REVIEW OF LITERATURE

1. Introduction :-

Among various factors which control crop growth and development, soil is regarded as one of the most important factor. The texture and physicochemical properties of soil vary from place to place and they exert tremendous influence on various facets of plant growth right from seed germination. The soil water status is also very significant factor in their respect. The composition of soil solution determines the nutrient uptake pattern and is responsible for various nutritional disorders such as toxicity or deficiency. Thus study of various soils and their composition is very essential in understanding the agricultural problems in a particular country

India, situated between the latitudes of 08^0 04' and 37^0 06'N and longitudes of 68^0 07' to 97^0 25'E, has a geographical area of 329 Mha. The soil is uppermost layer covering the surface of earth. It may be defined as a natural body formed through pedogenic processes taking place during and after the weathering of rocks and in which plants and other forms of life are able to grow. The soil conditions determine the types of vegetation in an area. India with a great variety of landforms, geological formations and climatic conditions, exhibits a large variety of soils; the variety is so diverse that barring a few soil orders (Andisols, spodosols). India represents all the major soils of the world. The major soils of India are depicted in **Fig.1.**

2. Soil Types :-

The soils are classified on the bases of their properties , as alluvial soils, black soils, red soil, laterite soils, desert soils and problem soils. The problem soils are acid soils, saline and alkali soils.

3. Acidic Soils :-

Among all soil types, lateritic soils are formed in tropical climate experiencing alternate wet and dry seasons. The monsoon type of climatic conditions acting on the basic parent rock, the siliceous matter is leached almost completely during weathering and the sesquioxides are left behind. On drying, these are converted into irreversible iron and aluminum oxides. The soils thus form are rich in sesquioxides, devoid of bases and primary silicate minerals, hard or capable of hardening like bricks when exposed to drying after wetting. It is a compact to vesicular rock like material

composed of a mixture of hydrated oxids of iron and aluminum with smaller anions of Mn-oxides and titania.

The major limitations posed by these soils are deficiency of P, K, Ca, Zn, B etc, and high acidity and toxicity of Al and Mn. Such soils are widely distributed in the states of Maharashtra, Andhra, Karnataka, Tamilnadu and North-East regions and occupy about 25 Mha of the total geographical area.

In general a soil with pH less than 7.0 is an acid soil while soils having a pH between 6.5 and 6.0 is more slightly acidic, pH between 6.0 and 5.0 indicating moderately acidic soil and pH between 5.0 and 4.0 more strongly acidic.

Acidic soil has poor fertility, which is due to Aluminum toxicity ,Manganese toxicity and also due to Phosphorus, Calcium, Magnesium, Molybdenum deficiency. Along with natural acidity, intensive use of nitrogenous fertilizers, industrialization, urbanization increases soil acidity (Haug,1984). Al^{3+} and Fe^{3+} are most important soil cations plays important role in increasing soil acidity (Thomas and Hargrove, 1984). According to Broomfield (1987) the availability of soil Al increases rapidly at pH<5 which adversely affects the root system and thereby yield of crops.

4. Causes of soil acidity :-

In many regions of the world, the development of acid soils is a natural result of the weathering process. The soil acidification is affected by high rainfall, similarly abiotic and biotic factors. Amount of H^+ ion activity in soil solution is a major cause of soil acidity.

All the hydrogen ions around acid clay particles are not held close to the soil particle surface. Some of the H^+ ions move in oscillation volume. Which go out to a considerable distance and mingle with other ions in the soil solution. These H^+ ions constitute as "active" acidity and their concentration is designated the "intensity" factor of acidity, on contrary to this, some H^+ ions which remain in an exchangeable but unionized state make up the 'reverse' or potential acidity. But these together caused total soil acidity. Rowell and Wild (1985), recorded causes of acidity which are natural and anthropogenic. Long term leaching and microbial respiration are the main causes of acidification. Carbonic acid which is found in rain water and in decomposing organic material (humic and fulvic acid) can stimulate leaching by dissociating into H^+ ions and their component anions which then from the soil

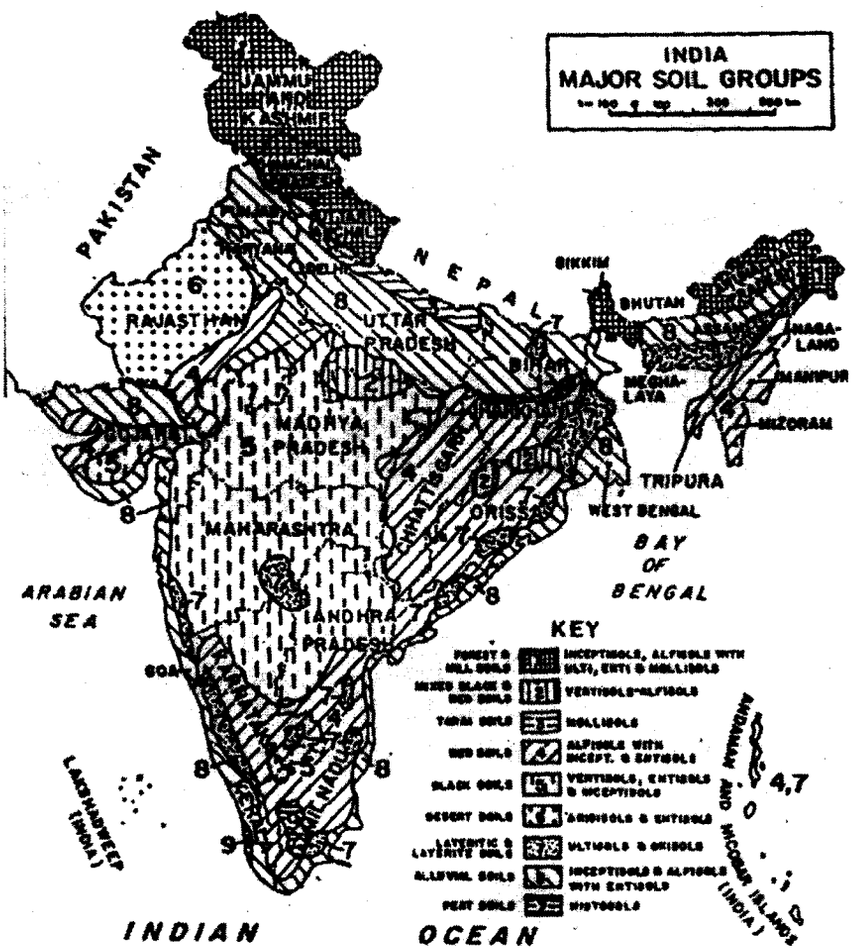


Fig.1. Major Soils of India.

exchange complex displace or attract base cations. Soil acidification is also takes place due to microbial respiration through the production of CO_2 which is dissolved in soil water to form carbonic acid.

Nitrification and plant growth also increases soil acidification. Nutrient base cations are obtained through root system in exchange for H^+ ions during plant growth and increases soil acidity. (Ellis and Mellor, 1995).

During Nitrification by nitrifying bacteria NH_4 (ammonium) ions are converted to NO_3 (nitrate) with H^+ ions as a by product.

$$NH_4 + 1.50_2 \longrightarrow NO_3 + 4H^+$$

These ions are then available for displacing and attracting base cations from soil exchange complex and causes soil acidification.

While anthropogenic causes of acidification include needleleaf afforestation, exclusive use of inorganic nitrogen fertilizers, land drainage, urban and industrial pollution also causes acid deposition. According to Hornung (1985) and Miller, (1985), needleleaf afforestation increases acidification of soil, because needleleaf trees produce litter which is very acidic as compare to most broadleaf litter; thus due to their high canopy surface area, needleleaf trees are capable to 'Scavenge' acid pollutants from the atmosphere, later releasing them into the soil and lastly due to modifications of the surface and soil hydrology by drainage channels and shallow root network, water transfer is rapid and is concentrated either at the surface or in the uppermost layers of soil. (Bache,1983., Miller,1985).

