

My journey in changing facets of agronomic research during three decades of green revolution in India

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ABSTRACT

The changing facets of agronomic research in India as observed and followed by me during the past three decades, are reviewed in this paper. Green Revolution ushered in a new paradigm of agronomic management of crops in India. Fertilizer responsiveness of dwarf wheat generated heavy demand of fertilizers and gave major boost to the Indian fertilizer industry. Thus, due to the increased availability of fertilizers in the market, sugarcane farmers also started using heavy doses of N fertilizer to improve the cane yield, but at the cost of sugar content. Therefore, determination of optimum dose of N became important. In the first decade of my research career, I worked in this direction to work out the optimum dose and time of N application in sugarcane. Later on, with the introduction of fertilizer-responsive short-duration varieties in many crops like pulses and oilseeds, multiple cropping emerged as an important concept for intensification of agriculture. Consequently, I reoriented my research activities to develop companion cropping system with sugarcane and worked out fertilizer requirement of different crop combinations. Within two decades of Green Revolution, due to expansion of irrigation facility, rice–wheat crop rotation became predominant production system in the Indo-Gangetic plains, with gradual decrease in the area under pulse cultivation. Efforts were made to introduce pulses as companion crops of sugarcane for sustaining soil fertility and providing extra income to cane growers. Within a short span of time rice-wheat system, due to heavy demand of nutrients developed soil fatigue and witnessed decline in factor productivity. My research interest again changed during 1980s towards conservation of soil-organic carbon, by utilizing the organic farm waste material and crop residues. Various options of green-manuring were also tried in rice-wheat and sugarcane-based cropping systems to achieve this objective and to increase the fertilizer-use efficiency. From high-input agronomy, my research interest thus, finally changed to conservation agronomy. Conservation of soil moisture through trash mulching, *in-situ* decomposition of trash using bio-agents and bio-manuring to improve the soil fertility as well as nutrient-use efficiency has now become my prime concern. In sugarcane, the improvement in productivity of ratoon crop remained a major research activity throughout my career.

Key words: Sugarcane, Soil fertility, Fertilizer-use efficiency, Planting technique, Intercropping, Ratoon-ing, Carbon sequestration, Trash mulch, *Trichoderma*, *Gluconacetobacter*

The Indian Society of Agronomy has taken an initiative to share personal experiences and has ventured to publish a special issue departing from usual course of publication of research papers, research reviews or symposium proceedings. The research papers only highlight a person's special interest in a particular period of time, whereas the narration of experiences will elucidate the total persona from the ground zero. Obviously successes and failures go hand in hand and one has to make one's own way to carry forward researches under given circumstances and translate own ideas into actual practice. The Society deserves congratulations for this praise-worthy initiative.

In the backdrop of India–Pakistan conflict in 1965, India was reeling with acute food shortage and was virtually

begging food from the USA and elsewhere to feed its population. A conscious decision to import seeds of dwarf varieties of wheat from Mexico and evaluate them for the Indian environment became the God-send boon for India. It gave the desired impetus to food production, and India was able to subvert the looming famine. This laid the foundation of robust (self-sufficient) Indian agriculture, which became instrumental in transforming a hungry India with a begging bowl to a developing nation with vibrant economy. At the beginning, research on the Indianization of these imported dwarf varieties began at three centres, viz. Indian Agricultural Research Institute, New Delhi; Punjab Agricultural University, Ludhiana and G.B. Pant University of Agriculture and Technology, Pantnagar. As a student of agriculture, I witnessed the birth of Green

Revolution from its cradle while studying at Hisar campus of PAU (now CCSHAU) and at GBPUA&T, Pantnagar.

Agronomy : the subject of my preference

My journey in the realm of Agronomy dates back to my PAU days. I took Agronomy as a subject of my research by choice, to drive away the competition for scholarship (given only to the top-rankers in each discipline) from Plant Breeding and Soil Science, the then preferred disciplines by the students at PAU.

In the formative phase of Green Revolution, works were initiated on different aspects of dwarf wheat regarding its suitability and manoeuvrability in the prevailing edaphic and climatic conditions of north Indian plains. I was no exception; I took up research on thermo-insensitivity of dwarf wheat to find out the possibility to extend the sowing period without adversely affecting its yield potential. The research showed the feasibility of late sowing of dwarf wheat in north-west India. In three decades, rice has come in a big way in north-west India and late-sowing of wheat has become the most prevalent practice in this region. Obviously, the research, which seems more of academic interest today, may become the most practical and adaptable practice tomorrow.

Events leading to inception of Agricultural Research Service of ICAR

Some unfortunate events changed the course of agricultural research in India. The suicide of Dr V. K. Shah, a well-known Agronomist working at IARI, in protest to the prevailing selection procedure, forced the policy-planners to revamp the recruitment procedure of scientists in the ICAR. As a result, Agricultural Research Service (ARS) was created. This opened up new avenues for agricultural students to join as scientists in the service of the ICAR instead of becoming Research Assistant (RA) and Senior Research Assistant (SRA) or Assistant Professor (JRO) in State agricultural universities (SAUs). I was selected as JRO in HAU, Hisar and Assistant Professor in GBPUAT, Pantnagar but I preferred ARS. I took up the ARS examination in 1975 and got selected in the first batch. As in Administrative Service, we were sent to Central Staff College for Agriculture, Hyderabad for training in Agriculture Research Management.

