covered by residue after planting primarily to reduce water erosion. ICAR-IISS tested different conservation tillage practices (No Tillage and Reduced Tillage) for soybean-wheat system. In 'no tillage' system the kharif soybean crop was directly sown with a no-till seed drill while wheat residues were kept on the surface. Under reduced tillage system soybean was sown using a no-till seed drill in wheat residue retained field after one pass ploughing by duck foot sweep cultivator. An increase in soil water retention and soil properties were observed in both systems compared to that of field with conventional tillage but yield advantage was visible in the soybean crop grown in the reduced tillage system.

14. **Broad Bed Furrow (BBF) with Reduced Tillage:** BBF system consists of 100 cm wide semi-permanent broad beds (for growing crops), separated by 50 cm wide and 15 cm deep furrows with a rolling slope of 0.4-0.7percent, ideal for cultivating crops profitably in waterlogged areas. Field trials at ICAR-IISS showed that BBF system is profitable for sole maize crop and for intercropping of maize with pigeon pea during rainy season followed by chickpea in winter season with application of FYM @ 5 tha^{-1} and fertilizers (GRD). Compared to flat bed system BBF system generated 11-18 percent yield increase in different cropping systems viz., soybean-chickpea, maize-chickpea, soybean/maize-chickpea, soybean/pigeonpea, and maize/pigeonpea. The maize-chickpea system benefited most by the BBF technology. The soybean crop grown on BBF generated 44 percent higher seed yield than that of farmers' practice (one drainage channel after every 11-12 rows).

15. **Bioremediation of Heavy Metal Contaminated Sites:** Bioremediation is an emerging technology that uses microorganism/living plants to reduce and/or remove pollutants or contaminants from soil, water, sediments, and air. Phytoremediation is a tool of bioremediation where green plants are used in situ for cleaning the contaminated sites. The institute has screened and identified some plants like marigold, chrysanthemum, gladiolus, tuberose, agave, cotton, and mauritius hemp; and bio-agents like Trichoderma viride for the management of heavy metal contaminated areas.

16. **Field Analysis of Physical Parameters of Soil Health:** The institute has developed a simple procedure to measure various physical parameters of soil health like soil compaction, field capacity, aggregate stability, soil structure etc. in a participatory mode. Equipments to make qualitative measurement of soil physical parameters can be made easily using locally available resources alike PVC pipe, coat hanger, tensile wires etc. The qualitative parameters assessed through this procedure were backed up by their respective quantitative values obtained in the laboratory.

INFORMATION & COMMUNICATION TECHNOLOGY (ICT) BASED SOIL HEALTH MANAGEMENT TOOLS

17. **GIS based Soil Fertility Maps:** ICAR-IISS has generated GIS based nutrient index maps (N, P and K) of 173 districts and micronutrient fertility maps of 508 districts of India through AICRP on Soil Test Crop Response Correlation and AICRP on Micro and Secondary Nutrients and Pollutant Element in Soil and Plants, respectively.

18. **Soil Carbon and Nitrogen Turnover Model:** The soil carbon and nitrogen turnover model developed by the institute using the soil and crop dataset of long term fertilizer experiments of India simulates the soil carbon dynamics for different annual crops and plant communities. The model computes total organic carbon, Walkley & Black C content, carbon in resistant (passive) and mineralizable (active+slow) pools, carbon stocks, total N, and available N. This model uses a yearly time step and users have to define only initial soil carbon content. The model itself determines the relative allocation of carbon in different pools. The model automatically computes the carbon and nitrogen turnover based upon these parameters and output is displayed in excel sheet.

19. **Soil Quality Index Software:** Software 'SQI CAL' was developed using R-platform for the calculation of Soil Quality Index (SQI) in a fast mode. The software calculates SQI in a four step process viz., i) selection of the minimum dataset using PCA; ii) scoring of indicators; iii) weight determination of the individual soil properties; iv) integration of weight and score into SQI.

