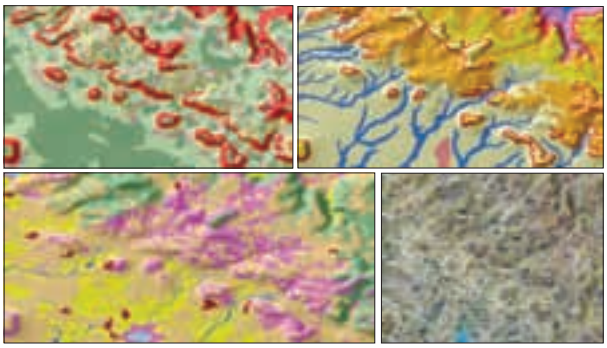
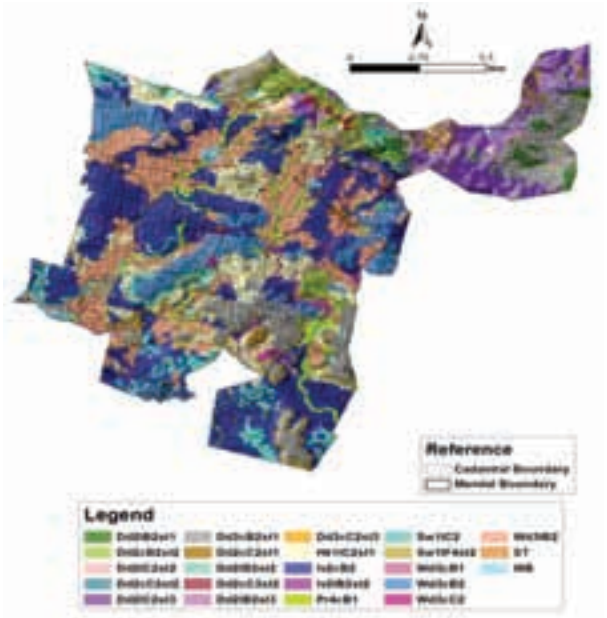
2. Soil and Water Productivity

Soil resource inventory and land use planning

Land resource inventory (LRI) on 1:10000 scale: In the first phase (2014-2018), land resource inventory of 60 blocks/mandals/talukas covering 60 agro-ecological sub-regions (AESRs) of the country targeting 3.3 million ha area has been taken up as a model. During 2014-15, 34 blocks were surveyed, 5 from Southern; 10 from Western; 14 from Eastern; 5 from North-eastern; 3 from Northern and 2 from Central region. Landscape ecological unit (LEU) consisting of landforms, land use and slope is taken as the base map for LRI instead of landforms alone. Contours at 10 m interval and drainage pattern were developed for delineation of slope and landforms using Cartosat digital elevation model. Other remote sensing data like IRS-LISS IV of 5.8 meter resolution and those available in public domain are used for land use-landcover (LULC) mapping. Landforms, slope and LULC maps are integrated for developing landscape ecological unit in GIS environment as shown for a part of Indervalle mandal, Adilabad district, Telangana. Interpretation of each LEU is done in terms of physiography, sub-physiography, broad landforms, landform units within broad landforms, slope and land use as shown for Indervalle mandal. Soil-landscape ecological unit relationship is developed by studying soil profiles, minipits and auger observations. On laboratory confirmation, phases of series are delineated on soil map on 1:10,000 scale.

