Dhaka Univ. J. Biol. Sci. **20**(2): 173-182, 2011 (July)

PHYSICO-CHEMICAL CHARACTERISTICS OF THE SEASONALLY FLOODED SOILS OF BANGLADESH AND THEIR MANAGEMENT IMPLICATIONS

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Key words: Seasonally flooded soils, Physical and chemical attributes, Management implications

Abstract

The seasonally flooded soils of Bangladesh are unique in respect of several specific characteristics and contribute toward producing bulk of its staple food - mainly rice. Having fine texture these soils are similar to the "paddy soils" of Southeast Asian floodplains and have high production potential under proper management. Six representative soil series, *viz.* Arial, Debidwar, Naraibag, Jalkundi, Siddirganj and Tippera from the central region of Bangladesh have been studied to evaluate some of their intrinsic physico-chemical properties and their sustainable management requirements. These soils are slightly acidic to neutral and are negatively charged with ΔpH values ranging between –0.2 and –1.2. The organic matter content in the surface soil is relatively low that decreases steadily with depth. The cation exchange capacity (CEC) of the soils varies on the basis of their clay and organic matter contents while base saturation per cent (BSP) is high. The contents of available N, P, K and S and DTPA-extractable Fe, Mn, Cu and Zn in soils are moderate and are commensurate with the contents of colloidal fractions. These soils receive several mineral nutrients annually with the sediments deposited during the monsoon floods. The characteristics like organic matter content, particle size distribution, CEC, pH and BSP that have important management implications have been discussed.

Introduction

The flat deltaic region of the Ganges-Brahmaputra-Meghna (GBM) river system occupies the larger part of Bangladesh and around one-fourth of these flat lands are seasonally flooded during the monsoon to variable depths and durations. The seasonally flooded areas of Bangladesh as per Ramsar Convention are categorized as wetlands(1) and soils of these wetlands have been categorized as surface-water gley soils(2), aquorizems(3) and gray hydromorphic soils.(4) These soils are aquic/udic in respect of moisture regime and cultivation of paddy - both local and HYVs - are the major land uses that support over 160 million people in Bangladesh.(5) These soils in the past, though were considered as fertile for growing traditional wetland crops without using agro-chemicals, but for growing HYVs require variable doses of chemical fertilization at the present time. Under

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the changed situation it is, therefore, essential that the intrinsic properties of these soils are determined accurately and evaluated carefully in an effort to stabilize the sustained agricultural productivity of these soils. There are innumerable examples in history that due to lack of adequate knowledge and improper uses the seasonally flooded floodplain soils in the past centuries became degraded and unproductive causing disappearance of many civilizations.

The seasonally flooded soils of Bangladesh are characterized by excess water in the monsoon and very little in the dry season. The seasonal flooding of soils is considered as a natural phenomenon which is caused either by rain water or by river water or by both or by standing irrigation water in rice fields. The heavy monsoon rainfall in Bangladesh comes at a time when the major rivers bring in a large volume of water from their upper reaches that causes flooding on the floodplains. Around 23% of the area of Bangladesh is routinely flooded every year for varying periods.(6) Land in Bangladesh has been divided into five inundation land types.(5) Seasonally flooded soils undergo the following developmental stages: initial deposition of alluvium, ripening, formation of mottles, homogenization, development of structure, formation of flood coating, changes in subsoil reaction, ferrolysis, formation of gleyans and formation of ploughpan.(5) On submergence many physico-chemical and chemical properties of soils undergo both reversible and irreversible changes.(7) The floodplain soils in Bangladseh have undergone seasonal flooding for many hundreds of years. Because of their location in the tropics high temperature and abandunt moisture result in stronger pedochemical weathering and quicker soil profile development.(5)

Authors of this paper intent to highlight the phygico-chemical characteristics of several representative seasonally flooded soils developed in the central region of Bangladesh for determining their abilities to maintain sustainable productivity for its fast growing population.

