But we are late adopters of this technology. Although hybrid program in Sri Lanka was delayed, the hybrid varieties developed by FCRDI of DOA are superior to many exotic hybrid varieties. In 2015 the 1st local chilli hybrid, MICH HY 1 was developed by the Department of Agriculture in their chilli hybridization program that started in 2009. MICH HY 1 performs well in all the major chilli growing areas within the country during both Yala and Maha seasons. This variety is moderately resistant to Chilli Leaf Curl Complex, the major problem in chilli cultivation within the country. The price of imported hybrid seeds is very high and most of the exotic chilli hybrids are highly susceptible to major pest and diseases in chilli showing less adaptability under local condition. Local hybrid varieties exhibit superior characters than most hybrid imports. Therefore this technology breakthrough can shift chilli production frontier with supported intervention and there is a scope for harnessing hybrid vigour further through the varietal development program.

As the Biosafety Decree’s Vietnam was approved in 2010, Ministry of Agriculture and Rural Development of Vietnam began issuing permits and regulating field trials of GE crops (USDA a, 2018). Since 2015, Vietnamese farmers have started to commercially grow genetically modified (GM) corn for animal feed to reduce its reliance on foreign suppliers mainly from the world's top producers of GM crops like Brazil and Argentina. Vietnam ranks 23rd on the list of 29 countries that allow GM crops and has plans to increase the country's farmland with GM crops. A report on GM crops grown in southern Vietnam shows that productivity has increased by between 16.5 per cent and 25 per cent compared to non-GM crops. Vietnamese farmers are cultivating three varieties of genetically-modified corn supplied by the Swiss firm Syngenta that are resistant to pests and produce higher yields.

In Bangladesh GM crop development programs are underway, although commercial cultivation has not begun yet. Bangladesh Agricultural Research Council (BARC) and Bangladesh Agriculture Research Institute (BARI) jointly with Michigan State University are researching to introduce '3R-gene potato', a genetically modified organism (GMO) or biotech potato variety. BARC recently developed GM blight resistant (RB) potato and are waiting for approval for field cultivation (BARI, 2020). The Philippines takes lead in approving/commercializing Bt maize and Glyphosate tolerant maize (USDA b, 2018).

Jones envisages a continuum of technologies within modern biotechnology, existing as a gradient from “lower-tech” processes from biologic nitrogen fixation to tissue culture, to the “higher-tech” recombinant DNA techniques for diagnostics and genetic engineering (Davies 2003).

In Sri Lanka, Biotechnology research in agriculture is confined to “lower-tech” processes. Nevertheless, tissue culture technology has only been successful in potato propagation and banana propagation in Sri Lanka. Until the biosafety policy is formulated in Sri Lanka, higher technology cannot be tested in the fields.

It is evident from above that Sri Lanka has somewhat drifted away from the global research and development programs since the mid-'80s. Several reasons can be attributed to this including internal and external factors.

Changing the development paradigm played a significant role in agricultural productivity improvement in developing countries. CGIAR played an important role in agricultural productivity improvement during the green revolution period. International agricultural research was seen as an example par excellence of open-source approach to biological research. International agricultural research centres act as a global biological commons in genetic resources and this formalization was implemented through an elaborate system of international nurseries with a breeding hub, free sharing of germplasm, collaboration in information collection, the development of human resources, and an international collaborative network (Byerlee, 2009). Sri Lanka was successfully engaged in collaborations with international partners during this period. Gene transfers for paddy NIV during the green revolution period is a historical breakthrough in technology generation.

In the early to mid-1990s, the germplasm sharing and international breeding programs of the CGIAR that had operated as what was essentially informal open-source programs came under stress from a number of quarters. The first of these was the decline in funding for core operating costs of the networks. Second, private sector breeding and biotechnology programs rapidly expanded in the North with implications for a free exchange of germplasm. Third, two international treaties were developed largely outside of the agricultural arena, but which impinged strongly on the incentives and rules of germplasm sharing. These changes affected the freedom to exchange germplasm at different stages in the breeding/seed cycle and led to uncertainty and higher transactions costs in international germplasm exchanges, which in some cases resulted in reduced germplasm flows (Byerlee, 2009).

