1. INTRODUCTION
Introduction

Phosphorus (P) is an essential element next only to nitrogen influencing plant growth and production throughout the world. Unlike nitrogen, this element is not supplied through biochemical fixation but comes from other sources to meet plant requirements. The sources include chemical fertilizers, animal manures, and plant residues including green manures, human, industrial and domestic wastes and, native compounds of phosphorus, both organic and inorganic already present in soil.

Importance of phosphorus

Phosphorus is essential for plant growth. It is a component of adenosine diphosphate (ADP) and adenosine triphosphate (ATP), the two compounds involved in mostly significant energy transformations in plants. ATP, synthesized from ADP through both respiration and photosynthesis, contains a high energy phosphate group that drives most biochemical processes requiring energy.

Phosphorus also plays a critical role in the life cycle of plants. It is an essential component of deoxyribonucleic acid (DNA), the seat of genetic inheritance in plants as well as animals and of the various forms of ribonucleic acid (RNA) needed for protein synthesis. Thus phosphorus plays a leading role in living things and it is said to be the “key element in metabolism”.

Among the most significant functions and qualities of plants on which phosphorus has important effects are photosynthesis, nitrogen fixation, crop maturation (flowering and fruiting including seed formation), root development (particularly of the lateral and fibrous rootlets), strength of straw in cereal crops (thus helping to prevent lodging) and improvement of crop quality especially of forages and of vegetables.
Introduction

The phosphorus problem is three-fold. First, the total phosphorus level of soils is low. Second, the native phosphorus compounds are mostly unavailable for plant uptake, some being highly insoluble. Third, when soluble sources of phosphorus such as those in fertilizers and manures are added to soils, they are fixed or changed to unavailable forms and in time react further to become highly insoluble forms.

Phosphorus compounds in soils

Both inorganic and organic forms of phosphorus occur in soils and both are important to plants as sources of this element. The organic fraction generally constitutes 20 to 80% of the total.

Inorganic compounds

Most inorganic phosphorus compounds in soils fall into those containing calcium and those containing iron and aluminium. The simpler compounds of calcium such as mono and dicalcium phosphates are readily available for plant growth. Much less is known of the exact constitution of the iron and aluminium phosphates contained in soils. The compounds involved are hydroxy phosphates such as strengite and variscite (Brady, 1996).

Organic phosphorus compounds

There has been relatively a little information on the organic phosphorus compounds in soils. However, three main groups of organic phosphorus compounds found in plants are also present in soils. These are inositol phosphates (phosphate esters of a sugar like compound, inositol), nucleic acids and phospholipids.
Soil organisms and phosphorus

Soil, serving as a medium for crop growth, is more than a three-phase system, i.e., solid, liquid and gaseous. It has in addition, a “living phase”, consisting of soil bacteria and other organisms which must always be taken into account. The term “plant available soil phosphorus” is used to indicate the portion of soil phosphorus that can be used for crop growth.

Phosphorus in plants and microorganisms

It is quite probable that plants and microorganisms require the same major nutrient elements. Many plant nutrient elements are required for microbial growth. Unlike plants, microorganisms are heterotrophic. Many heterotrophic organisms can satisfy their dietary needs exclusively from inorganic sources if they have also a supply of carbon and energy source.

Transformations of organic phosphorus in soil are of significant importance in so far as they concern the supply of phosphorus to the crop. Some soil phosphorus is contained in soil microorganisms. A significant proportion of inorganic phosphorus may be “biologically fixed” by microorganisms when soil phosphorus levels are low. In some cases microorganisms compete with plants for phosphorus when soil phosphorus levels are low. Phosphorus is temporarily tied up in the organic components of microorganisms. However, the phosphorus is eventually returned to soil when the microorganisms die. After mineralization (conversion from organic to inorganic phosphorus), it may be used again by plants.
**Introduction**

**Solubilization of phosphorus by microorganisms**

Several soil bacteria, particularly those belonging to the genera *Bacillus* and *Pseudomonas*, and fungi belonging to the genera *Penicillium* and *Aspergillus* possess the ability to bring insoluble phosphates in soil into soluble forms by secreting organic acids such as formic, acetic, propionic, lactic, glycolic, fumaric and succinic acids. These acids lower the pH and bring about the dissolution of bound forms of phosphates. Some of the hydroxy acids may chelate with calcium and iron resulting in effective solubilization and utilization of phosphates (Gerretsen, 1948; Sen and Paul, 1957; Sperber, 1957; Louw and Webley, 1959; Katznelson and Bose, 1959; Subba Rao and Bajpai, 1965; Chhonkar and Subba Rao, 1967; Sethi and Subba Rao, 1968; Gaur and Ostwal, 1972; Ostwal and Bhide, 1972).

