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IPA - Systemic nutrition in foliar fertilizers

INTRODUCTION

The genetic improvement in plant varieties and the use of fertilizers (NPK) and plant care products have made an enormous contribution over the last 50 years to the development of farming. Such intensification has, as a result, underlined the limits of fertilization based solely on the major nutrients by revealing the predominant role of other nutrients such as micronutrients or certain organic substances present in smaller quantities but just as essential to good crop development.

Today the micronutrients which are proposed to farmers in the form of foliar fertilizers, with formulations specifically adapted to the needs of different crops, are designed either to prevent or to correct certain deficiencies. In recent years, a number of improvements have been made to the effectiveness of such foliar fertilizers: complex forms of micronutrients and amino acids which boost their assimilation, the use of betaine glycine as a biostimulant and a factor of resistance to hydric and thermal stress.

The product with the code of "IPA", corresponding to substances in the Adenine family, is an example of this trend. Various studies have illustrated the big part of these molecules which are acting on the phenomena of nutrient migration in plants, stimulation or protection of the photosynthetic organism and induction of a number of stages of crop development.

Of these phenomena, particular emphasis will be placed on the outstanding innovation generated by the effect of IPA on the systemic action of the nutrients in the plant. All these elements boot yields and crop quality.

THE IPA PRODUCT - ADENINE-TYPE MOLECULES

The product referenced "IPA" corresponds to adenine derivatives: it is made notably from molecules extracted from seaweed.

The process used to procure the marine molecules includes a hot extraction phase in an acidic medium followed by various separation and concentration-purification phases permitting the standardization of the product.

Identification was led by Van Staden and his team after passing the marine extract over a cation exchanging resin. As a result of isolation and analysis by HPLC followed by a soybean callus assay of the activity of the adenine-type molecules, two main regions of activity were detected (Figure 1).

In one of the regions, two of the peaks were identified as isopentenyl adenine and its riboside, isopentenyl adenosine (1). Experiments were carried out on the IPA product alone and together with various foliar fertilizer formulas.

SYSTEMIC ACTION FOR IMPROVED EFFECTIVENESS OF FERTILIZER NUTRIENTS

The systemic effect of IPA has been demonstrated on the systemic action of amino acids and of micronutrients presented either under their mineral form or under a complex form of amino

Figure 1 - Adenine-like activity detected in marine using the soyben callus bioassay after purifying by cation exchange/chromatography, isolation and identification by HPLC

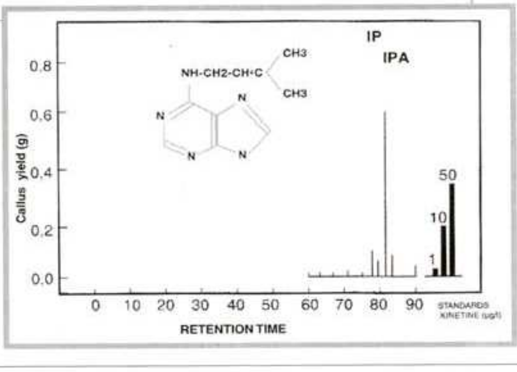
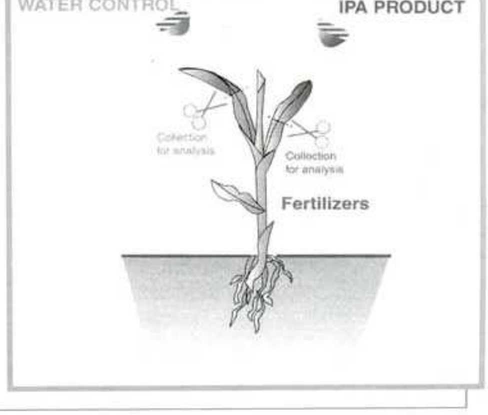