20. **Software for Evaluating Municipal Solid Waste (MSW) Compost:** Municipal Solid Wastes have considerable potential to contaminate the environment but recycling of this waste material through composting can generate valuable resources for augmenting crop productivity. The institute has developed a new method that enables the grading of MSW compost based on its quality. With this method, grading can be done for Marketable class on a four point scale or for Restricted Use class on a three point scale based on the Fertilizing Index and Clean Index of the MSW compost. The Fertilizing Index is calculated with the weighing factors assigned to the compost quality parameters while Clean Index is calculated based on the weighing factor assigned to different heavy metals as well as their content in the prepared compost. The software developed with this method is available with the institute in a CD format.

21. **Software for Soil Health Card (SHC) Preparation:** ICAR-IISS has developed a user friendly software for preparing SHCs using the soil test values. The user needs to feed some necessary information along with the soil test values before clicking the "generate soil health card' cell in the software. The SHC generated through this software provides customized fertilizer prescription (based on the soil test values) for different crops.

SOIL FERTILITY/ SOIL HEALTH MANAGEMENT TECHNOLOGIES UNDER FIELD TRIALS

22. **Process to Mitigate Greenhouse Gas Emission from Soil using Biomass of *Jatropha curcas*:** *Jatropha curcas* is a bio-energy crop known for biodiesel preparation. It is identified that soil incorporation of *J. curcas* biomass @ 2 $t\ ha^{-1}$ could mitigate GHG emission from agriculture. Based on this finding, ICAR-IISS developed a novel bio-product from the leaf extract of *J curcas*. Final products were prepared in aqueous and granular forms. These products can be used either as seed coating material or as soil treatment. Aqueous extract is recommended to use at 0.1-1.0 % v/v as seed coating material or as leaf spray for the crops. It can also be sprayed over soil for beneficial effect where soil enzymatic activity can be enhanced. Greenhouse experiments showed that when used as soil amendment the bio-product increased abundance and activity of N_2 fixers, P solubilizers, heterotrophs, and methanotrophs. The product minimized N loss (low N_2O-N loss) and aided in C storage (CH_4 mediated C sequestration). Product enhanced seed germination rate by about 20-30 percent in case of soybean and *J curcas*. The cost of the product is ₹ 200/litre.

23. **In-situ Decomposition of Rice-Wheat Residue:** The technology developed by the Institute for in-situ decomposition of rice and residue makes use of consortia of ligno-cellulolytic microorganisms (four Bacteria, four Fungi and two Actinomycetes) for the field decomposition process. In this technology, a mixture of fresh cow dung @1.5 $t\ ha^{-1}$, molasses @2 $kg\ ha^{-1}$, curd @1 $Kg\ ha^{-1}$, mycelia mat @500g/ton residue, microbial inoculums (lignocellulolytic bacteria and actinomycetes) and urea are spread over the residue in the field. The residues and ingredients are incorporated into the soil by tractor drawn rotavator. The field needs to be irrigated immediately after soil incorporation of these residues and left for 30 days for the decomposition process. Sowing can be done after 30 days.

24. **Decomposer for Accelerated Agro-waste Decomposition:** The institute has developed three microbial consortia based products like solid carrier based fungal culture, liquid bacterial culture and fungal culture in capsule form for the accelerated decomposition of crop residue and agro-wastes.

25. **Gluconite Nano Particles - A Potential Source of Potassic Fertilizer:** India imports potassic fertilizer worth about Rs. 1200-1500 crores to meet the K fertilizer demand of the country. To reduce the financial burden on K fertilizer import an alternative source of potassic fertilizer needs to be identified within the country. ICAR-IISS has prepared glauconite nano-particles (GNP) of size 19.9 nm from glauconite mineral by top down method through mechanical grinding using high-energy planetary ball mills. GNP contains 6-10% K_2O along with elements like Si (51%), Al (2%), Fe (16%) etc. Evaluation studies under laboratory condition (incubation study, release kinetics experiment, solubility test) as well as green house experiments (Hoagland solution culture and pot culture) to assess the efficacy of GNP as an alternative source of potassic fertilizer recorded higher biomass production and crop yield with the use of GNP.