Chalmers (1995) shows, excessive use of inorganic nitrogen fertilizers in agriculture also causes soil acidification partly through the process of nitrification. Soil pH decreases with increased use of fertilizers.

Land drainage is another important cause of soil acidification .Once land has been drained, improves soil aeration and sulphate compound are formed from sulphide minerals oxidation. Sulphate ions can then combine with H^+ ions the soil to produce H_2SO_4 . In some extreme condition soil acidity may fall below pH 3.0 as in case of acid sulphate 'cat-clay' soil are in mangrove swamp environments (Foth,1990).

Atmospheric deposition is also cause of soil acidification. Fowler *et al.* (1985), noticed gases derived from industrial and motor vehicle emissions mainly NO_x (oxides of nitrogen) and SO_2 (Sulphur dioxide) are either deposited directly or

dissolved in precipitation. Essentially acidity is derived from H_2SO_4 (Sulpharic acid) and HNO_3 (nitric acid) which undergo dissociation in rain and soil water.

There are few acidic soils which contain a sufficient amount of iron sulphids so that appreciable amount of sulphuric acid develops through oxidation. Similarly traces of inorganic acids also caused acidity in soil.

In most mineral soils a very large part of the acidity residue in the clay fraction. It has been observed that soil acidity largely resulted from humus. Humus has very high capacity of cation exchange as well as contain carboxyl group from which hydrogen will dissociate and so there may be small amounts of true organic acids present. Soil acidity is closely related to many other soil properties such as organic content, exchangeable base content, CEC etc. As compare to calcareous plant material, the acidic soil which is developed from granite parent material and Sandy soil with relatively clay particles becomes acidic very fastly (Hede *et al.*,2001). Soil acidification increased by removal of cations through crop harvesting. Rhizobial nitrogen fixation plays significant role in soil acidification in cultivated soil (Slavich,1984).

Al^{3+} and Fe^{3+} are most important soil cations which play important role in increasing soil acidity (Thomas and Hargrove, 1984). In soil acidity generation, Al^{3+} ions play an important role particularly in soils that are already acidic (Ellis, Mellor, 1995), Al^{3+} ions by hydrolysis release H^- ions into soil solution.

$$Al^{3+} + H_2O \rightleftharpoons Al(OH)_2^+ + H^+$$

Positively charged hydroxyl aluminum species can then occupy exchange sites, and reduced CEC (cation exchange capacity). More H^+ ions and stable aluminum hydroxide (gibbsite) is produced by further hydrolysis of hydroxy-aluminum species.

$$Al^{3+} + (OH)_2 + 2H_2O \longrightarrow \underset{\text{gibbsite}}{Al(OH)_3^+} + 2H^+$$

Hence through aluminum hydrolysis, soil acidity promotes the development of further acidity and this becomes an important source of H^+ ions., when soil become acidic. Al^{3+} ion have higher valency, due to which it begin to occupy the exchange sites. If soil pH falls below 5.5, Al^{3+} ions are absorbed much more strongly than divalent and monovalent cations, therefore level of exchangeable aluminum level increases, and amounts of exchangeable bases decreases, as pH declines, i.e. soil acidity increases.

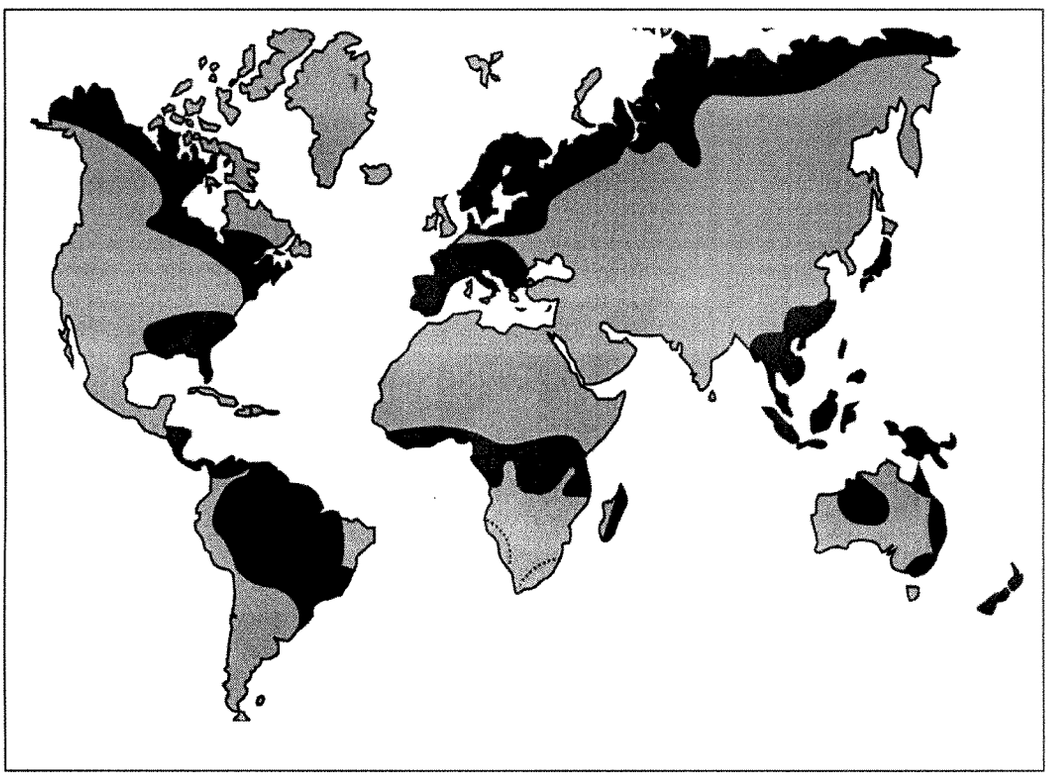


Fig.2. World acid Soils, Areas of predominance are highlighted in dark color.

5. Acidic Soils in World :-

There are several records of the extent of acid soils in the world. According to Van Wembeke (1976), acid soils occupy 1,455 Mha (11%) of the world's land while Haug, (1984) recorded 30-40% world's arable soils and upto 70% of potentially arable land are acidic.

According to Von Uexkull and Mutert (1995), the maximum acidic soil noticed in America. It records about 41% (1616 Mha) of acidic land and ranks first **Table No.1** while Asia as second largest area records 26% (1044 Mha). They further noticed that acid soils occurs mainly in two global belts, **Fig.2** .The northern belt, with cold humid temperate climate. The southern tropical belt with warmer humid condition. Cereals are the most prominent crops grown under acidic soil .The number of crops grown in acidic soils in world depicted in **Table No.2.** The details of these crops with respect to area, production and productivity are listed in **Table No.3.** From this table it is clear that some crops like Tea, Rubber, oil palms etc are commonly grown in totally acidic soils. Eswaran *et al.*,(1997) estimated that around 26% of total ice-free land is acidic.

Globally most of the forests and woodlands are having acid soils (66.3% or 2.261 Mha), while 17.7% (699 Mha) are covered by Savanna, Prairi and Steppe vegetation. The acid soils of the world consist of Savanna region to Brazil occupying 205 Mha of which 112 Mha are potentially arable, Colombia, Venezuela, Central Africa and Southeast Asia are similar areas. (Borlaug and Dowswell,1997).

6. Acidic Soil in India :-

Mandal, (1997) recorded the total geographical area of India is 329 Mha, out of which net cultivated area is nearly 145 Mha and 100 Mha soil is acidic. The acid soil regions in various states in India is depicted in **Table. No 4 and 5.** From this data it is clear that about 25 Mha soil record pH below 5.5, while 23 Mha soil record pH between 5.6 and 6.5. Assam and North Eastern India, covers 20 Mha of acidic land which is highest in Indian soil while Tamilnadu has lowest acidic land and occupying 2.6 Mha.