The United States first introduced the idea of patenting living materials in the 1980s and Western countries soon followed their lead. The number of patents on plants worldwide has increased a hundredfold from just under 120 in 1990 to 12,000 today – 3500 of them are registered in Europe (Tippe et al 2020).

Private sector and multinational companies are dominating in the seed industry and patenting of plants. Patents add to a picture of decreasing competition that benefits large companies, but is detrimental to small-scale, regional plant breeders and farmers - and ultimately to the food security. Furthermore, these patents are not restricted to seed production, they are also being granted on the harvest e.g. on kernels, fruit, vegetables and food production. For example, in 2016, patents were granted that cover conventionally bred barley, the process of brewing and the resulting beer. There is growing discontent over the role and practices of the EPO, which regards the granting of patents as a business and a service for industry, but which disregards wider public interests (Tippe et al 2020).

In parallel, there are increasing concerns about market concentration in the field of plant and animal breeding. Companies such as Bayer (Monsanto), DowDuPont and Syngenta are the 'seed giants' that are increasingly attempting to monopolise seed, harvest and food production, in particular, through the abuse of patent law. As a result, Bayer (Monsanto) controls around 30 per cent of the international seed markets. The second-largest seed giant, the US-based company DuPont, recently completed a merger with the US company, Dow AgroSciences to become DowDuPont, and now has a market share of around 20 per cent. This means that just two companies, Bayer (Monsanto) and DowDuPont, will control more than half of the global seed markets. The third-largest company in this sector is the Swiss company Syngenta, which was bought up by ChemChina, and controls a further approximately 10 per cent of the trade-in seeds (Tippe et al 2020).

International development assistance also took a different dimension that multinational companies that are themselves became part of development assistance. The conditions of international philanthropy capital in agriculture technology development in foundations such as the Rockefeller and Ford foundation during the green revolution are different from those at present like the Gate foundation. The alignment of capital to state is no longer a phenomenon. The interests of Yara and Monsanto (now Bayer) are disjoined from the interests of governments of Norway and the United States. During the Green Revolution, the developmental state mattered. Years after the Green Revolution, state matters and inter-state and inter-firm competition is seen as the emergence of sovereign wealth funds, particularly from China, India and Brazil (Patel 2013).

The emerging private seed sector in Bangladesh includes both multinational companies and domestic seed businesses. The leading seed companies in Bangladesh are Monsanto (Bangladesh) Limited, Syngenta (Bangladesh) Limited, BRAC, Pioneer, Advanta, National Agri Care, CP seed, Alfa Seed International, Rashel Seed, Lal Teer Seed Limited, ACI Seed, Auto Equipment Ltd., Kushtia Seed Store, Siddiquis Seeds, Supreme Seed Company Ltd., Alpha Agro Limited, Getco Agro Vision Ltd., United Seed Store, Agri Concern, etc. Most of the world‟s seed multinationals get cultivars into Bangladesh through locally owned collaborating companies (Siddique et al, 2015). Indian private sector investment in the crop breeding programs and the seed industry is significant.

Sri Lanka also benefited from the varietal technology development products of these multinationals and other countries through imports. In particular, liberalization of seed imports in the country in 1990 and the withdrawal of local extension agents of DOA, KVSs, private sector became the main player in the seed trade and government gradually withdrew from seed production. However, some varietal imports were restricted according to the Seed and Plant Quarantine Act. The first hybrid maize seeds were introduced by Ceylon Agro Industries in 1998 to the country. Cultivation of imported seed became cost-effective such that some local vegetable germplasm has been threatened to extinct. But some imported varieties were very costly and some were not tolerant to biotic and abiotic stresses that its adoption is very low. Therefore varietal development for local conditions at a lower cost is vital for the food crop sector development.

However, Sri Lanka continued to distance from the main innovation path. The political instability after 1983, the gradual distancing from working collaboratively with International NGO and other international agencies with the development of distrust on NGO activities in Sri Lanka can be identified as factors Sri Lanka not following the strategy of the neighbouring countries. Since the countries were getting stricter about the conditions under which they were willing to share germplasm with the new development as discussed above, new germplasm has been a limitation for Sri Lanka researchers to break the yield plateaus. Funding for CGIAR research is also now dominated by few countries and few philanthropic funding agencies.