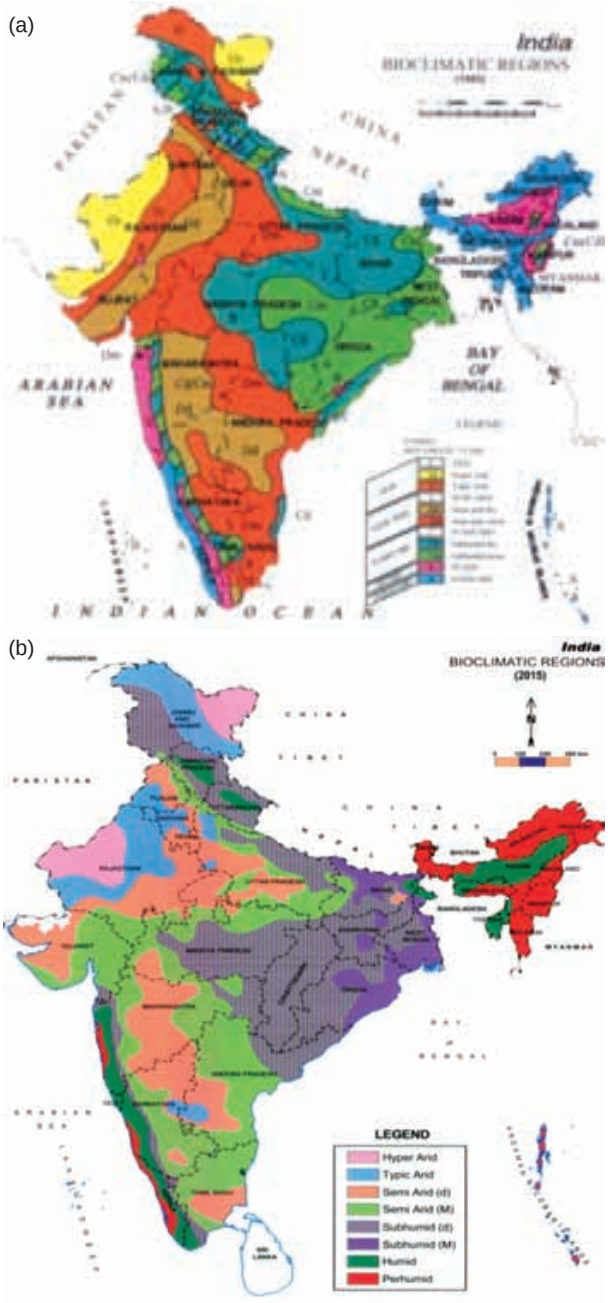


Landscape ecological unit in a part of Indervalle block, Adilabad district, Telangana



Soil map, Gajwelmandal, Medak district, Telangana

Refinement of bio climatic maps of India: Change in the bio-climate map published by ICAR-NBSS&LUP