Figure 2 - Experimental scheme to illustrate the systemic effect



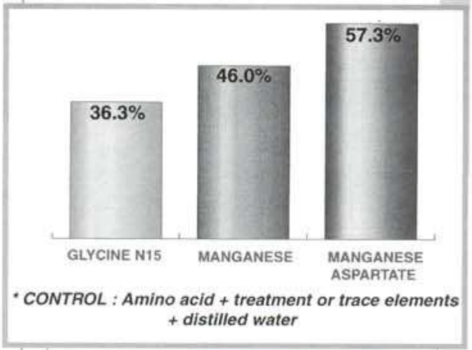


Figure 3 - Effect of IPA on the systemic action of plant nutrients

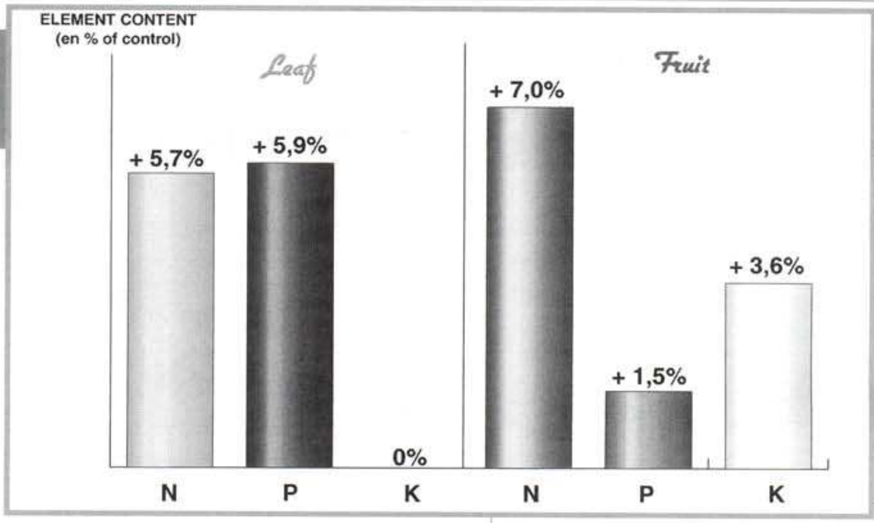


Figure 5 - Effect on the mineral composition of leaves and fruit on pear trees

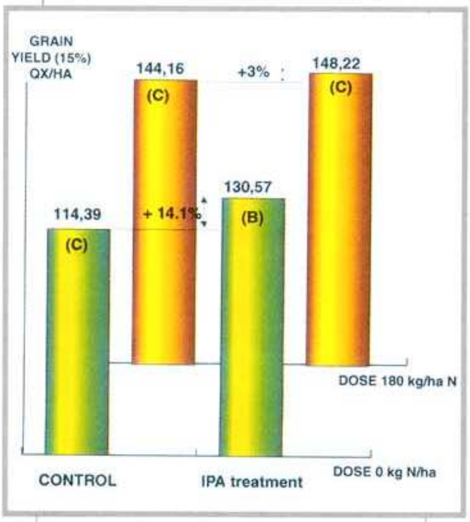


Figure 4 - Influence of the IPA treatment on the grain yield of maize (two levels of nitrogen: 0 and 180 kg N/ha)

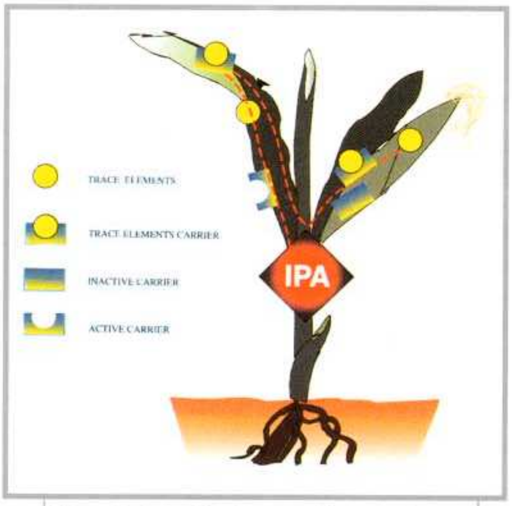


Figure 6 - Synoptic diagram of transport process of elements in the plants

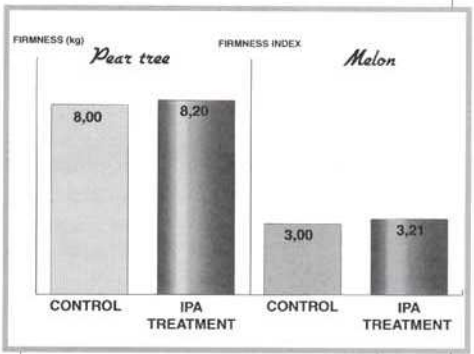


Figure 17 - Effect of IPA on the firmness of fruit

amino micronutrients. The migration rate of such nutrients has been determined on a maize crop with and without the use of IPA.