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ICAR-IISS EXTENSION FOLDER (2021)

FARMER FRIENDLY SOIL HEALTH MANAGEMENT TECHNOLOGIES FOR ENHANCED CROP PRODUCTION

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TECHNOLOGIES FOR ENHANCING SOIL FERTILITY AND CROP PRODUCTION

1. **Mridaparikshak:** The institute has developed Mridaparikshak mini lab. Mridaparikshak is a digital, mobile, quantitative, rapid, affordable and easy to operate mini laboratory, for the estimation of 15 soil health parameters, fertilizer recommendations, and generation of soil health cards. It gives quantitative results of the soil health parameters that can be disseminated on real time basis to the farmers' mobile through Short Message Service (SMS). The results include, in addition to soil test parameters, the advisory on nutrient recommendations, specific to crop and soil. The results can also be stored in memory and the output can be saved in external storage devise. Subsequently, a soil health card can be generated which can be sent to farmers either electronically or by post in the form of hard print.

2. **Integrated Plant Nutrient Supply (IPNS) system for Soybean-Wheat Cropping System using Enriched Compost:** The general recommended doses (GRD) of fertilizers for the soybean-wheat cropping system are 20:60:20 kg ha^{-1} NPK for soybean and 120:60:40 kg ha^{-1} NPK for wheat. The IPNS system developed by ICAR-IISS for the soybean-wheat crop rotation system of central India recommends application of FYM @ 5t ha^{-1} and seed treatment with biofertilizer (Rhizobium @750 g ha^{-1}) along with the application of 50% GRD of NPK (Urea 1.75 kg ha^{-1}, DAP 65 kg ha^{-1}, MOP 16.5 kg ha^{-1}, and Gypsum 55 kg ha^{-1}) for the soybean; seed treatment with phosphate solubilizing bacteria (PSB) @3.5 kg ha^{-1} along with the use of 75% GRD of NPK (Urea 158 kg ha^{-1}, DAP 98 kg ha^{-1}, MOP 25 kg ha^{-1}, and Gypsum 83 kg ha^{-1}) for the wheat crop. Though the system proved profitable, a survey conducted by the institute in Madhya Pradesh revealed that non-availability of sufficient quantity of cow dung (due to its use as a cooking fuel) is preventing many farmers from adopting it. Hence, the institute has developed an alternative IPNS recommendation for the soybean-wheat system replacing FYM @ 5t ha^{-1} with enriched compost (phospho-sulpho-nitro compost) @ 2t ha^{-1}. Farmers' field trials of the modified IPNS system for a period of three years (2013-14 to 2015-2016) generated 25 percent more yield for the soybean crop and 19 percent more yield for the wheat crop compared to farmers' practice. The modified IPNS system provided more net income to farmers (₹ 68,000) compared to farmers' practice (₹ 46,700). Moreover, the system motivates farmers to adopt recycling of farm waste through composting instead of burning in field.

3. **Integrated Plant Nutrient Supply (IPNS) System for Maize-Chickpea Cropping System:** Long term field experiments conducted on the Soil Test Crop Response (STCR) correlation equation based IPNS module developed for the maize-chickpea cropping system indicated that the crop yields, system productivity and sustainable yield index (SYI) of the cropping system were significantly improved with the application of FYM @ 5t ha^{-1} and 75% NPK of STCR based fertilizer nutrient dose over the GRD. Maize crop showed an increased grain yield of 20.9 percent and chickpea 13.08 percent than that of GRD system.

4. **Soybean based Intercropping System Ideal for the Vertisols of Madhya Pradesh:** Intercropping systems are sustainable as they minimize runoff and soil loss compared to sole cropped systems. Field trials conducted by ICAR-IISS showed intercropping of soybean with Maize (2:1 ratio) during *Kharif* with the application of FYM @ 5 t ha^{-1} (without any nitrogen application) followed by wheat in *Rabi* is more productive and economical (benefit-cost ratio of 2.37) than mono-cropped soybean-wheat system. This intercropping system is the best possible option for those farmlands where soils are susceptible to erosion.