Materials and Methods

The study area covers over a million hectare in the central hydro-ecological region of Bangladesh. Soil samples for the study have been collected from river alluvia of the GBM system. Locations of the sampling sites are shown in Fig. 1 and the parent materials, cropping pattern and taxonomic classification of soil series are presented in Table 1. The exact locations of the selected pedons were determined with GPS and were shown in the above figure. A total of 30 soil samples were collected from six pits on natural horizon basis. The soil samples were duly processed, preserved and analyzed for determination of their physico-chemical characteristics. The morphological and chemical properties of the studied soils have also been discussed.(8) The annual flooding characteristics, subsoil horizon, plough-pan, flood coatings, matrix colour and mottles and consistence are the notable morphological features relevant to the management of these soils.(8)

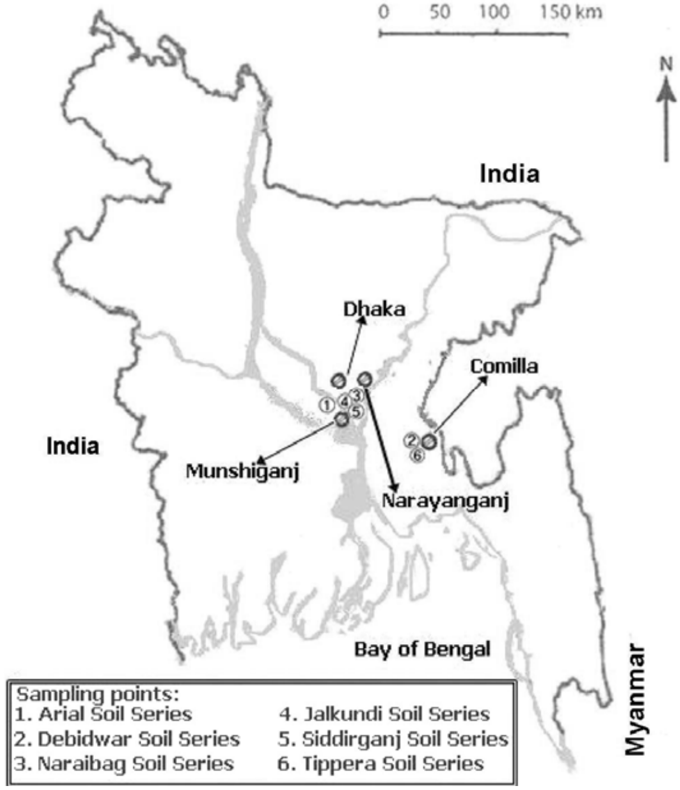

Fig. 1. Location map of the study area showing soil sample sites.

Table 1. Location and classification of some representative seasonally flooded soils.

Soil series*	Location (Latitude and Longitude)	Parent material	Landuse/ cropping pattern	Soil clasification** (Subgroups)
Arial	Srinagar upazila 23°25´N & 90°15´E	Ganges river alluvium	Boro-fallow	Vertic Endoaquept
Debidwar	Chandina upazila 23°24´N & 91°02´E	Meghna river aluvium	Boro-fallow/ T. aman	Aeric Endoaquept
Jalkundi	Rupganj upazila 23°45´N & 90°32´E	Meghna river alluvium	T. aman-fallow	Aeric Endoaquept
Naraibag	Rupganj upazila 23°45´N & 90°31´E	Brahmaputra alluvium	Boro-fallow- T. aman	Aeric Endoaquept
Siddirganj	Rupganj upazila 23°35´N & 90°30´E	Mixed Meghna and Brahmaputra river alluvium	B. aman-fallow	Typic Endoaquept
Tippera	Debidwar upazila 23°30´N & 91°01´E	Meghna river alluvium	Rabi and kharif vegetables	Typic Epiaquept

Source: *SRDI Staff [15]; **Soil Survey Staff.[24]

The particle size analysis of soils has been carried out by sieving and using hydrometer method as per Gee and Bauder.[9] The pH determination has been done using glass electrode in soil suspensions in H_2O and 1 M KCl. The ΔpH was calculated by subtracting pH in H_2O values from pH in KCl values. Organic carbon was determined by Walkley and Black[10] wet oxidation method and total nitrogen was estimated by digestion of the soil in the sulfuric acid followed by a Kjeldahl distillation.[11] CEC was measured leaching the soil sample with neutral 1 *N* ammonium acetate solution[12] and exchangeable bases were determined from the same 1 *N* ammonium acetate leachate using atomic absorption spectrophotometer. Available N, P, K and S have been determined using standard volumetric and colorimetric procedures.[13] Determination of available Fe, Mn, Cu and Zn was done from DTPA-$CaCl_2$ extracts using atomic absorption spectrophotometer.[14]

