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Role of Soil Microbes on Crop Yield against Edaphic Factors of Soil

Shishir Raut

Abstract

Soil degradation is one or the other form and consequent decline in soil productivity which has been the experience of the farmer since ancient times. As population pressure on agricultural land increases, concerns for ensuring sustained agricultural productivity of soils are being voiced more vociferously now. Chemical degradation of soils takes place as these accumulate soluble salts or toxic elements in amounts deleterious for plant growth or their chemical properties are so transformed as to adversely affect their productivity. The losses in soil productivity may also be accompanied by ecological obliteration and environmental degradation of the whole area. Continuous use of inorganic fertilizers coupled with depletion of organic matter results in deterioration of soil structure and soil productivity. It leads to reduce input/output ratio unless soils are replenished with organic matter through green manure, farm yard manure (FYM), compost or through microbial activity. Due to repeated application of microbes like blue green algae (BGA), bio-fertilizer soil organic carbon content is not only maintained but enriched too. The increase in carbon content of saline soil of Andhra Pradesh (India) has been shown to be up to 22%. The microbial polysaccharides are regarded as the most important natural products in the formation and stabilization of soil aggregates.

Keywords: soil salinity, alkalinity, acidity, organic matter, microbes

1. Introduction

Increasing pace of production to meet the demands of growing population is resulting in overexploitation of both renewable and non-renewable resources and accumulation of contaminants in environment, as wastes. Amongst other things, more emphasis is now being placed on recycling technology to prevent the depletion of resources and to limit environmental degradation due to overloading of soil and atmosphere with residues/byproducts of chemical and physical processing industries. Initially, this technology dealt with protection of environment through waste water treatment, disposal of human excreta, use of crop residue for improving soil fertility, etc. The field has now widened to control environmental pollution, waste land reclamation and conversion of wastes into industrially valuable products. In this context, bioconversions/bio transformations through microbes are attracting greater attention, since enzymes carry out very specific reactions under mild conditions, larger water insoluble molecules can be transformed and biogeochemical cycling do not require external energy inputs [1].

Soil and water conservation has been practiced extensively by settled agriculturist traditionally to maintain the productivity of any country. When the population pressures increase, the farming systems break down as there is an upper limit for any land water system to support increasing number of human beings and livestock without affecting the ecological balance. Over the years the population pressure has been increased and per capita availability of arable land is decreased. Thus soil and land resources, in recent years, are under tremendous pressure with highly conflicting and competing demands of rising population. The increased claims on land for settlement, urban growth, industrialization and other development purposes apart from increased demands for food, fodder and fibre, has set in an imprudent trend of land utilization with disregard to risks of damage to the ecosystem. The apathy for the harmonious use of land in accordance with potentialities and capabilities of soils has given rise to a multitude of serious problems. The major soil problems in some tropical and subtropical countries are salinity, alkalinity, waterlogging, acidity and soil fertility. Soil degradation thus refers to appreciable loss of productivity and is defined as a process which lowers the current and/or potential capability of soil to produce goods or services [2].

2. Chemical degradation of soils

Chemical degradation of soil is mediated through processes that induce leaching of bases, development of acidity, deficiencies of certain nutrient elements or accumulation of metallic ions in quantities toxic for plant growth. Reducing conditions of soil following prolonged waterlogging may generate toxic levels of organic constituents and certain metallic ions. It also includes the processes that help accumulate harmful levels of salts of various kinds in the soil.

2.1 Soil degradation through base unsaturation

Excessive removal of bases from surface soil leads to disorder in crop plants grown in highly acid soils met under different pedogenic environments. In high altitude soils of cold climate, soil acidity and base unsaturation is associated with soil forming processes normal to the given climate and local conditions. Apart from lime needs soil degradation is not a major threat to agricultural productivity in the above regions. In high rainfall tropical areas excessive soil acidity may assume discernible proportions in soil types like laterite, lateritic, red and even alluvial soils borne on different parent materials. In the high rainfall forest soils of the hilly region, high organic matter and rainfall tend to produce acidity and base unsaturation in soils with concomitant increase in exchangeable Al of the soil. Often local conditions like rise in water table along with high organic matter and rice cultivation may lead to high active iron in the soil with its content as high as 3%. Besides toxicity of iron, the crops may experience deficiency of phosphorus and zinc. Often toxic concentration of M_n may also be encountered in such soils [3]. All these factors, lead to loss in soil productivity.