5. **Protocols for the Preparation and Application of Nano-Fertilizers:** A protocol to prepare nano particles of rock phosphate (RP) collected from different sites namely Sagar, Jhabua and Udaipur (containing 11-14 percent P) in bulk amount of approximately 100 kg, was developed using a top down approach using a high energy ball mill. Similar protocols were also developed for preparation of nano particles of mineral ores containing potassium, zinc etc. Also, a protocol to coat seeds of maize (*Zea mays L.*), soybean (*Glycine max L.*), pigeon pea (*Cajanas cajan L.*) and ladies finger (*Abelmoschus esculentus L.*) with nano scale (<100 nm) ZnO powder @ 25 mg Zn g^{-1} seed and @ 50 mg Zn g^{-1} seed was developed to make requisite amount of Zn available to plants.

6. **Nano-Rock Phosphate:** The institute conducted greenhouse experiments using nano-rock phosphate with maize crop. Maize grown in four soils (Vertisols, Alfisols, Inceptisols, and Aridisols) revealed that crop utilization of P from nano-rock phosphate is on par with that of normal sized SSP in vertisols and inceptisols. Nano-rock phosphate (size: 110.1 nm) from Sagar Rock Phosphate (SRP) increased the crop yield by 20 percent in vertisols, 61 percent in alfisols, 31 percent in inceptisols, and 14 percent in aridisols than normal sized SRP (size: 13.4 µm). Further, nano-rock phosphate (size: 70.89 nm) from High Grade Rock Phosphate (HGRP) increased the crop yield by 31 percent in vertisols, 88 percent in alfisols, 27 percent in inceptisols, and 15 percent in aridisols than the normal sized HGRP (size: 12.9 µm). Multi location field trials of nano-rock phosphate @ 50 kg ha^{-1} P_2O_5 (as water suspension stabilized with linear Alkyl Benzene Sulphonate) at ICAR-IISS, Bhopal, AAU, Anand, OUAT, Bhubaneshwar, PDKV, Akola and ANGRAU, Hyderabad generated good results. With the application of nano-rock phospahate average seed yield of sorghum increased to 22.2 q ha^{-1} from 13.5 q ha^{-1} and that of finger millet to 10.4 q ha^{-1} from 6.4 q ha^{-1}.

7. **Nano Zinc Oxide:** Greenhouse experiments conducted at ICAR-IISS revealed that Nano ZnO can be used as a direct source of Zn to crops. Application of nano Zn at relatively lower level (0.28ppm) enhanced the growth of maize compared to normal $ZnSO_4$ (0.5ppm).Seed treatment with nano-ZnO @ 50 mg Zn per gram seed also could meet the Zn requirement of the crop. Moreover, no toxic effect was observed either on seed germination or plant growth.

8. **Protocol for Fortification of Urea with Micronutrients:** ICAR-IISS developed a protocol for the preparation of urea fortified with a consortium of nano-particles of Zinc, Copper, Iron, and Silicon by using oleoresin. The fortified product contains 0.438 g N, 2.2 mg Zn, 1.10 mg Fe, 0.66 mg Cu and 1.06 mg Si per gram of urea. If applied @200 kg h^{-1} this fortified urea could supply 87.68 kg N, 440 g Zn, 220 g Fe, 132 g Cu, and 212 g Si to crops.

9. **Agronomic Intervention for Increased Maize Yield in Vertisols:** Application of fertilizers needs to be synchronized with the plant requirement to increase their nutrient use efficiency to produce the best possible crop yield. Field experiment to evaluate the multi-split top dressing of N fertilizers in maize showed that application of N (@120 kg ha^{-1} in 2 equal splits at the knee high and tasseling stages with no basal application of N, could increase grain yield significantly. This way of N application is one of the best possible agronomic approaches to achieve higher yield from rainfed maize grown in the Vertisols as it synchronizes the crop N demand with availability of N in the soil. The maize crop with the modified agronomic intervention performed better than the crop with conventional N application with more agronomic efficiency (16.3%), partial factor productivity (45.1%), physiological efficiency (15.3%) and recovery efficiency (14%).