Results and Discussion

The sand fraction in the studied soils varies from 2 to 25 per cent while the silt fraction ranges from 23 to 60 per cent showing a mean value of 41 per cent (Table 2). The high clay content (21 to 73 percent with a mean value of 45 per cent) of the studied soils is indicative of their favourable agricultural use potential. The rather erratic vertical distribution of particle size components indicate the heterogeneity and lithological discontinuity of the sediments and the turbulent condition under which they were deposited. The silt/clay ratio in many horizons varied erratically (0.31 to 2.67) and indicated that the observed variation of silt/clay ratio is lithological rather than weathering of silt into clay *in situ*. The sand/silt ratio of the soils is less than 1.0 with a mean value of 0.34.

The soils under study being fine-textured show textural variations ranging from silt loam to clay (Table 2). The Tippera series occurring on floodplain ridges is texturally lighter while the Debidwar, Arial, Jalkundi, Naraibag and Siddirganj series occurring on basin margins and bottoms are texturally finer. In general the ridge soils have silt loam to silty clay loam texture while the basin soils are clayey.[5,15]

The data in Table 3 show the pH (water) value of soils range from 5.4 - 7.0. The pH values show increasing trends with the increase of depth a feature common in the seasonally flooded/saturated soils of Bangladesh.[5] Brinkman[2] working with several surface-water gley soils of Bangladesh that are subject to seasonal flooding and droughtiness cause seasonal pH fluctuation in surface horizon that break down the clay lattice releasing the silicon and sesquioxides in which the pedogenic feature was termed by him as ferrolysis. An observed decline of pH (1*N* KCl) in all the soils and the ΔpH values are presumed to be due to the difference in reserve acidity.

Organic matter contents in the surface horizons of the studied soils ranged from 1.76 to 2.05 per cent that decreased steadily with depth (Table 3). The variation in organic matter content in different horizons of hydromorphic soils is used as a criterion in defining the Cambic horizon in soil taxonomy. The organic matter content in surface and subsurface horizons remains in equilibrium with the prevailing environmental components particularly the land use of a region. Under Bangladesh condition, the organic matter content in the surface soil drops abruptly down with the change of land use from forestry to agriculture.

Table 2. Particle size distribution and textural classes of some seasonally flooded soils from Bangladesh.

Soil Series	Horizon	Depth (cm)	Particle size distribution (%)			Textural class	Sand/silt ratio	Silt/clay ratio
			Sand	Silt	Clay			
Arial	Apg	0-20	3	27	70	clay	0.11	0.39
	B2g	20-60	4	23	73	clay	0.09	0.31
	B3g	60-100	2	31	67	clay	0.06	0.46
	IICg	100+	8	27	65	clay	0.30	0.42
Debidwar	Apg	0-12	8	60	32	silty clay loam	0.13	1.88
	B1g	12-26	6	49	45	silty clay	0.12	1.09
	B2g	26-48	10	50	40	silty clay	0.20	1.25
	C1g	48-72	11	60	29	silty clay	0.17	2.56
	C2g	72-100	13	60	27	silty clay	0.21	2.48
Naraibag	Apg	0-20	11	40	49	clay	0.26	0.82
	B2g	20-38	11	38	51	clay	0.29	0.75
	B3g	38-60	12	46	42	silty clay	0.26	1.10
	C1g	60-80	10	35	55	clay	0.30	0.58
	C2g	80+	11	42	47	silty clay	0.26	0.89
Jalkundi	Aplg	0-10	8	42	50	clay	0.19	0.84
	Ap2g	10-15	15	43	42	silty clay	0.35	1.02
	B21g	15-40	20	48	32	silty clay loam	0.42	1.5
	B22g	40-67	20	51	29	silt loam	0.49	2.13
	B23g	67-90	22	43	35	clay loam	0.51	1.23
	IICg	90+	22	33	45	clay	0.67	0.75
Siddirganj	Apg	0-20	15	23	62	clay	0.65	0.37
	B2g	20-30	12	31	57	clay	0.39	0.54
	B3g	30-54	15	28	57	clay	0.54	0.42
	IICg	54-74	15	25	60	clay	0.60	0.41
	IIC2g	74-100	15	30	55	clay	0.50	0.55
Tippera	Apg	0-12	25	52	23	silt loam	0.45	2.26
	B1g	12-26	25	53	22	silt loam	0.47	2.41
	B21g	26-46	23	56	21	silt loam	0.41	2.67
	B22g	46-76	25	50	25	silt loam	0.50	2.00
	C1g	76-100	25	53	22	silt loam	0.47	2.41
Mean		-	**14**	**41**	**45**	-	**0.34**	0.91