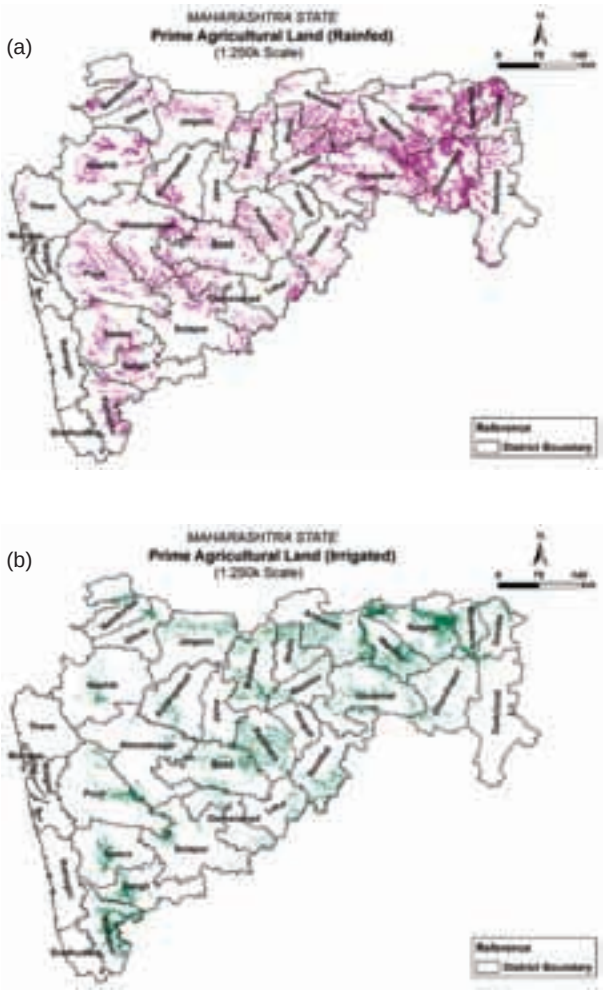
Bio-climatic maps. a, 1992; b, 2015

in 1992 was analysed, and revised bio-climate map was developed in 2015. New soil data (derived from 1:1 million soil database) and rainfall data of 530 stations were used in the process along with the variations in Moisture Index (IM), length of growing period and the average data value of 1,900 stations computed earlier. The Hyper Arid zone which covered 22.9 million ha in 1992 has considerably reduced to 12.5 million ha (i.e. a decrease by 45.4%), whereas Typic Arid area has increased by 8.4% from the earlier value of 22.7 million ha. Semi-arid (dry) areas have shown insignificant change (2.5%) but semi-arid (moist) areas have increased by approximately 30% from earlier estimated 72.2 mha. This is at the expense of dry and moist sub-humid areas of the country. The dry sub-humid areas have increased by approximately 47% from the earlier estimate of 54.1 million ha at the expense of moist and transitional sub-humid areas in Maharashtra, Madhya Pradesh, Chhattisgarh (north west), Andhra Pradesh (central) and north fringes of Odisha, Jharkhand and Bihar (south). The humid area has increased by 74% from earlier estimated value of 16.6 million ha, which falls under coastal parts of West Bengal and Odisha, deltaic regions of Andhra Pradesh, Bengal basin, Tarai plains of West Bengal, Brahmaputra Valleys and Western Coastal Plains.

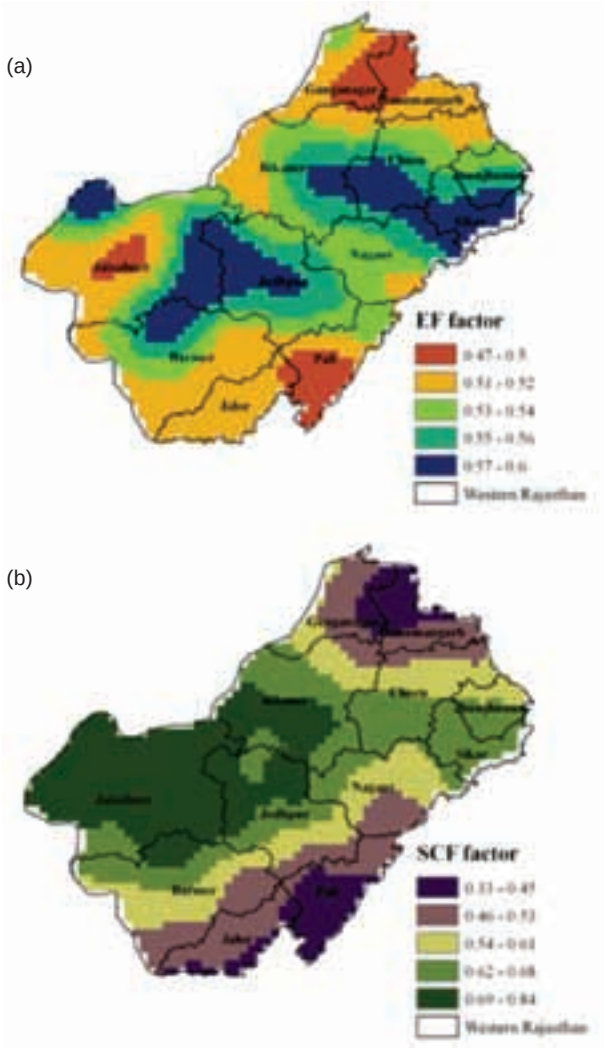
Delineation of prime and non-prime lands in Maharashtra: Prime land is characterized as the land having less than 8% slope, moderately deep to deep (soil depth >75 cm) and pH ranging from 6.5 to 8.5. An exercise of delineating prime and non-prime land has been taken up for Maharashtra as a pilot study using available soil information at 1:250,000 scale. Extent of irrigation, both in prime and non-prime land, is defined by superimposing LULC map of 2013-14. The area under the double/triple crops is considered as the irrigated part of prime and non-prime lands.

