Indian Journal of Agricultural Sciences **88** (10): 1568–72, October 2018/Article

Soil manganese dynamics and its uptake in wheat (*Triticum aestivum*) influenced by chloride and manganese application

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Received:07 May 2018; Accepted: 10 July 2018

ABSTRACT

Manganese (Mn) is one of the essential micro-nutrients having an important contribution in paddy (*Oryza sativa* L.)-wheat (*Triticum aestivum* L.) cropping systems. Wheat is an important cereal crop of Haryana State and is highly susceptible to Mn deficiency. During submerged paddy, solubility of Mn increases appreciably because of its reduction and continuous leaching from upper to lower soil layers which in turn results in its deficiency in the succeeding winter season crops especially wheat. Often, Mn fertilization under salinity stress is of main concern to be investigate, especially in arid and semi-arid regions of Haryana. So, in order to evaluate soil manganese dynamics and its uptake in wheat influenced by chloride (Cl^-) and Mn application, laboratory as well as a screen house experiment was conducted at CCS HAU, Hisar, Haryana. Results revealed that a decreased grain and straw yield and Mn uptake in wheat with graded doses of Cl^- application. The highest grain and straw yield of wheat were recorded with 25 mg Mn/kg and without chloride application. However, maximum Mn content and its uptake in wheat was recorded under treatment of 50 mg Mn/kg. Among all Mn fractions in post-harvest soils, maximum Mn was associated with residual (RES) fraction followed by MnOX > AFeOX > CFeOX > EX > CARB > OM fractions. Organic matter bound (OM) showed a very little amount of Mn content due to low content of organic carbon in experimental soil. Thus, chloride application along with Mn fertilizers showed antagonistic effect on wheat yield and its uptake as well as Mn dynamics in soil.

Key words: Chloride, Fraction, Manganese, Uptake, Wheat yield

Plant nutrition holds utmost importance in crop production and improvement of produce quality. In most regions of the world, the use of chemical fertilizers is imbalanced and is not based on plant requirement. The soils of Haryana are known to be getting depleted in available Mn due to continuous cropping, non-conventional rice cultivation, intensive cropping involving high-yielding varieties, increased use of high analysis NPK fertilizers without supplementation through micronutrient fertilizers (Fageria *et al.* 2002). The uptake, dynamics and mobility of Mn within shoot and to the grain are mainly affected by the fertilizer application such as chloride, bicarbonate and other factors like growth stages (Pearson and Rengel 1994); sucrose status and humidity (Pearson *et al.* 1996); heat stress which generally increases Mn uptake (Dias *et al.* 2009). It is also expected that chloride application affect Mn nutrition through various mechanisms in soil on the root surface as well as in plant system.

The availability of these micronutrients to crop plants is affected by many soil factors which varied from one micronutrient to another as well as their relative degree of effectiveness (Malik *et al.* 2017). Manganese being one of the essential micronutrients, which has an important role in plant nutrition as a component of enzymes meditating photosynthesis and other metabolic processes. Manganese requirements of plants are generally low, but with increasing use of high analysis micronutrient free fertilizers, Mn deficiency is likely to be intensified particularly in light texture soils due to leaching losses, poor uptake due to salinity and sodicity going to be a major constraint in realising yield potential of high yielding varieties of wheat (Nayyar *et al.* 1990). Yield of cereals grown on calcareous soils is frequently limited by Mn deficiency resulting from low Mn availability, rather than low Mn content in the soil (Reuter *et al*. 1988).

Understanding the distribution mechanism of soil Mn in different fractions helps to know its retention in soils and release to plants (Shuman 1979). Releasing pattern of soil Mn in different cropping systems varies from soil to soil as well as system to system (Narender *et al.* 2017). Magnitude

Based on a part of Ph D Thesis of the first author submitted to CCS Haryana Agricultural University, Hisar 125 004, Haryana, India.