2.2 Sources of salts in soil (Indian context)

2.2.1 Relic salts

Prior to the orogeny of the Himalayan ranges, the Tethys sea extended in a large part of the present Indo Gangetic plains, Western Rajasthan and the Kuchh. With uplift of the Himalayas the foredeep was filled up with detritus. Some of the sea

salts precipitated during the process of deposition while other entrapped in the alluvium are present mainly in the arid parts of the country [3]. In the lower Himalayas the rock salt deposits of the pre-cambrian saline series in Himachal Pradesh and the salt range of Pakistan and numerous brine springs in the Shivalik region rich with as much as 3243 mg l^{-1} chlorides, are important sources of salts [3].

2.2.2 In-situ weathering

The only source of in-situ release of salts is weathering of minerals constituting the soil regolith below it. Its ample evidences are available in peninsular regions. The alluvial zone in the north is composed of strongly saline sedimentary rocks which originated during the Tertiary and Pleistocene times. Their decomposition is incomplete in the arid climate. Hence there are constant sources of salts under environments which favour their further break down. For example almost 44% of light minerals in sand dunes of Rajasthan contain orthoclase feldspars which undergo weathering and release minerals like illite and montmorillonite [4]. Salts are natural by products of such weathering.

2.2.3 Overland flows

Run off waters pick up salts on their way to natural depressions. In some areas, the natural settings are such that they have centripetal drainage which attracts salt bearing over land flows from the surrounding areas. Minor channels feeding these basins owe their salinity to salt releasing marine lithological formations [5]. Even rivers flowing in the regions pick up lot of salts. In Luni basin of Rajasthan, India flash flood deposited thick layer of sediments composed of very fine sandy to coarse silty material charged with salts over highly productive agricultural lands rendering them so saline that cultivation had to be abandoned [6].

2.2.4 Sub-terranean flux of salts

In the peninsular regions, much of salinity in valley lands is traced to salts travelling from uplands laterally along the interface between the soil and the underlying 'murrum' or through the porous 'murrum' itself. Irrigation canals and channels are on the ridge causing seepage water to pick-up salts and move down to valley lands. The morphogenesis of salt lakes and palayas in Western Rajasthan of India is traced to the confluence of prior drainage channels. Rain water sinks through their beds and flows subterraneously along buried channel patterns carrying soluble salts washed down from the catchment. Evaporation of water from the bed concentrates salts in the path raising their salinity to as much as 3.2 gkg^{-1} of salts [7].

2.2.5 Rain and wind borne salts

The rain in salt water originate either from strong winds that sweep over oceans or salts picked from dust storms causing salt content of rain water to vary with locality and season. Salt additions from rains and winds may thus constitute an important source of salts in soils [7, 8].

2.2.6 Tidal floods and sea water intrusion

Coastal regions experience tidal floods especially through backwater creeks and rivers which spill over lands during high tide. Sub-surface intrusion of sea water in coastal areas is threatening agriculture in those areas [8].

2.2.7 Irrigation waters

All irrigation waters, irrespective of their source contain some soluble salts (**Table 1**). Even rivers of the Indo-Gangetic system which are snow fed may carry salty sediments during rainy season and significant salt loads during the lean discharge period. But in the absence of any exit, even small additions of salts over long periods can render the soil saline. In many arid and semi-arid regions, where canal water is scarce or not available, ground water is the sole source of irrigation. Even tank and lakes of many areas carry large salt loads. Prolonged use of such water in low rainfall areas, where natural leaching of salts fall short of their input into the soil, may render irrigated soils saline.