Joining at the IISR, Lucknow

After completion of the training, I was posted at the Indian Institute of Sugarcane Research, Lucknow under the able leadership of the then Director Dr Kishan Singh. Three of us (I along with Dr A.K. Shrivastava in Plant Physiology and Dr Jagdish Lal in Agricultural Economics) fresh ARS recruits joined IISR in 1976. It was a drastic

change for me. Pursuing Ph.D. programme in the agronomy of dwarf wheat, I had to switch over to a crop that was altogether different. At Hyderabad, during the course of ARS training, Dr N.K. Anant Rao, Special Officer on Duty, time and again emphasized that “*We have selected potential talent to work on anywhere in the country and in any crop rather than for any crop specialization or for any particular location.*” The young mind should adjust according to the situation. Thus we were adequately conditioned to join in any ICAR institute and I had no hiccups in joining sugarcane; rather I was happy to be in the state capital of Uttar Pradesh.

Complexity of sugarcane crop

Sugarcane was the crop I was destined to conduct research during the next three decades. It is a cash crop and grown mainly to meet the sugar requirement. Production of sweetener is carried out both in organized sector (sugar mills) as well as in unorganized sector (*gur* and *khandsari* units). In fact, the first Green Revolution, though mostly unsung, took place in sugarcane in 1920s, when the new interspecific hybrids (*Saccharum officinarum* x *S. spontaneum*) - starting with cultivar ‘Co 205’ - yielded 2½ times more than the traditional canes (varieties belonging to *S. barberi* and *S. sinense*, mostly used for sugar making). This success of new hybrids may be gauged from the fact that within 10 years number of sugar mills in India rose from 20 in 1920s to 110 in 1933-34. The architect of this unsung revolution, Dr T.S. Venkatraman, the then Director of Sugarcane Breeding Centre, Coimbatore, was Knighted in 1942 by the then Imperial Government. Today, the cultivated sugarcane is no longer *S. officinarum* but a *Saccharum* hybrid complex involving different species of *Saccharum* and allied genera. The process of producing cane hybrids using *S. officinarum* as female parent is called ‘*Nobilization* of sugarcane’. The Coimbatore-bred hybrid canes (popularly known as ‘Co canes’) supported the sugar industries of different countries including those of the United States of America, South Africa and many others. In India, before the advent of these hybrids more than 80% sugar was produced in the states of Indo-Gangetic plains. The development of hybrids gradually increased the cane cultivation in the tropical states. Sugarcane is considered a tropical plant and grows well in that environment. Thus tropical states with longer growing period of sugarcane always have more cane yield than the subtropical states, where the growing period for sugarcane is shorter due to climatic extremes (very high temperature during the formative phase and very low temperature during the maturity phase). This natural disparity may be minimized through appropriate agronomic interventions.

The increased yield potential and realisation of yield

put much demand on the soil-nutrient reserve. Thus, fertilizer application became an integral part of sugarcane agronomy. In sugarcane, the economic product comes from the stalk, a vegetative part, and the vegetative growth is influenced highly by the application of fertilizer N. Sugarcane is different in relation to harvesting, as the canes are harvested almost for 5 months from November to March during the normal crushing season. Thus sugarcane varieties are grouped as early, mid-late and late, depending on the accumulation of sugar. Early varieties accumulate sugar early but are low yielder; mid-late varieties are moderate in sugar and moderate in yield; and the late varieties are high yielders with moderate sugar. Sugar mills crush the canes following this maturity sequence of varieties.

Another important aspect of sugarcane is the ratoon crop. The crop raised from the regeneration of stubble after harvesting the existing crop is termed ratoon or stubble crop. Theoretically, 50% area is always under ratoon crop, if one plant and one ratoon crop are taken. However, due to maintaining of more than one ratoon in some parts, its area remains more than 50%. Ratoon crop matures earlier than the plant crop and is thus crushed preferentially in the early part of the crushing season. Maintenance of ratoon crop is often neglected by the farmers and hence on an average always yields less than the plant crop. However, ratoon is the most profitable proposition in sugarcane agriculture, as it does not incur the cost of land preparation, seed and cost of planting.