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of inherent release of Mn is governed by many factors, i.e. type and amount of clay, soil Mn status, alternate wet and dry cycles, pH, moisture content etc. For efficient utilization of manganese by the crops, knowledge of behavioural interaction of fertilizers with soil Mn is essential. Although huge amount of literature is available on Mn responses to different crops across the globe but meagre work has been reported on its behavior when added in salt affected ion rich soils. In the present study, we aimed to evaluate the effect of graded doses of chloride application along with manganese fertilizers on Mn dynamics in soils of Haryana and its uptake by wheat.

MATERIALS AND METHODS

A pot experiment was conducted in the screen house of Department of Soil Science, College of Agriculture, CCS HAU, Hisar. Surface soil (0-15 cm) was collected from Village Dhani Lamba, District Fatehabad, a Mn deficient-area in the state and used for pot experiment. The doses comprising of the three level of chloride (0, 20, 40 meq./L) applied through sodium chloride (NaCl) with three level of manganese (0, 25, 50 mg/kg) as manganese sulphate ($MnSO_4.H_2O$) and the experiment was laid out in factorial CRD with 3 replication in the screen house according to Steel

Table 1 Initial physico-chemical characteristics of experimental soil

Characteristic	Value	Methods used
pH (1:2)	8.10	Richards (1954)
EC (dS/m)	0.40	-do-
Organic carbon (%)	0.40	Walkley and Black (1934)
Calcium carbonate (%)	1.10	Puri's method (1930)
Sand (%)	82.5	International pipette method (Piper 1966)
Silt (%)	13.3	-do-
Clay (%)	4.20	-do-
Textural class	Loamy sand	-do-
DTPA-Mn (mg/kg)	2.10	Lindsay and Norvell (1978)

and Torrie (1980). Recommended doses of N, P and K as basal was applied using 50 mg N/kg soil as urea, 50 mg P/kg soil as potassium di-hydrogen orthophosphate (KH_2PO_4) and 15 mg K/kg soil as potassium sulphate (K_2SO_4) in each pot. Ten viable seeds of wheat variety (WH-1105) were sown in each pot. Thinning was done after fifteen days and four uniform healthy plants per pot were allowed to grow up to maturity. Pots were irrigated with distilled water as and when required.

The crop was harvested at maturity. Grain and straw samples were collected, processed and analysed for nutrient content. The Mn content in grain and straw was estimated with the help of atomic absorption spectrophotometer. The soil samples were also collected from each pot after harvest of crop and processed for analysis of different fractions of Mn in soil. A seven step sequential fractionation procedure (Fig 1) of Tessier *et al* (1979) was followed for Mn partition into exchangeable (EX), carbonates bound (CARB), organic matter bound (OM), Mn oxide bound (MnOX), amorphous Fe oxide bound (AFeOX), crystalline Fe oxide bound (CFeOX) and residual fraction (RES). Manganese in all extracts was determined by atomic absorption spectrophotometer. The standard methods used for soil analysis and DTPA- Mn are given in Table 1.