Total net sown area in Maharashtra is 21.82 million ha. Rainfed and irrigated agriculture are practiced in 63.1 and 36.9% of the total area, respectively. Out of the net sown area, 6.2 and 15.6 million ha were classified as prime and non-prime land, respectively. About 30 and 37% area of prime and non-prime land, respectively were irrigated.

Wind erosivity assessment: Average wind erosivity factor for four selected locations in Western Rajasthan was calculated as per the revised wind erosion equation (RWEQ) using long term (2000-2010) wind speed data. In general, wind speed becomes erosive from first fortnight of May and remains active up to second fortnight of August for all four selected locations. Jaisalmer and Chandan sites have been found more



Prime land in Maharashtra. a, Rainfed; b, Irrigated



RWEQ factors in western Rajasthan. a, Soil erodible fraction (EF) factor; b, soil crust factor (SCF)

erosive than other sites. Highest wind erosivity has been observed during the second fortnight of July at Chandan (2.81 kg/m/s).

Thematic maps of soil erodibility factors, e.g. erodible fraction (EF) factor and soil crusting fraction (SCF) factor as per RWEQ were prepared for Western Rajasthan. Area covering Jaisalmer, Bikaner, Churu, Jhunjunu, Sikar, Jodhpur and Nagaur district of Western Rajasthan lies under high EF factor (0.57-0.60). Jaisalmer, Bikaner and Western part of Jodhpur lies under high SCF factor (0.69–0.84).

Development of spectral algorithm for rapid soil assessment: A soil spectral library consisting of 138 spectra of surface soil representing different land use situation of Western Rajasthan covering Jaisalmer, Barmer, Jodhpur, Pali, Churu and Jalore was developed. Sand and clay content of arid Western Rajasthan were satisfactorily estimated from linear models (R^2 = 0.41 to 0.43). Soil reflectance spectra based algorithm was developed for rapid assessment of soil erodibility factor in Western Rajasthan.

Soil and water productivity

Bio-engineering interventions for degraded ravine lands: Bamboo plantation based bio-engineering interventions, viz. (i) Bamboo plantation with staggered contour trenches, (ii) Bamboo plantation as live check dams, and (iii) Bamboo plantation supported by *bori* bunds were found promising for reclamation and productive utilization of three major ravine systems of India namely, Mahi ravines at Vasad (Gujarat), Chambal ravines at Kota (Rajasthan), and Yamuna ravines at Agra (Uttar Pradesh). These interventions could absorb more than 80% of rainfall and reduced the soil and nutrient losses by 90% and 70%, respectively. The system increased the soil organic carbon content by 5 times on degraded ravine bed over the years. The gully head and bank extension was checked completely. These interventions gave average annual net return varying from ₹ 63,910 to 88,780/ha with benefit cost ratio from 1.96 to 2.09. Upscaling the package in one third of ravines is estimated to give a present net worth of ₹ 6,430 million over 20-year period, build 44 million tonnes soil carbon and conserve soil worth ₹ 4,100 million at 2011-12 prices.

Bamboo plantation with staggered contour trenches in degraded Mahi ravines of Gujarat

The density of staggered contour trenching (SCT) of size 4.5 × 0.6 × 0.45 m^3 has been optimized for horti-pastoral land use system in medium deep ravines of Chambal river for their economic utilization. Results showed that the highest reduction in mean runoff (86.1%) was in a small ravine watershed treated with SCT density of 417 trenches/ha over the control (no trench), followed by watershed with 278 trenches/ha (60.5%). Similar trends were also recorded in soil loss reduction from the treated watersheds. It was also observed that runoff trapped by the SCT significantly affected the productivity of the system. The total productivity of ravine lands was observed as 2.28, 3.8, 5.9 and 7.46 tonnes/ha/yr aonla fruit equivalent under trenching density of 417, 278 and 139 trenches/ha, respectively. Net income varied from ₹ 344,378 to ₹ 659,229.