10. **Micro and Secondary Nutrients Recommendation for Indian Soils:** A systematic procedure to diagnose and correct micro and secondary nutrient deficiencies of Indian soils has been developed by the Institute through its AICRP on Micro and Secondary Nutrients and Pollutant Element in Soil and Plants. A micro and secondary nutrients recommendation chart for the application of various micro and secondary nutrients for different crops and cropping systems has been developed.

11. **Biofertilizers:** Biofertilizers are microbial formulations containing living microorganisms that are helpful in promoting plant growth by increasing the availability of essential nutrients in soil through various mechanisms like biological nitrogen fixation, phosphate solubilization, oxidation of sulphur, zinc solubilization, production of growth hormones, developing disease resistance in plants etc. Some successful biofertilizer technologies developed by ICAR-IISS through its All India Network Project (AINP) on Soil Biodiversity-Biofertilizers are given below.

   a. **Mixed Consortium Biofertilizers:** The mixed biofertilizer formulation (BIOMIX) developed under the AINP contains a consortium of N fixers, P solubilizers and plant growth promoting rhizobacteria (PGPR) that can promote healthy plant growth in cereals, legumes and oilseeds. Field trials conducted at various centers of AINP showed that BIOMIX could save 25 percent of N and P fertilizers. Its application also produced a yield increase of 13 percent in rice, 9 percent in wheat, 10 percent in millets, 13 percent in pulses, 14 percent in oil yielding crops, and 10 percent in vegetables.

   b. **Liquid Biofertilizer Formulations:** Liquid biofertilizer formulations have considerably higher shelf life. In an evaluation period of 360 days liquid media of different biofertilizers maintained huge number of viable cells. Number of viable cells maintained by liquid media of Rhizobium (LM3), PSB (LM3) and Azospirillum (LM2) were log 8.433 viable cells ml^{-1}, log 8.208 cells ml^{-1}, and log 8.643 CFU ml^{-1}, respectively after 360 days. Moreover, liquid inoculants found to be free of contamination and dose of 4-5 ml of liquid inoculum (population of $3x10^8$ cells ml^{-1}) is enough to coat 1 kg seed. The AINP centers like ANGRAU Amaravathi, JNKVV Jabalpur, CCSHAU Hisar, Dr. YSP-UHF Solan, and TNAU Coimbatore have developed liquid bifertilizers for cereal crops, legumes, fruit crops etc.

   c. **Zinc and Potassium Solubilizing Biofertilizers :** The AAU Jorhat and TNAU Coimbatore centres of AINP developed Zinc Solubilizing Biofertilizers (ZSB). For rice crop of North-East region this biofetilizer is used as seedling root dip in transplanted rice crop @ 2kg ha^{-1} for improved grain yield. Paddy seedlings need to be dipped in slurry made out of ZSB, compost and water around 8 hours before transplanting. TNAU centre also developed Potassium Solubilizing Biofertilizers for various crops.

   d. **Biofertilizers for Spices and Vegetable Crops:** The KAU Thrissur centre of AINP developed low cost biofertilizers for spices like black pepper and ginger. Different biofertilizers prepared using *Microbacterium, Cellulosimicrobium, Paenibacillus* sp. and *Azospirillum zeae* performed good under field trials generating a yield increase of 18-27 percent in black pepper and 15-50 percent in ginger. AINP centers also developed biofertilizers to enhance the yield of different vegetable crops like brinjal, chilli, tomato, amaranthus, okra, cowpea, cucurbits, cauliflower etc. For example, the KAU Thiruvanathapuram developed PGPR Mix-I for vegetable grown in Kerala and Dr. YSP-UHF Solan centre developed charcoal based biofertilizers for vegetable crops of temperate Himalayas. Field trials revealed that with the use of biofertilizers yield of vegetable crops could be increased by 20-25 percent.