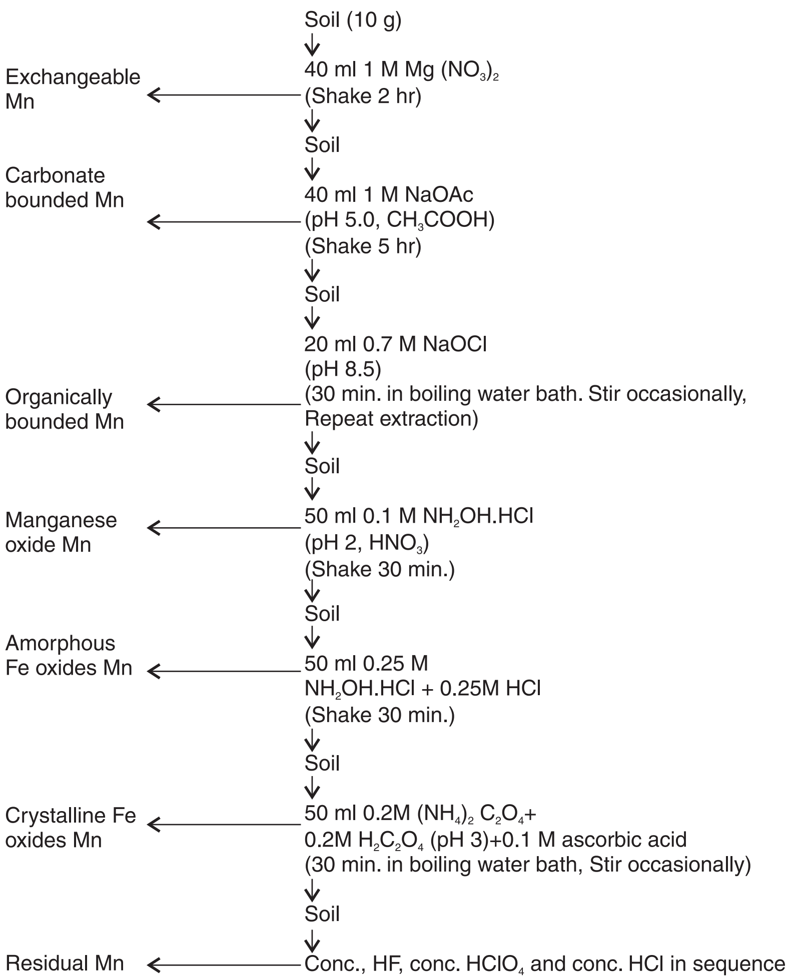

Fig 1 Sequential fractionation scheme for partitioning Mn in soil.

RESULTS AND DISCUSSION

Physico-chemical characteristics of experimental soil

A representative soil sample before fertilization was air-dried and analysed for physico-chemical properties and DTPA-extractable Mn. Data presented in Table 1 revealed that the soil used in pot experiment was non-calcareous, non-saline and slightly alkaline in nature with EC 0.40 dS/m and soil pH 8.10. Texturally, soil had the composition: sand 82.50%, silt 13.30% and clay 4.2% and was classified as loamy sand. The native content of DTPA-Mn was found 2.10 mg/kg. The experimental soil was almost low in Walkley-Black carbon and deficient DTPA-Mn content.

Wheat yields

Results revealed that wheat yields decreased with increased chloride application and increased up to 25 mg Mn/kg application (Table 2). Compared to without application of chloride salt, the wheat grain yield was 5.90 and 5.70 g/pot lower in pots with 20 and 40 meq Cl^- /L, respectively. The corresponding decreases in straw yield were 8.87 and 8.46 g/pot with graded doses of chloride salt as soil application. However, the yield of grain and straw were 6.41, 6.35 and 9.39, 8.86 g/pot at 25 and 50 mg Mn/kg soil application over control. The highest grain (6.41 g/pot) and straw yield (9.39 g/pot) were recorded with 25 mg Mn/kg as soil application (Table 2). From these results, it may be concluded that 25 mg Mn/kg soil application is optimum dose for proper growth and development of wheat. The response of wheat to Mn in the present study may be accounted for the low amount of DTPA-Mn in soil. The Cl^- application had an antagonistic effect on physiological performance of wheat. These results are in close agreement within findings of Thomson *et al.* (2001) who reported a negative response of wheat to Cl^- application. Similarly, Narender and Malik (2015) found a negative response of wheat grain yield to bicarbonate application.