The applications of plant nutrients and IPA are brought separately. The IPA is sprayed on the upper third of the leaf next to apex whereas the amino acid or micronutrient treatments are either deposited or sprayed locally on the lower third of the leaf on the petiole side. The amino acid, micronutrient and amino micronutrient treatments are applied respectively using a glycine N15 solution, manganese nitrate and manganese aspartate. The foliar samples from the upper third of the leaf are made 24 to 72 hours after treatment. The micronutrient or amino acid content is then determined in order to assess the improvement in the migration rate compared with the reference (Figure 2).

We can note a remarkable effect of the IPA treatment on the systemic transportation of the various plant nutrients with a superior migration rate over the reference of more than 36% for amino acid, 46% for manganese and more than 57% for the amino micronutrient. The IPA substances therefore guarantee more effective fertilization (Figure 3) in amino acid and manganese.

The effect of foliar treatment with the IPA product has also been shown on the systemic transport of N, P, K elements which are in the soil. Experimentation has been made in pots on a spring culture of hard wheat. IPA extract is pulverized at the beginning of stem extension . Young plants of wheat are cut at heading step when starmens come out. The lower part of stems is squeezed in order to get back juice. Nitrogen, phosphorus and potassium analysis is made on this juice and results are expressed in mg/ml of sap. Treatments with the IPA extract are significantly different from the control, on the threshold of 80%. We can note according to the quantity an absorption improvement of 54% for nitrogen, between 10 and 18% for phosphorus and between 4 and 9% for potassium.

Other experimentations have confirmed this phenomenon by stressing specially the IPA efficacy on nitrogenous nutrition. Villais (2) has particularly emphasized a beneficial effect when there was no nitrogenous fertilization. In the absence of a nitrogen fertilizer, Villais also illustrates the beneficial effect of the treatment on the soil nutrient assimilation in maize. It is conveyed by a significant increase in the foliar protein content at the ensilage stage, up from 6.74 to 7.96 mg of protein per gram of dry matter (i.e. +18%) in a nitrogen-depressed situation.

During another test, in the absence of nitrogen, supply IPA generates a significant increase in yield, in excess of 14% over the reference. When a nitrogen dressing of 180 units is applied, the increased yield which is non significant is still favourable to the IPA treatment (+3%). It is also noted that the drop in yield caused by an absence of fertilization compared to a 180 unit nitrogen dressing is 30 quintals per hectare between the reference plants without IPA. The difference is only 16 qx/ha between the maize crops treated with IPA (Figure 4).

In an orchard of Williams pears, we showed the favourable effect that the IPA treatment has on the mineral composition of the leaves regarding their contents in N and P and fruits contents in nitrogen, phosphorus and potassium (Figure 5).

Let us present processes which are running the performance of substances such as IPA ones. Present both in the raw sap and in the elaborated sap. They would condition the transportation of nutritive substances in the plant by controlling the formation and regeneration of carriers (Figure 6). The carrier molecules, activated by the IPA-type substances, appear therefore to attach themselves to the nutrients before routing them to all parts of the plant.

The nutrients would then be deposited at storage or growth sites by the inactivation of the carriers. The molecules, freed of their contents, would be reactivated by the action of the IPA substances and be available once again for the transportation of other nutrients, and so on …

The results of our work relating to the study of the migration of locally applied amino micronutrients and marked amino acids to areas

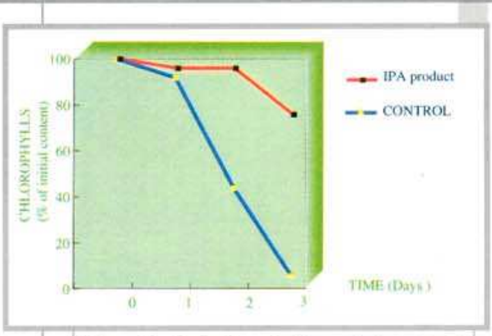


Figure 8 - Evolution of chlorophyll content of excised barley leaves during 3 days after cutting

treated in the presence of IPA substances respond to mechanisms described below. Under nitrogen-limited conditions or at the end of cultivation, the IPA substances would also appear to improve or extend the protein synthesis phase by delaying the blockage of carriers.