Managing dry spells through foliar sprays of thio urea and KNO_3: Foliar sprays with various chemicals were evaluated by All India Coordinated Research Project for Dryland Agriculture (AICRPDA) network centres to mitigate dry spells during crop growing season across diverse rainfed agroecologies. Foliar spray of thiourea at 250 g/ha improved the yields of fingermillet (10%) at Bengaluru, maize (9.5%) at Ballowal Saunkhri and soybean (30%) at Indore, resulting in higher net returns and rainwater-use efficiency (RWUE) compared to water spray. Similarly, at Agra, foliar spray of urea and KNO_3 at 2% each in pearlmillet helped in mitigating the dry spells during August and improved crop yield by 27% closely followed by 2% KNO_3 (22%) compared to water spray. At Solapur, foliar spray of 1.0% KNO_3 at 35 and 55 days after sowing enhanced the crop yield by 12% with higher net returns and RWUE compared to water spray.

Resource conservation and mini-sprinkler in semi-reclaimed sodic soil: A field experiment was initiated in 2011 to evaluate the effect of resource conservation strategies, viz. tillage, residue and irrigation methods for enhancing crop productivity and sustaining the health of semi-reclaimed sodic soils. The results indicated that highest grain yield of rice (7.8 tonnes/ha) was recorded in conventional transplanting method (CV) with wheat residue incorporation followed by conventional tillage (7.3 tonnes/ha) and DSR with reduced tillage and surface irrigation. The highest grain yield of wheat (6.5 tonnes/ha) was recorded in reduced tillage with rice residue incorporation as compared to conventional tillage (5.7

tonnes/ha). Crop residue incorporation increased the grain yield of wheat by 10.2 per cent over CV. Optimum soil moisture and favourable temperature regulation under residue incorporation treatments facilitated better seed germination and crop growth as compared to no-residue treatments.

Sprinkler irrigation system saved 48.3% water over the surface irrigation in wheat. Zero tillage with 100 per cent rice straw mulch produced the highest wheat yield (6.41 tonnes/ha) under surface irrigation system followed by 5.72 tonnes/ha in zero tillage with 100 per cent rice straw mulch with mini sprinkler irrigation system. About 1.94 times higher wheat and water productivity was obtained in mini sprinkler irrigation method with ZT and 100 per cent rice residue mulch as compared to conventional wheat sowing with surface irrigation. Considerable electric energy (17.12%) was saved in mini sprinkler irrigation in comparison to conventional wheat sowing method. The highest nitrogen use efficiency (76.3 kg/kg nitrogen) was observed in mini sprinkler fertigation method as it saved 50 per cent of the recommended nitrogen (75 kg) in wheat as compared to conventional surface irrigation method.

Effects of stage dependent deficit irrigation on tomato: In a two-tier experiment with tomato imposed with either the regulated deficit irrigation (RDI) or at phenological stages and disruption of irrigation, the marketable fruit yield (MFY) was not affected at RDI (0.8 × ETc) but there was loss of about one-fourth MFY with RDI (0.6×ETc). Nevertheless, the water productivity (19.2 kg/m^3) was the maximum under RDI (0.8 × ETc). When the deficit irrigation (RDI, 0.6 × ETc) was applied at vegetative stage, MFY was rather improved by 4% while a decline of 7% was monitored with DI at fruiting. The DI applied at either of the two stages amongst vegetative, flowering and fruiting resulted in 14-18% decline in MFY. The crop was able to tolerate interruptions of irrigation for 15 days, i.e. simulating canal closures and the decline in yield was only 3-7%, the highest being at fruiting stage. The major advantage of DI was improvement in quality in terms of total soluble solid, ascorbic acid, acidity and colour index (lycopene) though the fruit size was affected. It was concluded that

View of farm pond and catchment area

Vegetable on bench and fodder (hybrid Napier on terrace riser)

benefits of deficit irrigation in terms of improved quality and water productivity while sustaining fruit yield could be achieved with regulated DI at 0.8 × ET and at 0.6 × ET during vegetative stage followed by flowering.