7. Acidic Soil in Maharashtra:-

In Maharashtra, soil is acidic mainly due to presence of Al, Fe, Mn cations. In Maharashtra,the area occupied by acid soils are 1.7% of pH 4.5-5.5 and 16.7% of pH 5.5-6.5. It is found in Thane, Ratnagiri, Kolhapur, Bhandara, Chandrapur, districts as well as small portions in other adjacent areas. (Sahu and Mitra,1997).

8. Beneficial effect of Aluminum :-

Aluminum promotes plant growth and brings out favorable effects when supplied in lower concentration (Lee, 1971). The lower doses of Aluminum has beneficial effects on certain crops, such as rice (Howeler and Cadavid, 1976), wheat (Foy, and Fleming, 1978), tropical legumes (Andrew *et al.,* 1973) and Maize. According to Foy, (1984) the beneficial effect of Al may be due to increasing the availability of iron and restricting Fe deficiency or in slightly acid neutral or alkaline nutrient solutions by the hydrolysis of Al and a pH decrease; uptake of nutrients promoted by blocking negatively charged cell walls (Mulette, 1975), preventing or correcting P toxicity, delaying a root deterioration in low Ca solutions by slowing growth and preventing depletion of Ca the medium. In peach roots, Al alters the distribution of growth regulators. In citrus and Atriplex, the toxicity of Cu and Mn also prevented. It also serves as a fungicide. The root formation in Tea plant accelerated by Al and might be transferred to leaves and epidermal cells as waste material. Al plays significant role in reduction of chlorosis caused by excess Zn or Mn influx.

9. Phytotoxicity of Al :-

Acid soil causes complex phytotoxic effects on crop plants. The physico-chemical characteristics of acidic soils of India depicted in **Table No 6.** Aluminium (Al) ranks third among the most abundantly present element in earth's crust. Due to its chemical activity, Al never occurs in the metallic form in nature, but its compounds are present to an appreciable extent in almost all rocks and soils. In mineral soils Al is a major constituent present as alumninosilicate minerals and other precipitated forms such as gibbsite (Al $[OH]_3$)(Lindsay, 1979). When soils become acidic these hydroxy-rich minerals solubilize to a limited extent into the soil solution which equilibrates into a large number of chemical species that depend upon the

Table. 1. Area of acid soils present in various regoin of the world (Source : FAO 1991, Von Uexkull and Mutert, 1995).

Sr. No	Region	Area (m.ha)	% of Total area
1	Africa	659	16.7
2	Austalia and New Zealand	239	6.1
3	Europe	391	9.9
4	Asia	1044	26.4
5	America	1616	40.9
	Total	3950	

Table. 2 . Area of arable and permanent crops on acid soils of the world (Source: FAO, 1991, Von Uexkull and Mutert, 1995).

Sr. No	Crops	Area (Mha)
1	Tree crops	33.1
2	Legumes	35.8
3	Roots and Tubers	35.8
4	Cereals	94.8
5	Sugarcane	11.8
6	Fruits and Vegetables	1.0
	Total	212.2

Table. 3. Area, production and productivity of arable and permanent crops on acid soils in the world (Source : FAO, 1991, Von Uexkull and Mutert,1995)

Sr. No	Crop	% on Acid Soils	Area (000ha)	Production (000t)	Productivity (kg/ha)
1	Tea	100	2710	2522	930
2	Coffee	90	10126	5367	530
3	Cocoa	60	3344	1438	430
4	Rubber	100	9850	5108	518
6	Oil Palm	100	5271	12039	3622 (Oil)
7	Sugarcane	70	11815	62617	5300 (Sugar)
8	Coconut	20	1787	706	395 (Oil)
9	Soyabean	35	20227	11125	550
10	Groundnut	70	13978	4948	354 (Oil)
11	Castor beans	90	1550	1024	661
12	Cassava	100	15635	125080	8000 (Tapioca)
13	Sweet potatoes	80	9528	105360	11058
14	White potatoes	60	10613	67397	15098
15	Rice	13	18600	20460	1100
16	Rye	85	14000	25910	2235
17	Oats	70	14354	26196	1999
18	Wheat	5	6968	18054	2581
19	Barley	20	14565	36338	2498
20	Fruits & Veg	-	1000	20000	20000
	Total		212,224		

Table. 4. Approximate area falling under acid soil regoin (pH below 7.0) in various states in India (Sorce : Mandal, 1997)

Sr. No.	States	Area under acid soil (Mha)	Percent of Total geographical area
1	Assam and North Eastern India	20.0	80
2	West Bengal	3.5	40
3	Bihar	5.2	33
4	Orissa	12.5	80
5	Madhya Pradesh	8.9	20
6	Andhra Pradesh	5.5	20
7	Tamil Nadu	2.6	20
8	Karnataka	9.6	50
9	Kerala	3.5	90
10	Maharashtra	3.1	10
11	Uttar Pradesh	2.9	1
12	Himachal Pradesh	5.0	90
13	Jammu and Kashmir	15.5	70

Table. 5. .Physico-chemical characteristics of selected acid soils of various states in India (source : Murthy *etal.*, 1982)

Sr No.	States	Areas and Series	Clay %	Org C%	pH	CEC	Base saturation
1	Mizoram	Phullen, Linthic Ustorthent	33.1	0.73	5.2	16.4	60
2	Manipur	dialog, Ultic Hapludalf	27.4	1.74	4.5	14.4	55
3	Meghayala	Selsekgri, Typic Haplualf	31.6	2.37	4.0	25.1	-
4	W.B.	Hangram, Vertic Entrochest	46.4	1.26	5.5	18.4	78
5	W.B.	Jagdishpur, V. Ochraqualf	18.9	2.68	4.8	10.1	57
6	Arunachal	Gemotali, Typic Dystrochrept	24.3	1.29	4.2	13.6	50
7	M. P.	Chougel, Plinthusalf	29.3	0.70	5.7	10.5	64
8	Karnataka	Vijayapura, Oxic Hapludalf	16.5	0.44	5.6	3.0	87
9	Kerala	Trivandrum, O. Distropept	51.6	1.39	4.5	6.7	28
		Kunnamangalam, T. Haplothox	27.6	1.63	5.4	3.2	25
10	Bihar	Pusaro, Ultic Paleustalf	19.9	0.26	5.1	8.5	55
		Hatiapathar, T. Ocharaqualf	15.6	0.59	4.4	12.5	54
11	W.B.	Mrigindihi, Utic Paleustalf	14.1	0.27	4.9	5.8	57
12	Orissa	Bhubanesh war, Typic Hapludalf	9.1	0.59	4.7	6.2	37

Table. 6. Some important food crops considered to be generally tolerant of acid soil conditions in the tropics.

Generally tolerant species	Generally Sucesptible species with acid tolerant cultivars
Rice (*Oryza Sativa*)	Maize (*Zea mays*)
Groundnut (*Arachis hypogea*)	Sorghum (*Sorghum bicolour*)
Cowpea (*Vigna unguiculata*)	Wheat (*Triticum aestivum*)
Pigeon pea (*Cajanus cajan*)	Soyabean (*Glycine max.*)
Cassava (*Manihot esculanta*)	Common bean (*Phaseolus vulgaris*)
Banana (*Musa spp*)	
Potato (*Solanum tuberosum*)	

After Duke (1978) and Sanchez and Salinas (1981).

presence of ligands for Al. The mononuclear Al species that may develop include Al^{3+}, $AlOH^{2+}$, $Al(OH)_{2+}$, $Al(OH)^{0}3$, AlF^{2+}, AlF_2^{+}, $AlF^{0}3$, $AlSO_{4+}$ and many others including organic complexes. Among all these, $AlSO_4^{+}$, and $Al(SO_4)$ or Al-F (e.g. AlF^{2+} and AlF_2^{+}) are not phytotoxic. Acid damage symptoms are complex symptoms induced by high Al^{3+} concentrations. In solution, 1 ppm Al^{3+} ion concentration sufficient to inhibit root growth. However the concentration depends on the aluminum saturation of the exchange capacity of soil (Bohn *et al.,* 1979). Al is more toxic in soil at pH 4.1, but in nutrient solution it is toxic at pH 4.5. Al toxicity is more severe due to formation of $Al(OH)^{2+}$ ions and it more toxic than Al^{3+}. Tea is indicator plant of high acidity and low Ca. The cereals crops escape Al toxicity as the Al is least in the surface soil, while root of horticultural and crops goes beyond 100cm where toxicity is more (Singh, 2000). Foy *et al.,* (1978) noticed, symptoms of excess Al, always appears on root which reduce elongation, swelling and distortion of differentiated cell, and root discoloration.

