

Zinc deficiency in soil and role of zinc in human and plant

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Received: 4.2.2017/Accepted: 12.6.2017

ABSTRACT

Zinc deficiency is one of the most widespread micronutrient deficiencies in crops and pastures worldwide and causes large losses in crop production and crop quality. Almost half of the world's cereal crops are grown on zinc-deficient soils. As a result zinc deficiency in humans is a widespread problem. Zinc deficiency is common in different types of soils; some soils have low total zinc concentration and others have low plant-available zinc due to its strong sorption. Soils low in organic matter and compacted soils that restrict root proliferation also have a high risk of its deficiency. Liming of soils also frequently induces zinc deficiency by increasing zinc sorption. Zinc is an essential micronutrient which means it is essential for plant growth and development but is required in very small quantities. Application of zinc may not correct its deficiency in alkaline soils because even with the addition of zinc it may remain unavailable for plant absorption. Foliar applications of it as zinc sulphate or as zinc chelate are also widely used especially in fruit trees and grape vines. Zinc can also be supplied as a seed treatment or by root-dipping of transplant seedlings. It occurs in plants as a free ion, as a complex with a variety of low molecular weight compounds or as a component of proteins and other macromolecules. The article gives an insight into the role and importance of zinc in plants and for human beings.

Keywords: Zinc; deficiency; soil; plant; application

INTRODUCTION

Agriculture provides the primary source of the nutrients required by humans and animals. Two-third of the world's population depends on cereal or tuber-based diets which tend to satisfy the demand on calories intake but not essential micronutrients (Anon 2002). Micronutrient deficiency is considered as one of the major causes of the declining productivity observed in rice growing countries. The use of increased amounts of nitrogenous and phosphate fertilizers with high yielding varieties of rice, wheat, maize and other crops often causes or exacerbates Zn deficiency where the plant available Zn levels in soils are marginal.

Zinc is one of the most important micronutrients essential for plant growth especially for rice grown under submerged conditions. Globally the soils are found to be deficient in zinc and most of the food crops contain less amount of it in the edible parts.

Zinc deficiency in soil

Losses of micronutrients through erosion, leaching, liming of acid soils, decreased proportions of farmyard manure compared to chemical fertilizers and use of marginal lands for crop production are the factors that have increased the incidence of micronutrient deficiencies in agricultural soil worldwide (Fageria et al 2002). Zinc deficiency can be found in every part of the world and almost all crops respond positively to application of Zn (Welch 2002).

Normal soils inherit their trace elements which include Zn primarily from the rocks through geochemical and pedochemical weathering processes. Besides mineralogical composition of the parent material, the total amount of Zn present in the soil is also dependent on the type, intensity of weathering, climate and numerous other predominating factors during the process of soil formation. As per Imtiaz (1999) the high pH and high concentrations of CaCO_3 , organic matter, clay and phosphate can fix Zn

in the soil and give rise to the reduction of available Zn (Imtiaz 1999).

Quartz in the soil dilutes Zn from it because the reported concentrations of Zn in quartz are very low which range from 1.0 to <5 to 8 µg/g (Wedepohl 1978). According to the Food and Agriculture Organization (FAO) about 30 per cent of the cultivable soils of the world contain low levels of plant available Zn.

Generally Zn deficiency is expected in calcareous, sandy, peat and soils with high phosphorus and silicon. The submerged soils are well recognized for the lack of Zn availability to the plants particularly due to the reaction of Zn with free sulphide. In soils with slight Zn deficiency the yield and quality can be affected without any visible symptoms (Alloway 2009) which can result in food production with comprised nutritional value. Therefore the enrichment of such cereals with Zn is an important global challenge and of great priority in research (Cakmak et al 2010).

Zinc deficiency in the world

Zinc is an element required virtually by all organisms as it is a critical component of many enzymes and proteins. Its deficiency was first reported from lowland rice field in India (Nene 1966) that spread widely thereafter covering a vast area in the country. Zinc deficiency in calcareous soils is one of the widest ranging abiotic stresses in world agriculture (Fig 1) particularly in Turkey, Australia, China and India. Alloway (2008, 2009) reported widespread deficiencies of Zn throughout India and Pakistan (50-70% of soils), Bangladesh (about 2 Mha of paddy soils), China, Japan and Philippines (>8 Mha) and the United States. Global studies initiated by FAO recorded the Zn deficiency in 50 per cent of the soil samples collected from 25 countries.