Wheat Mn content and its uptake

Results presented in Table 3 revealed that Mn content in grain (24.7 to 17.2 mg/kg) and straw (41.1 to 37.1 mg/kg) decreased from 0 to 40 meq Cl^-/L soil application. However, application of 25 and 50 mg Mn/kg in grain increased Mn content from 16.2 mg/kg in control to 22.2 and 25.1 mg/kg and in straw the Mn content increased from 35.3 mg/kg in control to 40.1 and 42.9 mg/kg, respectively. The highest content of Mn in wheat grain and straw were also recorded with application of 50 mg Mn/kg (Table 3). Increased Cl^- application induced salinity in soils, which in turn increased root osmotic pressure. Higher root osmotic pressure hindered Mn uptake in chloride applied pots. Similarly finding was reported by Hu and Schmidhalter (2001) revealed that chloride fertilization decreased Mn availability in soil resulting in reduced Mn uptake by crops.

Similarly, Mn uptake by wheat cultivar WH 1105 decreased with each increasing level of chloride and increased with increasing level of manganese application. The maximum uptake of Mn by wheat crop was recorded at 50 mg Mn/kg application. The wheat grain Mn uptake decreased from 162 µg/pot in control to 99.8 µg/pot and in straw the decreased varied from 389 µg/pot under control to 315 µg/pot with application of high dose of chloride as 40 meq Cl^- /L. Application of 25 and 50 mg Mn/kg in grain increased Mn uptake from 86.5 µg/pot in control to 144, 161 µg/pot and in straw the increased in Mn uptake varied from 302 µg/pot in control to 376 and 380 µg/pot, respectively (Table 4). All the levels of Mn proved superior over control with respect of Mn uptake by wheat grain and straw. Maximum uptake was recorded with 50 mg Mn/kg and without any addition of Cl^- application. Jhanji *et al.* (2014) also reported an increased in Mn uptake with increasing level of Mn addition. From the present study, it can be concluded that salinity can restricted nutrient uptake by wheat roots and consequently lower their content in grain and straw.

Table 2 Wheat yield (g/pot) as affected by chloride with Mn application

Cl^- levels (meq/L)	Mn levels (mg/kg)			Mean
	0	25	50	
		Grain		
0	5.93	7.07	6.45	6.48
20	5.18	6.11	6.40	5.90
40	4.83	6.05	6.22	5.70
Mean	5.31	6.41	6.35	
LSD (P = 0.05)	Mn = 0.29	Cl^- = 0.21	Mn × Cl^- = NS	
		Straw		
0	8.75	9.66	9.86	9.42
20	8.69	9.25	8.69	8.87
40	8.08	9.25	8.05	8.46
Mean	8.51	9.39	8.86	
LSD (P = 0.05)	Mn = 0.48	Cl^- = 0.40	Mn × Cl^- = NS	

Table 3 Wheat Mn content (mg/kg) as affected by chloride with Mn application

Cl^- levels (meq/L)	Mn levels (mg/kg)			Mean
	0	25	50	
		Grain		
0	17.8	27.1	29.1	24.7
20	17.4	21.9	25.6	21.6
40	13.3	17.6	20.6	17.2
Mean	16.2	22.2	25.1	
LSD (P = 0.05)	Mn = 2.53	Cl^- = 2.13	Mn × Cl^- = NS	
		Straw		
0	36.9	40.9	45.6	41.1
20	35.7	39.9	44.6	40.1
40	33.4	39.5	38.5	37.1
Mean	35.3	40.1	42.9	
LSD (P = 0.05)	Mn = NS	Cl^- = NS	Mn × Cl^- = NS	