Most of Al is incorporated into aluminosilicate soil minerals, and small quantities (at submicromolar level) appear in soluble forms capable of influencing biological system (May and Nordstrom,1991). In soil, depending upon pH value, different forms of Al occurs are as follows.

pH.	Forms of aluminum
4 - 5	$Al(OH)^{2+}$, $Al(OH)^{2+}$
5. 5 - 7	Al^{3+}
7 - 8	$Al(OH)^{-}_4$,

The mononuclear Al^{3+} is highly toxic form of Al. There are three phototoxic Al species existing in solution viz-mononuclear species of Al^{3+}, polynuclear Al and Al as low molecular weight complexes. (Horst *et al.,* 1983, Kinraide and Parker, 1990). Among these, $AlSO_4^{+}$ and $Al(SO_4)_2^{-}$ or Al-F (e.g. AlF^{2+} and AlF_2^{+}) do not shows phytotoxicity. However status of $Al(OH)^{2+}$ and $Al(OH)_2^{+}$ is uncertain (Kinraide, 1997). In wheat root, the toxic Al species, are in increasing order is as follows.

$$AlF_2^{+} < AlF^{2+} < Al^{3+} < Al_{13}.$$

10. Symptoms of Aluminium Toxicity :-

According to Foy *et al.*, (1978) the primary symptoms observed on roots. The rapid inhibition of root growth is the main symptom of Al toxicity. The roots injured by Al are stubby and brittle, especially root tips and lateral roots thicken and turn brown resulting in a reduced and damaged root system followed by limited water and mineral nutrient uptake. Taylor *et al.*, (1998) in cowpea, noticed Al toxicity symptoms at 0.1 µM Al however above 40 µM Al the growth was completely inhibited. The interaction of Al is within plasma membrane or cell wall or root cytoplasm cause rapid inhibition of root growth (Taylor, 1988; Marschner, 1991; Horst, 1995; Kochian, 1995). Ryan *et al.*, (1993) noticed root apex is the critical site for Al toxicity in Maize (*Zea Mays* L.), which becomes stubby and brittle, while root tips becomes thick and brown similarly seen in lateral roots. (Narayanan and Shyma, 1988; Mossor–pietraszewska *et al.*, 1997). These roots are inefficient in absorbing both nutrients and water. Young seedlings are more susceptible than older plants.

Al toxicity shows reduction in shoot growth in Rice, Barley, Wheat, Snapbean, Oat, Sorghum, Corn, Rye and Coffee. Leaf tip bronzing, younger leaves becoming small and chlorotic and curling along the margin where the characteristic symptoms of Al toxicity. Decrease in dry weight (biomass) of root and shoot in almost all crops was also noticed due to Al toxicity by, Balakumar (2000).

11. Uptake and distribution of Aluminium :-

In plants, Al ions are taken up mostly through the root system, out of which only small amounts penetrate in the leaves. However specific Al carrier has not yet been found.

A primary response of Al has been localized to root apex (Kochian, 1995; Taylor, 1995; Sivaguru *et al.*, 1999). After exposure to Al, within short period of time, the primary effects are seen on root membrane permeability. Al induced growth inhibition mechanism remain poorly understood and controversial. According to Lazof *et al.*, (1994), the entry of Al to root symplast in considerable quantities possible affecting growth of the membrane from cytosolic side.

According to Rengel, (1996), major portion of absorbed Al is localized in apoplast, ranging from 30-90 % of total tissue Al content. However the exact cellular

site of Al toxicity is still unresolved. Symplastic versus apoplastic target are being discussed by Marienfeld *et al.*/(2000).

Meristem is the primary site of Al toxicity (Ryan *et al.*, 1993), particularly it is plasma membrane (Takabetake and Shimmen, 1997). Al binds with carboxyl and phosphate groups of cell wall and cell membrane and mediates these effect. (Gunse *et al.*, 1997). Many research groups have suggested Al integrates with many cellular sites such as cell wall, plasma membrane, DNA (Rengel, 1996; Silva *et al.*, 2000; Taylor *et al.*, 2000). According to Rengel and Reid, (1997), in giant cell of *Chara corallina*, 99.99% of the total cellular accumulates Al in the cell wall. This concern mainly the part of cell wall pectin which remains in the protoplast even after digestion of cell wall enzymatically. According to these authors, during Al treatment, Al may bind to newly produced pectin. Thus to understand the mechanism of Al toxicity, quantitative information on uptake and cellular distribution of Al is required. At present there is no sufficient data available, about which molecular forms of Al are capable of crossing membranes and what is the rate of Al transport. The mechanistic basis of Al transport and overall sub cellular distribution yet not know clearly.

According to Horst *et al.*, (1997), the induction of callose (β-1, 3-glucan) formation is sensitive marker for genotypic Al toxicity. In root of various plant, callose is accumulated in the cell wall around plasmodesmata in response to damage caused by Al. In wild type *Arabidopsis* seedling roots, increase in callose deposition with increasing Al concentration over the range of 0 to 100 μM $AlCl_3$. The callose may cause the blockage of cell to cell transport by blocking plasmodesmata (Sivaguru *et al.*, 2000).

12. Physiological effect of Aluminium Toxicity :-

Many workers like Carver and Ownby/(1995), and Jayasundara *et al.*/(1998), reported reduction in plant growth by aluminium toxicity mainly of plants that grown in acidic soil. Root and shoot are targets of aluminium toxicity but exact mechanism of Al toxicity is not clear. (Horst, 1995; Rengel, 1996; Kochian and Jone, 1997). The overall mechanism of Al toxicity and tolerance in plant cells summarized in **Fig. 3.**

According to Ryan *et al.*, (1993), root apex is the main site of Al toxicity, the decapped roots shows growth similar to intact roots and concludes that root cap does not provide protection from Al damage. This is not correlated with studies which

shows protection given by root cap through its involvement in signal perception and hormone distribution (Bennet and Breen, 1991). However recent work of Panda (2007) ruled out a role of root cap and emphasizes that root meristem is the sensitive site. Gunse *et al.*,(1997) recorded the primary effect on root membrane, within few minutes or after hours of Al uptake. The effect are likely to be mediated by Al ability to bind to carboxyl and phosphate groups of the cell wall and cell membrane respectively. The swelling of root and inhibition of growth were associated with Al exposure, which suggest that target of Al-toxicity may be cytoskeleton (Elison *et al.*, 1998).

Blancaflor *et al.*, (1998), have studied Al induced effects on microtubules and actin microfilaments in elongating cells of maize root apices and related the Al induced growth inhibition to stabilization of micro tubules in central elongation zone. Recently Salaskar *et al.*, (2008), noticed the influence of Al on different growth parameters i.e. fresh weight, dry weight, root growth, shoot growth etc in *Sesbania rostrata* L. (TSR.L). They observed growth based on fresh and dry weights was unaffected by Al upto 750 μM, it declined with 1000 μM Al treatment.