2.2.8 Coastal saline soils

A major portion of coastal saline soils occurs in the deltaic regions of major rivers, for India, falling either into the Bay of Bengal or the Arabian sea. A relatively smaller area of coastal saline soils occurs as narrow strips of lands along the sea coast and along the water lakes such as Chilika lake in Odisha. The soils of deltaic

Irrigation source	Surface waters				
	EC (dS/m)	pH	SAR		
Rivers					
Ganges system	142–647	7.6–8.4	—		
Indus system	370–420	7.2–7.7	—		
Krishna-Godavari	725–1392	—	—		
Vedavathi, Karnataka	1900	8.8	12.8		
Tanks					
Gosikere, Karnataka	1400	8.6	10.8		
Etah (U.P.)	3752	9.0	—		
Kanpur (U.P.)	1766	8.5	—		
Canals					
Dodherde (Karnataka)	1400	8.6	10.8		
Nannewa (Karnataka)	1900	8.6	26.8		
Ground waters					
State	No. of samples tested	% distribution in EC _{iw} (dS/m) classes			
		Up to 3	3–5	5–10	>10
Punjab	12,500	68.0	20.0	8.0	4.0
Haryana	3637	58.5	17.5	13.2	10.8
U.P. (Aligarh)	390	78.4	18.7	2.9	—
A.P. (Coastal)	1082	78.2	16.1	5.7	—
Karnataka (Bijapur)	404	87.6	8.9	3.2	0.2
Gujarat (Ahmedabad-Kheda)	505	84.0	100	5.7	0.2

EC, electrical conductivity; SAR, sodium adsorption ratio; iw, irrigation water.

Table 1.
Salt load of some irrigation waters in India [8].

regions, usually have flat topography and finer texture, than the other types of coastal soils, depending on the geomorphology of flood plains; coarse texture soils may also be found in the deltaic regions. The coastal soils of deltaic region are usually formed from the indirect deposits of alluvial materials going to the sea and transported back by the tides and redeposited in the estuarian/deltaic regions. The coastal saline soils have saline ground water at shallow depth. Both the ground water and the soils are rich in chlorides and sulphates of sodium, magnesium and calcium. The soil salinity and the depth to ground water vary with the season. Soil salinities are maximum in dry season and minimum in monsoon months (Indian Society of Coastal Agricultural Research 1987;5:1-14). The clay minerals vary with the region. The pH of the soils usually varies from slightly acidic to slightly alkaline except that the soils with high content of pyritic materials become strongly acidic on drying. Some such acidic soils are present in the coastal regions of Kerala, Sundarbans delta of India and in Andaman and Nicobar islands. Many a time, the exchangeable sodium percentage (ESP) of coastal saline soils is more than 15, but because of high salt content, it does not show strong alkali soil characters. The soils under cultivation are deficient in available nitrogen and organic carbon varying from 0.1% to 1.0% (Indian Society of Coastal Agricultural Research 1990;8:61-78). The organic matter content and its humic components also differ in different landforms as shown in **Table 2**. The humic acid (H.A.) and fulvic acid (F.A.) fractions of organic matter for a coastal soil of West Bengal, are given in **Table 2**. Humus is the major soil organic matter component making up 75–80% of the total [10]. Fractionation of organic matter showed that the fraction of H.A. was the highest (0.31%) in depressed low (DL) soil and the fraction of F.A. was the lowest (0.10%) in the surface layer of the same soil. On the other hand, the F.A. fraction was the highest in non-cultivated deltaic (NCD) soil (0.12%) for which these soils were more capable of infiltration. DL soil with greater fraction of insoluble humic acid exhibited less cumulative infiltration. Mud flat (MUD) soils showed intermediate values (0.11%). In the lower soil layers also H.A. percentage was higher in the DL soils (0.27–0.29). The H.A./F.A. ratio decreased with depth (0.7–0.5 for NCD and 3.1–3.0 for DL land soils) [11, 12]. Presence of humic acid in soil generally

Name of soil	Total organic matter	H.A	F.A.	H.A/F.A. ratio
0–20 cm				
NCD	2.1	0.08	0.12	0.7
MUD	1.8	0.18	0.11	1.7
DL	1.1	0.31	0.10	3.1
20–40 cm				
NCD	1.9	0.08	0.13	0.6
MUD	1.1	0.16	0.10	1.6
DL	0.93	0.29	0.09	3.0
40–60 cm				
NCD	0.88	0.07	0.11	0.5
MUD	1.1	0.14	0.09	1.5
DL	0.87	0.27	0.09	3.0

NCD, non-cultivated deltaic; MUD, mudflat/mangrove; DL, depressed low land.