Among cereals wheat in particular suffers from Zn deficiency in large areas of the world particularly in Turkey, Australia, China, and India. In India presently up to 50 per cent of the agricultural land has been reported to be Zn deficient (Alloway 2007). Use of high yielding varieties and high input approach in the last few decades has resulted in wide spread nutrient imbalance in the cereal growing tracts of India.

Singh et al (2010) reported that correction of soil Zn deficiency through addition of Zn fertilizers is neither economical nor environmental friendly as only

20 per cent of the applied Zn is available for plant uptake while the remainder gets adsorbed on soil minerals and is therefore rendered immobile. Further grain yield reductions up to 80 per cent along with reduced grain Zn concentrations have been observed under Zn deficiency (Alloway 2004). This has serious implication for human health in countries where cereal-based diets predominate.

Zinc deficiency in India

In the Indian context more than 50 per cent of the agricultural soils are Zn deficient (Fig 2). Total zinc concentration in Indian soils varies widely as the nature and type of soils of India are diversified. The wide variation is due to the difference noticed in nature of parent material, soil forming processes, climatic conditions etc. In soils the total concentration of Zn was reported to be in the range of 10-300 mg/kg (Kiekens 1995). The total Zn concentration in Indian soils varied from 2 to 1205 mg/kg.

Jalali et al (2000) reported that the total Zn concentration in soils irrespective of block varied from 170 to 270 mg/kg and the DTPA-Zn concentration of surface soils varied from 0.02 to 3.86 mg/kg. They found that thirty per cent surface soil samples were below the critical value of 0.60 mg/kg zinc in soils of cold arid zone of Ladakh.

The total area under Zn deficiency is about 10 Mha in India and approximately 85 per cent of rice-wheat system. Zinc deficiency is likely to sink profits in paddy cultivation especially in the late Kharif season (October, November-March). Analysis of 256000 soils and 25000 plant samples from all over India showed that 48.5 per cent of the soils and 44 per cent of the plant samples were potentially zinc-deficient and this was the most common micronutrient problem affecting crop yields in India. Deficiency of zinc has increased in southern states due to extensive use of NPK without micronutrients (Singh 2006).

In India analysis of 14863 soil samples from all over the country showed that 49 per cent of the soils were potentially deficient in Zn, 33 per cent in B, 12 per cent in Fe, 11 per cent in Mo, 5 per cent in Mn and 3 per cent in Cu (Singh 2008, 2009).

Badole et al (2001) reported that DTPA extractable Zn ranged from 0.32-1.14 mg/kg in rice grown on soils of the eastern Maharashtra and more