However, according to Kochian, (1995); Taylor, (1995); and Sivaguru *et al.*, (1999), even though Al has shown its primary effect on root. The exact mechanism is still unsolved and controversial.

Ma *et al.*,(1997a) noticed that the translocation of Al into upper plant part is very slow. The Al in shoot causes cellular and ultra structural changes in leaves, increased rates of diffusion resistance, reduction in stomatal aperture, decreased photosynthetic activity which ultimately causes chlorosis and necrosis of leaves. According to Thornton *et al.*, (1986), the size and number of leaves also decreases due to Al toxicity. The alteration of both root and leaf architecture due to Al treatment noticed by Kidd and Proctor, (2000). They recorded the significant increase in leaf expansion due to low Al concentration i.e. below 5 ppm, but it reduced by higher concentration i.e. above 25 ppm.

In plants, root system takes the Al ion and no specific Al ion carrier yet has been found but it is an active ion transport mechanism and only small amount of Al penetrate into leaves, (Deleers *et al.*, 1985; Takabatake and Shimmen, 1997).

The reduction in water uptake, uptake transport metabolism of several essential minerals are also affected by Al. It apparently interacts directly and/or indirectly with the factors that influence organization of cytoskeleton, such as

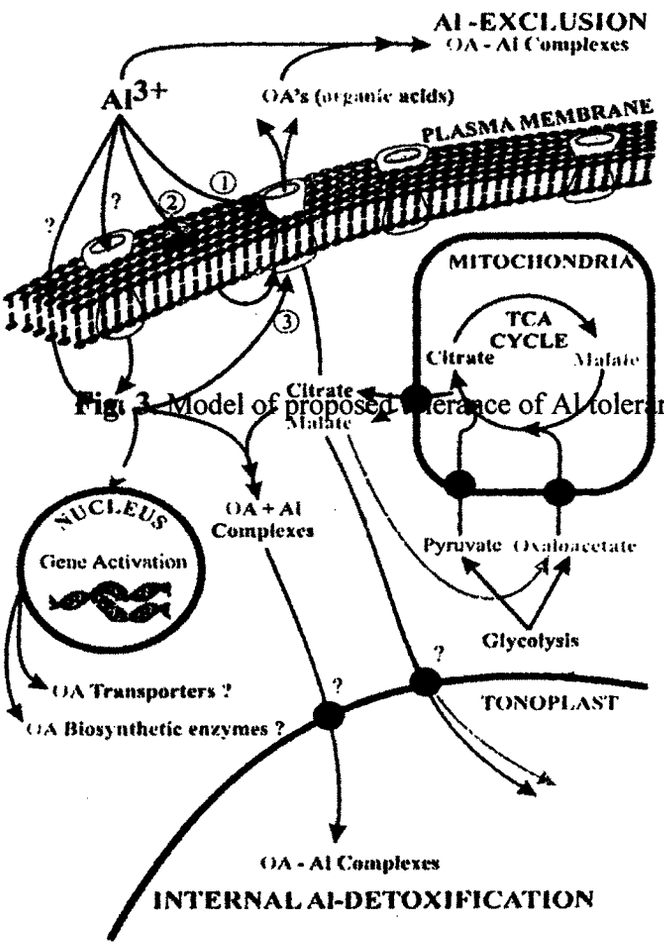


Fig. 3. Model of proposed tolerance of Al tolerance

cytosolic level of Ca^{2+} (Jones *et al.,* 1998), Mg^{2+} and Calmodulin (Grabski *et al.,* 1998), Cell surface electrical potential (Takabatake and Shimmen, 1997), callose formation (Horst *et al.,* 1997), and lipid composition of plasma membrane (Zhang *et al.,* 1997). The effect of Al (*in vitro and in vivo*) on root plasma membrane has been studied by Lindberg and Griffith (1993) in two sugar beet (*Beta vulgaris* L.) varieties .The lipid analyses of the plasma membrane revealed that the acyl composition differed little by in vivo Al treatment, but the ratio of phosphatidyl choline :phosphatidyl ethanolamine was increased. Yamamoto *et al.,* (2001) have shown that peroxidation of lipids is relatively early event following Al exposure and appears to partly influence the Al induced production of callose but not the Al induced inhibition of root elongation. By comparison the loss of plasma membrane integrity is relatively late event and seems to be a consequence of the cracks in the root formed by inhibition of root elongation. The effect of Al (*in vitro and in vivo*) on root plasma membrane has been studied by Lindberg and Griffith (1993) in two sugar beet (*Beta vulgaris* L.) varieties. The lipid analyses of the plasma membrane revealed that the acyl composition differed little by *in vivo* Al treatment, but the ratio of phosphatidyl choline: phosphatidyl ethanolamine was increased.

In plants, Al toxicity has shown to interfere with root by affecting cell division, decrease root respiration, (Ryan *et al.*,1993), fix less 'P' as well as affecting certain enzymes. Al interferes with many enzymes. Al treatment increases the activity of enzyme superoxide dismutase, catalase, lipid peroxidase and ascorbate peroxidase (Cakmak and Horst, 1991). The increased activity of acid phosphatase was interpreted as damage to membrane which leads to liberation of enzymes from lysosome mitochondria and other phosphate containing cell structure.

Al forms strong complexes and precipitate nucleic acids and are used to isolate polynucleotide from leaves. In barely roots, Al decreased hexosephosphorylation and increased concentration of ATP. In plant Al inhibits activities of ATPase; therefore, it directly or indirectly prevents the use of ATP in glucose phosphorylation. Decrease in production and transport of cytokinins (Kumar and Purohit, 2003). Lindberg and Griffiths (1993), observed the adverse effect of Al on the activity of ATPase in sugarbeet cultivars as *Monohill* Al sensitive and Al tolerant cv. *Regina.* This reduction in activity was not due to the formation of Al-ATP complex but may be due to binding of Al with membrane bound enzymes and/or modify the lipid environment. Aluminium also affect plasma membrane characteristic (Horst, 1995). In contrast, in

pea roots, it was reported that Al increased the activities of ATPase and acid phosphatase. It injured the cell walls by activating polygalacturonase which hydrolyzes pectin and Al penetrate fastly.

According to Nosko *et al.*, (1988), resistance of older plant is more than young seedling. However, seed germination is apparently not influenced by Al, but the growth in new root, also establishment of seedling was affected by Al.

The reduction in photosynthetic pigments, degradation of thylakoids and induction of lignin deposition was noticed by Sarkunan *et al.*, (1984). In isolated spheroplast of *Beta vulgaris*, Al suppressed the PS-I mediated electron flow and stimulated PS-II catalysed electron flow and O_2 evolution.

Al causes deposition of polysaccharides in cell walls. Thus cell wall rigidity increased, also interfere with uptake, transport and use of several element like Ca, Mg, P, K and water by plants.

Al interfere signal transduction process (Haug *et al.*, 1994). Stress recognition activates signal transduction pathways that transmit information within individual cells and throughout the plant. These pathways lead to the expression of genes and resultant modification of molecular and cellular processes. In plants, there is little research on Al signaling mediated by second messengers.

Under Al stress, there is existence of cascade pathway. In wheat root apexes Al toxicity may be related increase in cytoplasmic Ca^{2+} level (Zhang and Rengel, 1999). According to Osawa and Matsumoto, (2001), for the signal transduction in Al-activated malate efflux, protein phosphorylation is required, and that malate could pass through organic anion-specific channels. Because of it's rapidness and specificity to Al, Al-induced malate efflux is a useful system for studying how the Al signal is transmitted into cell that expresses physiological responses underlying Al-toxicity or tolerance (Teresa, 2001).

13. Mineral nutrition under Al toxicity :-

For healthy plant growth and development mutual interaction of metal ions is very important. The knowledge of mineral nutrition under Al treatment and acidic soil is very scanty. The Al is not considered as essential element for plant growth but under low concentrations it can promote plant growth. However in different plant

genotypes and growth media, this effect may be different. The knowledge of mineral nutrition under Al treatment and acidic soil is very scanty.