Management of soil-fertility and fertilizers in sugarcane

To understand the intricacies of fertilizer N and different maturity group of varieties, because the same dose of fertilizer is applied irrespective of the maturity or yield of a variety, I took up my first research project on “*Varietal response to rates of fertilizer N application*”. This project gave me the understanding and confidence to work in sugarcane. This was a true learning-by-doing for me, and it helped me understand the nuances of sugarcane agriculture that otherwise I could not have perceived by reading the literature alone. During the run-of-the project, I took fortnightly observations on dry matter and nutrient accumulation from germination (April) till harvest. From November to March, fortnightly observations were also taken on sugar accumulations in different varieties falling in the three maturity groups. Observations were taken on the tillering patterns and conversion of tillers into number of millable canes (NMC). In sugarcane, single-cane weight and NMC determine the yield. Observations were obviously also taken from the ratoon crop and it became apparent that ratoon crop demands more N than the plant crop. These basic observations taken in this project actually

shaped my direction in research and future thinking. Based on these observations, I was able to publish research papers in *The Indian Journal of Agricultural Sciences*, and *Indian Journal of Agronomy* (Yadav and Sharma, 1979, 1980a, 1980b).

The autumn (October)-planted cane yields 20% more than the spring (February-March)-planted cane, and matures earlier but it needs 30% more time. However, there was no separate recommendation of fertilizer for the autumn crop. Hence an experiment was undertaken to study the removal of N by both the types of cane. Experiment was conducted in randomized block design (RBD with ‘Co 1148’ as the test variety and four dosages of N, viz. 0, 75, 150, 225 kg N/ha (applied as urea). Observations were taken on dry-matter production, and on the uptake of N, P and K. It was concluded that the uptake of N increased with the increase in N dose. The recovery percentage of applied N was more in the autumn cane than in the spring cane, usually in the range of 20–30%. Though the autumn cane stayed longer in the field, it did not demand more N fertilizers, (Yadav and Sharma, 1982, 1983)

In another experiment, the possibility of growing short duration sugarcane in subtropical India was explored to vacate the land in November for wheat. Four contrasting sugarcane varieties viz., ‘CoJ 64’, ‘CoJ 67’, ‘Co 1148’ and ‘Co 1158’ were taken along with four dosages of N and two harvesting dates. It was observed that on an average 17–18% increase in sucrose content in normal harvest (12 months) in comparison to early harvest (9 months) except in the early variety ‘CoJ 64’. Similarly, the mid-late varieties yielded 20–25% more at 12 months harvest in comparison to the harvest at 9 months (Yadav and Sharma, 1980b, 1982).

Use of slow-release fertilizers and nitrification-inhibitors

As an agronomist, I was always bogged down to economise on N application and sustain the soil-N content. As in other crops, in sugarcane also, half of the N is applied as basal, i.e. 75 kg N/ha; almost the same amount that is applied to wheat. Sugarcane takes 45–60 days for completing germination and thus has less developed root system to efficiently trap the applied N (Yadav, 1985). Nitrogen losses through leaching could be minimized by increasing the size of N-fertilizer granules or by coating urea with nitrification-retarding chemicals or materials like sulphur and neem-cake. Such coated fertilizers and large granules have increased the efficiency of N uptake of several other crops and helped in to economize the N use in the succeeding crops by leaving large residues of fertilizer N. To confirm these in sugarcane, a field experiment was conducted where traditional N source (prilled urea, PU)

was compared with new N-carriers like urea supergranule (USG), neem-coated urea (NCU), Dicyandiamide (DCD)-treated urea. The soil of the experimental plots was an alkaline sandy loam (pH 8.1), having 0.62% organic carbon, 0.03% total N, 11.2 kg available P and 132 kg exchangeable K/ha. The study suggested that in sugarcane, which requires a lot of water, these new fertilizers are not better than the traditional prilled urea (PU) in terms of yield. Although N uptake of sugarcane was increased with the new carrier, it did not leave significant N residues for the subsequent ratoon crop (Yadav *et al.*, 1990).

Legumes in cropping system

There is extensive evidence to indicate that legumes incorporated in a cropping sequence increase the soil-N content and the yield of succeeding crops (Yadav, 1984). Therefore, field experiments were conducted for three years, covering four crop seasons, to study the utility of pigeonpea as an intercrop in economizing N for maize and to assess the residual fertility of rainy season (*khari*f) crops on autumn-planted sugarcane. In the experiment observations were also taken on nodulation, leghaemoglobin, N fixation by pigeonpea, grain and total biological yields of maize and pigeonpea and the yield of sugarcane. Pigeonpea, a good N₂-fixer, increased the soil N content due to nodulation. Apart from N-fixation by nodules, increase in soil N after pigeonpea was also due to *in-situ* decomposition of its fallen leaves, which added 30–36 kg N/ha. Yield of sugarcane, which tested residual fertility, indicated significant differences due to different treatments. Sugarcane grown after pigeonpea yielded 43% more than after maize and nearly 2.7% more after maize + pigeonpea (Yadav, 1981). Thus inclusion of legumes in cropping sequence showed definite advantages, irrespective of whether they are grown in association with cereals or before them (Yadav, 1984).

Efficiency of fertilizer N is reduced due to leaching of N beyond the root zone. Studies were undertaken to determine the nitrate-N profile of soil in sole and parallel multiple cropping systems of pigeonpea and maize and of sugarcane and blackgram. In sole cropping, there was more nitrate N in the deeper horizons due to leaching from the inter-row spaces of row crops, whereas in parallel cropping its content decreased greatly at more than 30 cm depth because N in the inter-row spaces was better utilized by the crops. Parallel cropping always yielded better than either of the sole crops (Yadav, 1982).