PHOTOSYNTHETIC PERFORMANCE FOR OPTIMAL PRODUCTIVITY

Photosynthesis Stimulation

Adenine-type substances have long been known for their effects on photosynthesis. Several studies have notably demonstrated their stimulating action on the synthesis of chlorophyll pigments while acting on chloroplast differentiation. They are also capable of restoring chloroplastic structures and inducing chlorophyll synthesis once again in etiolated leaves (3). According to Steher and Laetsh (4) the presence of such substances is essential for chlorophyll build-up.

Several experiments carried out on IPA have confirmed the effects on the photosynthetic organism with regard to the synthesis of chlorophyll and starch. IPA therefore induces a significant increase in the chlorophyll content from the very first month of cultivation in peas, beet and maize (2) (Figure 7). These results are also confirmed on field crops of maize. At the ensilage stage, the chlorophyll content differs significantly from over 7 to 15% (P > 0.01-0.5) in favour of IPA treatment in relation to the reference. The stimulating effect on photosynthetic activity is also underlined on the starch synthesis. During the daytime, the leaf synthesizes glucids accumulates starch which is hydrolyzed at night and is being transported to the storage sites. Experiments were conducted on adult young plants exposed to light during ten hours. The leaves were then removed decolorized in boiling alcohol and treated by an iodized solution which shows the presence of starch. Regarding the plants treated with IPA, the strong brown colouring reveals a far greater build-up of starch compared to the reference plants, i.e.a. more intense photosynthetic activity.

Photosynthesis stimulation appears through a better vegetative development and then a favorable effect during flowering time .