Table 2.
Humic acid, fulvic acid content of organic matter and their ratio [9].

decreases volumetric water content of soil. Decline in water repellency of soil is due to the presence of water soluble fulvic acid [13, 14]. In general, with increase in EC values, there was a decrease in organic carbon content. This may be attributed to the decrease in activity of organic matter sequestering organisms. The organic C percentage was high at EC values 4–4.5 (dS/m) which may be because of addition of FY.M. (Figure 1).

2.3 Alkalinity (sodicity) of soil and their reclamation

The distinguishing characteristics of a sodic soil are high exchangeable sodium percentage (ESP) sufficient to interfere with plant growth; high sodium adsorption ratio (SAR) of saturation extract; presence of large concentration of sodium carbonate type salts, and low permeability. In sodic soil the ESP is more than 15, EC_e (electrical conductivity of saturation extract) is less than 4 dS/m and pH of the saturation paste is usually more than 8.5. The work at the Central Soil Salinity

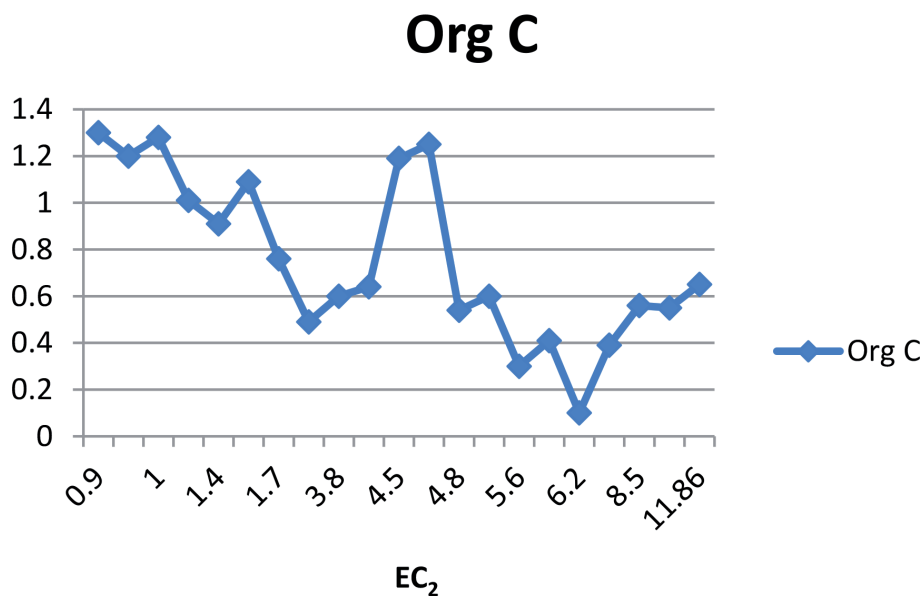


Figure 1. Soil salinity and organic carbon relationship [9]. X, electrical conductivity values of 1:2 soil:water solution; Y: organic carbon %.

Soil	Saturation extract (mmolL ⁻¹)		
pH _s	10.3	Na ⁺	37.0
EC _e	3.4	K ⁺	0.1
CEC [cmol (p+) kg ⁻¹]	7.7	Ca ²⁺	1.4
Exchangeable [cmol (p+)kg ⁻¹]		Mg ²⁺	0.6
Na ⁺	5.1	CO ₃ ²⁻	12.0
K ⁺	0.3	HCO ₃ ⁻	5.4
Ca ²⁺	1.2	Cl ⁻¹	10.2
Mg ²⁺	0.7	SO ₄ ²⁻	12.6
ESP	66.2	SAR	37.0

Source: Report No. 8, Central Soil Salinity Research Institute, 1978, p. 72. pH_s refers to pH of saturation soil paste.

Table 3. Characteristics of a typical sodic soil from Karnal, Haryana, India.

Gypsum ^{''} (t/ha)	Wheat cultivation at 1970–1971	Rice 1971	Wheat 1971–1972	Rice 1972	Wheat 1972–1973
0	0	4390	1520	7180	1350
7.5	1890	6210	2790	7230	1960
15.0	3490	6390	3450	7130	2430
22.5	4160	7080	3720	7170	2260
30.0	3790	6660	3980	7030	2740
CD (p = 0.05)	640	810	70	NS	500
Source: Soil Science 1970;127:79. ^{''} Gypsum was applied to wheat in 1970.					

Table 4.
Effect of gypsum treatments on the yield of wheat and rice (kg ha⁻¹).