   e. **Mechanized Seed Coating of Biofertilizers:** This technology was developed by the TNAU, Coimbatore center of AINP. To make biofertilizer coated seeds using the standardized seed coating machine, biofertilizer formulation and binder material are fed to a specific slot of the machine before adding seeds to the machine. The machine uniformly coats the biofertilizer as a thin film over individual seeds. The seeds collected from the machine need to be air dried for about 15 minutes.

12. **Enriched Compost Production:** Enriched composting is the process where the ordinary compost is fortified with necessary plant nutrients so that it becomes a complete food for the plant. The institute has standardized different types of enriched composts:

   a. **Phospho-Sulpho-Nitro (PSN) Compost:** Biodegradable waste materials can be converted to nutrient rich phospho-sulpho-nitro compost in a 3 months period adding natural mineral resources like rock phosphate, pyrite, mica, phospho gypsum, and fresh cow dung. Microbial enriched PSN compost were also prepared at the institute adding phosphate soulubilizing microbes like *Aspergillus awamori, Bacillus polymixa* and *Pseudomonas striata* to the composting mixture. Well decomposed PSN compost contains major plant nutrients in the range of 1.5-2.3 percent N and 3.2-4.2 percent P.

   b. **Enriched Organo - Mineral Compost:** This compost is prepared by pit method and major raw materials used for producing organo-mineral compost along with crop residues are cow dung, low-grade rock phosphate, waste mica and mineral gypsum. The composting period for this compost is around four months. The nutrient value of this enriched compost is 1% N, 1% P, 2.1% K and 1.7% S. Application of 1 tonne organo-mineral compost can supply 10 kg N, 10 kg P, 21 kg K, and 17 kg S to the crop. Field demonstrations using organo-mineral compost as a part of Integrated Nutrient Management provided promising crop yield.

   c. **Microbial Enriched Municipal Solid Waste (MSW) Compost:** Recycling of MSW through composting would resolve the issues of environmental pollution due to heaping of MSW in dumping sites to a greater extent. For preparing one tonne microbial enriched MSW compost required raw materials are 1.6 tonne waste material, 320 kg fresh cow dung and 21 kg urea. Microbes used to enhance the decomposition process in this composting were celluloytic fungi like *Aspergillus flavus, A. heteromorphus, A. terrus,* and *Rhizomucor pusillus.* During the composting period bioinoculum needs to be added twice; initially in the first five days and then after 30 days of decomposition. The compost gets ready in 2.5-3 months. Nutrient value of the matured compost used to be 0.73% N, 0.79% K and 11.3% organic carbon.

   d. **Rapid Composting Technique:** The rapid composting technique developed by ICAR-IIS makes use of a power operated shredder and bioreactor along with microbial consortium to convert food waste to compost in a short period of 25-30 days. For making the compost, the shredded food waste mixed with fresh cow dung, urea, mesophilic microbial consortium (developed for the purpose) and water (required quantity) is fed in the bioreactor. After 15 days, thermophilic bio-inoculum is mixed with partially decomposed compost. To make 100 kg compost through this rapid composting technique raw material required include 150 kg waste material, 50 kg fresh cow dung, 1.1 kg urea, and microbial consortia.

   e. **Family Net Vessel Composting (FNVC):** The FNVC technology is an advanced step of vermicomposting made for those urban families who want to recycle kitchen waste into compost for their balcony garden. The technology makes use of a plastic basket and a nylon vessel along with cow dung and three epigeic earth worm species viz., *Eisenia fetida, Eudrilus eugeniae* and *Perionyx excavates* to compost kitchen waste. The capacity of FNVC is around 10-15 kg and it can be easily hanged in space available outside the home.

13. **Conservation Tillage for Soybean-Wheat Cropping System:** Conservation tillage maintains at least 30% of the soil surface