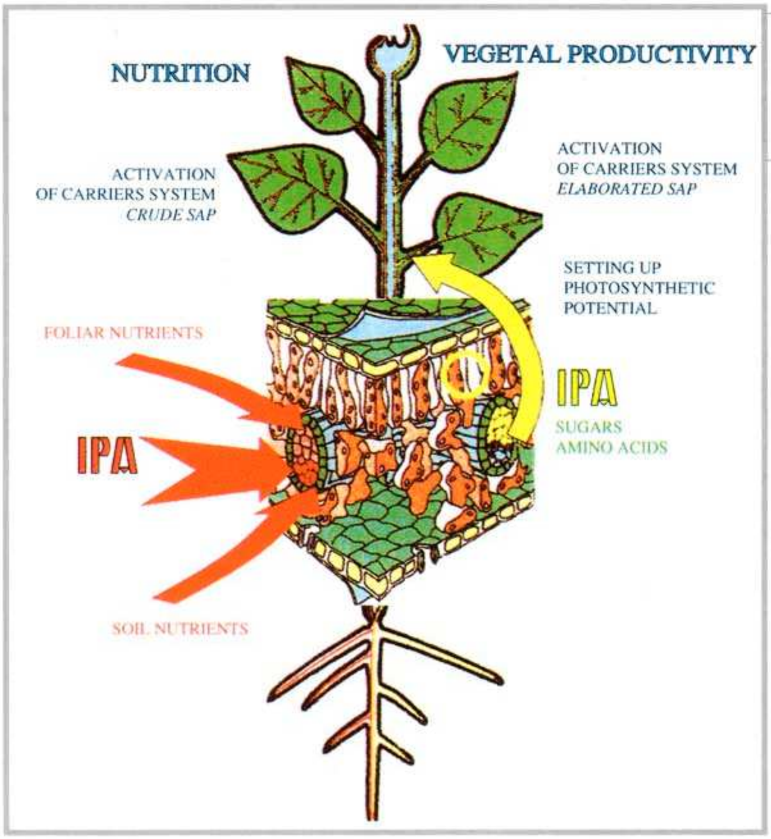
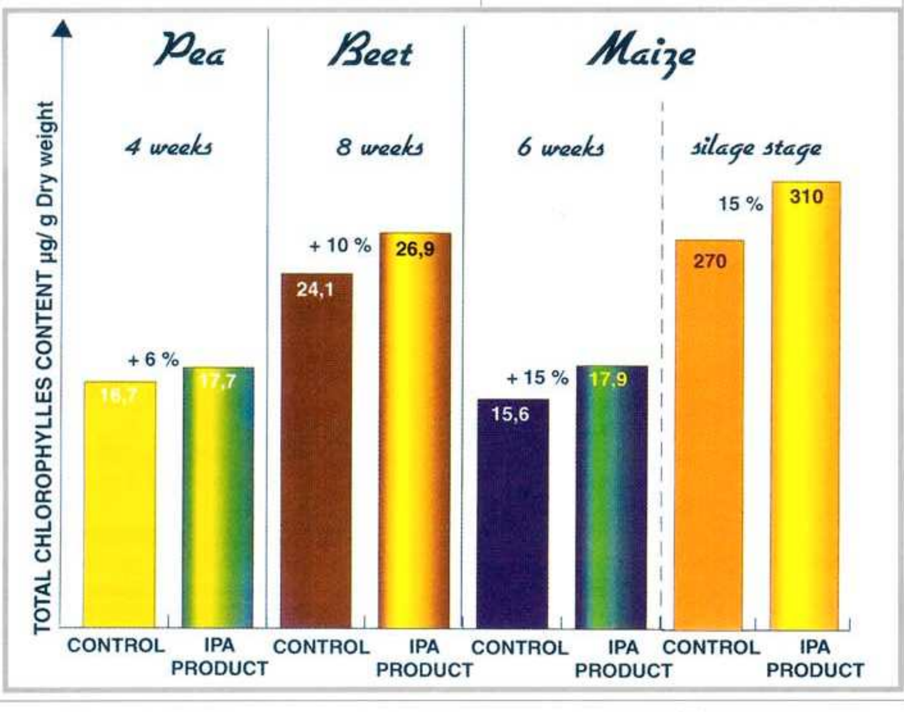


Figure 18 - Block diagram of IPA actions on the crop

Figure 7 - Influence of the IPA treatment on the chlorophyll content of various crops



Protection

In plants, senescence manifests itself by the synthesis of proteolytic enzymes and chlorophyllases, initiating the degradation of protein and chlorophyll respectively. The adenine-type compounds can extend the phase of photosynthetic activity by maintaining the synthesis capacity of RNA and proteins they defer the synthesis of the proteolytic enzymes and chlorophyllase (5,6). This phenomenon is also observed in excised barley leaves treated with IPA. In this case, 94% of chlorophyll is destroyed in three days for untreated leaves whereas treatment with IPA preserves 76% of the initial content (Figure 8).

The application of IPA on field crops of maize at the three or four-leaf stage or peas at the flower bud stage appears through the presence of a greater quantity of chlorophyll and, the prolongation of photosynthesis during the

Figure 9 - Maintenance of photosynthetic activity in lower leaves in maize at the end of cultivation

senescence phase of the crop. In maize, this effect was marked by the fact that the lower leaves drying out is delayed (Figure 9). In peas, the photosynthetic activity which was extended by almost a week compared with the reference itself by producing fuller grains and pods.

It can therefore be assumed that IPA, like all other adenine-type substances referred to in the literature, controls the set-up of photosynthetic structures and the build-up of chlorophyll. In this context, IPA would also act on an early stage of senescence by delaying the appearance of messenger RNA which precede the degradation of the plastidial system.

In summary, IPA would control the set-up and maturation of photosynthetic structures and the build-up of chlorophyll and delay the appearance of messenger RNA responsible for chlorophyll degradation. In other words, IPA substances would improve photosynthetic productivity then delay the degradation of the plastidial system at the end of cultivation in favour of the yield.