Research Institute, Karnal, India suggests that for diagnostic purposes, pH 8.2 of the saturation paste may be taken as the lower limit of pH. In literature such soils have often been referred to as alkali soils. Characteristics of a typical sodic soil are presented in **Table 3**.

The problem of sodic soils is the high exchange sodium percentage. Obviously, the basic principle underlying reclamation of these soils is to adopt those ameliorative measures by which the exchangeable sodium will be replaced by calcium and the exchangeable sodium thus released as sodium salts will be leached out of the root zone. Because of low cost and easy availability, gypsum (CaSO₄.2H₂O) has been used widely and intensively as an amendment for reclamation. Hydraulic conductivity of sodic soils is very significantly increased by gypsum application and this result in increased yield of crops. An example of increase in crop yield by gypsum application is given in **Table 4**.

3. Soil degradation through water logging

Waterlogging of soils occurs when water balance of an area gets disturbed due to external inputs of water. Important source are heavy rains, overland flows, seepage from canals, tidal flooding especially through back water canals and coastal lakes. The soil situations favouring excess water concentration in a given area are basin type of topography with no natural outlet of water. Waterlogging creates anaerobic condition in soil which hampers the activity of beneficial soil microbes [14].

4. Environmental factors influencing microbial activity

Soil microflora, just like higher plants, depends entirely on soil for their nutrition and growth.

4.1 Water

Water is a major component of protoplasm in a microbial cell and is essential for growth. In the presence of excess water, say waterlogging, the environment becomes anaerobic because of lack of soil aeration, the aerobes becomes suppressed and inactive and anaerobic bacteria dominates. Nitrogen-fixing algae like *Tolypothrix tenuis*, *Scytonema cinnatum* and *Hapalosiphon fontinalis* can be used

in waterlogged areas which will fix nitrogen and will be useful to improve yield of crops (rice).

4.2 Temperature

Temperature is the most important factor influencing the biological processes and the microbial activity. The optimum temperature range at which a particular microorganism grows is narrow. Most of the soil organisms are mesophiles and grow well between 15 and 45°C.

4.3 Aeration

Microbes consume oxygen from soil air and give out carbon di oxide. Waterlogging reduces soil aeration and carbon di oxide is accumulated in soil which is toxic to the microbes.

4.4 Soil reaction

Bacteria, in general prefer near neutral to slightly alkaline reaction between pH 6.5 and 8.0; fungi grow in acidic reaction between pH 4.5 and 6.5.

4.5 Soil factor

A soil in bad physical condition as in degraded soil has not having good aeration and water supplying capacity which affect optimal microbial activity.

4.6 Microbial inoculation to ameliorate soil

Continuous use of inorganic fertilizers coupled with depletion of organic matter results in deterioration of soil structure and soil productivity. It leads to reduced input/output ratio unless soils are replenished with organic matter through green manure, FYM, compost or through microbial activity. Due to repeated application of BGA biofertilizer, soil organic carbon content is not only maintained but enriched too [15, 16]. The increase in carbon content of saline soils has been shown to be up to 22%. The microbial polysaccharides are regarded as the most important natural products in the formation and stabilization of soil aggregates. Presence of excess neutral soluble salts or high level of sodium in soils leads to rise in soil pH and soil finally become saline or sodic. These soils usually give poor crop yields or crops altogether fail. The crop failure is brought about either by nonavailability of plant nutrients or by the toxic effect of sodium ions per se. Repeated application of suitable BGA strains in such soils helps to bring down the level of soluble salts, pH towards neutrality and sodium content in exchange complex [17]. The cumulative effect of reduction in soil pH, electrical conductivity and exchangeable sodium, improvement of soil aggregation and permeability of air and water, together with enrichment of soil carbon content brings an overall improvement in soil health and thus productivity.