Mn dynamics in soil

Total soil-Mn was partitioned in different pools i.e. readily soluble Mn {exchangeable (EX)}, carbonates bound (CARB)-Mn, weakly adsorbed Mn {organic matter bound (OM)} and oxide Mn {Mn oxide bound (MnOX), amorphous Fe oxide bound (AFeOX) and crystalline Fe oxide bound (CFeOX)}. Results revealed that Mn content in all the fractions increased with increasing level of Mn application with zero application of chloride. The interaction effect between chloride and manganese was with OM bound-Mn (Table 5). Among all fractions, contribution of Mn was associated higher with RES-Mn fraction followed by MnOX > AFeOX > CFeOX > EX > CARB > OM fractions (Fig 2). Organic matter bound (OM) showed a very little amount of Mn content due to low content organic carbon in the experimental soil. The form of Mn feeding is the most important to determine nutrient uptake and growth under salinity stress conditions. Similar results were reported by Dhaliwal *et al.* (2011) and Narender *et al.* (2016) which showed that Mn-exchangeable, weakly adsorbed, moderately adsorbed, strongly adsorbed, associated with organic matter, occluded and bound by carbonates/acid soluble minerals were in very low proportion and residual micronutrients as the dominant proportion of total Mn.

Hence, the present study concluded that chloride salt application along with Mn fertilizers affects wheat yields and its uptake and also Mn dynamics in soil pools can be achieved with the application of Mn. The highest yield of wheat grain and straw obtained with the application of 25 mg Mn/kg. Maximum Mn content and its uptake in wheat grain and straw were recorded with the highest application of 50 mg Mn/kg level. These results showed that Mn application is a good predictor of Mn availability in Mn deficient light texture soils. So, to sustain productivity and quality of wheat on such soils, the judecious use of Mn in proper amount becomes essential.

Table 4 Mn uptake (µg/pot) by wheat as affected by chloride with Mn application

Cl^- levels (meq/L)	Mn levels (mg/kg)			Mean
	0	25	50	
		Grain		
0	106	191	188	162
20	88.9	134	163	130
40	64.5	106	128	99.8
Mean	86.5	144	161	
LSD (P = 0.05)	Mn = 13.4	Cl^- = 12.2	Mn × Cl^- = NS	
		Straw		
0	323	396	450	389
20	311	369	388	356
40	275	364	303	315
Mean	302	376	380	
LSD (P = 0.05)	Mn = NS	Cl^- = NS	Mn × Cl^- = NS	

Table 5 Effect of chloride with Mn application on Mn pools in soil

Cl^- levels (meq/L)	Exchangeable (EX) –Mn (mg/kg) Mn level (mg/kg)			Mean
	0	25	50	
0	0.89	0.95	0.99	0.94
20	0.91	0.91	0.97	0.93
40	0.90	0.90	0.95	0.91
Mean	0.90	0.92	0.97	
LSD (P = 0.05)	Mn = 0.03	Cl^- = NS	Mn × Cl^- = NS	
	Carbonate bound – Mn (mg/kg)			
0	0.23	0.25	0.23	0.23
20	0.22	0.20	0.22	0.21
40	0.20	0.20	0.21	0.20
Mean	0.21	0.21	0.22	
LSD (P = 0.05)	Mn = NS	Cl^- = 0.01	Mn × Cl^- = NS	
	OM bound – Mn (mg/kg)			
0	0.02	0.05	0.06	0.04
20	0.02	0.02	0.04	0.02
40	0.01	0.01	0.03	0.01
Mean	0.01	0.02	0.04	
LSD (P = 0.05)	Mn = 0.009	Cl^- = 0.007	Mn × Cl^- = 0.015	
	MnOX bound – Mn (mg/kg)			
0	65.3	66.3	66.9	66.5
20	63.6	66.2	66.3	65.4
40	60.2	57.5	65.4	61.0
Mean	63.0	63.4	66.2	
LSD (P = 0.05)	Mn = NS	Cl^- = NS	Mn × Cl^- = NS	
	AFeOX bound – Mn (mg/kg)			
0	31.8	32.9	36.4	33.7
20	29.6	31.9	32.7	31.4
40	29.5	31.5	31.8	30.9
Mean	30.3	32.1	33.7	
LSD (P = 0.05)	Mn = NS	Cl^- = NS	Mn × Cl^- = NS	
	CFeOX bound –Mn (mg/kg)			
0	9.94	10.3	11.3	10.5
20	8.31	9.69	10.2	9.41
40	7.09	9.27	9.99	8.78
Mean	8.45	9.76	10.5	
LSD (P = 0.05)	Mn = 0.98	Cl^- = 0.92	Mn × Cl^- = NS	
	Residual – Mn (mg/kg)			
0	188	214	204	202
20	183	210	209	200
40	179	206	209	198
Mean	183	210	207	
LSD (P = 0.05)	Mn = 10.4	Cl^- = NS	Mn × Cl^- = NS	
	Total – Mn (mg/kg)			
0	297	319	320	312
20	285	306	319	303
40	277	305	318	300
Mean	286	310	319	
LSD (P = 0.05)	Mn = 5.38	Cl^- = 5.18	Mn × Cl^- = NS	