BIOSTIMULATION, FOR IMPROVED CONTROL OF THE STAGES OF DEVELOPMENT

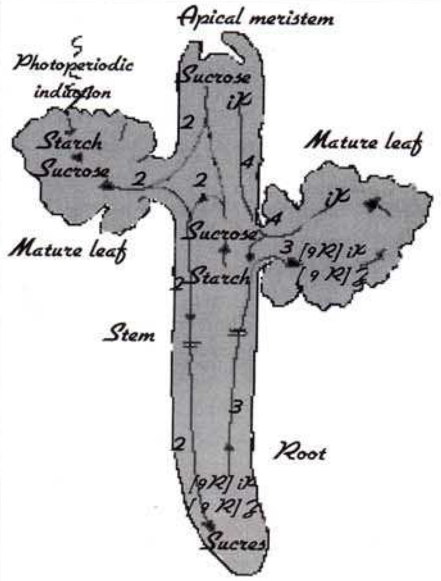
Vegetative Biostimulation, Floral Induction and Fructification

Stimulation of photosynthetic activity favourable to the vegetative development of the crop will also play a decisive role during the stage of transition to flowering.

This transition, generally under the control of photoperiodic induction, is conditioned by an increase in the various endogenous substances comprising carbohydrates (sugars, etc.) and adenine-type compounds. Floral induction is thus a result of the concomitant increase in the flow of these compounds and the interactions between their flows. The increase notably in Isopentyl Adenine in the raw sap is said to be essential to growth and flowering. Similarly, the increase in sugars from the starch leads to the activation, in the foliar and apical meristems, of a variety of processes such as cell division which is particularly active during the vegetative growth, flowering and fructification of the crop (Figure 10). The effect of IPA was firstly shown during the vegetative growth phase and, more specifically, on the implantation of the crop.

For example, IPA treatment combined with a liquid NP (Mg) fertilizer on wheat at the suckering stage reveals, twelve days after treatment, a favourable action on crop development with a gain of 26.8% in the vegetative organism and 16.8% in the root system over the reference plant. Under these conditions, the contribution of the NPMg fertilizer is just 7.4% and 14% respectively (Figure 11).

Afterwards, the effect of IPA on floral induction and fructification was subsequently confirmed.



Step 1 (way arrow) : perception of LD induction by mature leaves;
Step 2 (solid arrow) : starch mobilization in leaves and stem followed by transport of sucrose in the phloem to both the apical meristem and roots;
Step 3 (dashed arrow) : transport in the xylem from roots to leaves of zeatin riboside ([9R]iP);
Step 4 (dotted arrow) : transport in the phloem from leaves to the apical meristem of isopentenyladenine (iP).

Figure 10 - Diagram of a regulatory loop participating in the control of the transition to flowering in *S alba* and involving sucrose and adenine substances (8)

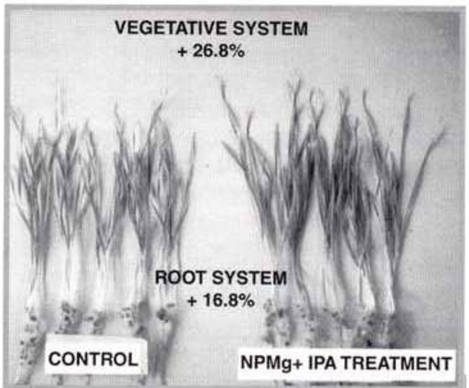


Figure 11 - Effect of IPA enriched N P Mg fertilizer on the development of wheat after 12 days of treatment

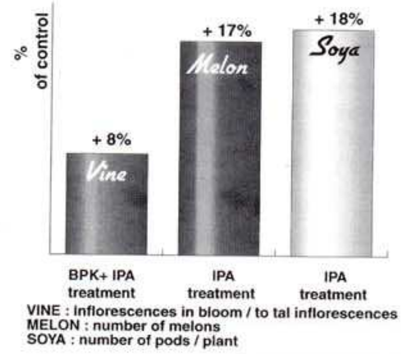


Figure 12 - Effect of IPA with or without liquid fertilizer on floral induction and fructification

The application of IPA to melon cultivated in tunnels was thus translated by an increase of over 17% in the number of melons produced in relation to the reference (Figure 12).