Water harvesting and multiple use of water in Southern hilly areas: The Nilgiri farm pond and integrated farming system module was developed by Research Centre, Udhagamandalam under rainfed ecosystem with the components of vegetable (potato, carrot, cabbage and beans) cultivation in the benches, growing hybrid Napier (CO 4) on the riser portion of the bench terraces, cold water fishes (minor carps) in the pond and livestock. Farmers' in the region hesitate to go for bench terraces, which is recommended for the region, as they have to lose some portion of the land (terrace risers) when it is converted into benches. This problem was solved by bringing riser portion of bench terraces under fodder cultivation. Farm pond of size 750 m^3 was created in the valley portion and the downstream side of the pond was lined with silpaulin sheet to arrest the seepage. This farm pond supports irrigation for 2.5 ha of land involving 5 farmers, increasing the cropping intensity to 300% vegetable yield by 20%. Fish production (4.5 tonnes/ha) from pond and fodder production (20 tonnes/ha) from the riser portion of bench terraces augment the agricultural output in this region besides arresting the soil erosion.

Terrestrial weed based phytoremediation system for waste water treatment for irrigation: To find out effect of waste water application on metal accumulation in soil and to assess heavy metal uptake in tomato at DWR farm, the eight treatment combinations were made including four main (tube well water, filtered water-I (*Typha* based), filtered water-II (*Vetiveria* based) and drain water as control as irrigation treatment, which were split-up with two treatment of with and without EDTA.

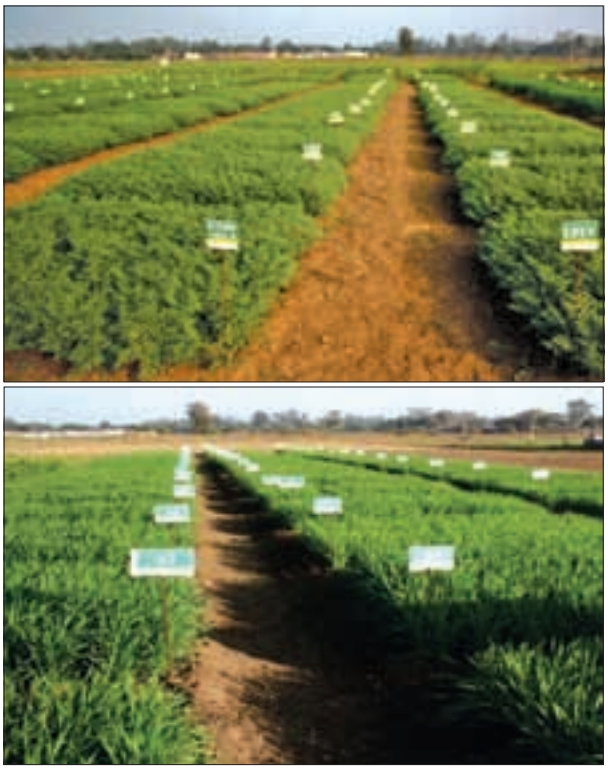
Higher concentration of DTPA extractable cadmium and lead were observed in plots irrigated with untreated drain water as compared to tube well water. The Pb accumulation in soils was 2.59, 2.67, 2.71, 3.08 mg/kg in surface soil under tube well water, filtered-I (*Typha* treated), filtered-II (*Vetiveria* treated) and drain water irrigated plots, respectively. After irrigation with drain

water tomato absorbed higher concentration of heavy metal than tube well water irrigation. Comparatively lower concentration of heavy metals was retained in fruits of tomato than its shoot part. EDTA application enhanced the translocation of heavy metals in tomato. Significantly higher tomato yield was observed under plots irrigated with drain water.