Al interfere with the uptake, transport and use of various elements including macro and microelements like N, P, Na, Cu, Mn, Zn. Excess of Al may increase or decrease (Balakumar *et al.,* 1992) the uptake of nutrients.

The presence of other elements in soil-plant system decides solubility of Al. Al toxicity is complex event which may be manifested as a deficiency of P, Ca, Mg, Fe (Foy, 1988).

Ca^{2+} in rooting medium is essential for root elongation even in absence of added toxicants. Generally root apex is primary site of Al accumulation. In initial phase of Al toxicity the transport of Ca^{2+} is inhibited. In wheat, as Al level increases around root, Ca in root and shoot decrease (Jones *et al.,* 1988). In presence the rhizotoxic level of Al^{3+}, H^{+} and in medium higher level of Ca^{2+} reduces growth inhibition. Ca and Mg accumulation is decrease by uptake of Al in plant than other mineral nutrient uptake (Rengel and Robinson, 1989). The interaction between Ca and Al are probably important factor affecting Ca uptake and transport in plants grown in acid soil (pH 5.5).

According to Huang *et al.* (1996) the transport of Ca^{2+} into roots, algal cells protoplast and membrane vesicles considerably inhibited by Al^{3+} e.g. by blocking Ca^{2+}, K^{+} channels.

In almost all soils, 'P' is often the most limiting mineral nutrient. The available phosphate (Pi) in the soil solution is commonly 1-2 μM (Bieleskai, R. L. 1973). It is a major factor limiting the crop production in acid soils (Sanchez *et al.,* 1973). In many plants 'P' use efficiency is associated with aluminum tolerance as Al plays important role in increasing the redox potential of root tissues decreases the contents of high energy bond 'P' and increase the contents of mineral 'P' in the roots. (Slaski *et al.,* 1996). Organic acids binds to Al, prevent formation of P-Al complex which results in an increased availability of 'P' in the root cell. Therefore there is lower demand for 'P' in Al-tolerant plant.

According to Lee (1971) the accumulation of Mn due to Al injury, was observed in root tissue of potato content. In Al treated rice, inhibition of Mn content was noticed by Alam (1983). In acidic soil, concentration of soluble Al and Mn frequently reach to phytotoxic level. In cowpea, combine effect of Al and Mn on

growth and metal accumulation was studied by Taylor *et al.*, (1998). When concentration of Al increases upto 100 μM, the accumulation of Mn decreases in shoots, while low concentration of Al i.e. 1-8 μM accumulates less amount of Mn in roots and shoots. But high concentration of Mn (50 μM) increases Al accumulation in roots and shoots.

In a variety of species silicon (Si) can ameliorate Al-toxicity. Al detoxification by Si is controversial, by formation of aluminosilicate species in the external growth media Al availability is reduced, by increasing Si increase pH of soil solution (Cocker *et al.*,1998).

In higher plants, boron plays major role in short and long distance transport of sugar by formation of borate-sugar complex. According to Lukaszewski and Blevins, (1996), Al toxicity and boron deficiency symptoms are very much similar and generally associated with root growth and impaired membrane function. Le Nobel *et al.*, (1996), experimentally proved that inhibition of root and shoot growth due to Al can be protected by supplement of boron.

14. Tolerance to Aluminium toxicity :-

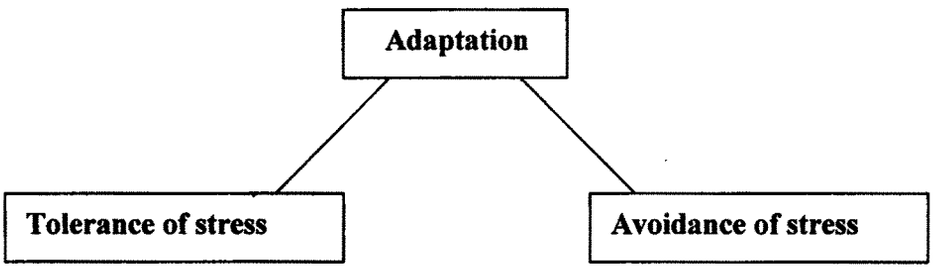
The different Al-tolerance mechanism have been proposed by various workers such as Delhaize and Ryan, (1995); Kochain, (1995); Ma *et al.*, (2000); Matsumoto, (2000) and Osawa and Matsumoto, (2001). Kidd and Proctor (2001) were carried out a work in the university of Stirling (UK) to investigate the role of toxicity of H+ on plant growth. According to them plants were separately adopted to H^+ or Al^{3+} toxicity, it depends upon the soil characteristics from which they were collected.

The general outline of strategies of plant adaptation to acid mineral soils shown in **Fig. 4.** Aluminium tolerance can be divided into external tolerance mechanism and internal tolerance mechanism. The internal tolerance mechanism confer the ability to tolerate aluminium in the plant symplasm. (Taylor, 1988; Carver and Ownby, 1995; Kochian, 1995). While external tolerance mechanism facilitate aluminium exclusion from root apex (Somers *et al.*, 1996; Basu *et al.*, 1999).

a) The external tolerance mechanisms :-

This mechanism involved various responses which are as follows.

1) **Exudation of organic acids** (Hue *et al.*, 1986; Suhayda and Haug, 1986; Miyasaka *et al.*, 1991; Delhaize *et al.*, 1993; Basu *et al.*, 1994 b; Ryan *et al.*,



- High tissue tolerance to toxic mineral elements (Al, Mn), "includer"
- Low internal nutrient demand.
- Effective retranslocation and compartmentation of nutrients.

- Exclusion of Al (and Mn) from sensitive sites.
- Exclusion from uptake by root induced changes in the rhizosphere.
- High efficiency in nutrient acquisition
- Favorable thizosphere microorganisms associations, Mycorrhizas.

(cf – Marschner, 1995).

Fig. 4. Strategies of plant adaptation to acid mineral soils.

1995; Pellete *et al.,* 1995; de la fuente *et al.,* 1997). The secretion of organic acid from the apex of root is primary response to Al was most accepted view proposed by various workers. The general model proposed mechanism of Al tolerance is depicted.

According to Ryan *et al.,* (1995), malate is released from wheat root when exposed to Al. The exudation of citrate in response to Al treatment was also noticed by Yang *et al.,* (2000) in *Zea mays and* Soyabean. While secretion of both malate and citrate in wheat plant was recorded by Ma *et al.,* (2000). Similarly exudation of oxalate in Al treated *buckwheat* was reported by Ma *et al.,* (1997a).

Osawa and Masumoto, (2001) noticed loss of organic anions, citrate, succinate as well as malate from the apex of Al resistant wheat cv. *Atlas* immediately after exposure to Al. The Al resistant plants release organic anions only in presence of Al thus prevent excess loss of carbon, from the root. In response to Al, different organic acids are released and also have different ability to precipitate with Al. Oxalic acid has maximum ability to precipitate with Al, while succinic acid has minimum ability to precipitate with Al (Hue *et al.,* 1986). The sequence of precipitation in decreasing manner is oxalic acid > citric acid > malic acid > succinic acid.

Secretion patterns of organic acid is of different types and hence several different mechanisms are involved in this process (Delhaize and Ryan, 1995). The presence of anion channel on plasma membrane, which secrets organic acids through it (Ryan *et al.,* 1995; Pineros and kochian, 2001). According to Delhaize and Ryan, (1995), Al induced, activation of anion channel might be due to,

a) Interaction with specific receptor of the membrane.

b) Entrance to cytoplasm and through a signal transduction pathway, altering channel protein. (or altering channel protein through signal transduction pathway)

c) A direct action on the channel protein thus its conductance.