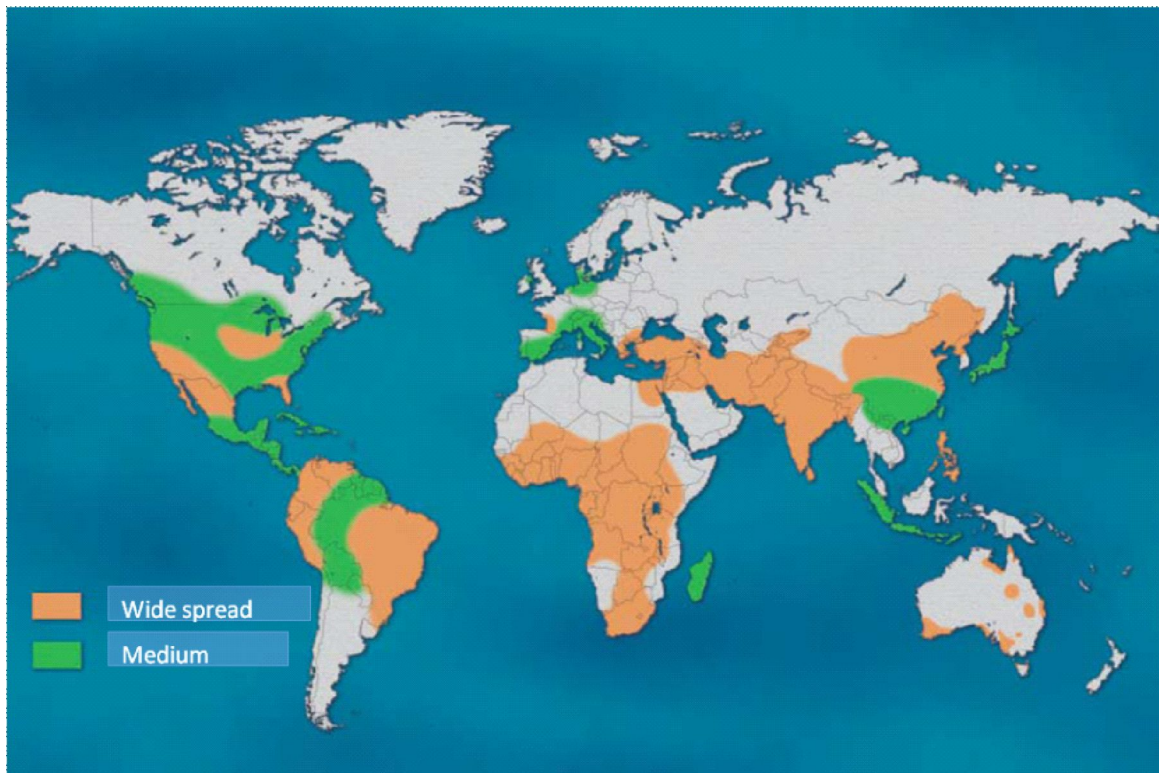


Fig 1. Soil zinc deficiency in the world (Alloway 2008).

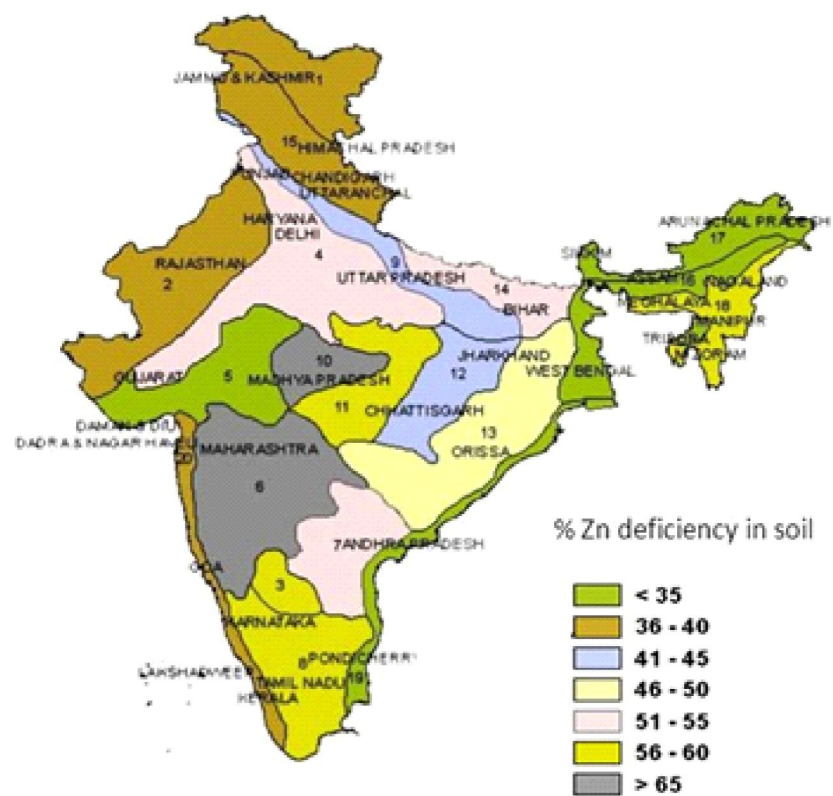


Fig 2. Soil zinc deficiency in India (Singh 2009)

particularly of Chandrapur district. Verma et al (2005) observed that the DTPA-Zn in surface soil ranged from 0.36 to 0.78 mg/kg irrespective of physiography and depth in soils of different physiographic units of Fatehgarh Sahib district of Punjab and reported that the surface horizons contained higher amount of Zn which progressively declined with depth in all the pedons.