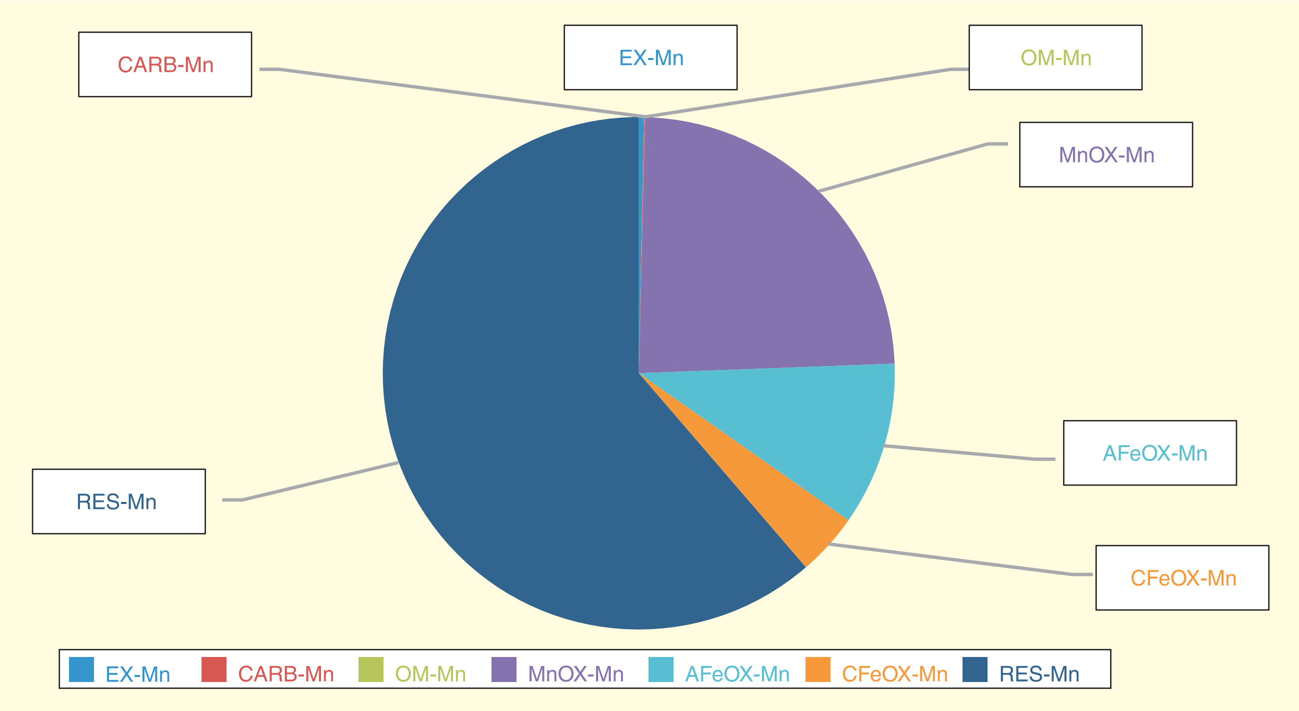

Fig 2 Contribution of Mn pools affected by chloride salt application.

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