Inter-row spaces of long-duration row crops like sugarcane could be utilized by growing short-duration pulses. However, it needs the identification of compatible pulses and their varieties that will cause least adverse effect on sugarcane, as well as to find out optimum plant popula-

tion. Experiments were undertaken with three cropping systems, viz. sole sugarcane, sugarcane + blackgram, and sugarcane + greengram; at 2 fertility levels, viz. no fertilizer to pulses, and 40 kg N, 60 kg P₂O₅ and 60 kg K₂O to the pulse crop. It was observed that the germination and initial population of sugarcane remained unaffected due to intercropping, because enough space remained available for germination and early growth of both the crops. However, tiller population in sugarcane was adversely affected. Greengram and blackgram reduced the tillering by 19.5% and 4.5% respectively in comparison with sole sugarcane. Greengram in 1 sugarcane : 2 pulse row arrangements decreased the tillering by 23%, whereas blackgram in the same row arrangement decreased it by 6% only. Organic carbon content of soil increased after the harvest of pulses in the intercropping system, but in sole sugarcane, it remained unchanged when fertilizer dose equal to that of pulses was added. In the absence of fertilizer application, organic C content decreased from 0.36% to 0.34%. However, intercropping of pulses in sugarcane increased the total N content of soil from 0.030% to 0.035% (Yadav *et al.*, 1987).

Legumes were also introduced in sugarcane farming as sequential crop. Introduction of a short-duration pigeonpea in the sequential cropping system produced an opportunity for the introduction of autumn-planted sugarcane in north India for extending the growing period. Since autumn sugarcane was replacing wheat, an important food crop, we developed companion cropping system of wheat (Verma and Yadav, 1988a, b), Indian mustard and potato (Verma and Yadav, 1986) with autumn-planted sugarcane. Fertilizer scheduling in these companion cropping systems were also worked out. The optimum N doses for sugarcane were 152, 175, 186 and 231 kg/ha when grown in association with potato, coriander, Indian mustard and wheat respectively (Verma and Yadav, 1988a). This work fetched our team the Silver Jubilee Award of Fertilizer Association of India, New Delhi in 1988.

Short stint at CIMAP, Lucknow

In 1980, an opportunity came before me for the post of Scientist C (Agronomy) at the Central Institute of Medicinal and Aromatic Plants, Lucknow, under the leadership of Dr Akhtar Hussain. While applying for the post, I was quite apprehensive about the response of my present Director. Incidentally, both the Directors were Plant Pathologists and close friends. With a fear in mind, I applied for and got selected. My stay at CIMAP did not last long and I rejoined IISR on the post of Scientist S-3 (Agronomy) in 1983. During my short stay at CIMAP, I worked on mentha (*Mentha arvensis*). It is an important essential oil crop, grown during summer, which requires lot of irriga-

tions which leads to considerable loss of N through leaching. I tried different N-carriers to minimise the N losses in mentha. It was observed that due to slow rate of mineralization and consequent decrease in N, loss from USG, LCU and NCU, addition of these carriers led to higher uptake of N and its apparent recovery by the crop. On an average the recovery of nitrogen from these sources was more than double than that of prilled urea (PU). Low N recovery from prilled urea was due to rapid volatilization and leaching (Muniram *et al.*, 1988).

Improvement in ratoon productivity (I phase)

As mentioned earlier, ratoon crop covers 50% sugarcane area. This crop often gets neglected due to various reasons. Initiation of ratoon depends on the harvesting of plant crop. Winter-harvested crop does not give rise to a good ratoon crop due to poor germination of stubble bud. The ambient temperature is not conducive to bud germination. Suppression of germination in stubble bud due to low temperature is attributed to several bio-chemical changes like the reduction in availability of reducing sugars (higher concentration needed for germination) due to the reduced activity of acid invertase and increased activity of indole acetic acid (IAA) and the content of total phenols and proline. The *in situ* build up of these compounds led to the dormancy of stubble buds. At 25°C stubble bud sprouting was 89%, whereas at 15 and 6 °C it was 56 and 23% respectively (Jain *et al.*, 2007). To enhance sprouting of buds in cold temperature, stubbles were treated with different hormones to boost the process of sprouting. For this work, I collaborated with my fellow colleague, Dr A. K. Shrivastava, a Plant Physiologist, at IISR, Lucknow.

Dr A.K. Shrivastava showed me an announcement of the Indian National Science Academy (INSA) for Young Scientist Award and encouraged me to submit my above-mentioned work for this award. To my surprise, I received a call from INSA for oral presentation of my work before the Award Committee, whose Chairman was Dr M.S. Swaminathan, and the members were Dr H.K. Jain, Dr N.S. Randhawa and Dr S.P. Raychaudhuri. I was awarded INSA Young Scientist Medal and it was presented by Mrs Indira Gandhi, Prime Minister, Government of India, at Mysore Science Congress in 1982.