4.7 Crop response to algalization (in India)

Large numbers of field trials were conducted in different agroclimatic regions of India to assess the effect of algalization on rice yield. Agencies involved were state department of agriculture, All India Coordinated Rice Improvement Project (AICRIP), Hyderabad and progressive farmers [18]. In areas where chemical

State/organization	No. of trials	Yield (t/ha)		% increase over control
		Control	BGA	
Andhra Pradesh	1	3.64	4.44	21.9
AICRIP	20	3.04	3.37	10.8
Bihar	1	2.13	3.06	32.8
J & K		3.75	3.90	4.0
Madhya Pradesh	1	2.48	2.85	14.9
Maharashtra	161	3.05	3.91	28.1
Orissa	91	2.97	3.71	24.6
Punjab	1	5.04	5.27	4.5
Uttar Pradesh	1	3.29	3.82	16.1
Total trials	17			
Average	294	3.28	3.81	16.1

Table 5.
 Yield of rice due to algalization in absence of inorganic nitrogen fertilizer [18].

State/organization	No. of trials	Nitrogen kg/ha	Average yield t/ha	% increase
J & K, M.P., U.P.	7	20	3.78	9.74
		20 + BGA	4.15	
AICRIP, Maharashtra	43	25	3.71	10.21
		25 + BGA	4.09	
J & K, Kerala, U.P.	15	30	3.49	12.28
		30 + BGA	3.92	
J & K, M.P., U.P.	7	40	4.27	5.54
		40 + BGA	4.51	
A.P., J & K, Maharashtra	29	50	4.38	11.93
		50 + BGA	4.90	
Kerala, M.P., U.P.	22	60	3.87	11.93
		60 + BGA	4.34	
Maharashtra	27	75	4.46	9.50
		75 + BGA	4.88	
Punjab, U.P.	6	80	5.56	0.23
		80 + BGA	5.58	
Kerala, U.P.	14	90	3.64	9.77
		90 + BGA	3.99	
A.P., Maharashtra, T.N.	46	100	5.02	7.22
		100 + BGA	5.38	
Kerala, Punjab, U.P.	15	120	4.73	6.25
		120 + BGA	5.03	
A.P.	1	150	5.84	11.60
		150 + BGA	6.52	
Total trials	232			
Average % increase				

Table 6.
 Effect of algalization on the yield of rice at different levels of nitrogenous fertilizers [18].

N-fertilizers are not used for various reasons, algal inoculation enhances the crop yield with a minimum of 45 and a maximum of 32.8% in different places with an Indian average of 16.1% (Table 5). Even at the recommended levels of chemical nitrogen fertilizer being used in different areas application of BGA bio-fertilizer results in an increased yield of about 8.85%. Depending upon the level of nitrogen fertilizer and agro-climatic zones the yield increase varies from less than 1% to 12.28% (Table 6).

5. Conclusions

Use of microbes in resource management has been an age-old practice although the scientific reasoning for such practices has come to be known only recently. For instance, a common wetland plant, *Phragmites karka*, is traditionally used in rural Bengal (India) to make waste water suitable for fish culture. It has now been found that the detoxification is actually due to biodegradation of harmful elements by microorganisms associated with the roots of this plant. This knowledge led to worldwide use of such plants to recycle sewage, paper mill and distillery effluents, etc. for making water not only suitable for irrigation and aquaculture but also potable. The technology is known as 'root zone method'. The method is being used to treat effluents containing sulphur compounds, reactive dyes, ammonia, phosphates, chlorinated hydrocarbons and heavy metals. Similarly growing legumes with nonlegumes in the cropping system improves soil fertility by introducing *Rhizobium* both in saline and alkali soils [18]. Microbes play a dominant role in mobilization of immobile elements like phosphorus, zinc and copper in soils high in pH. These organisms release nutrients by organic acid or net excretion of H^+ or HCO_3^- ions. Nitrogen fixing algae like *Tolypothrix tenuis* and *Scytonema cinnatum* can be used in waterlogged areas which fix nitrogen and are useful to improve yield of crops. In the saline and alkali soils organic contents are usually low. In these soils, repeated application of blue-green algae (BGA) bio-fertilizer, helps to bring down the level of soluble salts, pH and sodium content in exchange complex [19]. Hence, soil organic carbon content is not only maintained but also enriched too. Thus the microbes can be utilized to overcome the harmful effect of chemical degradation of soil and waterlogging which improves soil fertility.

Acknowledgements

Author acknowledges the contribution of Director, Central Soil Salinity Research Institute, Karnal, India for his encouragement during doing the study and research.

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Author details

Shishir Raut
ICAR-Central Soil Salinity Research Institute, South 24 Parganas, West Bengal,
India

*Address all correspondence to: shi_cssri94@yahoo.com

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