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Spraying Technology and Foliar Application Result in a Smooth Layer of the Spray: a Literature Review

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Abstract: Using of foliar fertilizer application is an important issue in many crops plantation in different countries. Various studies have been conducted on this method, especially with fruits and horticulture. Few studies were performed on essential crops such as maize compared to the orchards. Concerning crops, most of these studies were performed using foliar spraying with phosphorus, and potassium, and a few attempts were carried out with foliar fertilizer during the season at different concentrations starting from the first stage of the plant. The foliar application may be sprayed with a suitable concentrate depending on the type of crop planted, growth stage, leaves age, and physicochemical properties of the sprayed liquid. As reported in the current literature, there are previous studies on this application with insufficient knowledge of mechanisms and factors governing the nutrient uptake by leaves that still need to be improved. The insufficient information about the effect of foliar fertilizer at different application rates is one of the reasons that the study focused on it, which was probably the leading cause of sometimes controversial effects with foliar fertilizers being reported. Most previous studies revealed that is necessary to apply foliar fertilizer on the plant leaves at a proper concentration and application rate compatible with the age of the crop applied. The results also indicated that a suitable concentration of foliar fertilizer no doubt leads to improved fertilizer effectiveness and can even increase plant growth activity, especially when spraying with modern technology. For an optimum both of the crop vegetative growth and yield response to foliar fertilization, it is possible to diagnose the optimum growth stage of the plant and leaf age for the starting of foliar fertilizer application related to metrological conditions such as the air temperature, and relative humidity at the time of spraying. It is necessary to recommend the crop growth stage before foliar application at a known application rate and concentration to a crop to achieve maximum efficiency at low cost as possible.

Keywords: Application method, Foliar spraying, Spray droplets characteristics, Sprayer setup.

Introduction

Application fertilizer is a widely used for a long time in the agriculture process for planting crops to maintain the availability of soil fertility and to increase both the vegetative growth indicators and crop production (Hasnain *et al.*, 2020; Krasilnikov *et al.*, 2022). There are two types of fertilizers commonly used in the fields as chemical or organic types, which they applied to the soil or leaves directly using a suitable method in the application process to supply essential nutrients to the plant intended at different stages of growth. Adding these fertilizer types with practical application has a significant impact on the crop yield (Alheidary *et al.*, 2020; Mulyati *et al.*, 2021; Wierzbowska *et al.*, 2022).

For this reason, applying fertilizer in the agricultural field is considered an important element for improving crop yield thereby increasing the food production in the world with the increase in the population in growth (Falls & Siegel, 2005). Varieties chemical fertilizers are used as N, P, and K (Finch *et al.*, 2014). The traditional ways to add these fertilizers in many farms are applied using soil fertilization in two or three steps depending on the crop planted and the purpose of planting (Barłóg *et al.*, 2022a). The soil fertilization method is commonly used for long times to supply mineral nutrients via the roots but with a small efficient way to increase both the growth and the yield of crops (Gebrehiwot, 2022).

Availability of fertilizers in the soil varied related to several factors such as soil type, moisture content, temperature, and nutrient movement to the roots (Fageria & Baligar, 2005). As fertilizer is applied to soil for the crop, a large amount of fertilizer drains away from the plant roots with water (Morari *et al.*, 2011). Arunrat *et al.* (2020) compared the sandy soils with little to no clay or organic matter, soils with a finer texture (more clay) and higher levels of organic matter (5–10%) are better at retaining nutrients. Because the water takes nutrients such as nitrogen, potassium, or sulfur below the root zone, the plants can no longer access them.

Many researchers and applicators are looking at techniques to reduce spending in adding fertilizer methods without effect on producing satisfactory maize growth and yields (Laskari *et al.*, 2022). The soil fertilization is used in nitrogen fertilization, which may be reduced by adding foliar biologically active fertilizers (Fageria *et al.*, 2009). Additionally, unfavorable soil and climate conditions reduce the availability of these nutrients to plant roots, and adding micronutrients to soil proved less beneficial. (Elbasiouny *et al.*, 2022). The micronutrient content of the soil has been steadily declining as a result of intensive farming and the use of high-yield cultivars (Kopittke *et al.*, 2019; Adeoluwa *et al.*, 2022). Using soil fertilizer is a costly input and less effective to plant benefit (Morari *et al.*, 2011). Various attempts performed on crop plantations, especially maize crops using modern ways for improving crop production that required foliar fertilizers on the leaves to be combined with the application of soil fertilization depending on the crop characteristics (Shang *et al.*, 2019; Grzebisz *et al.*, 2022; Izydorczyk *et al.*, 2022).

Foliar application is a highly used technique to remedy nutrient deficiencies in plants and overcome the soil's inability to transfer nutrients to the plant under unfavorable conditions like soil structure, low moisture content, high temperatures, and caused by the inappropriate supply of nutrients to the plant roots (Ferrari *et al.*, 2021). Maize is sensitive to micronutrient deficiency, especially manganese, and zinc (Saboor *et al.*, 2021). High nitrogen rates typically increase crop susceptibility to pests and diseases (Veresoglou *et al.*, 2013). To augment the economic impact of mineral fertilization and decrease the danger of environmental damage by reducing nutrient rates, foliar fertilizers can be applied alone or in conjunction with pesticides (Morari *et al*., 2011).

The main objective of this review is to outline the growing interest in maize foliar fertilization as a method for application. Away from analyzing data from the previous studies and the mechanisms of absorption of nutrients through the leaves of the crop, it is important to determine the advantage and disadvantages of foliar fertilization applied to crop leaves.

Theoretical background of the fertilization absorption into the plant

Different studies were performed by researchers on foliar fertilization using chemical products of fertilizers (Alheidary *et al*., 2020; Kentelky & Szekely-Varga, 2021; Rodolfi *et al*., 2021).Nitrogen fertilizer, for example, is considered one of the main products that can be supplied to plants in different forms through the soil, foliage, or together (Bhattacharya, 2019). Nitrogen element is also considered one of the main food components that crops need it in most cases, especially in large amounts than other nutrients (Jain & Abrol, 2017). Plant roots' main forms of nitrogen uptake include inorganic compounds as nitrate or aluminum (Myrold, 2021, Fig. 1). The amount of nitrogen needed by some common crops varies by crop type, growth period, soil type, etc. (Wilfret, 1992). The soil organic matter can store large quantities of nitrogen, often upon 1.12 kg.ha^{-1}. However, the amount of nitrogen released from the soil to be ready for the plant to absorb it is insufficient for the same time as the plant needs. The rocks and minerals are often considered relatively low in nitrogen percent (Ladha *et al*., 2020).

Organic matter has a very slow-moving, minute amount of nitrogen released by a method controlled by soil microorganisms, which are in turn influenced by soil temperature, humidity, pH level, and soil structure (Zhang *et al*., 2019). While using foliar fertilizer, it is crucial to emphasize the plant's nitrogen absorption process. (Ferrari *et al*., 2021, Fig. 2). The physiological function of plant and foliar fertilization are closely connected. When researchers quickly scanned the data from the previous studies that were published in scholarly publications, they found that these studies had made references to absorbing leaf surface, penetration, cuticle, stomata, uptake, and permeability to learn more details about the foliar fertilizer during their application (Fernández & Eichert, 2009).

Salehi *et al*. (2020) mentioned that is important to know about the effect of plant morphology and the absorption of nutrients especially leaf surfaces and nutrient absorption as (Table 1). The plant surfaces are permeable to nutrients from the stomata on the leaf during the application of foliar fertilizer (Fernández & Brown, 2013). The type of fertilizer solution, the spray liquid's physicochemical characteristics, and the liquid concentration all affect how much nutrient is absorbed by the leaves (Xie *et al*., 2020).

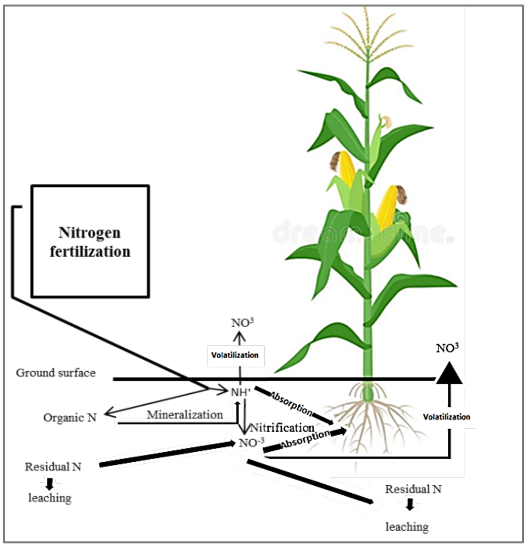

Fig. (1): Mechanism of the soil fertilization.

Several investigations have been conducted on the nitrogen absorption process in plants using foliar fertilizer and factors affecting the effectiveness of uptake and use (Barłóg *et al*., 2022).

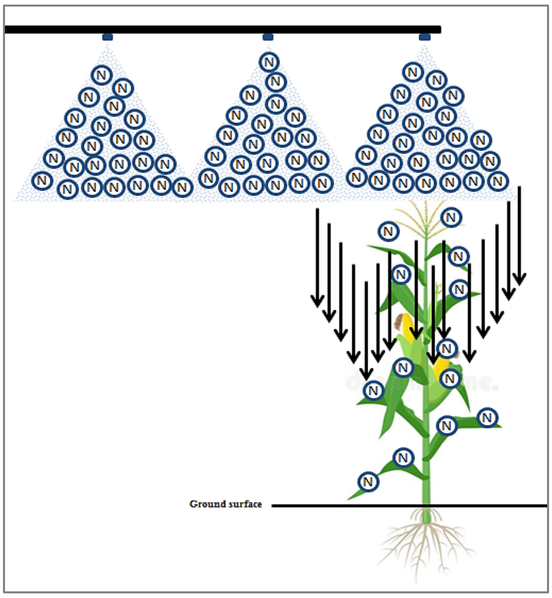

Fig. (2): Spraying application on the plant canopy.

Programing of foliar application for crop

When considering production potential and plant vegetative growth stages, the programming of the foliar spraying method is thought to be one of the most crucial factors. The plant's leaf features may directly reflect the optimal application volume. As a result, the smallest application volume that is administered to the plant canopy by the required dosage may produce meaningful outcomes, particularly when utilized at the right time and by choosing the most appropriate nozzle type and size under ideal operating conditions (Al-Maliky *et al*., 2019; Ferrari *et al*., 2021). When foliar treatment is performed by the Diagnostic and Recommendation Integrated System (DRIS), it is the greatest way to minimize losses and time while receiving the highest benefit from this application (Parent *et al*., 2020). Maximizing the absorption of nutrients in tissue leaves depends on good tissue crop quality. Finally, to enhance vegetative growth and productivity, components are transferred by foliar fertilizer to other sections (Oliveira *et al*., 2022). Good plant properties may be a factor in the optimal spray deposition of the liquid solution. Conversely, foliar treatment on the surface of plant leaves and tissue impact on meteorological variables such as wind speed and turbulence, air temperature, and relative humidity (Failla & Romano, 2020; Jiang *et al*., 2023). According to the application timing, these conditions have refuted the association with foliar application. The preferred application timing and weather, as stated in table (2), are corresponded to the critical moments for successful foliar application.

Table (2): Summarize meteorological conditions favoring foliar applications.

Parameter		Values
Application time		6:00 p.m- 9:00 a.m
Weather conditions	Wind speed ($m.s^{-1}$)	<5mph
	Air temperature (°C)	140-160
	Relative humidity	>70%

Foliar treatment is typically the method that crops will respond to nutritionally. Improve tissue quality (enabling optimal nutrition absorption into the stem and leaves) and improved growth life are the reasons for this strategy (allowing for translatable nutrients to be rapidly moved to the rest of the plant (Ferrari *et al.*, 2021; Görlach & Mühling, 2021). Due to lower rates of leaf and stem absorption, crops that are stressed by air temperature or moisture respond to foliar treatments less effectively (Fahad *et al*., 2017). Nonetheless, foliar spraying improves crop performance and production if applied before the temperature or moisture stress (Venugopalan *et al*., 2022). With the right foliar treatments, recovery from cold growing conditions and meteorological stress can be accelerated. In areas where nitrogen solutions were administered topically, corn with light to severe hail damage has been demonstrated to recover well (Soussi *et al*., 2022). However, due to the practical limitations on the amount of nutrients that may be applied topically to produce a good growth response, foliar spraying only has a limited ability to save most situations; (Dass *et al*., 2022; Ishfaq *et al*., 2022). Environmental factors, such as the time of day, temperature, humidity, and wind speed impact foliar spray' biological and physical features (Alshaal & El-Ramady, 2017). Several factors, including temperature, humidity, and calmness, influence the ability of plant tissue to absorb nutrient. Late at night and occasionally early in the morning is when these situations are most common (Ciampitti & Vyn, 2011; Farooq *et al*., 2015). In addition, the foliar application is related to crop conditions in the vegetative growth stage. As an example, table (3) illustrate maize foliar application of the programming of foliar sprays at different growths.

Table (3): Programing of the foliar application at different plant stages.