Introduction of autumn cane in subtropical India has the possibility to increase the cane yield through lengthening the growing period. However, autumn cane as well as intercropping could not become much popular with the farmers. At this stage I learned that getting the award and developing adaptable technology by the farmers are altogether different things. All the research do not end in adaptable technology.

Plant-population management and yield maximization

The number of millable canes (NMC) per unit area of land at harvest holds the key to cane and sugar yield. The length and girth of cane also influence the yield but with a lesser degree. Among these, NMC and cane length are amenable to agronomic intervention through the modification of micro-environment and providing optimum conditions for plant growth. It has been estimated that at maximum photosynthetic efficiency of leaves and under ideal conditions of crop growth, sugarcane-stalk yield may go up to 364 t/ha/year. In the conventional sugarcane agronomy, 1 lakh NMC/ha is targeted from a tiller population of 2.0-2.5 lakhs. Tiller mortality is a dominant feature in sugarcane, which hinders the realisation of its yield potential. Thus, a great scope exists to improve the cane productivity by increasing the number of surviving tillers alone.

An analysis of causes of tiller mortality indicated that it is highly influenced by the method of planting, time of planting, seed rate, row spacing, edaphic condition and geographic location. Under Lucknow condition shoot mortality was higher in autumn-planted cane than in spring-planted one. Mortality increased when row spacing was reduced and seed rate was increased. The high leaf area index (LAI) of 7.4 in June, by restricting uniform distribution of solar energy to individual tiller, reduced the shoot population by 7, 49, 15, 5, 2 and 3% respectively in June, July, August, September, October and November. In wider rows (150 cm), on the contrary, maximum stalk density was attained in June. About 52% of the smaller stalks in wider rows and 71% in the narrower rows got decayed until August (Yadav, 1991).

From IISR, Lucknow the IISR 8626 method of planting to sustain greater population of shoots per unit area was developed earlier. However, due to operational difficulties it did not click at field level. The spaced transplanting technique (STP) also developed from IISR helped to increase tiller production but shoot density did not go beyond 1.5 lakh/ha. In the ring-pit technique, a shoot density of 1.62 lakh/ha was achieved using the variety 'Co 1148' (Singh *et al.*, 1984).

Development of ring-pit technique of planting

The mother shoot/no-tiller cane technology therefore, was conceptualized and ring-pit planting technique was developed to increase the cane yield and fertilizer-use efficiency (Yadav, 2004b) through mother shoot, because it always gets more time to grow and gain weight.

In ring-pit planting more sugarcane seed (setts) are placed in pits, with localised placement of fertilizers and

irrigation to increase the number of mother shoots and to decrease the number of tillers. Using the variety 'Co 1148', a yield of 184 t/ha was realised in comparison with 70-80 t/ha in conventional plantings (Yadav and Singh, 1986). This technology brought laurels and I received Prof. Hiralal Chakravarty Award of Indian Science Congress Association, Calcutta. Mr. Rajiv Gandhi, Prime Minister, Government of India presented this award to me at Madurai Science Congress in 1989. I received the award, and I was very elated but the euphoria did not last long. The technology boomeranged from the farmers.

On the insistence of Dr Kishan Singh, Director, IISR, Lucknow, Mr M.P. Sharma, an Agricultural Engineer at IISR, Lucknow, fabricated a tractor-operated pit digger to ease pit making. With this, more than 200 demonstrations were carried out in different areas of Uttar Pradesh. Unfortunately, in spite of its excellent performance, farmers were not willing to adopt it. The major bottleneck in adoption remained the pit digging. Due to high vibration in pit-digging operation, tractor drivers were getting too fatigued and were reluctant to undertake the operation. Thus the technology went in oblivion.

However, after 17 years, when Punjab state faced acute shortages of cane, the technology was revived by the Sugar mills in Punjab. One young mechanical engineer of a co-operative sugar mill developed two-row pit digger, which reduced the discomfort to the tractor drivers due to less vibration in operation. Thus, in 2003 ring-pit technology was taken up in large scale for sugarcane planting in Punjab state.

While I am writing these experiences, news has been flashed through *Kheti ki Duniya* dated 18 February 2009 that Government of Haryana is now providing cash incentive of Rs 5,000/acre to the farmers who are taking up sugarcane planting through ring-pit method to increase cane production in Haryana state. It is heartening to learn about the success of the technology. Similarly, Shakti Sugar in Tamil Nadu is popularizing ring-pit technology with drip irrigation in the sugar mill-reserved zone. One should not get disheartened at the failure of any technology in mass adoption. Success and failure depend on the prevailing market condition and opportunity in farming.