Geographically the seasonally flooded soils of Bangladesh including the studied soils belong to the Typic, Aquic, Aeric and Vertic subgroups based on texture and hydromorphic properties. In great group level these hydromorphic soils are Aquepts (with

Table 3. Chemical properties of the seasonally flooded soils of Bangladesh.

Depth (cm)	pH H_2O	pH KCl	ΔpH*	Organic matter (%)	Total N (%)	CEC	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	BSP**
						cmol (p+)/kg					
					Arial soil series						
0 - 20	6.8	6.1	-0.7	2.05	0.16	29.5	19.5	6.1	0.75	0.42	90
20 - 60	6.5	5.8	-0.7	1.85	0.13	33.0	22.0	6.9	0.67	0.44	91
60 - 100	6.8	6.0	-0.8	1.56	0.11	15.8	10.0	2.7	0.42	0.24	84
100+	6.9	5.9	-1.0	1.39	0.12	17.5	9.5	2.4	0.45	0.23	72
					Debidwar soil series						
0 - 12	5.9	5.7	-0.2	2.01	0.12	13.6	6.5	3.1	0.87	0.31	83
12 - 26	7.0	6.7	-0.3	1.72	0.08	12.3	6.5	3.6	0.21	0.15	88
26 - 48	7.0	6.6	-0.4	0.96	0.06	12.0	6.5	3.5	0.22	0.14	89
48 - 72	6.8	6.6	-0.2	0.58	0.05	9.0	3.5	2.4	0.35	0.08	75
72 - 100	6.8	6.2	-0.6	0.48	0.05	9.6	4.0	2.7	0.16	0.07	79
					Naraibag soil series						
0 - 20	6.2	6.0	-0.2	1.99	0.15	18.6	9.5	2.4	0.85	0.20	69
20 - 38	6.6	6.2	-0.4	1.65	0.10	14.4	7.5	2.7	0.89	0.17	78
38 - 60	6.5	6.0	-0.5	1.12	0.08	15.9	9.0	3.3	0.92	0.15	84
60 - 80	6.5	5.9	-0.6	0.77	0.07	20.8	12.5	5.1	0.83	0.23	89
80+	6.5	6.2	-0.3	0.60	0.05	12.7	8.0	2.5	0.76	0.16	89
					Jalkundi soil series						
0 - 10	5.9	5.4	-0.5	1.92	0.19	18.9	9.5	3.5	1.00	0.24	76
10 - 15	6.7	6.4	-0.3	1.62	0.08	12.5	7.5	2.2	0.75	0.12	84
15 - 40	6.6	6.1	-0.5	0.65	0.05	12.3	6.5	2.1	0.85	0.11	77
40 - 67	6.6	5.8	-0.8	0.48	0.05	11.6	7.0	2.3	0.81	0.13	88
67 - 90	6.6	5.6	-1.0	0.48	0.04	12.6	8.0	2.7	0.65	0.10	90
90+	6.6	5.4	-1.2	0.60	0.05	14.4	8.5	3.4	0.77	0.18	89
					Siddirganj soil series						
0 - 20	5.9	5.6	-0.3	1.97	0.19	16.8	7.5	2.0	0.59	0.21	61
20 - 30	6.6	6.4	-0.2	1.67	0.08	12.0	6.0	1.9	0.52	0.17	71
30 - 54	6.5	6.2	-0.3	0.62	0.06	9.3	4.5	1.8	0.57	0.16	75
54 - 74	6.2	5.8	-0.4	0.45	0.05	10.8	5.5	2.1	0.70	0.18	78
74 - 90+	6.2	5.1	-0.8	0.65	0.06	16.6	9.0	3.6	0.60	0.28	81
					Tippera soil series						
0 - 12	5.4	5.0	-0.4	1.76	0.11	11.1	5.5	1.5	0.22	0.20	67
12 - 26	6.2	5.4	-0.8	1.46	0.09	11.1	5.5	3.7	0.35	0.10	87
26 - 46	6.2	5.4	-0.8	0.62	0.06	10.5	5.0	4.3	0.41	0.15	93
46 - 76	6.2	5.5	-0.7	0.53	0.05	11.0	4.5	4.4	0.58	0.11	86
76 - 100	6.4	5.2	-1.2	0.58	0.05	11.4	5.5	4.0	0.59	0.14	89
Mean	**6.5**	**5.9**	**-0.5**	**0.88**	**0.09**	**14.9**	**8.2**	**3.2**	**0.60**	**0.19**	**82**