Spray No.	Growth stage	Recommended nutrients										
		N	P_2O_6	K_2O	Ca	Mg	S	Zn	Mn	Fe	Cu	B
		Suggested application rate (pounds.acre^{-1})*										
1	Cold and wet conditions (3-4) leaf stage	0.62 to 0.75	1.25 to 2.25	0.62 to 0.75	0.30 to 0.40	0.05 to 0.125	0.12 to 0.25	0.25 to 0.5	0.08 to 0.5	0.25 to 0.5	0.09 to 0.17	0.25 to 0.1
1	Normal conditions 6-8 leaf	0.62 to 0.75	1.25 to 2.25	0.62 to 0.75	0.30 to 0.40	0.05 to 0.125	0.12 to 0.25	0.25 to 0.5	0.08 to 0.5	0.25 to 0.5	0.09 to 0.17	0.25 to 0.1
2	7-10 days after spray No. 1	0.62 to 0.75	1.25 to 2.25	0.62 to 0.75	0.30 to 0.40	0.05 to 0.125	0.12 to 0.25	0.25 to 0.5	0.08 to 0.5	0.25 to 0.5	0.09 to 0.17	0.25 to 0.1
3	Early silk	4.0 to 5.0	2.0 to 2.5	2.0 to 2.5	5.0 to 1.0	5.0 to 1.0	5.0 to 1.0	0.17 to 0.35	0.25 to 0.5	0.5 to 1.0	0.17 to 0.35	0.1 to 0.2
4-5	7-10 days after apart	4.0 to 5.0	2.0 to 2.5	2.0 to 2.5	5.0 to 1.0	5.0 to 1.0	5.0 to 1.0	0.17 to 0.35	0.25 to 0.5	0.5 to 1.0	0.17 to 0.35	0.1 to 0.2

- 1pound.acre-1= 1.121 kg.ha^{-1}

From the values above (Fig. 3), to apply the foliar application at different stages, it is crucial to take into account the following points:

1-Determine the crop stage where the amount of foliar application can vary based on the crop growth stage.

2-Choose the appropriate foliar spray product. Different foliar applications are formulated to meet specific crop nutrient needs. Choose a product that is specifically designed for the crop's vegetative growth.

3-Calculate the appropriate spray application rate. The application rate will depend on the product type for using it at the different growth stages of the crop planted.

4-Spray solution preparation. Mix the foliar spray product with water according to the label instructions.

5-Apply foliar spray. Use a calibrated sprayer to apply the foliar spray to the leaves of the crop.

6-Monitor the final results. Observe the vegetative growth and yield after foliar application to see if there are any signs of improvement.

Plant response to the nitrogen fertilizer

The most typical fertilizer addition for newly planted crops, along with other essential nutrients, is nitrogen. Table (4) illustrates how adding nitrogen fertilizer and more number of maize plants can raise the amount of maize produced and increase the rate at which nitrogen is absorbed, together with other best management techniques (Asibi *et al.*, 2019).

Also, it is more environmentally safe and generates higher economic profits. This idea is valid as long as the crop responds to the addition of compost, as is demonstrated in table (5) since crops react quickly to nitrogen additions, and nitrogen addition has mostly stayed the same with changes in crop or compost prices.

Table (4): How nitrogen amount and maize plant numbers and their interaction on crop production and improving nitrogen absorption.

Plants number.ha^{-1}	Grain yield (ton.ha^{-1}) at different rates of N (kg.ha^{-1})	Plant response to the highest N rate (ton.ha^{-1})
	0	
54375	6.28	1.69
79090	7.97 (31)*	2.64
103806	8.10 (21)*	3.20
Response of the highest number of plants (ton.ha^{-1})	1.82	

*Efficiency of the nitrogen absorption

Table (5): A slight change in the optimal rate of nitrogen adding with the crop and fertilizer prices changing (Ciampitti & Vyn, 2011).

Maize crop price (dollar.kg^{-1})	Nitrogen fertilizer price (sent.ha^{-1})			
	44	88	132	176
	Optimal nitrogen fertilizer rate in maize (kg.ha^{-1})			
0.109	181.4	171.4	162.4	152.3
0.153	183.7	177	169.1	162.4
0.197	184.8	179.2	173.6	168

The management of the proper nitrogen application in fields is based on several factors, such as choosing the right fertilizer source at the right time of application, the right amount in the right place, and so on. This maximizes crop production and returns income while minimizing the potential risks of adverse environmental impacts (Ciampitti & Vyn, 2011; Asibi *et al*., 2019).

Principle of leaves penetration

The leaf crop penetration utilizing foliar fertilization as a complement to soil fertilizer was the subject of various laboratory and field experiments and studies (Ebel, 2020; Görlach *et al*., 2021a; Barłóg *et al*., 2022). This research's uncertainty led to conflicting plant responses and overall uncertainty in estimating the efficacy of foliar sprays (Wang *et al*., 2020). Due to the difficulties faced by those who practice foliar fertilization and researchers trying to understand the variables that affect foliar fertilizer effectiveness, efforts to fully comprehend this phenomenon continues today (Eibner, 1986). Foliar fertilization mechanisms such as foliar adsorption, cuticle penetration, uptake, and absorption into the metabolically active cellular compartments of the leaf are involved in supplying a nutrient solution to the leaf surfaces that are mostly absorbed by the crop (Asibi *et al*., 2019). Once the nutrients have been able to translocate and do so, the plant can then use the absorbed nutrient. While the term "foliar uptake" is sometimes used to refer to a rise in the tissues nutrient content without precisely measuring the proportional biological benefit of the application to the plant as a whole, it can be difficult to distinguish between these processes despite extensive trials (Sun *et al*., 2021). The ambiguity and imprecision make interpreting both controlled environments significantly more difficult. The spraying application on the plant's surface is described by the complex and varied array of specialized chemical and physical modifications that serve to consolidate plant vulnerability to a long list of factors, including unwelcome irradiation, temperatures, vapor pressure deficits, wind, herbivory, physical damage, dust, rain, pollutants, and anthropogenic chemicals (Tudi *et al*., 2021). In order to prevent the loss of nutrients, metabolites, and water from the plant to the environment under unfavorable conditions, external plant surfaces and structures are also adequately acclimatized. In addition to providing the mechanisms regulating foliar nutrient uptake, these properties of plant surfaces enable them to protect the plant from environmental stress and to adapt to water, gas, and nutrient replacement (Vega *et al*., 2023). Knowledge of the physicochemical characteristics of the spray liquid that attributes to plant surfaces and the processes of penetration into the plant parts is necessary to improve in the effectiveness of foliar fertilization (Kentelky & Szekely-Varga, 2021).

The concept of foliar application and the plant's ability to benefit from it depends several of variables, including application volume, the physical and chemical characteristics of the spray liquid used, liquid concentration, molecular weight, droplet size, leaf surface characteristics, charge liquid density across the cuticles of leaves, and the weather at the time of application (REFs) (Asibi *et al*., 2019). Any liquid sprayed by agricultural sprayers often entered plant tissue by the ectodesmeta. This ectodesmeta has a diameter of almost 1 nm and a total density of 1010 pores. cm^{-1}. Moreover, the density of this ectodesmeta is increased inward due to the presence of a negative charge, allowing the activities to flow more easily. Because of water deficit stress, the cuticle surface of the leaf might occasionally change. As a result, cuticles were thickened up to 33 centimeters (Chen *et al*., 2020). An abnormal fear of water is mainly caused by a change in the cuticle's composition, which is typically caused by a wax leaf's surface's long chain of molecules (hydrophobicity). This occurrence caused the plant's ability to absorb agrochemical liquids (such as nitrogen) to decline, which had an impact on the plant's output and vegetative growth.

Applying foliar application to supply leaf-containing with nitrogen

In general, nitrogen fertilizer, which impacts on vegetative growth, is most frequently employed in maize fields and other crops to provide plant nutrients (Asibi *et al.*, 2019). Nitrogen deficit has an impact on how carbohydrates and sugar are processed. Consequently, a decrease in nitrogen availability may result in low nitrogen levels in the leaves, which would diminish plant height and flower production, ultimately impacting (Maia *et al.*, 2020). Foliar nitrogen administration during plant growth is a popular technique for providing crops with the nutrients to increase both growth and yield quality. Many applications of nitrogen fertilizer combine foliar and soil treatments. In certain fields, additional nitrogen fertilization is applied to the soil and foliar applications to meet the plants' need for these vital nutrients (Hu *et al.*, 2023). The over-dosage of nitrogen to plants can lead to several issues with soil and plant physiology. Currently, not all farmers and field workers are using the best management to apply the optimum dosage of nitrogen as a foliar application at the best time to gain the most advantage of employed nitrogen. Depending on the timing, concentration, and quantity of droplets sprayed on the leaves, improper nitrogen treatment in the fields may result in crop leaf damage or death (Fageria *et al.*, 2009).

Mechanism of foliar fertilizer uptake through the plant leaf

The addition of fertilizers containing nutrients necessary for the plant in proportion to the growth stage is known as foliar fertilization, a popular practice today. Foliar fertilization, as is well knowledge, involves applying fertilizer by a spraying method above the component that needs to be treated (a leaf), with the fertilizer arriving on the leaves as droplets and coming into intended contact with the leaf (Fageria *et al.*, 2009). The fertilizer must first penetrate the leaf before accessing the cytoplasm of the cell within the leaf since it contains the nitrogen nutrient. Thus, depending on the spray liquid's physicochemical characteristics, the nutrient penetrates the outer leaf cuticle layer (Mosa *et al.*, 2022). The cuticle layer of the leaf is thought to exhibit the highest opposition as one of the primary components of the foliar fertilizer passage that is treated with plant nutrients. The environment in which each of these plant parts occurs is the primary difference between their nutrient absorption after it has occurred after spraying. The absorption of nutrients by leaves and roots is likely not much different (Adamec, 2002). There are two routes by which nutrients might enter the leaf when applied as foliar fertilizer. The first channel passes through the leaf's stomata layer, whereas the second does so via the exterior layer of the cuticle. The cuticle leaf accepts the greatest nutrients for absorption. The solutes may enter the leaf indirectly through the stomata as well. Yet, there is considerable disagreement regarding the significance of foliar fertilizer uptake by stomata. Since it was demonstrated that the water droplet could not enter the stomata of leaves of higher plants due to properties of the solution, such as the surface tension of the solution (water), the hydrophobicity of leaf surfaces, as well as the dimensions of the stomata, precluded the water droplet from entering the stomata of leaves of higher plants. Also, when the stomata are closed at night compared to open during the day, the ion uptake rate of foliar fertilizer sprays is often higher. In recent years, additional evidence supporting the uptake of significant anions through stomata has emerged, suggesting that these pores may explain how a small amount of the nutrient may enter the leaf (Corriveau *et al*., 2012; Görlach *et al*., 2021b). It is assumed that all liquid water and dissolved absorption chemicals only proceed through the leaf cuticle in the absence of surfactants. Agrochemical sprays often contain surfactants that provide surface tensions of around 30mN.m^{-1}, frequently insufficient to penetrate (Aveyard, 2019). However, adding surfactants to the liquid before spraying it can lower the aqueous surface tension to around 20 nN.m^{-1}, before spraying it, allowing nutrients to enter the plant through the stomata. Also, after spray application, the particular droplet deposits on the leaf surface, and the penetration from the stomata layer is accomplished.

Factors affecting on the foliar fertilization

When fertilizers are sprayed on the desired plant, one key indicator of efficacy is how well the plant absorbs the nutrients. The treated leaves absorb these nutrients and go throughout the plant sections. As illustrated in fig. (3), several parameters have an impact on how much plant absorption in from the leaves. Also, interactions between these parameters with soil and ambient circumstances during foliar application cause a significant deal of variability in foliar nutrient uptake, which in turn accounts for the varying response of foliar sprays in various plant sections.

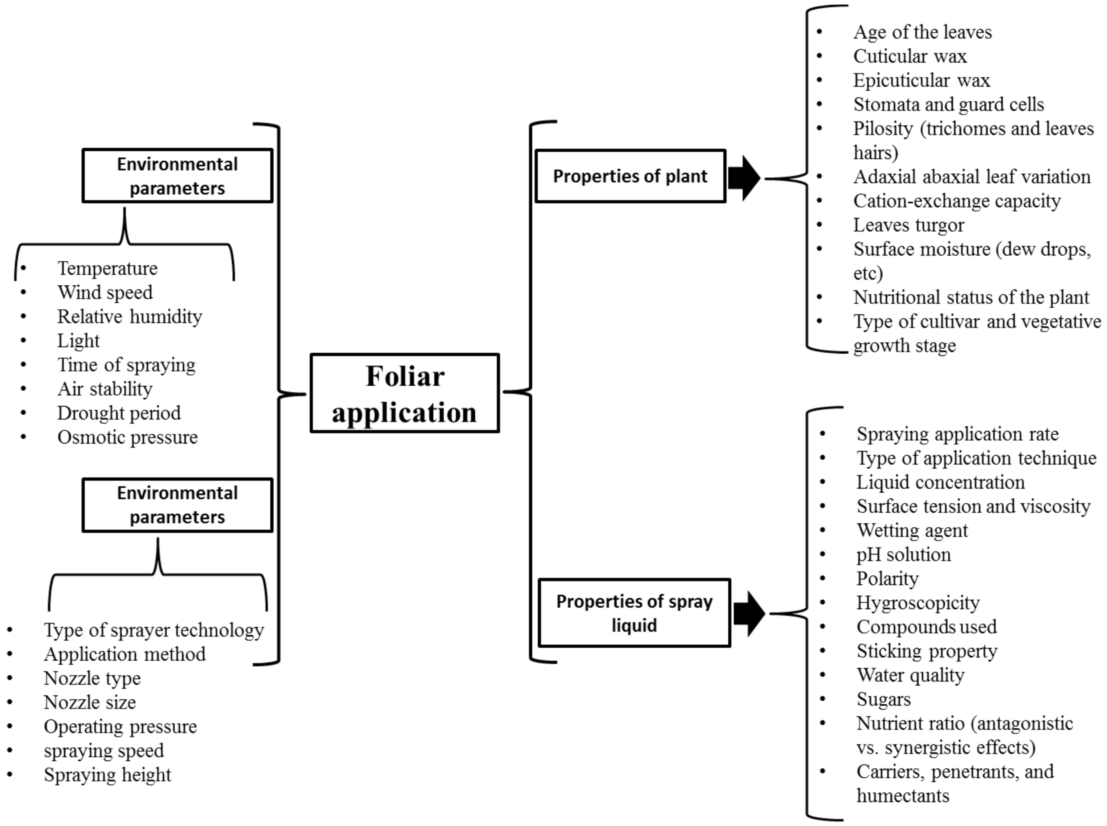

Fig. (3): Factors affecting the efficiency of foliar application.