Nutrient management

Soil test crop response based integrated plant nutrition packages: Soil fertility under drip fertigation plays a major role for attaining higher crop productivity with sustained soil health. Fertilizer prescription equations (FPEs) under IPNS were developed for Vertic Ustropept (mixed black calcareous soils) under drip fertigation.

Validation experiments were conducted with hybrid cotton at TNAU Farm, Coimbatore and at two farmers' holdings of Salem district (North Western Zone) of Tamil Nadu on Vertic Ustropept. It revealed that the targeted yield has been achieved within ±10 per cent variation suggesting validity of the equations. The highest mean yield of 3.97 tonnes/ha of seed cotton was recorded in STCR-IPNS for the yield target of 4.0 tonnes/ha with an increase of 41.3 and 44.9%, respectively, over blanket and farmer's practice. Further, it has proved its superiority over all other treatments in terms of RR, BCR and quality parameters.



Field testing of *Arthrobacter* isolates on maize and Actinomycetes consortium on chickpea in Vertisol

New microbial inoculants: Novel plant growth promoting rhizobacteria and *Arthrobacter* were isolated, characterized and field evaluated in Vertisols of Madhya Pradesh. Average yield increase of wheat due to actinomycetes inoculation (17 strains) at recommended fertilizer doses was 4.6 Mg/ha (16% higher) over control. Mixed consortium of superior actinomycetes isolates (A10 and A17), PGPR (P3, P10 and P25) along with *Rhizobium* R33 and R34 in soybean and *Rhizobium* R40 and R56 in chickpea were found very effective. Thirteen shortlisted *Arthrobacter* isolates were found very effective in maize and soybean.

Technique for acceleration of decomposition process using thermophilic microbes: A new technology Rapo-compost technique has been developed by ICAR-IISS in collaboration with ICAR-CIAE and

'Rapo-compost technique' developed by ICAR-IISS

ICAR-NBAIM, Mau to decompose kitchen waste and vegetable wastes. Using consortium of ligno-cellulolytic thermophilic organisms, decomposition period has been considerably reduced to 45 days. The samples were collected initially, at 15 days and 30 days of decomposition and were analysed for its physical, chemical and biological properties. At 30 days of decomposition the colour of the compost was dark brown, with no foul odour. C:N ratio fell from 62:1 to 14:1, cation exchange capacity (CEC) reached to 94 cmol(p+)/kg, lignin/cellulose ratio increased from 0.5 to 2.4%, CEC/TOC ratio was 4.56 at 30 days of decomposition, water soluble carbon reached to 0.5%. Dehydrogenase activity, FDA and alkaline phosphatase activity increased from 111 to 413 µg TPF/g compost/day, 98-260 µg fluorescein/g compost/h and 94-171 µg PNP/g compost/h, respectively.

Biofertilizers

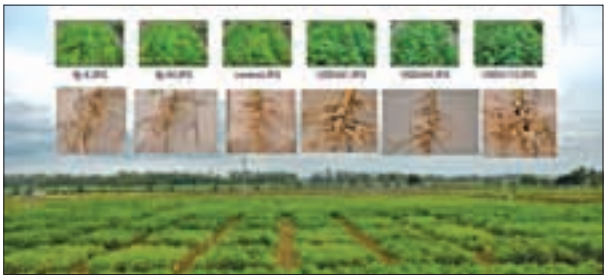
A novel "Actinobacterial Consortium" containing three *Streptomyces* spp. that have ability to solubilize insoluble P and Zn, suppress diseases and produce phytohormones and a variety of enzymes involved in organic matter recycling was developed. This consortium is a carrier-based product, which can be applied either through seed, seedlings, irrigation water or through the enrichment of compost/FYM/cocopeat. Its application improves yield of various vegetable crops from 13 to 24%.