Chahal et al (2005) reported that the total Zn concentration in soils in the different soil orders of semi-arid regions of Punjab varied from 19 to 113 mg/kg. Total Zn was lowest in the entisols (19-76 mg/kg), intermediate in the inceptisols (37-99 mg/kg) and the highest in the alfisols (43-113 mg/kg) while DTPA-extractable zinc (DTPA-Zn) ranged between 0.28 and 1.94 mg/kg.

Sharma et al (2006) noted that the total Zn concentration of soils of vertisols in India varied widely from one profile to the other and ranged from 24 to 102 mg/kg and also DTPA-extractable Zn of most of the soils (71 out of 75 samples) was deficient (<0.5 mg/kg). Sharma and Chaudhary (2007) reported that the available zinc content in soil was found deficient in 15.2, marginal in 23.7 and sufficient in 61.1 per cent of the studied samples while Cu, Fe and Mn were sufficient in all the eight soil series collected from lower Shiwaliks of Himalayas.

Jyothi et al (2009) reported that the DTPA-Zn concentration ranged between 0.69 and 2.24 mg/kg for 0-20 cm depth and from 0.65 to 2.04 mg/kg for 20-40 cm depth in traditional arecanut garden soils of Karnataka. Jibhakate et al (2009) reported that DTPA-extractable zinc was low to marginal in eleven soil series of Katol Tehsil in which Malegaon series recorded a maximum of 0.52 mg/kg (0.24 to 0.67 mg/kg) and Linga series the minimum (0.35 mg/kg).

Bali et al (2010) reported from the study on major physiographic regions of Punjab that DTPA-extractable Zn status of soils ranged from 0.14 to 2.90 mg/kg in Shiwalik hills and undulating eco-sub-region in which 67 per cent soil samples were above the critical value and 33 per cent were deficient. In piedmont and alluvial plain eco-sub-region the DTPA-extractable zinc in soils ranged from 0.06 to 2.89 mg/kg in which 80 per cent of the samples were sufficient and 20 per cent were deficient. The DTPA-extractable zinc ranged from 0.23 to 3.06 mg/kg where 80 per cent of soil samples were above the critical limit (0.60 mg/kg)

and 20 per cent were deficient in central alluvial plain eco-sub-region and in southwestern alluvial plain eco-sub-region DTPA-extractable zinc ranged from 0.33 to 2.05 mg/kg with a mean value 0.97 mg/kg in which 72 per cent were high in available Zn and 28 per cent were deficient.

Kumar and Babel (2011) reported that the surface soil (0-30 cm depth) collected from Jhunjhunu Tehsil, Rajasthan showed 70 per cent of deficiency in DTPA-zinc and the values ranged from 0.12 to 1.30 mg/kg. Behera et al (2011) observed that out of 400 representative surface (0-15 cm) soil samples collected from Orissa, Jharkhand, Himachal Pradesh and Kerala the DTPA-extractable Zn was deficient in 7 to 82 per cent samples.

Meena et al (2012) observed that the concentrations of available zinc were higher in surface horizons and decreased with depth in most of the pedons and ranged from 1.01 to 5.10 mg/kg with the study conducted on vertical distribution of DTPA-extractable zinc in ten typical pedons in Malwa plateau region of Banswara district in Rajasthan.

Upadhyay (2012) reported that the DTPA-Zn values varied widely (0.22- 6.71 mg/kg) in different soils of Hamirpur district of Uttar Pradesh. Accordingly 33 per cent of soil samples were classified as deficient, 36 per cent as marginal and 31 per cent as adequate in available Zn in Hamirpur district. Mahashabde and Patel (2012) reported that the available Zn in soils varied from 0.53 to 1.3 mg/kg with a mean value of 0.62 mg/kg in Shirpur Tehsil region.

Wani et al (2013) reported that the DTPA-Zn in soils varied considerably and ranged from 0.12 to 5.10 mg/kg and 53.3 per cent soil samples out of 625 soil samples were found to be deficient in DTPA-Zn under rice and maize ecosystems of northern district in Kashmir. The data indicated that 14.8 per cent (45063.7 ha) of the total geographical area of the district was deficient in Zn whereas the remaining area was sufficient. Joshi et al (2013) reported that DTPA extractable Zn varied from 0.08 to 6.30 mg/kg in the surface soil samples collected from different locations in acidic hilly tract of Uttarakhand.