As shown in fig. (4), which illustrates numerous parameters connected to the foliar application and their interaction with one another and how this ultimately influences the consequences of foliar spray on vegetative growth and yield, these elements are mentioned in four key categories. All of these variables, including those related to plant morphology such as leaf age and surface at the time of foliar application, powerful impact on translocation. In order to get the most out of foliar fertilization, it's important to choose the appropriate time to apply it when plant needs are at their peak and root uptake of nutrients is constrained. All of these elements depend on foresight. One of the primary causes of restriction in losses in foliar spraying during or immediately after spraying have impacted on the efficiency of foliar fertilization. The two main losses also include damage to the ground's surface, whether as a direct or indirect result, particularly when spray droplets of coarse sizes wash off from the leaf surface depending on the properties of the leaf surface. Spray drift is the term used to describe each spray droplet that is applied to the ground's surface and then transported away by air currents. The primary variables are an agricultural sprayer, nozzle properties, weather conditions, plant properties, spray liquid properties, spray deposition, and spray coverage.

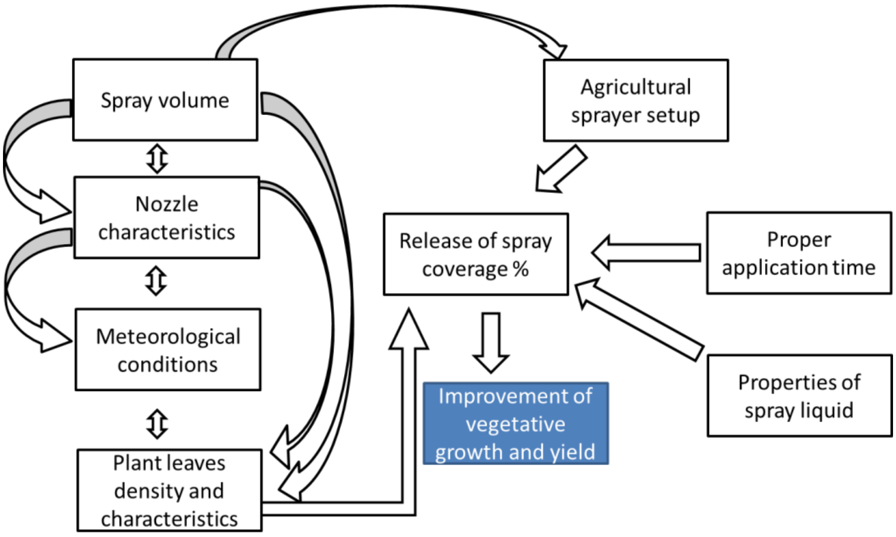

Fig. (4): Factors interaction between input and results for improving plant growth and yield.

Improving foliar application processing

In order to maximize the benefit to the plant during foliar treatment, several considerations must be made. The following variables affect how successful the foliar treatment is:

1. pH of the liquid

To ensure that nutrients can be absorbed into plant problems, it is crucial to evaluate the pH of the liquid containing the nutrients at the moment of spray application. The solubility of nutrients applied to plant leaves has the potential to change pH readings. Depending on the leaf's surface, the weather, and agricultural sprayer technology, choosing the appropriate pH value for the liquid solution can enhance nutrient penetration, uptake, and transmission into plants.

There are three ways that the plant's uptake of nutrients might influence pH value:

- cuticle charge (the waxy layer on the leaf's surface), followed by its ion selectivity.
- Ionic nutrient forms and how they impact liquid penetration rates.
- Depending on the liquid's composition, their impact on phytotoxicity.

2-Soil structure, root uptake, and foliar fertilizer

For the purpose of maximizing economic yield, essential plant nutrients are primarily administered to the soil and plant foliage. The soil application method is more popular and most efficient for fertilizers, which are needed in greater quantities dependent on soil structure (Barłóg *et al*., 2022). However, Foliar fertilization is more practical and cost-effective in some situations (Ferrari *et al*., 2021). Foliar symptoms, soil type, plant tissue, and crop growth responses are the primary diagnostic criteria for nutritional problems. Fertilizer treatments are often based on soil structure, whereas foliar nutrient applications are typically based on observable foliar symptoms or plant tissue tests. Thus, accurate detection of the nutrient deficit is essential for adequate foliar spraying. Foliar fertilization requires a higher leaf area index to absorb the nutrient solution in appropriate proportions; depending on the severity of the nutrient deficit, it can be essential to have more than one treatment (Ferrari *et al*., 2021). Nutrient concentration, daylight temperature, and water solubility of the fertilizer sources are ideal for preventing leaf burning. In addition to fertilizing the soil, crops may also receive foliar fertilization. By combining foliar fertilizer with postemergence insecticides, fungicides, or herbicides, it may be possible to improve yield response while spending less on application (Ferrari *et al*., 2021).

3-Application time and meteorological conditions

It is crucial to understand the treatment parameters, notably the time of foliar application, which is challenging to control fully, To assess the effectiveness of foliar spraying in the field. In order to maximize the effectiveness of foliar spraying application, the timing of foliar spraying can be crucial, especially in connection to plant growth and stage (Görlach, *et al*., 2021). This is because the seasonal pattern of nutrient intake varies depending on growth rate and stage but often follows a sigmoidal pattern with abrupt increases happening. Emerging crops have a high need for nutrients, particularly N, P, and K, and the soil does not always fully meet this demand, especially when unfavorable conditions predominate and when root growth is slow (Sharma *et al*., 2022).

According to Fick's law, the greater of solute concentration that can be applied to a leaf surface without damaging it and the longer it stays in an active state, or as a solution, on the leaf surface, the more probable rate and amount of penetration will occur (Li *et al*., 2021). The fundamental reason why a nutrient diffuses is due to a gradient in concentration between the open space in the cell wall and the cytoplasm inside the cell and the external leaf surface. There is a clear gradienFrom low to high charge density from the hydrophobic external surface to the hydrophilic inside cell As a result, along this gradient, ion penetration across the cuticle is preferred, which is crucial for both foliar spray uptakes and losses.

Amount of soil fertilizer vs. foliar application rate

It is widely recognized that fertilization is essential for enhancing output and vegetative development. Each researcher is aware that supplemental inorganic soil fertilization will increase productivity by 50% while only adding 10% to overall production costs (Alzamel *et al*., 2022). However, the locally required fertilizer is frequently challenging to find, and occasionally even does not exist, making it impossible to import for financial reasons. Also, even if it is true that in some locations fertilization, second only to water, is the most potent development element, people nevertheless need to be aware of the frequent and serious issues that arise specifically from fertilizer use, and not just in developing nations (Bijay-Singh & Craswell, 2021). One form of fertilizer that is frequently used in agricultural cultivation is soil fertilizer. The essential requirement for supplying plants with a suitable amount of minerals at various growth stages is always taken into consideration while fertilizing the soil. The primary organ for receiving nutrients and water from the soil in plants is thus their roots (Schjoerring *et al*., 2019). Because of the biological, chemical, and physical characteristics of the soil, which might reduce the availability of nutrients for cultivated plants, soil fertilization with any fertilizer, including both organic and inorganic forms, can occasionally be relatively ineffective (Shaji *et al*., 2021). Foliar fertilization is the only method that can address some of the problems that are caused by soil fertilization (Kentelky & Szekely-Varga, 2021). While nitrogen or another element also makes their non-traditional fertilizer applications, the improper application of soil fertilization also increase in the price of commercial fertilizers. Contrarily, applying foliar fertilization to plant leaves at various growth phases, particularly when the plant needs of nutrients, is a more appealing and cost-effective method (Ferrari *et al*., 2021; Liu *et al*., 2021). Furthermore, the foliar fertilization is frequently utilized to enhance disease resistance for better crop quality and promptly regulate nutritional status, development, and deficits (Hemida *et al*., 2023).

It is possible to use foliar application techniques to enhance the chlorophyll content in the crop as maize (Fig. 5), which can increase biomass production. However, the effectiveness of this technique may depend on several factors, including the behavior of droplets on the leaves. The droplet behavior on the leaves can influence the uptake and absorption of foliar application. The droplet size, surface tension, and viscosity of the spray solution can all affect how well the solution is retained on the leaves and how effectively absorbed. Therefore, it is essential to consider the droplet behavior when applying foliar sprays to maize crops to ensure optimal uptake and absorption of the solution and maximum enhancement of chlorophyll content and biomass production.

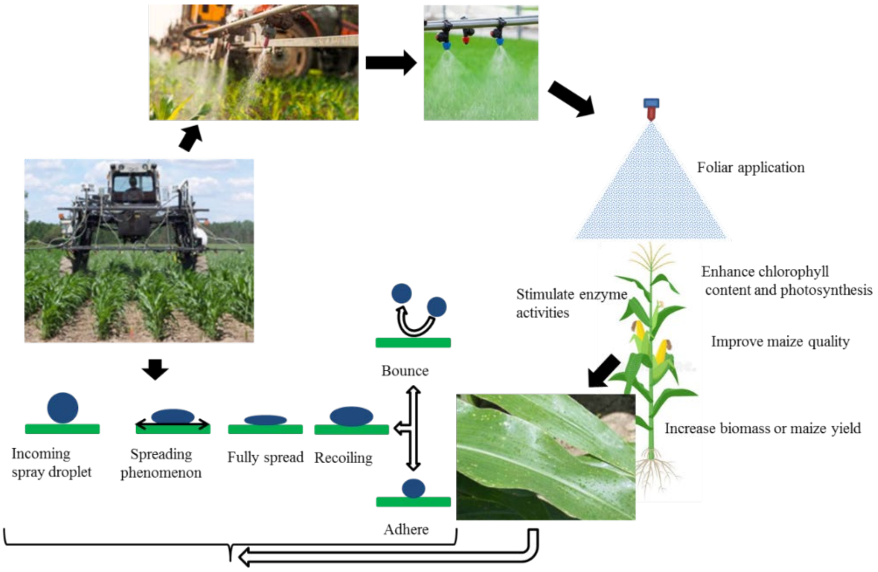

Fig. (5): General scheme for foliar application.

Table (6): Maize crop and responsiveness to foliar micronutrient application and their impact on crop leaf nutrient content and yield (Stewart *et al.*, 2020)

	Yield			**Plant tissue concentration**											
Site	**Trt**	**control**	**statistic**	**N**	**Control N**	**statistic**	**P**	**Control P**	**statistic**	**K**	**Control K**	**statistic**	**S**	**Control S**	**statistic**
	Mgha^{-1}		**P>F**	**gkg^{-1}**		**P>F**	**gkg^{-1}**		**P>F**	**gkg^{-1}**		**P>F**	**gkg^{-1}**		**P>F**
1	16.19^{++}	15.44^{++}	0.06	31.0	40.4	0.27$$	3.0	2.8	0.12	22.8	22.8	1.00	1.8	1.8	0.59$
2	15.75	15.13	0.40	31.2	30.3	0.61$$	3.1^{+}	2.9^{+}	0.07	24.7	25.3	0.67	2.0	2.1	0.21$
3	14.62	14.06	0.56	31.0	29.1	0.22$$	2.9	2.7	0.27	22.6	23.6	0.21	1.7	1.7	0.68$
4	15.57	15.69	0.87	35.1	34.8	0.81	3.7+	3.6^{+}	0.09	20.5	21.0	0.43	1.9	1.9	0.73$
5	15.94	16.38	0.42	32.5	33.7	0.46	4.3*	4.6*	0.03	19.3	20.7	0.19	2.3	2.1	0.19
6	15.25	15.19	0.20	28.2	30.2	0.41	3.7^{+}	4.4^{+}	0.08	22.4	21.9	0.30	2.7	2.6	0.13$
7	15.44	15.44	0.98	32.5	34.2	0.13	3.6	3.6	0.92	24.6	23.1	0.30	2.5	2.5	0.35
8	12.74	12.80	0.72	28.6	27.3	0.17	3.4	3.4	0.94	25.3	25.8	0.60	1.6	1.7	0.32$
9	16.19	16.19	0.69	33.7	33.4	0.28	2.9	2.7	0.50$$	22.1	22.7	0.54	1.9	1.9	0.64
10	14.62+	15.19^{+}	0.06	28.5	28.4	0.23$$	2.8	2.8	1.00	29.4	29.3	0.92	2.2***	2.3***	0.001$
11	15.13	15.06	0.69	29.7	29.5	0.93$$	3.1	3.0	0.43	30.0	30.0	0.89	2.3	2.3	0.81$
12	15.69	15.63	0.52	24.5	24.9	0.58	2.3	2.3	0.65	22.3	21.0	0.15	1.8	1.8	0.71$
13	15.38***	15.57***	0.001	25.9	26.1	0.71	2.6	2.7	0.43	22.3	22.7	0.28	1.9	1.9	0.62$
14	13.37**	12.68**	0.01	20.0	22.0	0.48	2.3	2.6	0.13	19	21.0	0.54	1.6	1.6	0.52$
15	13.62	13.37	0.62	22.5	22.7	0.67	3.1	3.0	0.59	20.7	20.9	0.73	1.9	1.8	0.33$
16	12.49	12.68	0.71	26.3*	23.5*	0.05	3.2	3.1	0.83	15.9	14.7	0.13	2.1	1.8	0.33$
17	11.42	11.80	0.58	31.9	30.9	0.34	3.2	3.4	0.35	23.9	24.2	0.42	2.1	2.1	0.47$
18	13.06	12.68	0.36	31.2	30.4	0.25	3.7	3.7	0.83	25.8	26.2	0.83	1.9	1.9	0.79$
19	14.25	13.68	0.12	31.4	29.7	0.21$$	3.1^{+}	2.9^{+}	0.08	26.8	26.3	0.74	1.8	1.9	0.84$
20	12.30	11.99	0.49	34.5	32.7	0.27	3.9	3.6	0.17	30.5*	26.3*	0.04	2.3	2.2	0.44
21	13.18	13.06	0.59	33.1	31.1	0.25	4.0	3.9	0.62	32.3	33.3	0.70	2.3	2.2	0.14
22	12.37	13.12	0.13	33.8	31.2	0.27	5.3	4.7	0.13	34.7	34.9	0.91	2.2^{+}	2.1^{+}	0.06
23	13.87**	13.24**	0.01	30.3	31.7	0.35	4.5*	5.0*	0.02	33.3	32.3	0.72	2.0	2.1	0.41
24	10.92	11.30	0.70	32.7	32.7	0.35	3.9	3.6	0.41	31.2	29.4	0.81	2.9	3.0	0.36
25	4.90	4.90	0.97	32.0	31.5	0.29$$	3.9*	3.6*	0.05	36.2	34.5	0.46	2.1	2.0	0.39
26	7.59	7.47	0.28	37.5	38.1	0.71	4.2	4.4	0.44	29.8	28.9	0.46	2.6	2.8	0.25

Table 6: (continued).