**Rhizosphere**

Rhizosphere is the zone surrounding the roots of plants in which complex relations exist among the plants, the soil microorganisms and the soil itself. It is the absorbing root soil interface. It is the zone about 1 mm in width surrounding the epidermis of living root hairs and the boundary cells of mycorrhizae. Rhizoplane is the boundary where soil elements in water are absorbed into the plant. A constantly changing mix of organisms inhabits the rhizosphere and surrounding soil. Bacteria, actinomycetes, fungi, protozoa, slime moulds, algae, small animals and soil viruses compete for water, food and space. Microorganisms compete in the rhizosphere, an area rich in exudates. The exudates contain carbohydrates, organic acids, vitamins and many other substances essential for the life.
Foxtail millet

Small millets, cultivated mainly by subsistence farmers as rain fed crops, play an important role in the diets of the people living in interior rural and tribal areas in the semi-arid tropics (Pushpamma, 1986). Small millets, also called minor millets borne on short and slender grass plants, are not unimportant as they have a wide adaptation. They can withstand a certain degree of soil acidity and alkalinity, stress due to moisture and temperature, and variations in soils from heavy to sandy infertile soils. Small millets are grown from the extreme southern tip of India at sea level to the temperate north Himalayan areas up to an altitude of 3,000 meters with consequent variation in photoperiod from short to long days (Sampath et al., 1986). Foxtail millet, a minor millet, is one of the ancient crops probably domesticated in eastern Asia and known to Chinese as early as 2700 B.C. Jars filled with husks of foxtail millet were found at Ban-po in Shanxi province dating from the Yang-sha period (Chang, 1973). It was also reported in early agricultural sites from Switzerland and Austria dating back some 2000 years and the species became widespread as a cereal crop in Europe during Bronze Age (de Wet, 1986). In India, it is mainly grown in Madhya Pradesh, Andhra Pradesh, Tamil Nadu, Karnataka, Orissa, Gujarat, Maharashtra and Uttar Pradesh. The genus *Setaria* belongs to the tribe Paniceae, sub-family Panicoidae and family Poaceae (Pohl, 1978).

Anantapur district of Andhra Pradesh receives a poor rain fall of 34.4 mm and a temperature of 31 ± 9°C resulting in frequent droughts. Under these conditions foxtail millet, one of the shortest duration crops (75 to 90 days) is cultivated as a minor millet mixed crop. The recommended varieties for the local area (Anantapur
Introduction

Districts of Anantapur (Andhra Pradesh) are Chitra, Lepakshi and Prasad and the recommended level of phosphorus fertilizer is 50 to 100 Kg $P_2O_5$ ha$^{-1}$. It is cultivated in 7,573 hectares during Kharif and Rabi seasons and is suitable for light black and red soils of Anantapur district. The irrigated hot weather Rabi crop is sown in January-February and Kharif season crop is sown in June-July. The vernacular names of foxtail millet are Korra (Telugu), Navane (Kannada), Tenai (Tamil), Tena (Malayalam) and Kangoone (Hindi). Foxtail millet is chosen for the present study because it is one of the staple food crops of this area which is nutritious (125 mg protein g$^{-1}$) and contains all the essential amino acids. Further, it not only resists drought conditions but also withstands delayed monsoon and hence widely cultivated in the local area. Worldwide there are 125 *Setaria* species (Pohl, 1978).

Despite some studies on phosphate solubilization, information on the phosphate-solubilizing bacteria (PSB) associated with the rhizosphere of foxtail millet is rather limited. Therefore, the present study is aimed at the following aspects of phosphate-solubilizing bacteria:

- Isolation of phosphate-solubilizing bacteria from the rhizosphere and non-rhizosphere samples of foxtail millet.

- Enumeration of phosphate-solubilizing bacteria in the rhizosphere and the non-rhizosphere samples.

- Purification of the isolates.

- Determination of the extent of solubilization of phosphorus by the different phosphate-solubilizing bacterial isolates.