Singh and Rathore (2013) observed that the available Zn concentration ranged between 0.04 to 0.66 mg/kg in soils of Aravalli mountain ranges of Rajasthan. The maximum concentration of available zinc was

observed in soils of very gently sloping plain (Charpotiya) and lowest in soils of pediment (Lodiya). In the soils of Malwa plateau Zn concentration was found to range between 0.04 and 2.19 mg/kg. The maximum concentration was observed in soils of pediment (Shahjikapathar) and the lowest in plain (Kuni). Soils were in general found deficient in DTPA-extractable Zn except Chiklad and Shahjikapathar occurring on hill top and pediment of the Malwa plateau.

Pandey et al (2013) stated that the DTPA-Zn in soils varied considerably and ranged from 0.38 to 0.74 mg/kg and 53.6 per cent samples were found to be deficient in DTPA-Zn in soils of Sonkatch and Dewas Tehsils of Dewas district of Madhya Pradesh. Ravi et al (2014) reported that the DTPA-Zn concentration in soils studied in Karimnagar district ranged from 0.16 to 1.83 mg/kg and zinc deficiency was reported to the extent of 58 per cent. The Zn concentration was recorded the lowest (0.33 mg/kg) in the soils of Sulthanabad and highest (1.49 mg/kg) in Kataram out of 54 Mandals and soils of 24 Mandals were deficient in available Zn.

Zinc deficiencies are rampant in the intensively cultivated areas of the country and on average 40 per cent soils are deficient in Zn as per the recent estimate made by Shukla et al (2014).

Vijayakumar et al (2011) reported that in Tsunami affected areas of Sirkali Taluk of Tamil Nadu the available Zn in the soil samples varied from 0.32 to 1.40 mg/kg with a mean value of 0.84 mg/kg in which 3 per cent samples were deficient, 82 per cent were marginal and 15 per cent were sufficient.

Arokiyaraj et al (2011) conducted a survey in Nagapattinam district of Tamil Nadu and found that the zinc content in soil ranged from 0.10-3.33 mg/kg with a mean value of 0.97 mg/kg in which 79.96 per cent samples were deficient in the available Zn. Kaleeswari (2012) reported that the available zinc in soils of Villupuram district, Tamil Nadu ranged from 0.19 to 4.94 mg/kg with a mean value of 0.89 mg/kg and it was found to be Zn-deficient in more than 84.2 per cent area.

Paramasivan et al (2014) reported that in major rice growing tracts of Srivaikuntum block, Tuticorin, Tamil Nadu the available zinc content was deficient. Karthikeyan et al (2014) revealed that the available Zn content of the soils under banana growing tracts of

Thoothukudi district, Tamil Nadu varied from 0.22 to 2.89 mg/kg with a mean value of 1.34 mg/kg and 38.7 per cent samples were found to be Zn-deficient.

Role of zinc in humans

Humans require at least 25 elements for their well-being. The most common deficient elements in human diets are Fe, Zn, I, Se, Ca, Mg and Cu (Stein 2010). The elements like Zn, Fe and Cu are as crucial for human health as organic compounds such as carbohydrates, fats, protein and vitamins. Zinc is an essential trace element for human health as detoxification of highly aggressive free radicals and structural and functional integrity of biological membranes also critically require Zn (Cakmak 2000).

Zinc plays a part in the basic roles of cellular functions in all living organisms and is also involved in improving the human immune system. The optimum dietary intake for human adults is 15 mg Zn per day. Zinc acts as a catalytic or structural component in various body enzymes. As per recommendations an average male needs 11 mg of Zn daily while an average female needs 9 mg of Zn. During pregnancy and lactation the female needs 13 to 14 mg of Zn daily. Infants from 7 months to 3 years need 3 mg, 4 to 8 years need 5 mg and children from 9 to 13 years need 8 mg of Zn daily (Bouis and Welch 2010).

Role of zinc in plants

Zinc is an essential micronutrient for the growth and development of plants, animals and human beings. It is required in small amounts for very critical functions and it plays an important role in biological systems such as maintenance of structural integrity of biological membranes and direct contributions to protein synthesis and gene expression. It is involved in several biochemical reactions in plant and its deficiency causes low crop yields.

Zn deficiency is the most widespread micronutrient deficiency in the world (Fageria et al 2002) because it is an indispensable micronutrient for proper growth and development of crop plants and the essentiality of it for higher plants was established by Sommer and Lipman (1926). Essentiality of it in plants was first shown in maize by Maze (1915) and subsequently in barley and sunflower (Sommer and Lipman 1926).