Modification in planting geometry

Planting geometry refers to the shape of land area it takes after establishment of plants the field. When the area per plant is constant, the shape of the ground area assignable to each plant is something like square with narrow rows, and rectangle with wider rows. Experimental results obtained under sufficient moisture and constant seed rate per plot or per row in subtropical sugarcane-growing belts indicated that when inter-row distance decreased, the stalk

number and the total cane weight per unit are increased, whereas the number of tillers and the individual stalk weight decreased. This indicated that the capacity of sugarcane to compensate for tiller production is limited by the shape of the ground area occupied by the plant. Variation in crop geometry as single rows, and double and triple pairs resulted into increased density of initial shoot population from single to double and then triple rows in that order (Yadav, 1991).

Initially, as the tillers survive on the resources of mother shoot, their growth is limited by the nutrient-absorbing capacity of the mother shoot. For greater survival of tillers, they should be conditioned in such a way that they develop roots quickly and start functioning as an independent unit (Yadav, 1991). In an experiment with same quantity of seed-sets when arranged in parallel and triangular geometries in a wide-base furrow, as high as 3.12 lakh shoots/ha were recorded in July in 'CoLk 8001' and 2.44 lakh/ha in 'Co 1148'. Thereafter due to shoot mortality the population density declined and attained a level of 1.49 lakh/ha in 'CoLk 8001' and 1.52 lakhs/ha in 'Co 1148' at harvest. A yield of 131.5 t/ha in 'CoLk 8001' and 148.4 t/ha in 'Co 1148' was obtained. Though the planting geometry did not influence the population density of millable canes significantly, parallel geometry gave higher yield than triangular geometry. It was inferred that so long as the initial populations are equal, row spacing does not cause much difference in yield. Therefore maintenance of higher initial populations appeared the feasible option in the maximization of yield (Yadav, 1991).

The initial failure or non-adoption of ring-pit technology prompted me to develop another technology to suppress the tillers and increase the mother shoot within the ambit of conventional sugarcane cultivation. Thus double-row planting was thought of. In this technology, one extra row of sugarcane is planted adjacent to the first row. As a result the planting geometry becomes 30 cm within two rows and 60 cm between the paired (double) rows. The double-row planting geometry, on an average minimized the nitrate-N leaching from inter-row spaces, leading to 15.8% increase in the recovery of applied N as compared with the of conventional planting. Consequently, the yield response/kg of applied N was 369 kg cane from double-row planting as compared with 278 kg cane from conventional planting. With increase in losses of nitrate N due to leaching, recovery of applied N decreased from 72.3 to 30.9% respectively when the rates of applied N were increased from 75 to 300 kg/ha. At the current rate of N application (i.e. 150 kg N/ha) the double-row geometry increased the yield by 39% over the conventional single-row planting. Thus double-row planting geometry was advocated to increase the cane yield and reduce nitrate leach-

ing (Yadav and Prasad, 1997; Yadav *et al.*, 1997).

Taking charge of PDCSR, Modipuram

In 1994 an opportunity came before me to run the newly established Project Directorate on Cropping Systems Research (PDCSR), Modipuram, (Meerut). I joined PDCSR as Director and developed the new Campus. Out of the meagre resources available, I arranged an international training on simulation modelling and nutrient management in collaboration with the International Fertilizer Development Centre, Alabama, USA. In this training nationals from 15 countries participated. This put PDCSR in the international map. Research collaborations with international institutes like IRRI, CIMMYT and ICRISAT were initiated. In this period the ICAR designated me as the National Coordinator for Rice-Wheat Cropping System to liaison with Rice-Wheat Consortium.

Factor productivity in rice-wheat cropping system

Rice-wheat cropping system has emerged as the major agricultural production system in the Indo-Gangetic plains after the Green revolution. This cropping system helped the farmers to boost the production but at the cost of over-use of natural resources.

Both rice and wheat are exhaustive consumers of nutrients. A rice-wheat system yielding 6.95 t rice/ha and 3.86 t wheat/ha removes as much as 316 kg N, 64 kg P_2O_5 and 401 kg K_2O /ha, as well as significant amounts of different secondary and micro-nutrients. As a consequence, in areas where the rice-wheat system has been practised for a considerable period, farmers are using more fertilizer nitrogen than the recommended level to sustain the productivity. This has been taken as the sign of decline in factor productivity (Yadav *et al.*, 1998). As fertilizer N is the most commonly used input for increasing the crop productivity, it is important to determine its partial factor productivity in intensive rice-wheat cropping systems in order to assess the benefits of prevailing rates of N application by the farmers to that of the fertilizer application prevailed two decades ago during the early phase of Green Revolution.