A fermented cocopeat-based VAM fungal inoculum production technology using sterile fermented cocopeat (100 kg) as the sole substrate and a carrier-based bacterial inoculum (50g) containing nearly five times more

infective propagules was developed. This inoculum can be prepared within 45-60 days both outdoor or in glasshouse.

Removal of heavy metals from municipal solid waste: Six mesophilic fungi have been isolated, viz. *Trichoderma viride*, *Aspergillus heteromorphus*, *Rhizomucor pusillus*, *Aspergillus flavus*, *Aspergillus terrus*, and *Aspergillus awamori.* The functional groups were mainly observed in the cytoplasmic membrane of isolated fungi namely, amide group (-NH), hydroxyl group (-OH), carboxylate anions (-COO), carbonyl groups (-CO), C-F and C-Br and these were mainly responsible for biosorption of heavy metals. It was also found that the four fungi, viz. *Aspergillus flavus*, *Aspergillus terrus*, *Aspergillus awamori* and *Rhizomucor pusillus* are having these functional groups. These functional groups ligands with heavy metal like Cd, Cu, Ni, Cr and Zn. The adsorption peak due to bonded OH groups (R-O-H, hydroxyl group) are observed in the range of 3,340-3,380/cm in *Trichoderma viride*, (3,376.94/cm) and *Aspergillus heteromorphus* (3,375.7/cm). These functional groups also help for metal ligand classes of Cr, Ni, Cu, Zn and Cd. Among these six fungi Pb biosorption was maximum and least was observed for Zn. The removal of heavy metals through bio-filter, Pb was maximum 31.6% over initial value followed by Ni (28.8%) and Zn (22.4%). Further it was observed that among the six fungi,*Trichoderma viride* performed better for removal of Pb, Ni, Zn and Cd followed by *Aspergillus flavus.*

***Bradyrhizobium* with rtx gene for induction of nodulation and drought tolerance:** In field experiments on virgin soils converted from basaltic murrum with very low fertility, inoculation with only the rhizobitoxine producing strains (*Bradyrhizobium elekani* USDA 61, *B. elekani* USDA 94 and *B. japonicum* USDA 110) was effective in inducing early stage nodulation in soybean and thus produce higher seed yields under drought stress conditions while none of the 79 nationally collected and 4 commercially available rhizobium strains was effective in nodulation in this soil.



The effectiveness of rhizobitoxine producing strains

e-Atlas of water bodies: Electronic atlas of water resources of Odisha and Himachal Pradesh was developed using vector data representing administrative boundaries of the blocks, districts and states. e-Atlas is user friendly and can be comprehended from a single screen display, ranging from the name of state to the details of village name, water body name, area during pre- and post-monsoon seasons as well as number of water bodies present in any hierarchical administrative unit. It is a useful tool for catch assessment and developing GIS based decision support system and will help planners to concentrate efforts, allocate resources and deploy manpower according to the distribution of fishery resources.

Organic matter degrading microbes: *Bacillus licheniformis* (strain CPSM8) grew well in sewage water and degraded 66% of organic matter present in sewage, 57% of glucose or 50% of peptone added to sewage, within 4 days of incubation showing its total organic carbon degradation ability. Its genome displayed several complex organic matter mineralizing genes for the production of glucanases, xylanase, glucosidases, galactosidases, lipase, proteases, phytase, alkaline phosphates, etc.

Bio-sorbent for amelioration of heavy metal contaminated wastewater: Cation-exchange bio-sorbent was developed from water hyacinth leaf biomass (WLB) and azolla biomass. Both bio-sorbents were effective in removal of copper up to 95% from wastewaters. Sorption equilibrium was reached within 10 min and 25 min for WLB and azolla biomass, respectively. These bio-sorbents can be reused up to five cycles and were effective for developing low cost re-circulatory aquaculture system.