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Potassium and Chloride in Crops and Soils: The Role of Potassium Chloride Fertilizer in Crop Nutrition

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PREFACE

This bulletin is a comprehensive compilation of information covering the scientific and applied aspects of the use of potassium chloride (muriate of potash, MOP) in agriculture.

Much of the data about potassium and chloride in soils and crops is independent of the source of either element and this is how the information is presented in the text. However, because both elements are added to soil when potassium chloride is used as a fertilizer, it is appropriate to emphasize potassium chloride in the title. Although the bulletin is primarily concerned with potassium chloride, because it accounts for some 92% of world potassium consumption in agriculture, it is nevertheless objective in its discussion of alternative sources of potassium fertilizers.

The vast majority of crops are fertilized with potassium chloride, including field, horticultural and plantation crops. Nevertheless, there are combinations of soil and climate where the use of the chloride salt can exacerbate the damaging effects of salinity. There are crops, like tobacco, where chloride is known to impair quality. There is an increasing amount of evidence that the use of potassium sulphate improves the quality of some crops. On the other hand, there are crops like coconut and oil palm, where chloride additions are an important part of nutrient management, as also for a wider range of crops in areas where atmospheric deposition does not supply sufficient chloride, for example, wheat in the Midwest of the USA.

There are instances, especially in intensive greenhouse production, in which it is more appropriate to use potassium nitrate and potassium sulphate rather than potassium chloride because of their lower salt index and lack of chloride. These comments imply that there are important considerations in deciding which potassium fertilizer to use. Many of these are discussed in this book.

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Introduction

Potassium (K) is the seventh most abundant element in the earth's crust. Liebig (1841) was the first to recognize that it is essential for plant growth. The potassium chemical industry dates from 1861, following the development of the extraction process to recover potassium chloride from potassium and sodium chloride salt deposits (Stewart, 1985).

Potassium chloride (KCl), known also as muriate of potash (MOP), is the most widely used source of potassium for agricultural crops. Throughout this book we will use the abbreviation 'KCl' and reserve the term 'potash' for K_2O as used frequently in statistics of fertilizer use. Only the cation K^+ in KCl is usually considered as one of the major plant nutrients; the accompanying anion Cl^- has been generally referred to as undesirable but unavoidable. However, Cl is now considered as an essential micronutrient for optimal growth (Fixen, 1993).

Both K and Cl are the main ions involved in the neutralization of charges, and as the most important inorganic osmotic active substances in plant cells and tissues (Clarkson and Hanson, 1980). The association of K and Cl in the opening and closing of stomata was proposed about 30 years ago, but was demonstrated quantitatively only in 1996 (Talbott and Zeiger, 1996).

The mechanisms for K and Cl uptake by plants have been topics of much research in plant physiology. The generaly accepted model of high and low affinity sites for K uptake was presented by Epstein in the early 1960s (Epstein *et al*., 1963) but this has been replaced recently by the demonstration of specific K channels in the various cell membranes (Anderson *et al*., 1992; Sentenac *et al*., 1992). The existence of Cl channels in plants has also been demonstrated (Lew, 1991; Lurin *et al*., 1996).

Potassium is required by plants in amounts (in kg unit) similar to or greater than nitrogen (N) (Daliparthy *et al*., 1994). Uptake of K by the plant is highly selective and closely coupled to metabolic activity (Marschner, 1995). At all levels in plants, within individual cells, tissues and in long-distance transport via the xylem and phloem, K exists as a free ion in solution or as an electrostatically bound cation. Potassium takes part in many essential processes: enzyme activation, protein synthesis, photosynthesis, phloem transport, osmoregulation, cation-anion balance, stomatal movement and light-driven nastic movements (Läuchli and Pflüger, 1978; Marschner, 1995).

Potassium has been described as the "quality element" for crop production (Usherwood, 1985). Potassium increases the protein content of plants, the starch content in grains and tubers, vitamin C and the solid solubles content in fruits, it improves fruit color and flavor, increases the size of fruits and tubers, it reduces the incidence of pests and diseases, enhances storage and shipping quality and extends shelf life. The crucial importance of K in quality formation stems from its role in promoting the production of photosynthates and their transport to storage organs like fruits, grains and tubers, and to enhance their conversion into starch, protein, vitamins, oil, etc. (Mengel and Kirkby, 1987). With a shortage of K many metabolic processes are affected, like the rate of photosynthesis and the rate of translocation and enzyme systems (Marschner, 1995; Mengel, 1997), while at the same time, the rate of dark respiration is increased. The result is a reduction in plant growth and quality.

Chloride is present in abundance almost everywhere in the world. The influence of the Cl on plant growth depends on the plant variety (Tottingham, 1919), while Lipman (1938) stressed its beneficial effect for buckwheat. Warburg (1949) claimed that chloride was an essential micronutrient for plant growth and showed that it was required for the water-splitting system at the oxidizing site of Photosystem II. That Cl is essential micronutrient in plant nutrition was not recognized until 1954 (Broyer *et al*., 1954). Chloride deficiency was first demonstrated in sugar beet (Ulrich and Ohki, 1956), and afterwards in eight other plant species (Johnson *et al*., 1957). Field responses by cereals to the addition of Cl were first reported in the 1980s (Christensen *et al*., 1981; Fixen *et al*., 1986a, b).

The amount of chloride found in plants varies with habitat because both the external chloride concentration and the balance of other available anions influences the content. The optimal concentration range in most crops is between 0.3 to 1 g Cl kg^{-1} dry matter (DM) (Marschner, 1995).

Chloride has a role in a number of biochemical functions in plants (Fixen, 1993). It operates as a counter ion for cation transport and as an osmoticum (Flowers, 1988). Chloride also plays a role in the regulation of stomatal movement (Talbott and Zeiger, 1996). The function of Cl in yield formation (Fixen, 1993) has been largely neglected, because it is not usually a limiting factor for plant growth. Chloride deficiency mainly occurs in areas far from the sea where airborne Cl is very small, and in areas where rainfall produces drainage which leaches out the Cl.

Negative effects of high Cl concentrations in the soil and irrigation water on crop production are observed in coastal, arid and semi-arid areas, where freshwater sources are often scarce and the available groundwater is saline. The dependence of modern agriculture on irrigation and chemical fertilization has served to emphasize the problem of Cl accumulation in soils and its adverse effect on plants rather than on problems arising from its deficiency. There are great differences in tolerance to chloride salts among crops and plants of the same species.

This book integrates and updates the information about K and Cl in both soil and plant systems, and their roles as essential plant nutrients. Potassium and Cl behaviour in soil, and their effects on plant physiology and metabolism at the cell and the whole plant levels are discussed. This basic information provides the background for the following chapters, which cover K and Cl effects on plant growth and development, disease suppression, and marketable yield and quality. Both positive and negative effects of Cl on crops are discussed, and mechanisms of tolerance to Cl are presented. Special attention is given to the role of K and NO_3 in increasing plant tolerance to Cl salinity and in reducing the hazard of using saline water.

Practical information on the agronomic management of KCl is presented subsequently, covering KCl application methods, with emphasis on modern fertigation techniques. Management practices for Cl salts in the root zone of irrigated agricultural soil are reviewed. Finally, environmental aspects of KCl, both in production and field application, are presented in detail.

We attempt to provide information on current and future use trend of KCl fertilizer and emphasize here its leading position as a fertilizer in future agricultural development, as well as suggestions for further studies on the roles of K and Cl in crop management.

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