Site	Yield			Plant tissue concentration											
	Trt	control	statistic	Zn	Control Zn	statistic	Mn	Control Mn	statistic	B	Control B	statistic	Fe	Control Fe	statistic
	Mg.ha^{-1}		P>F	gkg^{-1}		P>F	gkg^{-1}		P>F	gkg^{-1}		P>F	gkg^{-1}		P>F
1	16.19^{++}	15.44^{++}	0.06	32	30	0.32$$	87^{***}	75^{***}	0.001$$	6.3	5.0	0.27$$	189	181	0.47
2	15.75	15.13	0.40	35^{*}	31^{*}	0.03$$	80	71	0.41$$	5.0	5.0	1.00$$	124	122	0.75
3	14.62	14.06	0.56	31	27	0.16$$	84	77	0.58$$	7.0	6.3	0.53$$	158	153	0.65
4	15.57	15.69	0.87	34	33	0.25$$	73^{*}	57*	0.05$$	5.5	5.0	0.18$$	197	213	0.14
5	15.94	16.38	0.42	20	21	0.87	80	98	0.32	5.5	5.8	0.53$$	137	136	0.91
6	15.25	15.19	0.20	23^{+}	22^{+}	0.06$$	46*	57^{*}	0.03$$	4.2	3.7	0.58$$	138	140	0.87
7	15.44	15.44	0.98	29	27	0.13	67	64	0.76	5.0	8.0	0.16$$	176	171	0.19
8	12.74	12.80	0.72	23	18	0.10$$	54	59	0.28$$	6.5	7.8	0.19$$	118	124	0.27
9	16.19	16.19	0.69	17	18	0.24$$	50*	62^{*}	0.05$$	6.4	6.7	0.15	103	107	0.22
10	14.62+	15.19^{+}	0.06	27^{+}	23*	0.02$$	96*	109^{*}	0.05$$	8.5^{+}	9.3^{+}	0.08	128^{*}	141^{*}	0.04$$
11	15.13	15.06	0.69	22	19	0.23$$	67	78	0.51$$	9.2	9.7	0.66	125	122	0.84$$
12	15.69	15.63	0.52	23^{**}	18^{**}	0.0003$$	90	82	0.36$$	4.9	4.6	0.71$$	131	134	0.32
13	15.38^{***}	15.57^{***}	0.001	19	18	0.24$$	48	41	0.31$$	4.7	4.3	0.43$$	164	161	0.83
14	13.37^{**}	12.68^{**}	0.01	26^{*}	19^{*}	0.05$$	59	38	0.20$$	5.5	6.5	0.70$$	117	112	0.25
15	13.62	13.37	0.62	29	20	0.13$$	57	63	0.74$$	6.4	6.1	0.61$$	113	109	0.64
16	12.49	12.68	0.71	41^{+}	26^{+}	0.06$$	48	58	0.63$$	5.5	6.5	0.70$$	152	146	0.45
17	11.42	11.80	0.58	31^{*}	22^{*}	0.03$$	59	54	0.84$$	6.2	5.9	0.48$$	150	146	0.33
18	13.06	12.68	0.36	18	18	0.74$$	68	67	0.82$$	5.5	6.0	0.71$$	163	154	0.32
19	14.25	13.68	0.12	21	21	0.87$$	69^{*}	60^{*}	0.05$$	7.0	6.0	0.50	79	72	0.18$$
20	12.30	11.99	0.49	33	27	0.13	66	48	0.35	17.0	16.0	0.96	86	80	0.73$$
21	13.18	13.06	0.59	30	30	0.87	57	58	0.59	16.0	12.0	0.36	72	69	0.48$$
22	12.37	13.12	0.13	41	42	0.91	71	72	0.90	12.0	11.0	0.52	68^{+}	59^{+}	0.10$$
23	13.87^{**}	13.24^{**}	0.01	40	43	0.54	67	69	0.75	11.0	12.0	0.60	70	60	0.19$$
24	10.92	11.30	0.70	54	57	0.19	98	97	0.41	11.0	12.0	0.72	68	72	0.27$$
25	4.90	4.90	0.97	32	30	0.46	48	51	0.51	8.0	8.0	1.00	94	92	0.73$$
26	7.59	7.47	0.28	45	47	042	67	71	0.40	21.0	21.0	0.87	116	124	0.33$$

+ mean; * significant at 0.05; ** significant at 0.01; *** significant at 0.001; $$ application of foliar spraying on the plant

Table (7): Average response across ≥2 sites for identical foliar micronutrient administration in comparison to no application on grain yield and leaf tissue nutrient concentrations (Stewart *et al*., 2020)

Product+	Sites	Total reps	yield			N			P		
			Trt++	Site$$	Trt+site$$	Trt	Site	Trt+site$$	Trt	site	Trt+site
			Mgha-1	P>F	P>F	gkg-1	P>F	P>F	gkg-1	P>F	P>F
Brandt	1,2,3	9	0.7*	0.03*	0.97	0.13*	0.59$^{\#}$	0.62$^{\#}$	0.2**	0.13	0.68
MAX-IN B	5,7	12	-0.2	0.06+	0.56	-0.15+	0.77	0.74	-0.1	<0.001***	013
MAX-IN ZMB	4,6,14,15,16,17	25	0.1	<0.001***	0.63	-0.1	<0.001***	0.29	-0.2	<0.001***	0.17
MAX-IN ZMB+MAX-IN B	8,12,13,18	54	0.1	<0.001***	0.17	0.60	<0.001***	0.22	0.010	<0.001***	0.94
Attain (Zn,Mn,Fe,,B)+MAX-IN B	10,11	16	-0.3	0.35	0.05*	-0.4$^{\#}$	0.08+$^{\#}$	0.55$^{\#}$	0.07	0.10+	0.38
Verse Fe+LS (cor)	20,21,22,23	16	0.4**	0.04*	0.03*	1.20	0.44	0.28	0.20	<0.001***	0.02*
Verse Fe+LS (popcorm)	25,26	8	0.1	<0.001***	0.56	-0.06	0.002**	0.63	0.06	0.02*	0.07+

Product+	Sites	Total reps	K			S			Zn		
			Trt	Site	Trt+site	Trt	Site	Trt+site	Trt	Site	Trt+site
			gkg^{-1}	P>F	P>F	gkg^{-1}	P>F	P>F	mgkg^{-1}	P>F	P>F
Brandt	1,2,3	9	-0.5	0.01**	0.68	-0.03$^{\#}$	0.03$^{*\#}$	0.24$^{\#}$	3.4**$^{\#}$	0.34#	0.45
MAX-IN B	5,7	12	0.04	0.004**	0.10+	0.10	0.14	0.43	1.2	<0.001$^{***\#}$	0.14
MAX-IN ZMB	4,6,14,15,16,17	25	-0.2	<0.001***	0.26	0.02$^{\#}$	0.006$^{**\#}$	0.01$^{*\#}$	6.1$^{***\#}$	<0.001$^{***\#}$	<0.001$^{***\#}$
MAX-IN ZMB+MAX-IN B	8,12,13,18	54	0.10	<0.001***	0.45	-0.003$^{\#}$	0.02$^{*\#}$	0.48$^{\#}$	3.3$^{***\#}$	0.30$^{\#}$	0.01$^{**\#}$
Attain (Zn,Mn,Fe,,B)+MAX-IN B	10,11	16	-0.02	0.45	0.87	-0.07$^{\#}$	0.36$^{\#}$	0.58$^{\#}$	2.9$^{**\#}$	0.009$^{**\#}$	0.68$^{\#}$
Verse Fe+LS (cor)	20,21,22,23	16	1.00	0.02*	0.33	0.040	0.21	0.22	0.8	0.007**	0.50
Verse Fe+LS (popcorm)	25,26	8	1.30	<0.001***	0.72	-0.04	<0.001***	0.11	0.3	0.02*	0.26

Product+	Sites	Total reps	Mn			B			Fe		
			Trt	Site	Trt+site	Trt	Site	Trt+site	Trt	Site	Trt+site
			mgkg^{-1}	P>F	P>F	mgkg^{-1}	P>F	P>F	mgkg^{-1}	P>F	P>F
Brandt	1,2,3	9	9.3$^{*\#}$	0.44$^{\#}$	0.91$^{\#}$	0.7$^{\#}$	0.05$^{*\#}$	0.47$^{\#}$	5.0	0.17	0.25
MAX-IN B	5,7	12	-7.2	0.03*	0.28	-1.7$^{+\#}$	0.35$^{\#}$	0.15$^{\#}$	3.0	-0.09^{+}	0.16
MAX-IN ZMB	4,6,14,15,16,17	25	4.2$^{+\#}$	0.10$^{+\#}$	0.005$^{**\#}$	-0.03$^{\#}$	0.004$^{**\#}$	0.34$^{\#}$	-2.0	0.34	0.13
MAX-IN ZMB+MAX-IN B	8,12,13,18	54	1.7$^{\#}$	0.04$^{*\#}$	0.53$^{\#}$	-0.5$^{\#}$	0.01$^{**\#}$	0.53$^{\#}$	-2.3	0.01**	0.33
Attain (Zn,Mn,Fe,,B)+MAX-IN B	10,11	16	-1.5$^{\#}$	0.01$^{**\#}$	0.91$^{\#}$	-0.6$^{\#}$	0.60$^{\#}$	0.81$^{\#}$	-5.0$^{\#}$	0.01$^{+\#}$	0.22$^{\#}$
Verse Fe+LS (cor)	20,21,22,23	16	3.4	0.06^{+}	0.35	1.1	0.29	0.91	8.1$^{+\#}$	0.04$^{+\#}$	0.91$^{\#}$
Verse Fe+LS (popcorm)	25,26	8	-3.8	0.02^{+}	0.88	0.1	<0.001***	0.89	-3.6$^{\#}$	0.005$^{**\#}$	0.27$^{\#}$

+ Mean; * significant at 0.05; ** significant at 0.01; *** significant at 0.001; #, application of foliar spraying on the plant.

Micronutrient absorbance problems

Foliar micronutrient treatments display a wide range of efficacy depending on their solubility and that of additional compounds such salts, surfactants, complexes, or chelates. There may need to be more than a single micronutrient formulation to examine the effects of micronutrients (Stewart *et al*., 2020; Saquee *et al*., 2023). A study found that applying 1.0 to 1.5 kg ha^{-1} of foliar zinc per year resulted in a nearly 18% increase in maize grain output over the course of three years (Stewart *et al*., 2020), while many others stated that the yield did not significantly increase (Nelson & Meinhardt, 2011). When sprayed onto leaves, micronutrients have significantly impacted how much of them are absorbed. Many elements, such as the kind of nutrient, its concentration, the physicochemical properties of liquid, and the characteristics of spray droplets, are connected to the absorption of micronutrients (Alheidary *et al*., 2020). For instance, after foliar spraying applications, the concentrations of micronutrients for leaf growth increased by 4 to 9 mg Zn kg^{-1} at 5 of the 17 sites, 12 to 16 mg kg^{-1} Mn at 2 of the 17 sites, and an average of 8.1 mg kg^{-1} Fe across 10 sites with signs of Fe deficiency after the application of 123g foliar Fe ha^{-1}. The brown application had no impact on the concentration of foliar brown. Except for Mn ($r = 0.54$), increases in nutrient concentrations had little effect on grain yield responses (Stewart *et al*., 2020). For the 10 sites exhibiting symptoms of Fe insufficiency, the mean, meaningful grain yield response to 123 g foliar Fe. ha^{-1} was 0.4 Mg. ha^{-1} (Tables 6 and 7). If Fe deficiency signs are present, maize yield response to foliar Fe administration can generally be advantageous. Without solid proof of a nutrient shortage, response to other foliar micronutrient administrations is unlikely to be lucrative. Nutrient concentrations in plant tissue are widely used to gauge maize's nutritional condition during the growth season. Each one of the 14 basic plant nutrients can prevent plants from growing (Bojtor *et al*., 2022). Plant analysis applies this fundamental idea by comparing the nutrient concentration of a specific plant part to essential values or sufficiency ranges identified for a given species. Nutrient insufficiency and the probability of a yield response to nutrient administration are implied by nutrient concentrations below the sufficiency range or critical value (Souza *et al*., 2020). They further claim that plants with micronutrient applications will have higher nutritional concentrations of the nutrient applied in new tissues, as has been shown with maize under comparable field conditions (Stewart *et al*., 2020).