Al induced rapid secretion of organic acids suggest that gene induction is not involved. But, gene induction may be involved in the case of a lag phase in the excretion of organic acids. The gene involved is 'R', gene to the biosynthesis of organic acids, to the formation of anion channels on the

plasma membrane and/or tonoplast or to the transport, e.g. citrate from mitochondria (Ma *et al.*, 2000). Al-specific carrier protein has not been found.

Increase of organic acid release is induced 0-12 h after exposure to Al. There are two patterns for Al induces release of organic acids. In some plants there is immediate release of organic acids in response to Al. In Wheat cv. ET 3, which is Al tolerant genotype, secretion of malate from both intact roots and excised root apexes was observed within 20 min after exposure to Al (Ryan *et al.*, 1995). In *buckwheat*, within 30 min after the exposure to Al, the secretion of oxalic acid occurred (Ma *et al.*, 1997a). However Osawa and Matsumoto (2001), recorded release of malate started 5 min after the addition of Al in Wheat. The secretion of oxalic acid by roots due to Al treatment was noticed by Salaskar *et al.*, (2008) in *Sesbania robusta* L. Since accumulation of Al in roots of this species was high, which may be results in formation of Al-oxalic acid complex formation.

While in other pattern, in between the addition of Al and the onset of organic acid release, there is a marked lag phase is present. In *Casssia tora*, in response to Al, secretion of citrate takes place after 4 hrs (Ma, 2000). A considerable lag phase before maximal citrate efflux is observed, in an Al resistant cultivar of Maize (Pellet *et al.*, 1995). Hence, here efflux rate of organic acid varies with the time after exposure to Al, being initially low and high at a later time. Different plant species shows differences in the lag time required for the induction of efflux of organic action, the regulatory mechanism of organic anion efflux in response to Al stress is still lacking or unknown.

2) **Immobilization at cellwall** (Mugwira and Elgawhary, 1979; Blamey *et al.*, 1990; Taylor, 1991; kochain, 1995).

3) **Exudation of phosphate** (Taylor, 1991; Ryan *et al.*, 1993; Pellete *et al.*, 1997).

4) **Active Al efflux across plasma membrane** (Zhang and Taylor, 1989; Taylor, 1991). The Al binding proteins are present in cytosol, in vacuole compartmentation followed by evolution of Al tolerant enzymes and elevated enzyme activity (Taylor, 1991). There is also an experimental support for the synthesis of Al binding protein (Aniol, 1984b; Picton *et al.*, 1991; Rincon and Gonzalez, 1991; Somers *et al.*, 1996). According to Li *et al.*, (2000), Al forms

stable complex with ionic Al, and Al binding with intra and intercellular compound in roots prevented from Al toxicity.

5) **Production of root mucilage** (Horst *et al.,* 1982; Henderson and ownby, 1991). A number of processes could contribute to Al exclusion from the meristematic cell region, including increased secretion of mucilage (Crawford and Wilkens, 1997).

6) **Al exclusion via alteration in rhizosphere pH** (Foy *et al.,* 1965; Mugwira *et al.,* 1976; Mugwira and Patel, 1977; Pellet *et al.,* 1997; Foy, 1988; Taylor, 1988; Kochian, 1995). According to Kochian *et al.,* (2004), Al induced release of phenolics is very useful in detoxification of Al, in rhizosphere surrounding root apex. Strong correlation between rate of Al stimulated root exudation of flavonoids, catechin, quercetin and differential Al tolerance in three maize genotypes than release of organic acids (Kidd *et al.,* 2001), inorganic phosphate (Pellet *et al.,* 1996) and organic acids (Larsen *et al.,* 1998).

Al tolerance was correlated with Al activated root, apical H^+ influx. This H^+ influx increases alkalinization in rhizosphere and pH at the surface of root apex which considerably decreases the Al^{3+} toxicity around root tip and root growth is improved (Degenhardth *et al.,* 1998). The efflux of Pi from roots may be considered another mechanism of Al resistant in plants, by formation of Al-Pi complexes in rhizosphere (Taylor, 1991). Similarly the efflux of Al from symplast was also reported by Ezaki *et al.,* (1999). In roots exposed to Al, cell division is decreased mechanism about it is still not clear. But a direct effect assocciated with Al binding to DNA or other nuclear material cannot be excluded. (Matsumoto, 1991; Silva *et al.,* 2000).

Proline is amino acid in plants which play important role in plants during drought and salinity. Proline works as it stabilizes cellular structures also it acts as scavenger for free radicals, (Hare and Cress, 1997). The accumulation of Proline during stress condition including exposure Al was reported by Mossor Pietraszewska, (unpublished data). The formation of metal-protein complex may be supposed as a measure for Al-detoxification. Also there is formation of many Cytosolic Al-binding protein was noticed by Basu *et al.,* (1999); Snowden *et al.,* (1995); Somners and Gustafson, (1995); Wu *et al.,* (2000). Heavy metal tolerance in plants is due to production of phytochelatins was reported by Cobbet, (2000). But phytochelatins do not give

Al tolerance because phytochelatin do not bind Al effectively (Larsen *et al.*, 1996), because Chelatins contain- SH group and Al do not bind with this group.

b) Internal Detoxification of Aluminium :-

This internal tolerance mechanism is observed in cytosol. Recently, some workers have shown that, plant species can accumulate Al to high level in the shoot to look for the mechanisms of internal Al detoxification. The work of Ma *et al.*, (1997), has begun to provide insights into mechanisms of internal Al detoxification in two accumulator special *Hydrangea* and *buckwheat. Hydrangea*, which is ornamental plant whose flowers turn blue from red when soil is acidified, this change in color is due to Al accumulation in the sepals and formation of blue colored complex of Al, delphinidin-3-glucoside and 3-caffeolylquinic acid. *Hydrangea* can accumulate greater than 3000 ppm Al in its leaves .

Ma *et al.*, (2001) noticed that *Buckwheat* can also accumulate Al as high as 15000 ppm in leaves when grown on acid soil. Recently Salaskar, (2008) was noted a sharp increase in Al content in roots, stem, leaves of *S. robusta* with increase in Al concentration above 1000 μg gm^{-1} and observed more than 90% of Al found in roots as compare to stem and leaves.

In Biological system, either *in vitro* or *in vivo*, among the various effects induced by Al, is the destruction of membrane poly unsaturated fatty acids depending on oxygen free radicals (AOS). Al stress and oxidative stress are strongly linked in plants.

According to Ezaki *et al.*, (2000), transgenic *Arabidopsis* lines expressing nine Al induced genes, which can protect against Al toxicity and also provide genetic evidence for a link between Al stress and oxidative stress in plants. These nine genes are as follows.

An *Arabidopsis* blue copper binding protein gene (AtBCB), a tobacco glutathione S-transferase gene (ParB), tobacco peroxidase gene (NtPox) and a tobacco GDP dissociation inhibitor gene (Nt GDI1) gives degree of resistance to Al. Two genes AtBCB and ParB and a peroxidase gene from *Arabidopsis* (AtPox) also gives resistance to oxidative stress.

15. Molecular genetics in Aluminium toxicity and Aluminium tolerance :-

The solution for this problem is selection and development of genotype, with tolerance to acid soils and toxic level of Al. Generally by applying agricultural lime, acidity of the surface soil can be corrected. In Wheat, the genetics and chromosome localization of aluminum tolerance genes have been extensively studied by Aniol and Gustafson, (1984).

From different plant species more than 20 genes induce by Al stress have been isolated. These plants species are wheat (Aniol, 1995; Delhaize *et al.,* 1999), rye (Gallego and Benito, 1997), rice (Nguyen *et al.,* 2001), soyabean (Bianchi-Hall *et al.,* 1998), tobacco (Ezaki *et al.,* 1997), *Arabidopsis* (Richards *et al.,* 1998). Mostly stress genes are Al-induced genes. By similarity with other stress genes, Al-induced genes may play role in protection of cell from Al-toxicity.