*ΔpH = pH (KCl) - pH (H_2O); **BSP= Base saturation per cent.

Cambic horizon) or Aquents (without Cambic horizon). The other characteristics of tropical soils e.g. segregation of iron, *in situ* development of Oxic characteristics could not develop in these soils because of the time factor and prolonged seasonal inundation. On the contrary signs of gleization particularly in subsoil characteristics are clearly visible in these soils.(8) The seasonally flooded soils of Bangladesh are presently puddled using the mechanical or traditional ploughs to cultivate transplanted paddy.(5) Consequently, paddy straws are smeared in the topsoil in large quantity. Due to addition of paddy straw having wide C/N ratio the microbial activities in topsoil are augmented as the microbes can derive adequate energy from the added paddy straw. The phenomenon depletes the soil nitrogen content as the microbes derive the needed nitrogen for cell formation from the soil humus.

The organic matter contents in the hydromorphic alluvial soils of Bangladesh as in other tropical soils, even though a lithological feature declines with depth, but do not reach beyond 0.2 per cent level within 1.5 m depth. The relatively higher content of organic matter in the topsoil of the studied soil series are due to the reasons stated above help support the natural fertility of these soils.

The total contents of nitrogen in the studied soils range between 0.05 and 0.19 per cent with an average of 0.09 per cent (Table 3). The Jalkundi and Siddirganj series have the highest contents of nitrogen than the Tippera series. In all the soil series the content of nitrogen decreases regularly with depth like that of organic matter. Mazumder *et al.*(16) also reported similar trend for some seasonally flooded Brahmaputra floodplain soils.

The CEC of these soils based on texture ranges from 9.0 to 33.0 cmol (p+)/kg with a mean value of 14.9 cmol (p+)/kg (Table 3) showing a highly significant positive correlation with clay (r = + 67**) and organic matter (r = + 59**) contents. Obviously Ca^{2+} is the dominant cation in the colloidal complex followed by Mg^{2+}, Na^{+} and K^{+} (Table 3). The high Ca^{2+}/Mg^{2+} is an indication of a weak type of hydromorphism in these soils.(4) The BSP based on pH values that ranged between 61 to 93 indicate high content of basic nutrients in these soils. In Bangladesh varying doses of chemical fertilizers are added to soils to supplement the shortfall of nutrient elements present for growing the HYV rice. The high nutrient holding capacity of the seasonally flooded soils depend primarily on high CEC that controls the adsorption capacity of nutrient ions.

The available nitrogen in topsoils ranges from 104 to 140 mg/kg, available phosphorus content ranges from 6 to 8 mg/kg while available potassium content ranges from 78 to 168 mg/kg (Table 4). Mineralogical studies revealed that the seasonally flooded soils, particularly the ones developed in Ganges floodplain sediments contain adequate quantity of weatherable minerals like feldspar and biotite have high potential to release K^{+} nutrient.(17) However, the high content of smectite present in the soils have the potentiality to fix large quantity of added K^{+} fertilizer during each dry season. The quantity of K^{+} fixed by every year by soil minerals is needed to be determined through research.

DTPA-extractable Fe contents in the studied soils ranged from 73 to 131 mg/kg (Table 4). Prolonged submergence coupled with reducing conditions are reported to be the reasons for higher available Fe contents. Considering 4.5 mg/kg soil as the thresold value of DTPA-extractable Fe,[14] all the studied soils have more than sufficient quantities of available Fe.

Table 4. Nutrient elements in the surface horizon of some seasonally flooded soils.