The foliar micronutrient impacts on the concentrations in the leaf tissue. Applications of foliar micronutrients consistently increased the concentrations of their respective micronutrients in leaf tissue rather than grain yield, especially in the case of Zn (Figs. 6, 7, and 8). According to additional findings from a hydroponic greenhouse study, 47% of the sites that received foliar Zn had a nearly significant increase ($p < 0.10$) of an average of 4 mg Zn kg^{-1} in the leaf tissue (Stewart *et al*., 2021). The main factor influencing the decision to apply Zn was typically high-yielding maize areas looking to increase yields with low plant or soil Zn concentrations but otherwise above basic levels. Moreover, both concentrations of N and P in the plant were impacted by foliar treatment. The combined study of sites 1, 2, and 3 revealed an increase in plant N of 1.3 g kg^{-1} and plant P of 0.2 g kg^{-1} ($p < 0.05$) due to the 116, 87, 87, 87, and 7 g of N, S, Mn, Zn, and B that were applied to each site, respectively (Table 6). The addition of foliar N should enhance the amount of N, and applying sulfur also has a synergistic effect on plant uptake of N (Li *et al.*, 2019). It's possible that P's interaction with Fe, Mn, or Zn caused the increase in P (Warnock, 1970).

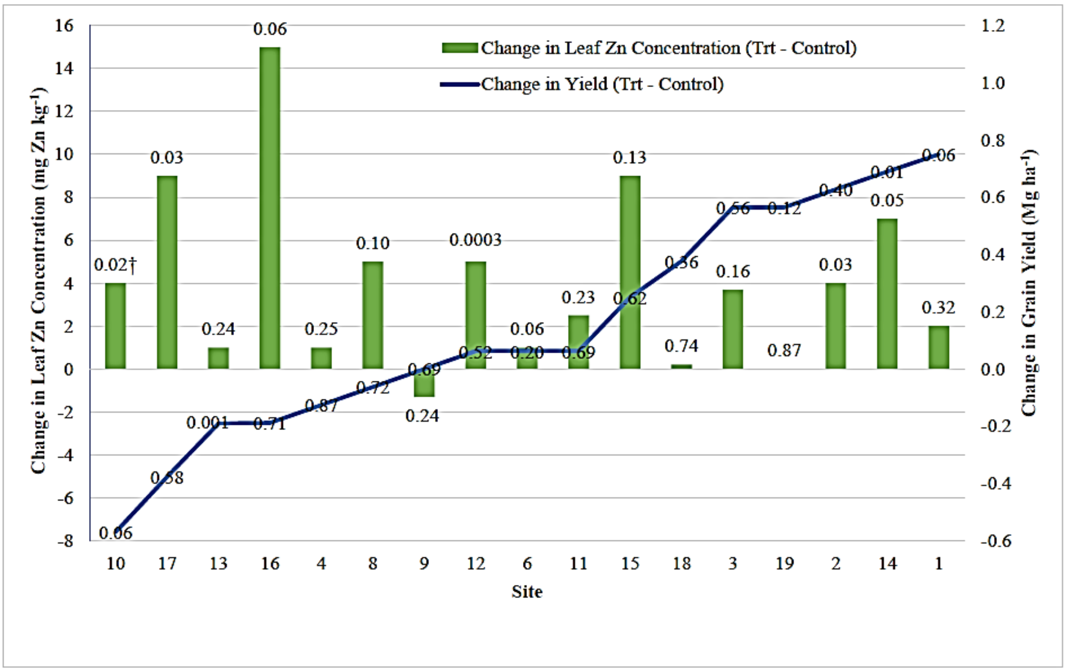

Fig. (6): Responses of 17sits to the foliar treatment of Zn in leaves (bars) and maize grain yield (line) (Stewart et al., 2020).

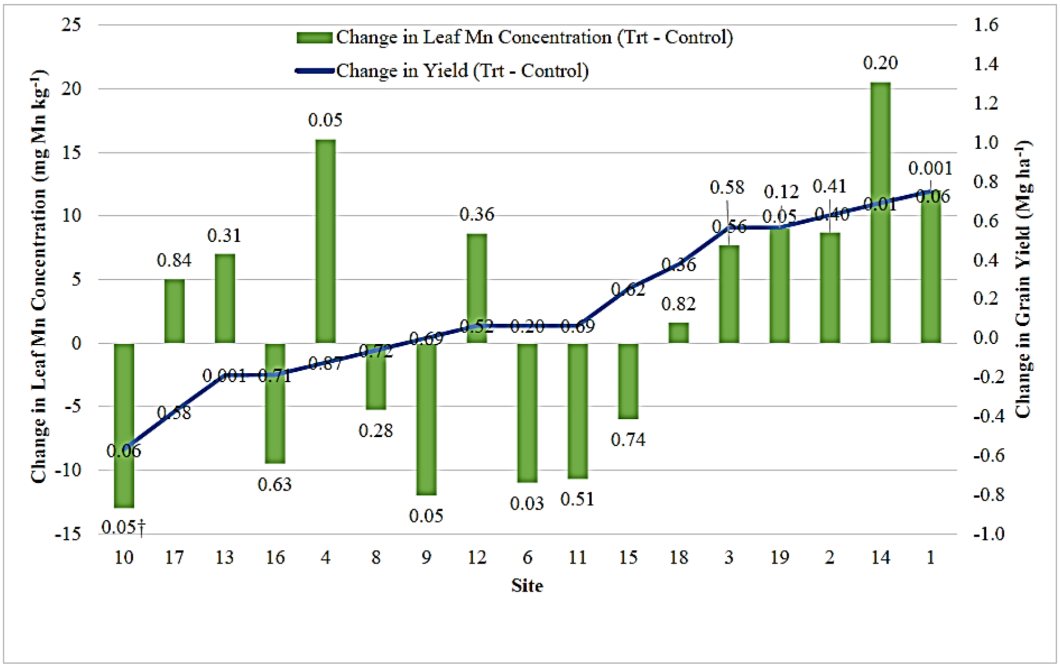

Fig. (7): Responses of 17sits to the foliar treatment of Mn in leaves (bars) and maize grain yield (line) (Stewart *et al.*, 2020).

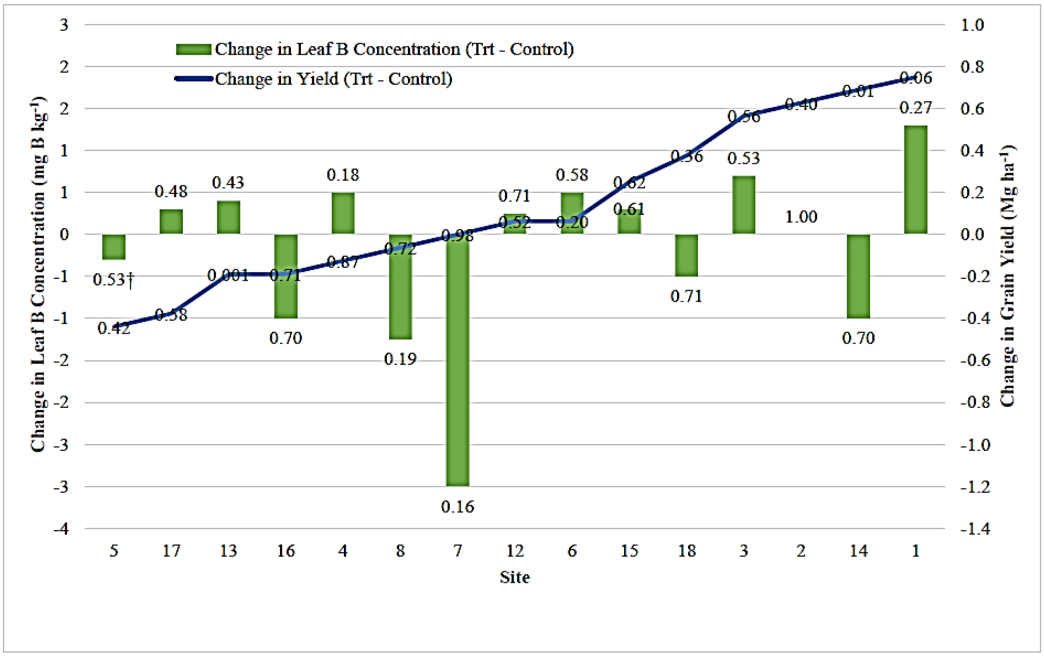

Fig. (8): Responses of 17sits to the foliar treatment of B in leaves (bars) and maize grain yield (line) (Stewart *et al*., 2020).

It has been hypothesized that locations with higher yields and lower micronutrient plant or soil concentrations, but not necessarily below critical levels, may be more likely to experience an increase in yield response as a result of foliar micronutrient supplementation because higher-yielding locations have a higher demand for micronutrients. No correlation (r = 0.03) was found between yield level and yield response to foliar micronutrient supplementation in the combined analysis for maize-producing locations (Fig. 9). Also, areas with soil or plant tissue micronutrient concentrations close to essential levels but not below were not consistently linked to enhanced chances of increased grain yield (r< 0.1). There was no correlation (r< 0.01) between soil organic matter, pH, or soil/plant P and an increase in grain yield.

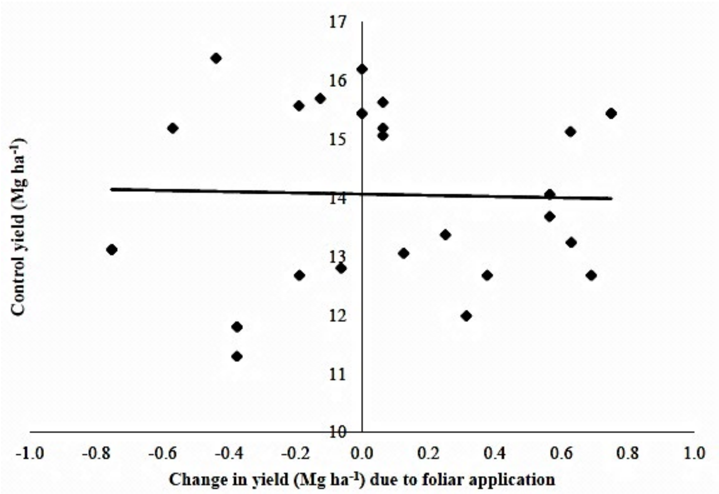

Fig. (9): Grain yield response to foliar micronutrient spray for 26 sites and the relationship between maize grain yields (Stewart *et al*., 2020).

Vegetative growth stage characteristics and their relationship with foliar spraying

Depending on the growth stage, plants require varying amounts of nutrients when foliar is sprayed. The balance of nutrients in the soil can be challenging to manage at times. Yet, applying foliar fertilizer with important nutrients at critical times can enhance plants' quality, productivity, and growth (Yuan *et al.*, 2023). Also, the timing of spraying and the concentration of any element are crucial factors for the plant and significantly impact on its production and vegetative growth characteristics (Abboud & Al-Assaf, 2020). For instance, when plants were sprayed with glutathione at various doses according to the leaves, compared to the control treatment, plants' vegetative development characteristics improved (treated with water only) (Tables 8 and 9).

Table (8): Effect of glutathions and spraying stages and their interaction in plant height (cited from (Hussein & Judy, 2019).

Spraying stages	Gltathione (mg.l^{-1})			
	0	50	100	Average of growth stages
6 leaves	212.67	229.33	241.00	227.67
9 leaves	223.33	226.67	235.33	228.44
12 leaves	225.67	236.33	243.67	235.22
6+9 leaves	216.67	249.00	242.33	236.00
6+12 leaves	219.00	251.33	249.00	239.78
6+9+12 leaves	214.00	259.00	245.67	239.56
Average of gltathione	219.10	242.05	242.81	
LSD concentration	3.48			
LSD stage	5.32			
LSD interaction	9.21			

Table (9): spraying stage and glutathione concentrations and their interaction in the total crop yield (ton.ha^{-1}) (Hussein & Judy, 2019).

Spraying stages	Gltathione (mg.l^{-1})			
	0	50	100	Average of growth stages
6 leaves	9.70	10.65	10.45	10.27
9 leaves	9.43	10.63	10.81	10.29
12 leaves	9.75	11.33	10.70	10.59
6+9 leaves	9.33	11.75	10.59	10.56
6+12 leaves	9.55	11.37	11.12	10.68
6+9+12 leaves	9.59	10.94	10.96	10.50
Average of gltathione	9.52	10.77	10.69	10.33
LSD concentration	0.25			
LSD stage	0.38			
LSD interaction	0.65			

Characteristics of spray liquid through foliar application

Studying the spray liquid's characteristics during foliar application is crucial for enhancing its effectiveness and maximizing plant benefits (Saadoun & Al-juthery, 2019).

The best spray liquid properties relate to the droplets' behavior on the leaves' surface and their penetration into the tissues of leaves by choosing the appropriate physicochemical properties at the spraying application (Fernández & Brown, 2013) (Fig. 10).

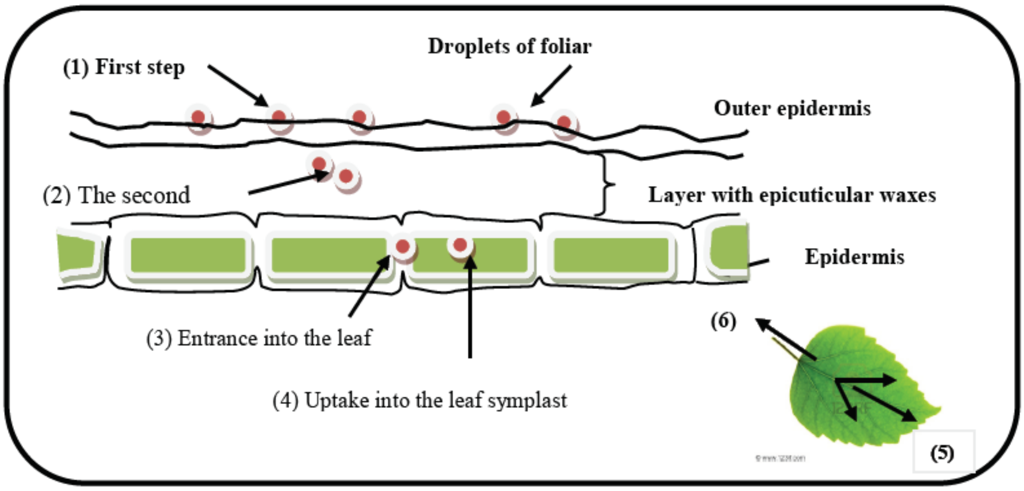

Fig. (10): Several steps involved in leaves absorbing nutrients (Alshaal & El-Ramady, 2017).