Genetic Control in Wheat

Wheat is the most extensively studied plant species for Aluminum tolerance. According to Aniol (1984a) for Al tolerance several genes are responsible, especially in wheat, *Atlas* 66, Al tolerance is determined by dominant genes, located on D genome and/or on B genome. These Al tolerance genes are present on chromosome arms are 6AL, 7AS, 4BL, 2DL, 3DL, 4DL and 7D. Confirming that in the A and D genome was noticed by Aniol and Gustafson, (1984). Recently Riede and Anderson, (1996) reported the presence of BH 1146, 4DL linked gene- giving Al tolerance in Brazilian Wheat variety. Gravin and Carver, (2003) have identified two loci for regulation of Al tolerance. Recently Sasaki *et al.*, (2004) have isolated characterized and cloned aluminum tolerance gene *ALMT* 1 for first time.

Genetic Control in Rye

In family Triticeae, Rye is one of the most stress tolerant plant species (Little, 1988). It is the highest Al tolerance, in cereals, followed by triticale, wheat, (Aniol and Madej, 1996., Hede *et al.,* 2001a). In rye, genes for Al tolerance have been located on chromosome 3R, 4R, 6RS (Aniol and Gustafson, 1984). It is controlled by at least two major dominant and independent loci: *Alt*1 and *Alt*3, located on 4R and 6R chromosome (Gallego and Benito, 1997). The DNA markers for Al tolerance were selected by Gallego *et al.,* (1998).

Genetic Control in Triticale

Many members of triticales show high Al tolerance but less than rye (Hede *et al.,* 2001c). In triticals, Al tolerance genes 3R are located, on short arm of chromosome, (Ma *et al.,* 2000). However according to Aniol and Gustafsan (1984), the expression of these genes depends on which chromosomes is substituted. These genes are necessary for release of organic acids

Genetic Control in Barley

Barley is most Al sensitive cereals. Al tolerance gene in barley cultivars found by Raid (1971), Daylon and smooth Awn 86 to be controlled by a single dominant gene *Alp*. This *Alp* is gene distally located from the Centromere on chromosome 4.

There are various molecular system such as use of Restriction Fragment Length, Polymorphism (RFLPs), Random Amplified Polymorphic DNA (RAPD), Simple sequence repeats (SSRs), amplified fragment length polymorphisms (AFLPs), has made tremendous advancement in the production of high density linkage maps, for localizing genes in plants (Gallego *et al.,* 1998; Ma *et al.,* 2001; Nguyen *et al.,* 2001; Wu *et al.,* 2000).

Recently in plants many technique have been used to create genetic and physical maps to obtain Al tolerant plants. Many efforts have been made by using biotechnological techniques e.g. transgenic rice (Wu *et al.,* 2000), *Arabidopsis* (Ezaki *et al.,* 2000).

16. Al-tolerant species :-

There are different plant species shows different response to Al toxicity. Some plant species are more tolerant to aluminium toxicity than other.

E.g. Cassava (*Manihot esculenta* crantz)
Cowpea (*Vigna uniguiculata* L- Walp)
Groundnut (*Arachis hypogaea* L.)
Pigeon pea (*Cajanus cajan* L Millsp)
Potato (*Solanum tuberosum*)
Rice (*Oryza sativa* L.)
Rye (*Secale cereale* L.) Little 1988

Table. 7 Groundnut – Major states by area unit

	1991-92	1992-93	1993-94	1994-95	1995-96	1996-97	1997-98	1998-99	1999-00
India	8667.9	8166.4	8321.7	7848.6	7524.0	7596.4	7088.2	7396.0	6865.1
Gujarat	1941.6	1884.0	2053.0	1989.3	1902.9	1834.9	1926.2	1940.8	1826.5
Andra Pradesh	2481.0	2372.4	2375.0	2176.0	2220.3	2198.0	1834.4	1940.6	1792.9
Karnataka	1331.9	1275.7	1228.3	1200.0	1191.9	1285.4	1040.0	1230.0	1107.0
Tamil Nadu	1099.2	1188.4	1158.3	1079.9	933.4	901.5	867.6	1086.5	834.6
Maharashtra	742.3	652.2	659.0	602.6	511.0	575.7	532.4	520.7	519.5
Rajasthan	248.3	242.8	287.4	249.9	216.2	245.3	328.9	330.0	273.7
Madhya Pradesh	280.4	258.8	275.8	266.2	251.7	254.7	254.7	216.5	262.9
Uttar Pradesh	126.1	118.8	138.6	136.2	138.5	137.8	146.0	124.0	112.4
Orissa	356.4	112.1	100.1	87.3	91.1	96.6	94.6	83.4	79.4
West Bengal	20.9	20.7	17.5	23.4	30.1	28.4	29.5	28.1	30.0

(CMIE-November 2001)

area is in acres / hectares to be mentioned.

Table. 8. Groundnut – Major states by production

	1991-92	1992-93	1993-94	1994-95	1995-96	1996-97	1997-98	1998-99	1999-00
India	7094.6	8564.6	7828.9	8061.6	7579.4	8642.9	7372.1	8981.6	5310.4
Tamil Nadu	1517.6	1766.3	1865.6	1762.4	1520.3	1438.3	1408.0	1960.6	1384.6
Andra Pradesh	2151.9	1964.8	2472.6	1670.7	2625.8	2045.5	1155.8	1920.2	1119.9
Karnataka	1110.0	1142.3	1167.3	945.5	1138.7	1147.4	714.0	1229.0	791.0
Gujarat	699.7	2068.4	676.6	2380.1	1028.3	2449.1	2615.9	2577.8	717.5
Maharashtra	546.1	755.1	769.2	629.2	576.4	755.9	565.8	633.6	545.2
Rajasthan	198.2	271.7	209.3	197.5	164.8	272.9	368.9	360.1	264.0
Madhya Pradesh	205.5	287.6	253.9	214.3	259.6	252.7	253.8	233.6	252.8
Uttar Pradesh	102.3	139.2	119.4	101.6	100.0	128.7	127.6	83.0	94.9
Orissa	497.1	108.2	114.0	98.2	92.3	78.8	89.5	71.8	72.6
West Bengal	29.0	23.0	21.1	26.3	42.1	36.4	38.7	37.9	39.6

unit

(CMIE-November 2001)

Among all species Rye having highest Al tolerance followed by triticale (X *Triticosecale wittmack*), Wheat (*Triticum aestivum* L) and Barely (*Hordeum Vulgare* L.), (Mugwira *et al.*, 1978; Aniol and Madej, 1996).

17. Groundnut :-

Groundnut (*Arachis hypogaea* L.) is one of the important legume crops of both the tropical and temperate regions of the world.

Groundnut is an important oil and protein source to peoples of Asia, Africa and the America. It is also known as Peanut, Earthnut, Monkeynut, Goober, Pinda and Manillanut.

India ranks first in the world in the groundnut area (7.6 Mha– 40%). However, regarding productivity India ranks 10^{th} in the world (7.3 million tones–33%).

Groundnut cultivation in India is mainly confined to different states viz Andhra Pradesh, Gujrat, TamilNadu, Karnataka, Maharashtra, Rajasthan, Punjab, Orissa etc. The groundnut growing states with their area and production are recorded in **Table No. 7 and 8.**

Groundnut in Maharashtra :-

In Maharashtra groundnut is cultivated in all district of the state and the total area and production was 7.4 lakh hectares and 5.7 lakh tones respectively. Some of the popular groundnut cultivars in Maharashtra are JL-24 (Phulepragati), SB-11, Karad 4-11, Kopargaon-1, TMV–10, TG-1 (Vikram), TG–17, W-44, W-55 etc. Groundnut is cultivated in both Kharif and Rabbi seasons.