Soil series	Available (mg/kg)				DTPA- extractable (mg/kg)			
	N	P	K	S	Fe	Mn	Cu	Zn
Arial	140	8	164	27	128	55	5.0	2.0
Debidwar	106	7	121	18	78	56	2.2	1.6
Naraibag	136	8	78	21	131	80	4.2	2.8
Jalkundi	118	7	94	23	90	87	3.7	2.5
Siddirganj	110	6	82	11	98	34	2.0	1.8
Tippera	104	6	78	10	73	39	2.0	1.2
Mean	119	7	103	18	100	58	3.2	2.0

The DTPA-extractable Mn contents in the studied soils vary widely ranging from 34 to 87 mg/kg. Lindsay and Cox[18] identified pH as the key factor that influences Mn availability in soils. Taking 3.0 mg/kg DTPA-Mn in soils as the critical limit,[19] it can be safely concluded that the studied soils contain more than adequate quantity of available Mn. The DTPA-extractable Cu in the studied soils varied from 2 to 5 mg/kg (Table 4). Katyal and Sharma[20] reported similar result in soils having aquic moisture regimes. Considering the 0.2 mg/kg of DTPA-extractable Cu as critical limit[14] the available Cu contents in the studied soils are adequate. The extractable Zn content in the studied soil series varied between 1.2 and 2.8 mg/kg (Table 4). The observed results agree with the ones reported by Hassan[21] and Khan *et al.*[22] Taking 0.8 mg/kg as the critical limit for extractable Zn,[14,19] the studied soils series contained available Zn above the threshold value.

The biggest problem in the management of seasonally flooded soils of Bangladesh is their annual inundation. The flooding imposes a serious restriction on cropping patterns. Unpredictable flush floods sometimes cause total damage to the existing crops in the field. There is uncertainty in the arrival and recession of flood water which impair the management plan of these soils.

Texturally these soils are fine-grained having high moisture retention capacity.[8] This helps in countering the ill-effects of short droughts. However, if there is any long drought there will be permanent damage to the growing crops. Nutrient availability for plants are linked with the type and amount of clay minerals and organic matter contents that regulates the CEC. The high CEC of the studied soils indicate a strong nutrient holding capacity. This helps in decreasing the loss of nutrients with the receding flood water. Because of flooding there is gain in nutrients as well coming in the sediments and flood water.

Formation of plough pan - a compact slowly permeable layer - below the Ap horizon has been formed due to puddling by using traditional ploughs to which the soils were subjected to for transplanted paddy cultivation. The plough pan being less permeable and compact is favourable for transplanted paddy cultivation but this compact layer restricts penetration of crop root below to harness moisture and nutrients present in the lower layers. Slightly acidic to neutral soil reaction and high BSP provide a congenial chemical environment for crop production in these soils (Tables 3 - 4). The presently studied soils in Bangladesh are subjected to seasonal inundation on the basis of which these wetland soils are separated from the viewpoint of land use potentials. Other physical limitations experienced by these soils are seasonal droughtiness, potential erosion hazards, shortage of nutrients, irregular relief condition, toxicity and sudden wetness by flush floods.

Finally it must be noted that because of multiple cropping the problem of nutrient shortage and loss have developed in these seasonally flooded soils. Researches have shown that the quantities of nutrient elements from the soil system per hectare to produce the stated quantity of rice is 45 Kg N, 25 Kg P_2O_5 and 70 Kg K_2O while the quantites of nutrient elements added to the soil system per each transplanted HYV paddy (boro and aman) are 100 Kg N, 35 Kg P_2O_5 and 45 Kg K_2O.[23] The quantity of nitrogenous fertilizer added in excess to the soil system is lost due to volaltilization, leaching, run-off and/or consumed due to growth of weeds while the excess quantities of phosphates and potash either get fixed in the soil system or remain as residues. Proper and scientific management of soil health and their sustained productivity can be maintained through balancing the incoming nutrients due to fertilizer addition, biological fixation, weathering of biotite and feldspar minerals, precipitation of thunder storms and decomposition of organic residues and the outgoing with the volatilization, etcetra. The soil properties though have roles in the management of soil but that only contribute if and when all the above factors are duly taken into consideration.

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(Manuscript received on 11 January, 2011; revised on 6 March, 2011)