1) Fertilizer solution is used to wet the leaf surface. 2) Penetration through the outer cell wall of the epidermis. 3) The leaf's apoplast entry. 4) Penetration of the leaf syplast. 5) Dispersion inside the leaf.6) Transportation out the leaf.

Understanding the specifics of this phenomenon, such as the properties of the spray liquid (liquid viscosity and surface tension), the properties of the plant surface, solubility, pH solution, liquid molecular weight, plant canopy, type of the formulation adding to the spray liquid, droplet characteristics, nozzle type, and size, operating conditions, and weather conditions, is crucial to achieving the highest level of efficiency when applying foliar fertilizer (Alberto *et al*., 2022). Under the right conditions, the plant responses to the foliar application may be boosted during the spray liquid, resulting in the absorption and transport of the applied nutrients into plant organs. Although the process of absorption of leaf-applied solutions is complex and currently remains unknown, the characteristics of the formulations are related to strict chemical principles as well as the prevailing ambient conditions (air temperature and relative humidity) at the time of spraying (Lichiheb *et al*., 2015).

Nanotechnology and foliar applications

The application of nanotechnology to agricultural spraying could greatly enhance crop quality and productivity (Shang *et al*., 2019; Rana *et al*., 2021). Nanotechnology has been used in the application of fertilization as nutrients for crop plants in the form of nano-droplets deposited on the leaves during the spraying process as well as crop protectants in the form of nano-solution for spraying applications. Moreover, this method can improve plant absorption and minimize losses from soil fertilizer (Predoi *et al*., 2020). Even yet, nano-foliar fertilization has significantly impacted crop output and precision farming practices. Unfortunately, the foundation of knowledge for using nanotechnology in spraying applications is still insufficient for agricultural productivity and their sustainable environmental (Beig *et al*., 2022). Also, there is still a knowledge gap regarding their mode of action and the potential dangers associated with spray administration (Jurkow *et al*., 2020).

Efficiency of foliar fertilizer application

In general, the reasons for increasing food shortages in the world are an increase in population compared to a constant loss in yields and the cultivable plot due to rising desertification, frequently due to human action (Komarek & Msangi, 2019). Due to the particularly substantial decline in agricultural production in many dry and semi-dry areas, there is a growing need to preserve the productivity of existing lands under cultivation and to improve the efficiency of their usage using new methods in agricultural operations (Begizew, 2021). To achieve a high output per unit area, agriculture must be based on a fertilizer application approach that includes an optimal nutrient delivery strategy (Singh *et al*., 2021). Because it may mainly compensate for nutrient deficiency, foliar fertilization is utilized worldwide as a preventive and therapeutic strategy (Shahrajabian *et al*., 2022). Several agricultural and environmental conditions influence foliar fertilizers' effectiveness. These elements distinguish between the effects of fertilization on various areas. Theoretically, using foliar spray to boost plant development and yields while lowering yield variability is plausible. The effectiveness of nitrogen absorption at the time of foliar spray applied per dose of fertilizer can be determined (Faber & Fotyma, 1986)

$$Nitrogen\,(\%) = \frac{N_p}{N_u} * 100 \ldots\ldots\ldots\ldots(1)$$

Where: Np, is the amount of nitrogen absorbed, Nu: is the amount of nitrogen applied

Weather conditions interactions

The crop growth stage, application rate, and weather at the time of foliar application all influence when foliar fertilizer is applied during spraying. The best crop stage and conditions that can be correlated to identify the greatest foliar fertilizer efficacy reach the intended objective and minimize losses due to climatic conditions. It is crucial to note that choosing the best foliar fertilizer concentration depends on the crop that was planted, the crop's stage of growth, the soil's composition, and the nutrients that plants need, such as N, P, and K. Also, the foliar fertilizer light increased focus on the plant and root diseases (Zhang *et al*., 2020; Dass *et al*., 2022).

Agricultural sprayer design and application parameters

Agricultural sprayers come in various shapes, sizes, and performance levels. During the spraying process, the type of agricultural sprayer affects both spray deposition and spray drift (Dengeru *et al*., 2022). Air-carrier ground sprayers are one of the primary types used in spraying applications with a high level of performance. The liquid of the spray is released radially using traditional air blast sprayers. Depending on the plant objective, other types of sprayers are offered with tower configurations that discharge it horizontally (Sapkota *et al*., 2023). Previous sprayer tower configuration results have reduced the risk of spray drift while maintaining acceptable deposition on the intended target (Dekeyser *et al*., 2014; Gil *et al*., 2014).

Airblast sprayers are typically used with an application rate of about 200–5000 $l.ha^{-1}$ (Neto *et al*., 2015). Application rate throughout the application procedure is correlated with many factors. For instance, the maximum rate of air blast sprayers and other varieties not included here is determined by various combinations of the nozzle's swath width, operating pressure, nozzle type, and forward speed. The spectrum of application rates can be divided into low-volume applications with more concentrated material applied at low volume (LV) and high-volume applications (HV). With a difference in droplet size at the moment of spraying, both LV and HV are applied at the same rate. Small droplet sizes used in low-volume spraying applications lead to the most significant amounts of spray drift during application as vapor or particle drift. Whereas, the coarse droplet sizes are used for high-volume applications (Garcerá *et al.*, 2020). There is a good correlation between application rate and the amount of spray deposition on target. The high-volume applications with a lower spray deposition on the surface of the target gave minor spray drift. On the contrary, higher spray deposition was achieved in the low-volume application resulting in the reduction of spray drift (Fornasiero *et al.*, 2017; Musiu *et al.*, 2019).

Nozzle characteristics

One of the critical factors affecting spray deposition, spray coverage, and spray drift during or shortly after the spraying process is nozzle characteristics. Many factors, such as nozzle type, nozzle size, height, angle, flow rate, and pressure, are considered to be nozzle characteristics. (Nuyttens *et al.*, 2007; Hanafi *et al.*, 2016) investigated how nozzle type, pressure, and angle spray affect spray deposition and coverage. The study's major finding demonstrated a considerable impact of these parameters on spray deposition and coverage (Table 10).

Table (10): How does nozzle type affect droplet properties deposited on maize leaves at different layers of the plant (Alheidary *et al.*, 2020).

Nozzle type		Droplet size (µm)	Spray coverage %	Droplet density (number.cm^{-2})
Flat fan nozzle	Top	$240^{a}\pm3.63$	$10.6^{cd}\pm0.67$	$4.26^{e}\pm0.75$
	Middle	$165^{d}\pm9.25$	$7.66^{de}\pm0.56$	$4.26^{e}\pm0.58$
	Bottom	$137.66^{f}\pm3.64$	$5.54^{e}\pm0.67$	$7.34^{c}\pm0.51$
Hollow cone	Top	$199^{c}\pm4.05$	$33.36^{a}\pm2.72$	$8.02^{c}\pm1.84$
	Middle	$133.7^{f}\pm7.6$	$21.26^{b}\pm0.25$	$8.02^{c}\pm0.73$
	Bottom	$120.6^{h}\pm4.05$	$18.67^{b}\pm2.72$	$10.92^{a}\pm0.93$
Tip nozzle	Top	$214^{b}\pm7.28$	$12.06^{c}\pm0.18$	$5.25^{d}\pm0.87$
	Middle	$154^{e}\pm7.2$	$8.22^{de}\pm0.46$	$5.25^{d}\pm0.87$
	Bottom	$126.2^{g}\pm7.28$	$7.96^{de}\pm0.19$	$9.53^{b}\pm1.28$
L.S.D (0.05)		**5.01**	**3.36**	**0.76**

Table (10) illustrates the findings of spray droplets' characteristics as coverage rates and densities on the samples of Water sensitive papers (WPCs) taken from three different plant sites (top, middle, and bottom). Because of the various nozzle types, these characteristics varied significantly. Greater droplet size (240 m) and a low coverage percentage (5.54%) were observed in samples of WPCs utilizing flat fan nozzles, which resulted in a lower droplet density (4.26 droplet. cm^{-2}) as compared to other nozzles. That's because the droplets don't have enough time to deposit on the WPCs due to their big size and rapid acceleration.

The outcomes also demonstrated that these characteristics were considerably impacted by the locations of WPCs on the plant. For all investigated nozzle types, larger droplet sizes, higher coverage rates, and higher droplet densities were found on the top WPCs compared to other places (42.65%, 47.73%, and 41.96%, respectively). This conclusion follows logically since the plant's top position is closed to the nozzle orifice.

Foliar application related to spray deposition and spray coverage

Crop canopy parameters like leaf surface are related to the features of agricultural sprayers, such as nozzle size, type, operating pressure, and spray solution characteristics. The effects of these characteristics will have an impact on how quickly a foliar nutrition spray spreads, wets, and is absorbed. Before applying foliar nutrients, if the crop leaves are moist from rain or dew, the absorption rate may be reduced (Li *et al.*, 2020; Foqué & Nuyttens, 2011). Spray effectiveness frequently depends on droplet size, with smaller droplets providing better coverage and having a higher tendency to drift and be retained on the leaf surface (Baales *et al.*, 2022).

The performance of foliar-applied plant protection agents can be significantly improved by electrostatic spraying technologies, which have recently been developed for agricultural applications. Nevertheless, these technologies still need to be thoroughly evaluated on foliar nutrition sprays (De Oliveira *et al.*, 2019). This technology greatly reduces the droplet's sizes and improves plant coverage still it also significantly raises the risk of drift and the evaporation of the small droplets off the plant surface, especially in dry and semi-dry regions. Moreover, a more extended application period is necessary to guarantee that the plant surface is adequately wetted, which is required to uptake of foliar-applied nutrients. Contrast this with traditional spraying methods, which produce coarser spray droplets that reflect a greater volume of liquid deposited on and saturating the surface of plants (Peirce *et al.*, 2019).

Plant characteristics

Table (11) shows that the nozzle type significantly affects plant characteristics such as the plant height, stem diameter, number of leaves, leaf area, number of grains, and yield. With a substantial increase percentage from the tip nozzle and flat fan nozzle (2.79% and 4.98%, respectively), the hollow cone nozzle was used for obtaining the highest average height (143.66 cm).

The values differ because of the various nozzle designs, resulting in different spray droplet characteristics deposited on the plant's leaves. The hollow cone nozzle outperformed as a result because it could deliver droplets to the leaves with optimal droplet sizes, density, and coverage percentage and contained the vital components of iron and zinc.

A good relationship between the different nozzle types, foliar spraying, and stem diameter has a substantial impact (Table 12). The stem diameter with a large amount was (13.25% more than other treatments) after foliar spraying with zinc and iron together (1.88 cm as the highest average). It results from improved plant ability to absorb water and essential nutrients through stomata for vital processes like increasing photosynthesis and nitrogen, which in turn increases vegetative growth. The stem diameter was impacted by the nozzle type for the nozzle type effect. The type of nozzle with a hollow cone recorded the greatest average (1.82 cm).

Table (11): The behavior of maize height during foliar application using different nozzle types (Alheidary *et al.*, 2020).

Foliar spraying	Nozzle type					
	N1	N2	N3	Average	SD	CV%
F1	129.72^{fg}	129.60^{fg}	127.05^{g}	128.79^{c}	±1.23	0.96%
F2	136.65^{ef}	133.57^{efg}	139.93^{cde}	136.72^{bc}	±2.59	1.90%
F3	142.03^{bcd}	137.69^{def}	147.61^{bc}	142.44^{b}	±4.06	2.85%
F4	150.62^{b}	146.50^{bcc}	160.05^{a}	152.39^{a}	±5.67	3.72%
Average	139.75	136.84	143.66			
L.S.D	F	N	N*F			
	7.95	3.34	ns			

N1: Tip nozzle, N2: Flat fan nozzle, N3: Hollow cone nozzle, F1: Control (water only); F2: Spraying with Fe, F3: Spraying with Zn; F4: Fe+Zn , CV: coefficient variance

Table (12): Results of maize stem diameter using foliar application at different nozzle types (Alheidary *et al.*, 2020).

Foliar spraying	Nozzle type					
	N1	N2	N3	Average	SD	CV%
F1	1.67^{g}	1.63^{g}	1.66^{g}	1.66^{d}	±0.02	1.00%
F2	1.75^{def}	1.70^{efg}	1.79^{cd}	1.75^{c}	±0.04	2.19%
F3	1.80^{cd}	1.75^{def}	1.86^{bc}	1.80^{b}	±0.04	2.49%
F4	1.89^{ab}	1.78^{cde}	1.97^{a}	1.88^{a}	±0.08	4.00%
Average	1.78	1.72	1.82			
L.S.D	F	N	N*F			
	0.04	0.06	ns			

N1: Tip nozzle, N2: Flat fan nozzle, N3: Hollow cone nozzle, F1: Control (water only); F2: Spraying with Fe, F3: Spraying with Zn; F4: Fe+Zn, CV: coefficient variance

To explain the leaves number using foliar sprayings and various nozzle types, the data in table (13) demonstrated significant changes in the number of leaves. The Zn and Fe spraying had the highest average number of leaves (13.98) compared to the other treatments. It is typical for the leaves to grow more as they absorb the zinc and iron needed for photosynthesis. The results also showed in table (13) that the nozzle type significantly impacted on how many leaves were produced. As usual, the hollow cone nozzle type produced noticeably more leaves than the other nozzles used in this study. Foliar spraying and nozzle type considerably impacted on the leaf area, as indicated in table (14) compared to the others, the foliar spraying with zinc, iron, and hollow cone nozzle produced the greatest average leaf area of 4559 cm^2 and 4243 cm^2 respectively.

Table (13): Maize leaves number and foliar application depending on nozzle type used (Alheidary *et al*., 2020).