The effect on floral induction has also been illustrated for other plant varieties. For instance, the application of IPA combined with a liquid BPK fertilizer in a vineyard stages A/B/C increase the percentage of inflorescences brought to flower expressed in relation to the total number of inflorescences from 56.8 to 61.2% between the reference and the treated plant. Villais (2) shows that similar effects of IPA applied alone to soybean at the two to three-leaf stage in poor soil increases the number of pods per plant by 18% ($p=0.01$).

Tuberization

Adenine-type compounds, and notably isopentenyl adenine, play a particularly important role in the formation and development of tubers

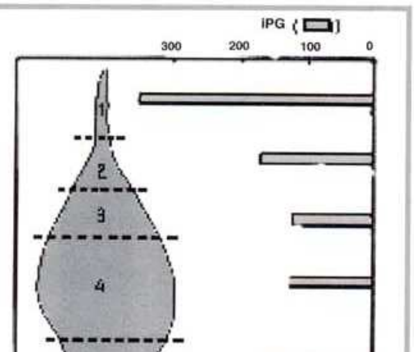


Figure 13 - Distribution of an adenine substance in potatoes

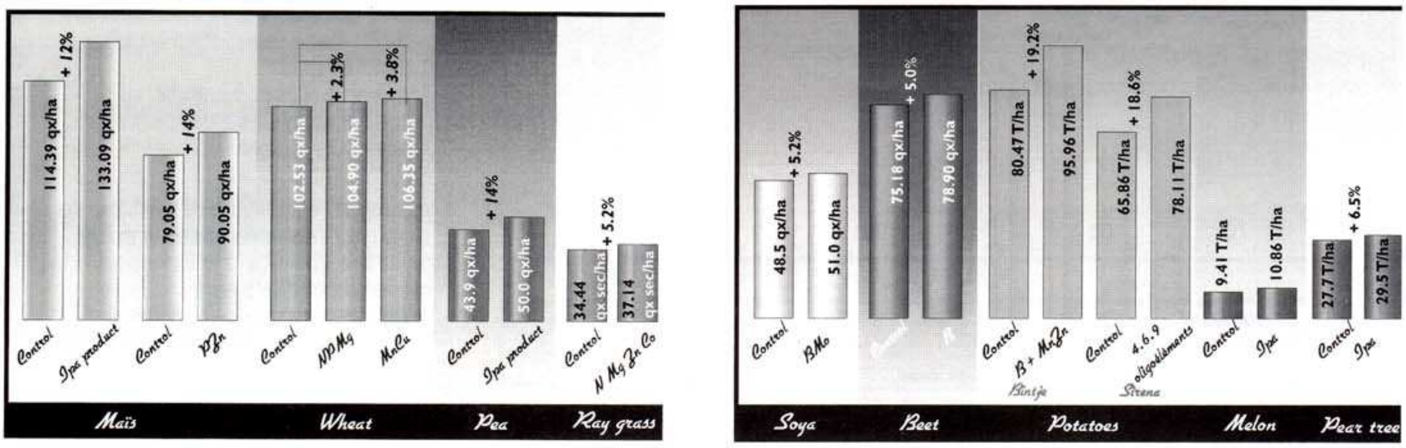


Figure 14 - Effect of IPA alone or combined with various liquid fertilizer formulas

(potatoes, dahlias, etc.) (7).

In potatoes, the higher concentration of adenine-type compounds coincides with the time (30 to 90 days after plantation) when the tuberization rate is at its peak. Adenine content is highest in the proximal part of the stem (Figure 13).

These compounds thus control the growth of the tuber in different ways according to its stage of development by acting either on the inhibition of the vertical growth of underground stems or on the induction and promotion of the horizontal growth of underground including cell division and expansion on the stimulation of transportation and build-up of carbohydrates accompanied by cell enlargement in the tubers.

The study carried out on the Sirtema variety has shown, after treatment of the crop with a 469-micronutrient fertilizer, a reduction in the number of small tubers for the potato ready for consumption.

AGRONOMIC EXPRESSION

Yield

The combined effects of IPA on the systemic action of plant nutrients, photosynthetic activity and the biostimulation of certain phases of crop development lead to increased effectiveness of fertilization.