Zinc plays very important role in plant metabolism by influencing the activities of hydrogenase

and carbonic anhydrase, stabilization of ribosomal fractions and synthesis of cytochrome. Auld (2001) observed that Zn is the only metal that is required in all six enzyme classes (oxidoreductases, transferases, hydrolases, lyases, isomerases and ligases). The requirement of it for the function of a wide range of enzymes indicates that the metabolism of proteins, carbohydrates and auxin as well as reproductive processes are hampered under Zn deficiency.

Zinc is required for integrity of cellular membranes to preserve the structural orientation of macromolecules and ion transport systems. Its interaction with phospholipids and sulphhydryl groups of membrane proteins contributes for the maintenance of membranes. Dang et al (2010) observed a marked reduction in leaf chlorophyll concentration, photosynthetic activity and leaf water potential as a result of Zn deficiency. Thus Zn has important roles in growth regulation, enzyme activation, gene expression and regulation, phytohormone activity, protein synthesis, photosynthesis, carbohydrate metabolism, fertility, seed production and defense against diseases.

Zinc is essential in chromatin structure, DNA/RNA metabolism and gene expression. Its deficiency causes a decrease in protein synthesis due to RNA degradation, decreased activity of RNA polymerase, ribosomal deformation and a decrease in the number of ribosomes. The regulation and maintenance of the gene expression required for the tolerance of environmental stresses in plants are Zn-dependent (Cakmak 2000). As Zn is required for the synthesis of tryptophan which is a precursor of IAA it also plays an active role in the production of an essential growth hormone auxin (Brennan 2005).

Safak et al (2009) stated that Zn is known to participate in plant metabolism as an activator of several enzymes and it is required for the maintenance of membrane integrity and hormone metabolism. Zn deficiency adversely affects the root membrane integrity in crops. It is essential element for crop production and optimal size of fruit; also it is required in the carbonic enzyme which is present in all photosynthetic tissues and is required for chlorophyll biosynthesis (Mousavi 2011, Xi-Wen et al 2011).

Among the micronutrients, Zn is essential for protein production in plants and it is a main composition of ribosome which is essential for their development. Under zinc deficiency amino acids are accumulated in

plant tissues and protein synthesis declines. One of the sites of protein synthesis is pollen tube in which the amount of zinc in the tip is 150 micrograms per gram of dry matter. In addition zinc contributes in pollination by putting impact on pollen tube formation (Pandey et al 2006).

Alloway (2008) stated that in plants Zn plays a key role as a structural constituent or regulatory cofactor of a wide range of different enzymes and proteins in many important biochemical pathways and these are mainly concerned with carbohydrate metabolism both in photosynthesis and in the conversion of sugars to starch, protein metabolism, auxin (growth regulator) metabolism, pollen formation, maintenance of the integrity of biological membranes and resistance to infection by certain pathogens.

According to the plant professionals' research Zn exerts a great influence on basic plant life processes such as nitrogen metabolism and uptake of nitrogen and protein quality, photosynthesis and chlorophyll synthesis, carbon anhydrase activity, resistance to abiotic and biotic stresses and protection against oxidative damage (Mousavi 2011).

Zinc is required as a structural component of a large number of proteins such as transcription factors and metalloenzymes (Figueiredo et al 2012). Sadeghzadeh (2013) stated that zinc is essential for the normal and healthy growth and reproduction of plants. This element is required in small amounts to allow the normal function of several key plant physiological pathways as well as to ensure the structural and functional integrity of membranes. Zinc has an important physiological role in maintaining the integrity and function of cellular membranes by controlling the generation and detoxification of reactive oxygen species. Hafeez et al (2013) reported that Zn deficiency can affect the plant by stunting its growth, decreasing number of tillers, chlorosis and smaller leaves, increasing crop maturity period, spikelet sterility and inferior quality of harvested products.

CONCLUSION

Zinc deficiency in soil causes deficiency in plant also which leads to Zn deficiency conditions in human and animals which leads to many problems in them. The possible solution to correct Zn deficiency is to increase its concentration in grains and plant parts by the application of Zn fertilizers and also to find the Zn efficient genotypes.

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