Foliar spraying	Nozzle type					
	N1	N2	N3	Average	SD	CV%
F1	12.26^{g}	12.22^{g}	12.24^{g}	12.24^{d}	±0.02	0.14%
F2	13.31^{e}	13.11^{f}	13.43^{de}	13.28^{c}	±0.13	0.99%
F3	13.59^{cd}	13.39^{e}	13.69^{bc}	13.56^{b}	±0.13	0.92%
F4	14.01^{a}	13.79^{b}	14.13^{a}	13.98^{a}	±0.14	1.03%
Average	13.29	13.13	13.37			
L.S.D	F	N	N*F			
	0.14	0.08	ns			

N1: Tip nozzle, N2: Flat fan nozzle, N3: Hollow cone nozzle, F1: Control (water only); F2: Spraying with Fe, F3: Spraying with Zn; F4: Fe+Zn, CV: coefficient variance.

Table (14): Maize leaf area by a foliar application using different nozzle types (Alheidary *et al*., 2020).

Foliar spraying	Nozzle type					
	N1	N2	N3	Average	SD	CV%
F1	3584^{ef}	3561^{f}	3439^{f}	3528.00^{c}	±63.63	1.80%
F2	4042^{cde}	3837^{def}	4321^{abc}	4066.67^{b}	±198.36	4.88%
F3	4321^{abc}	4151^{bcd}	4467^{abc}	4313.00^{ab}	±129.13	2.99%
F4	4513^{ab}	4421^{abc}	4744^{a}	4559.33^{a}	±135.87	2.98%
Average	4115	3992	4243			
L.S.D	F	N	N*F			
	446	130	ns			

N1: Tip nozzle, N2: Flat fan nozzle, N3: Hollow cone nozzle, F1: Control (water only); F2: Spraying with Fe, F3: Spraying with Zn; F4: Fe+Zn , CV: coefficient variance.

The results of this study indicate a robust relationship between the foliar application of zinc and iron (F4) and the hollow cone nozzle (N3) on both the number and yield of the grains (Tables 15 and 16). Comparatively, foliar spraying produces the most grains (376.51) and yields (5.51Mg.ha^{-1}). The hollow cone nozzle outperformed the other nozzles regarding average number (374.19) and yield (5.15 Mg.ha^{-1}) when the nozzle type was examined while maintaining foliar spraying.

Table (15): Maize grain number and foliar application using different nozzle types (Alheidary *et al*., 2020).

Foliar spraying	Nozzle type					
	N1	N2	N3	Average	SD	CV%
F1	300.64^{g}	295.56^{g}	310.77^{fg}	302.32^{c}	±6.32	2.09%
F2	332.75^{de}	321.54^{ef}	337.55^{de}	330.61^{b}	±6.71	2.03%
F3	340.87^{cd}	329.51^{de}	357.87^{bc}	342.75^{b}	±11.65	3.40%
F4	374.57^{b}	362.46^{b}	392.51^{a}	376.51^{a}	±12.34	3.28%
Average	337.21	327.27	349.67			
L.S.D	F	N	N*F			
	17.40	3.32	17.58			

N1: Tip nozzle, N2: Flat fan nozzle, N3: Hollow cone nozzle, F1: Control (water only); F2: Spraying with Fe, F3: Spraying with Zn; F4: Fe+Zn, CV: coefficient variance

Table (16): Maize grain yield and foliar application using different nozzle types (Alheidary *et al.*, 2020)

Foliar spraying	Nozzle type					
	N1	N2	N3	Average	SD	CV%
F1	4.15^{e}	4.07^{e}	4.21^{e}	4.14^{c}	±0.06	1.38%
F2	4.63^{cd}	4.51^{d}	4.70^{cd}	4.62^{b}	±0.08	1.67%
F3	4.72^{cd}	4.63^{cd}	4.80^{c}	4.72^{b}	±0.07	1.44%
F4	5.53^{ab}	5.34^{b}	5.66^{a}	5.51^{a}	±0.13	2.39%
Average	4.76	4.64	4.84			
L.S.D	F	N	N*F			
	0.27	0.03	0.26			

N1: Tip nozzle, N2: Flat fan nozzle, N3: Hollow cone nozzle, F1: Control (water only); F2: Spraying with Fe, F3: Spraying with Zn; F4: Fe+Zn, CV: coefficient variance.

Spray liquid characteristics

Water soluble fertilizers (e.g. urea), inorganic salts (e.g. KCl and K_2SO_4), or pre-made, concentrated of liquid solutions that may take the form of chelated compounds of metallic ions can all be used to create foliar solutions (also known as foliar fertilizers). They frequently list their application rates as the percentage of nutrient to be applied in solution form, for example, 1–2% Zn foliar fertilizer solution. This protocol outlines the steps to take in order to use a variety of sources to determine the amount of chemical material required to create a foliar solution mixture with a specific concentration (Imakumbili, 2020). Foliar fertilizers should ideally be applied across a designated region to ensure that plants receive an adequate volume of foliar solution, even though this isn't always stated, save on produced foliar solutions (Schreel & Steppe, 2020). As a result, this protocol also outlines how to create a foliar solution while considering the area in which they will be administered. Agricultural spray liquids have instructions on creating and applying their solutions over a designated region, just like ready-made manufactured foliar treatments. So, it will also be demonstrated how foliar solutions should be prepared and used by the provided guidelines.

Applying foliar nutrients to fields that have already been planted is explained in the following formulae on product labels. Read the directions and make a note of any important details listed on the labels. Observe how the preparation and application of spray solutions can depend on factors like vegetative growth for each crop, type of crop, soil structure, levels considered safe for the environment, etc. In contrast, foliar solutions can depend on factors like crop type, level of nutrient deficiency, plant growth stages, etc.

YaraVita Zintrac 700 contains total zinc (Zn) at a concentration of 40% (700g.l^{-1}). Using this formula at a rate of 1l/ha between the 3 and 8-leaf stages is commonly advised for maize crops. Applications for repeating a severe deficiency should be submitted at the abovementioned rate every 10 to 14 days. Water rate: 30 to 200 l.ha^{-1}.

The droplet size is directly correlated with the physical characteristics of the spray liquid. The spray liquid's physical characteristics and other factors affect the droplet size (surface tension and viscosity) (Al Heidary *et al*., 2014). These properties significantly influence droplet size and distribution. Notwithstanding the foliar spraying and sprayer characteristics, increasing liquid viscosity and surface tension causes poor atomization and produces coarse droplet size for the nozzle orifice. This reduces the effectiveness of the foliar application (Spanoghe *et al*., 2007; Alidoost Dafsari *et al*., 2021). Moreover, the spray liquid's surface tension tends to prevent surface distortion. Droplet density is influenced by spray liquid viscosity and surface tension, which affects spray penetration (Carvalho *et al*., 2017; Fu *et al*., 2019).

How to apply foliar fertilizer in the treated field

After comprehending fertilizer's structure and dosage recommendations, it is simple to apply any foliar fertilizer in the fields. Assume, for instance, that you have an agricultural sprayer with a (15L) capacity and that you wish to create (i) a foliar solution by mixing 1 L of foliar concentrate with 200 L of water and (ii) a spray liquid solution by mixing 75ml of liquid concentrate with 100 L of water.

Calculations for foliar spraying will be based on proportional ratios that take into account the recommended foliar solution composition. As a result, when performing the calculations, you must ask yourself: If volume X of concentrate must be dissolved in a certain volume of water, then what volume of concentrate must be dissolved in a desired volume of water to generate a solution with the same concentration? The calculations are shown below, and they indicate that 75 ml of foliar concentrate will need to be added per 15 L of water (75 ml.15 L^{-1} water), whereas 11.25 ml of liquid concentrate will need to be added per 15 L of water (11.25 ml.15 L^{-1} water).

(i) Calculating the appropriate dosage of foliar concentrate to mix with 15L of water

$$\frac{\text{1L of fliar concentrate}}{\text{X}} = \frac{\text{200L of water}}{\text{15L of water}}$$

$$=> \text{X} = \frac{\text{1L foliar concenrate} * \text{15L of water}}{\text{200L of water}}$$

$$= 0.075\text{L}$$

$$= 75\text{ml foliar concentarate}$$

Prior to the foliar application, each sprayer will have a certain quantity of foliar concentrate added to it, and water will then be added to bring the solution mixture up to the 15 L level. These steps are used to create dilutions. Hence, the volume of the solution mixture will be 15 L rather than 15.075 L (15 L + 0.075 L) for the foliar solutions.

To calculate the crop field's treated area (in ha), which will be covered by 15 L of foliar solution. It'll keep using the example above to demonstrate how this is done. The necessary computations are displayed below. Notably, the solution once more relies on proportional ratios. This time, however, they want to know how many hectares a 15 L volume of solution will cover if the recommended amount of foliar solution (200 ml) will cover a 1 ha area.

(ii) Calculating the area that 15 L of foliar solution will cover in hectare

$$\frac{200\text{L foliar solution}}{15\text{L foliar solution}} = \frac{1\text{ha}}{\text{X}}$$

$$=> \text{X} = \frac{1\text{ha} * 15\text{L foliar solution}}{200\text{L foliar solution}} = 0.075\text{ha}$$

Using the previous example as a guide, calculate how many times a sprayer with a 15 L capacity will need to be filled in order to completely cover a 0.1944 - hectare crop field (1944 m). These are the calculations that must be made. The foundation of measures is once more proportionality ratios. The analysis is based on an understanding of the area that a 15 L spray tank of foliar solution will cover. After that, it tries to determine how many full spray tanks can adequately cover a given area.

(iii) Calculating the quantity of 15L spray tanks filled with foliar solution required to cover a given area:

$$\frac{1\text{ full spray solution}}{\text{X}} = \frac{0.075\text{ha}}{0.1944\text{ha}}$$

$$=> \text{X} = \frac{1\text{ full spray solution} * 0.1944\text{ha}}{0.075\text{ha}} = 2.6\text{ full spray solution}$$

It can now simply compute the volume of foliar and liquid concentrate required to cover the whole crop field once it knows the quantity of 15 L full spray solutions required to cover the entire crop field, as illustrated below. It will use the two examples once more. Remember that the calculation will utilize the volume of foliar concentrate that must be applied to 1 complete 15 L of spray solution; this volume was previously calculated. Additionally, keep in mind that the concentrate quantities calculated below are only for a single spray event. Hence, to calculate the overall amount of concentrate required throughout the full crop growing season, multiply each volume of concentrate acquired by the number of spray times. This information is valuable for estimating how much foliar concentrate will be required to purchase.

Just multiply the number of times a full sprayer tank will be filled by the spray tank's volume to determine the total volume of solution to be sprayed like how much concentrate was used (15 L). Check out the equation below:

$$\text{Amount of concentrate required to cover a field of crops} = \text{number of full 15L spray solution} * \text{volume of concentrate to be placed in 1 full sprayer tank}$$

$$\text{Amount of concentrate required to cover a field of crops} = 2.6 * 15\text{L} = 39\text{L}$$

Applying foliar fertilizer solutions (Spraying)

In order to learn more about spraying, it should be noted that some of the data required for this has already been identified and justified above. Let's assume they are manually putting the foliar solution on the ground. It might be challenging to equally spray a large field (approximately 1 hectare) with several spray tank filings. Due to that they occasionally need to go back and re-spray all the crops when they still have some solution left. The entire crop field needs to be thoroughly and evenly sprayed with all of the prepared solutions. So, it is preferable to divide the crop field into equally manageable sections so that spraying will be simpler and more even. Using our example, each block of the crop field might be such a manageable part. To calculate the quantity of solution to be applied to one manageable portion of the crop field with the recommended amount of foliar solution, the total amount of solution that needs to be sprayed on the entire crop field should be divided by the number of manageable parts of the crop field (for example, three). The calculations that follow:

$$\text{The required volume of foliar solution to cover 1 controllable section of the agricultural field} = \frac{\text{total require volume to spray all the field}}{\text{total number of agricultural field parts}}$$

If they have 39L liquid volume to cover the entire field and there were 3 equal parts of the field to guarantee achieved same spray distribution. So, the required volume will be 13L manageable part.

The findings indicate that each manageable area of the agricultural field would require 13 L of the foliar solution to be sprayed. This capacity is less than one complete spray tank and is 2 L less than 15 L. They must now use ratios of proportion to calculate the amount of foliar concentrate to add to 13 L of water. A 15 L spray tank is much larger than this volume. It would be preferable to use a sprayer with an 8 L or 10 L capacity. This is since sprayers with a big capacity should not be used to deliver little solution amounts. This might also be resolved by splitting the agricultural field into two more manageable sections.

Make sure you administer all the necessary foliar solution to each manageable section of the crop field (one of the three portions), even if this necessitates evenly spraying the solution on plants numerous times to consume it completely. The major objective is to ensure that each solution is applied evenly to each plant. Spraying should be done as steadily as possible to ensure each plant receives an equal amount of solution. At the end of the spraying, every plant should have absorbed all of the foliar solutions. Don't overspray a field, leaving no spray left over for the plants that are still there.

Applying foliar fertilizers in a solution mixture

When spraying, pesticide solutions are frequently combined with foliar sprays. But, they have seen from the two examples that the amounts of foliar and pesticide solution sprayed over a specific area might vary significantly. The volume of concentrate would be adjusted to fit the desired volume of water as the perfect solution to this issue. The desired volumes, using our examples, might be either 100L or 200 L of water. For instance, if they dissolve the foliar concentrate in 100 L instead of 1 L, the ratio of 0.5L of foliar concentrate to 100 L of water will be changed from 1 L to 200 L. It is important to note that the former solution concentration is still maintained because the old and new foliar concentrations are the same. Hence, they can mix 100 L of water with 0.5L of foliar concentrate and 75 ml of pesticide concentrate. They would therefore need to add 150 ml of pesticide concentrate for every 200L of water, even though the solution concentration would still be 75 ml.100 L^{-1} of water if they decided to dissolve both the foliar and pesticide concentrates in 200L of water. Keep in mind that proportional ratios can be used to calculate how much more concentration to add to the necessary amount of water. However, if the two cannot be combined into a single foliar-pesticide solution mixture, they must take into consideration.