From the data of a long-term fertilizer experiment which was on progress since 1977-78 at Pantnagar (Uttarakhand), Faizabad (Uttar Pradesh), Sabour (Bihar) and Rewa (Madhya Pradesh) under the Network Research Programme of the PDCSR, it became apparent that, on an average, at all locations, continuous rice-wheat cropping for 16 years decreased the yield of rice by 57% in unfertilized plots and by 32% in plots receiving N and P fertilizers. Over the same period, wheat yield in the unfertilized plots declined by 18%; and in the plots receiving N, P and K its yield increased by 18% and in the plots receiving N and P fertilizers it increased by 33.6%. Partial factor pro-

ductivity of applied N showed similar trends. There was a marked depletion of organic carbon of the soil in the long-term rice-wheat cropping system. At locations such as Pantnagar it came down from 0.95% to 0.80% and at Sabour it reached to 0.41% from initial 0.84% per cent. (Yadav, 1998)

The success of rice-wheat cropping system changed the ways of farming in the Indo-Gangetic plains. Mechanisation of agriculture has become the reality. Use of tractors and combine harvesters drastically reduced the use of animal power in agriculture. This, in turn adversely affected the keeping of farm animals and thus, the production of cattle dung for making manure/compost. Similarly, burning of crop residues after harvest (through combine) led to the loss of precious organic matter (Yadav, 1997). This gradually depleted the inflow of organic matter in the soil.

In the subsequent analysis of rice-wheat system for green manuring and chemical fertilizer input practices utilising the trend in grain yield, partial factor productivity, agronomic efficiency, benefit : cost ratio, soil organic C content and sustainable yield, it became apparent that partial substitution of chemical fertilizers with *Sesbania* green manure brought improvement in yield and partial factor productivity in rice and the residual effect of green manure reversed the declining trend in wheat (Yadav *et al.* 2000a; b).

In this prevailing scenario green-manuring appears to be a viable proposition, because legumes are gradually phasing out from the irrigated ecosystem. The possibility of inclusion of a fast-growing legume as catch crop during summer after wheat harvest was explored. An experiment was conducted at Modipuram to measure the effect of summer cowpea raised as forage crop and its accrued benefit to the succeeding rice and wheat. Highest yields of rice and wheat were recorded in the treatments fertilized with 120 kg N and 26 kg P/ha, and skipping of either nutrient resulted in significant loss, irrespective of the growing forage legume during summer or maintaining the field as summer fallow. It was inferred that the soils having low organic matter and total N content can support highly productive rice-wheat cropping system only under assured and adequate supply of nutrients. Many reports from India and elsewhere amply showed the advantages of green-manure and grain legumes in improving the productivity of rice-wheat cropping system and in restoration of soil fertility mainly through biological N fixation and recycling of nutrients from deeper soil layers (Singh *et al.*, 2005). Where a large portion of legume biomass is removed from the field, legume crop may even deplete the soil-N fertility as in the case of forage legume (cowpea). Despite the removal of N and P in sizeable quantity from the soil by cowpea, its inclusion in the rice-wheat system increased

the wheat yield as well as fertilizer-use efficiency. Incorporation of cowpea roots and their subsequent decomposition helped in increasing the level of organic carbon content by 11.6% in the 0–15 cm soil layer and by 10.5% in the 15–30 cm soil layer. Moreover, reduction in bulk density helped better and deeper root growth in wheat, which often gets adversely affected due to forced soil compaction during rice cultivation (Dwivedi *et al.*, 2003; Yadav *et al.*, 2003).

In the same context, a study was also undertaken to introduce *Sesbania* as an intercrop in the direct-seeded upland rice for green-manuring to conserve organic matter of the soil and to increase the fertilizer N-use efficiency in rice-wheat system. Rice ‘Saket 4’ was sown in rows 30 cm apart using 40 kg/ha seed in the last week of June. A light irrigation was given a day after sowing and then one row of *Sesbania* was sown in between two rows of rice using 15 kg/ha seed. The *Sesbania* growth was manually turned into the soil at 30 days after sowing. Grain yields of rice and wheat were significantly higher in the plots receiving green-manuring than in those without green-manuring. The yield advantage was more at low levels of N than at higher N levels. However, the residual effect of green-manuring on succeeding wheat was very small (Yadav, 2004a). In the course we collected 32 germplasms of *Sesbania* to be tried as green-manure in rice-wheat cropping system.

Zero-till concept and brain-storming on organic farming

In 1998, a brain-storming session on Organic farming was organized under the Chairmanship of the Union Minister of State for Agriculture, Shri Som Pal Shastri. From the discussion it became apparent that not only the quantity of organic carbon but its quality is also important to sustain crop productivity and to improve the nutrient-use efficiency. At this time zero-tillage concept was being popularised by CIMMYT in rice-wheat system in the Indo-Gangetic plains region, where wheat was seeded directly after harvest of rice. Our experiments indicated that in wheat plots sown with zero-till, productivity of rice started declining after 7 years. This observation was contradictory to the general feeling of agronomists working at CIMMYT. As a result, I was not involved further in their zero-tillage programme. Today, my stand is vindicated. Most of the farmers in eastern Uttar Pradesh, where rice is the predominant crop, are reverting back from the zero-till wheat.

Rejoining IISR, Lucknow

I got an opportunity to take up the rein of the ICAR institute from where I started my research career. It was an

emotional home-coming. The experiences at PDCSR, Modipuram made me much wiser and changed my perspective of looking sugarcane farming as a part of larger agriculture where rice-wheat dominates as the food crops system. My interest in fertilizer economy got transformed and I switched to the carbon sequestration, soil health and improving the quality of organic carbon content in the soil. Bio-farming using bio-agents and bio-manures are now my current research interests. At the same time the phasing out of legume from the irrigated ecosystem of Indo-Gangetic plains prompted me to take up work on changing the root architecture to forage more nutrients from larger soil volume.