Apart from that, other internal factors such as fewer funds allocated for research and development, less human resource training opportunities given, adopting more inward-looking perspective can be explained as factors of low innovations in Sri Lanka domestic agriculture sector.

Most public expenditure was allocated to irrigation investments and as transfers in terms subsidies particularly fertilizer subsidy. Government expenditure on irrigation investments and fertilizer subsidy transfers constitute the main budgetary allocations and investment in research and development which has very high returns is less than 2% of the total agriculture and irrigation expenditure (Wickramasinghe et al, 2020).

Irrigation investment and fertilizer subsidy accounted for about 75 % of the total investment in agriculture and irrigation after 2011. It is a widely held opinion that monitory benefits of these transfers and investments have trickled down the line. Although irrigation and fertilizer are essential inputs for the realization of yields of new varieties, it was found in the '80s, 90's that paddy yields were stagnating and were declining in the absence of new technology. This leads to unnecessary resource use and inefficient production. If the technology frontier cannot be shifted upward by introducing new varieties and technologies, intensification of inputs or adding more capital on land would lead to diminishing returns like what was observed in the '80s and '90s in paddy sector. The growth in output due to factor accumulation will eventually taper off, making the growth process unsustainable in the long run. Therefore, investment in research and development is essential for long-term growth.

When the trend of national research expenditure by government in the neighbouring countries is compared since 2000, Sri Lanka's investment in agriculture research and development is diverging within the region. Investment in agriculture research has been declining until 2010 and rose to the same level of 2000 in 2016, mostly to the corresponding employees' salary increase in the state and statutory research institutes. In measured in 2011 PPP dollar terms, Bangladesh spends some 90 million US Dollars while Sri Lanka spends about 40 million US Dollars. However, research expenditure as a percentage of GDP is highest in Sri Lanka among the neighbouring countries, which is nearly 0.5% of agricultural GDP. In India, Bangladesh and Vietnam research expenditure as a percentage of GDP are around 0.3, 0.4 and 0.2 respectively. Nevertheless, the agriculture GDP in these countries are many time higher than Sri Lankan GDP (Wickramasinghe et al, 2020).

In India, funding comes from four main sources: the central government provides about 50 per cent; state governments, about 20 per cent; private companies and cooperatives, 16 per cent; and foreign donors provide the rest. Private-sector research consisted primarily of research on crop management and processing technology and private companies have also been investing in exploiting hybrid vigour.

Human resource development and the carder of national agricultural researchers were also dwindling. This was already noted by Adam Pain by quoting Senadeera and Seneviratne since the late '60s. The financial rewards for working within research were for many people insufficiently attractive to keep them and the loss and turnover of highly qualified people who moved to more financially rewarding positions in the Civil Service or abroad were noted. The orientation of DOA as a professional organization seems to be gradually transformed to a more an administrative set up for the same reason of financial benefits. The DOA Agriculture service minute of 1976 did not recognize the importance of professional and academic training to build a trained stock of researchers at DOA. In the late 80's other apex bodies like SLCARP, NASTEC were set up for research administration. This was a result of emulating NARS of other countries to Sri Lankan research system. Research prioritization and funding being a function of these apex bodies was also making an influence over DOA's prominence on broad research programs.

This paper attempted to address the problem of research and science gap experienced in the recent past in the Sri Lankan domestic agriculture sector by reviewing what happened in Sri Lanka and neighbouring countries during the green revolution and after. The research and science gap became first evident in the late '80s when Sri Lankan rice yields started stagnating and in mid-'90s when seed industry was opened. After the green revolution, Sri Lanka drifted from its innovation path for a number of factors. With the private sector and multinational companies started to dominate in the seed industry and the patenting of plants, they have made restrictions on open access genetic resources for varietal development in the developing countries. This affected Sri Lanka too. Also, the development assistance to CGIAR has contracted and the ownership of capital determined the needs of the seed industry. Developing countries' collective effort in search of new technology is now mostly bound to state capacity to invest in technology generation and hence innovation. Although Sri Lanka benefits from technology products from other countries, Sri Lanka has been diverging from its innovation path as state funds have not been adequate and human resource development is not far-reaching. Science and technology policy to address in filling the research and science gap given the current scenario and science diplomacy must have an important role to play.

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