Optimizing foliar fertilization use

The phrase "optimizing foliar fertilization use in the fields" is fairly generic and open to several interpretations. At one extreme, it may mean using as little foliar as possible while still getting the desired results in terms of plant growth and productivity. Yet, it is likely, if not guaranteed, that foliar fertilizer will continue to play a crucial role in effective and efficient food production in the near future (Javanmard *et al*., 2022). Importantly, foliar spraying techniques are necessary for adequate crop production outside of the developed world, including the use of fertilization in the form of a solution. In order to assure optimal practices, this review, which acknowledges that foliar application use will occur, aims to compile the vast array of scientific research relevant to different crop kinds. This will be done by monitoring crop development and production, refining how it is prepared, and applying it. Furthermore mentioned is the idea of "enhancing" or creating a novel way to maximize foliar utilization. Yet, as this is a topic in and of itself, it is better left to publications with greater expertise. The monitoring of usage, and technological advancements in the application, including specialized and sprayer applications, are all thoroughly covered in this review. Also, as rational foliar use is a development of integrated fertilizer management strategies, it must be taken into account as a key component of any optimization discussion. Fig. (11) illustrates the complicated connection between foliar fertilizer requirements of crops and crop growth till yield. If the amount of foliar spray is unstable, there are limited and unfavorable potential concerns related to the presence of nitrate residues in foods. It is also crucial to consider the unquestionable advantages of the management of foliar fertilizer applied to leaves on both vegetative crop growth and yield.

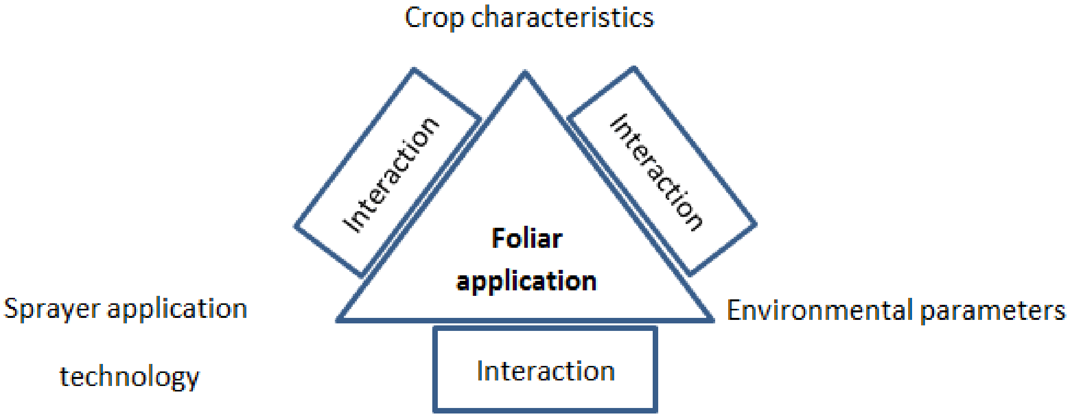

Fig. (11): Factors related with foliar fertilization.

The effectiveness of foliar application use can be increased when each of the parameters addressed in this review is taken into account separately. One can realistically envision an optimization in the use of foliar fertilization without compromising the quality and efficiency of the crop or the environmental impact when the advancements in crop features, sprayer application technologies, and environmental circumstances are combined. All attempts to alter foliar treatment procedures must be supported by the need to measure current behavior and evaluate the impact of any changes on crop development and yield. Statistics on the amount of foliar fertilization are gathered, and their interpretation forms the basis for tracking the effects of policy and legal changes. However, the properly gathering and analyzing of precise usage data is challenging and necessitates both caution and a thorough understanding of regional agricultural methods to protect crops during spraying from burns, especially when the concentration is too high.

According to a straightforward interpretation, the use of this range of substances, such as nitrogen, phosphorus, and potassium has increased in recent years. Yet, a number of elements have a direct impact on the foliar application's results and have helped to improve crop yield. Notwithstanding the complexity of the factors influencing changes in the usage of foliar fertilization, such survey data offers the greatest known baseline to assess changes in foliar application policies and practices.

Foliar fertilization application

Suppose foliar fertilization is employed in crop farming. In that case it is critical that the methods used to apply fertilizers are as effective as possible in aiming the active component at the stage at which it has the greatest impact on the intended section of the plant objective. It is necessary to simultaneously minimize fertilizer losses to the environment while also considering unintended targets, bystanders, and other areas. The review makes an effort to investigate the intricate physical processes and interactions that influence the efficient, focused distribution of foliar throughout agricultural applications. It also understands that the effectiveness of sharing best practices directly relates to efficacy and environmental impact. One of the spraying technologies used for foliar application does not start and stop at the place of usage. It is well known that choosing appropriate parameters, such as nozzle type, nozzle size, spraying height, working pressure, type of fertilizer, and the concentration to use, are crucial for increasing spray deposits on the target and reducing operator exposure and point-source pollution caused by pre-use handling operations. Depending on the characteristics of the plant, some manufacturers may have a considerable interest in standardizing sprayer designs. The discussion of sprayer technology, the layout of specialized spraying apparatus, and the various application techniques carry on this theme. A consideration of fertilization science is added to the difficulties of foliar application methods. The development of a practical and stable formulation of foliar fertilization that has precise chemical and physical properties to enable the delivery of the active ingredient to the leaves of the plant intended is central to this topic. Although the focus of this review is on developing a foliar application for crops using spray application equipment, it acknowledges that, first, the same considerations apply to other areas of application, and, second, formulation science, fertilizer concentration at the time of application on the plant's leaves, as well as influence the product's final safety and efficacy on crop production.

Finally, methods for maximizing the use of foliar fertilization might be the best examples of pragmatism. The "how, which, when, and why" of foliar fertilization is applied in a simplified schematic of the process (Fig. 12), which covers the topics covered in this review. These factors are crucial to the approval procedure and the post-approval, iterative reevaluation of chemicals and procedures. How can a certain chemical or technique be used in order to lessen its effects on crop leaves, crop yield, people, and the environment? What methods and tools are available to reduce the impact?

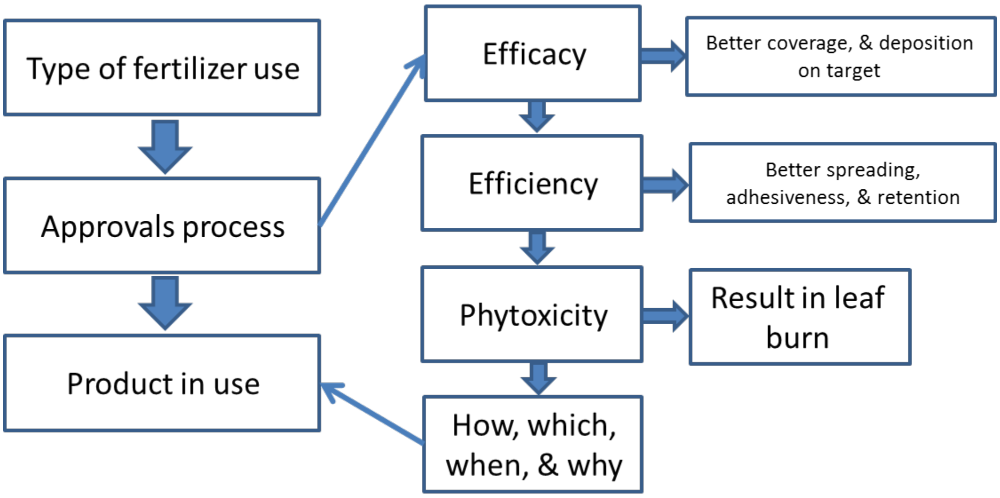

Fig. (12): A simplified diagram of the foliar fertilization approvals process.

When should a specific fertilizer be applied as a droplet spray and, less crucially, when should it not be applied to the leaves because the benefits of its use are limited or occasionally without any change in the characteristics of the vegetative plant and yield, then the amount of the risks are increasing, especially when spraying at the worst metrological condition?

Exist any fertilizer alternatives that are easily accessible without affecting crop growth and yield?

Why utilize a specific new foliar technique or application when soil fertilization is already done?

Which approach is the most effective one that is currently available? Again, are there many options? Available?

Finally, while alternative and complementary techniques for foliar application have advantages in certain situations, they do not provide actual amount of nutrients for the plant without repeating it several times depending on the type of plant, growth stage, plant age, leaf age, and metrological conditions. They are unlikely to result in an idealized agriculture system without the use of soil fertilizers. Using a pragmatic strategy based on a solid understanding of the foliar application method is the best way to optimize the use of foliar fertilization and minimize soil fertilization as much as possible in the agricultural process.

Advantages and disadvantages of foliar fertilization

Many benefits come with foliar fertilization. On the other side, numerous drawbacks exist if they are used improperly. As a result of the following factors, foliar fertilization is most commonly used in fields for the following reasons:

1. It is usable throughout the entire growing season.

2. A low relative cost for the application.

3. Prevent issues with the soil's structure, moisture, temperature, and other factors.

4. Quick crop response to address the deficiency.

5. A tiny amount of fertilizer and a different nutrient solution's composition from the soil fertilizer was applied at the time.

6. A large amount of fertilizer absorbed the leaf's plant parts.

7. Reach out quickly to the stomata or symptoms.

8. Suitable for the unique requirements at various stages of crop development.

9. Accelerate the mineral components' quick absorption.

10. Prevent soil interactions that could restrict root absorption.

11. Encourage the root system's capacity to take in nutrients from the soil solution.

12. Nutrients may be absorbed much more quickly than soil nutrient uptake.

13. Quickly treat physiological issues brought on by nutritional deficits.

14. Overcoming challenging weather circumstances to apply fertilizer. Additionally, it aids in overcoming numerous stress-related issues.

15. Improving both the vegetative crop growth and yield.

On the other hand, there are drawbacks to foliar fertilization application, including the following:

1-When sprayed with high concentrations of liquid fertilizer, some plant parts, mainly leaves, burn.

2-The cost of multiple applications can be prohibitive depending on the type of fertilizer and application method using modern technology.

3-The low solubility of some fertilizers, especially in cold water.

4-Incompatibility with certain other agrochemicals.

5-Sensitivity of foliar absorption by pH value for liquid fertilizers.

Conclusions and perspectives

Foliar fertilization can be used on crops to increase the effectiveness and speed of using of a nutrient that the crop urgently needs to achieve the greatest crop development and production. The development and productivity of vegetative crops were significantly impacted by the use of foliar fertilizer in agricultural plantations. Also, it demonstrated a practical, cost-efficient technique to lessen the environmental impact, especially when selecting suitable parameters for agricultural sprayers such as nozzle type, nozzle size, operating pressure, and spraying height. No additional information is available regarding the advantages of this approach for several important crops. Further research on these crops is necessary to ensure and optimize their responses to foliar fertilization treatment. Foliar fertilization is sometimes regarded as a crucial method of assisting soil fertilizer to continue crop growth in an acceptable state.

The advantage of foliar fertilization could be included as a part of the technology for growing different crops planted.

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Conflicts of interest

The authors declare that they have no conflict of interest.

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تقنية الرش والتطبيق الورقي في انتاج طبقة ناعمة من الرش: مراجعة بحثية

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المستخلص: يعد استخدام الأسمدة الورقية في زراعة المحاصيل مسالة مهمة في العديد من الدول. اجريت العديد من الدراسات المختلفة حول هذه الطريقة، خاصة مع اشجار الفاكهة والمحاصيل البستانية. نفذت القليل من الدراسات على المحاصيل الأساسية مثل الذرة مقارنة بالخضروات. فيما يتعلق بالمحاصيل، فان غالبية هذه الدراسات، نفذت باستخدام الرش الورقي بالفوسفور والبوتاسيوم. طبقت بعض المحاولات باستخدام السماد الورقي النيتروجيني خلال الموسم بتراكيز مختلفة بدءا من المرحلة الأولى للنبات. يمكن رش الرش الورقي بتركيز مناسب اعتمادًا على نوع المحصول المزروع، ومرحلة النمو، وعمر الورقة، والخصائص الفيزيائية والكيميائية لمحلول الرش. بينت المقالة الحالية، ان هناك دراسات سابقة حول هذا التطبيق مع تفاصيل غير كافية بالآليات والتأثيرات التي تحكم بامتصاص المغذيات من الأوراق التي لا تزال غير واضحة. لا تزال بعض المعلومات غير الكافية حول تأثير الأسمدة الورقية بمعدلات استخدام مختلفة أحد الأسباب التي ركزت عليها الدراسة، والتي ربما كانت السبب الرئيسي للتأثيرات المثيرة للجدل في بعض الأحيان مع الإبلاغ عن الأسمدة الورقية. أظهرت معظم الدراسات السابقة أنه من الضروري تطبيق السماد الورقي على أوراق النبات بتركيز مناسب ومعدل تطبيق متوافق مع عمر المحصول المطبق. كما أظهرت النتائج أن تركيزا مناسبا من السماد الورقي يؤدي بلا شك إلى تحسين من فاعلية الأسمدة ويمكن أن يزيد من نشاط نمو النبات، خاصة عند الرش بالتقنية الحديثة. لذلك، للحصول على أفضل نمو نباتي للمحصول واستجابته للتسميد الورقي، من الممكن تشخيص مرحلة النمو المثلى للنبات وعمر الورقة لبدء استخدام الأسمدة الورقية المتعلقة بالظروف الجوية مثل درجة الحرارة والرطوبة في وقت التطبيق الورقي. من الضروري التوصية بمرحلة نمو المحصول قبل تطبيق الأوراق بمعدل تطبيق وتركيز معروفين على المحصول لتحقيق أقصى قدر من الكفاءة وبتكلفة منخفضة قدر الامكان.

الكلمات المفتاحية: طريقة التطبيق، الرش الورقي، خصائص قطرات الرش، إعداد المرشة.