Improvement in ratoon productivity (II phase)

As explained earlier, taking of ratoon crop is an integral part of sugarcane farming. The ratoon crop, though matures earlier, gives poor yield. Improvement in ratoon yield holds the key to increase the overall productivity of sugarcane in the country. In subtropical India, the prevailing low temperature at harvest hinders the sprouting of stubble buds. Application of growth hormones and chemicals did not get acceptance by the farmers. In search of common chemicals acceptable to farmers, potassium chloride appeared promising. Potassium is important in maintaining water balance and helps in the increasing metabolic activities and thus may prove beneficial in stubble-bud sprouting. Experiments were conducted to assess the benefit of potassium application in standing cane and their effect in ratoon initiation. Experimental results on K application @ 66 kg K/ha in the standing crop along with irrigation water (one month before harvesting) indicated improvement not only in the germination of stubble bud but also in the dry matter accumulation and nutrient uptake (Shukla *et al.*, 2008, 2009).

In my initial experiments it became apparent that root architecture of ratoon crop changes greatly and becomes shallow. Thus the ratoon requires 25% more nitrogen than the plant crop to sustain productivity. In ratoon crop, number of tillers increases with concomitant decrease in single-cane weight. Modification of root architecture of ratoon and management of soil fertility are two important factors in the improvement in ratoon-cane productivity. Working in this direction led to the development of an implement named Ratoon management device (RMD) by Dr. A.C. Srivastava, an agricultural engineer at IISR, Lucknow. This device performs five functions in one pass of the tractor, i.e. off-barring (pruning of old stubble roots), placement of fertilizer in the vicinity of roots along stubble rows, deep tilling of inter-row spaces, earthing up of stubble rows and stubble shaving. This RMD equipment is now gaining wide acceptance by the farmers.

Conservation of soil-organic matter, carbon sequestration and soil health

The crop residue (trash) left after harvesting of sugarcane accounts for 10–20% of the weight of the cane harvest and the leftover root biomass in the soil constitutes 5% of the cane harvest. This amount of trash on decomposition may provide 30 kg N, 9 kg P and 24 kg K/ha. As a conventional practice, this trash is often burnt *in situ* to prevent the harbouring of insects and pathogens as well as weeds, and to clean of the field at one go. Two field experiments were conducted to study the effect of trash mulching and trash burning on the organic matter content of soil and their impact on yield of successive ratoon crop. Retention of trash as mulch, each year in the ratoon crop for three years increased the soil organic carbon by 0.13%, whereas trash burning decreased it by 0.02%. Similarly, bulk density increased after successive harvests of the crop in the plots with trash burning or trash removal, but decreased where trash was used as mulch. On the basis of yield and fertility status of the soil in these two experiments it was inferred that for sustainable cane productivity under a multiple ratooning system, retention of trash in the ratoon crop as mulch is more useful than burn it out. (Yadav and Prasad, 1992; Yadav *et al.*, 1994; Yadav, 1995; Yadav and Verma, 1995).

In July 2006, under the Chairmanship of Director-General, ICAR a meeting was organised at PDCSR, Modipuram on Mechanization of sugarcane cultivation. In the meeting many farmers informed that they are able to sustain wheat farming only because of sugarcane. Sugarcane fields always provide better yield of the succeeding wheat. It is quite surprising for all of us, as sugarcane is a heavy feeder of nutrients. This made me think, and I analysed wheat-yield trends of last 15 years in all the districts of Uttar Pradesh along the river Ganges. It became apparent that wheat yield is not showing declining trends in the districts where sugarcane occupied more than 20% of the cultivated area. Staying for over 30 years in sugarcane and rice-wheat cropping system, I failed to observe this phenomenon earlier. My focus of research again changed to understand the roots of sugarcane and their implication in sustaining soil health through the association of various microbes like *Trichoderma*, *Gluconacetobacter* and mycorrhiza (Shukla *et al.*, 2008; Suman *et al.*, 2008; Yadav *et al.*, 2009a;b).

CONCLUSION

It is amply clear that agronomy is not a static subject of research. It changes with market forces, plant architecture and prevailing edaphic environment, and is greatly influenced by the climate change. One has to have the desired flexibility and orientation to change according to the need.

Currently, Indian agriculture has major concerns in global warming, gradual drying of perennial rivers, changing rainfall pattern and loss of organic carbon content of the soil. Rhizospheric engineering, which encompasses modification of root architecture and modulation of soil-microbial activities, should become the major area of research for young agronomists. Research on carbon sequestration and modification of root architecture through planting methods and crop geometry for increasing foraging volume of roots is needed to sustain higher productivity and to improve the nutrient-use efficiency. Mobilization of soil nutrients using micro-organism holds the promise. Agronomists must take this opportunity to lead multi-disciplinary team for developing bio-farming practices.

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