Experiments carried out in the field during several years have been conducted on various major crops and on a number of speciality crops (Table I). Figure 14 illustrates some of the results obtained with IPA alone or combined with liquid fertilizer formulas. These formulas are designed to fulfil the specific needs of the crops.

An analysis of these results confirms the beneficial effect of IPA which increases the effectiveness of the nutrients from the soil or liquid fertilizers. Depending on the crop and the experimental conditions, this effect produces a 2 to 20% increase in yield.

Quality

Size

The benefit of IPA as a complement to liquid fertilizer is not limited to the sole factor of yield. It also has a positive effect on quality.

In fact, for certain speciality crops, an increase in yield is today no longer a decisive criterion especially as, in fruit growing, such an increase is generally countered by a reduction in size and gustative quality. Yet tests carried out on melons and pears have seen the yield increased while

Table I - Characteristics of experimentations made on the IPA product combined or not with foliar fertilizers

CROP	FOLIAR FERTILIZERS Denomination	Composition (g/l)	Dose (l/ha)	Supply number	Application stage
Maize	N PZn	40 g/l ureic nitrogen 190 g/l P (P 205) 60 g/l Zn	4	1	5-6 leaves
Pea	IPA				floral bud stage
Wheat	N P Mg	47 g/l N 438 g/l P (P 205) 63 g/l MgO	2	1	Tillering
	MnCu	60 g/l Mn 40 g/l Cu	2.5	1	
Soya	BMo	70 g/l B 4 g/l Mo			3 trifoliated leaves stage
Beet	B	80 g/l B	3	1	A/B
Potatoes	B + MnZn	70 g/l B + 60 g/l Mn / 44 g/l Zn	1.5/1/1	3	20 cm / +15 days/+15 days
	469 oligo-elements	4, 6, 9 1.3 g/l Mn 0.65 g/l Zn 0.65 g/l B 0.26 g/l Cu 0.26 g/l Fe 0.13 g/l Mo	5	4	20 cm/+15 days/ +15 days/+15 days
Vine	BPK	13 g/l B 78 g/l P205 160 g/l K_2O	8	3	G/H/J
Melon	IPA			1	2 leaves stage
Pear tree	IPA			1	Stage F
Ray grass	N Mg Zn Co	200 g/l total nitrogen 90 g/l MgO 0.45 g/l Co 22 g/l Zn	4	3	2 days after cutting

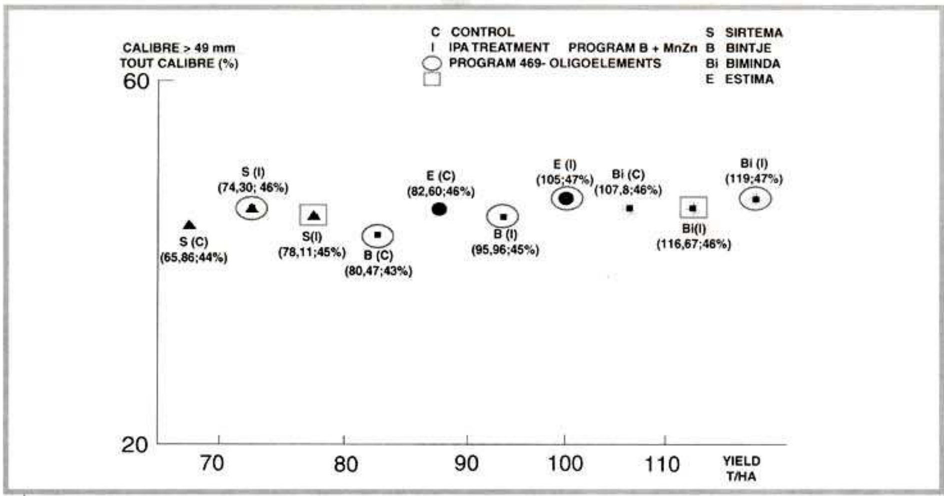


Figure 15 - Effect of IPA combined with two foliar programmes (469 micronutrients and B MnZn) on yield and size maintenance of assorted varieties of potato

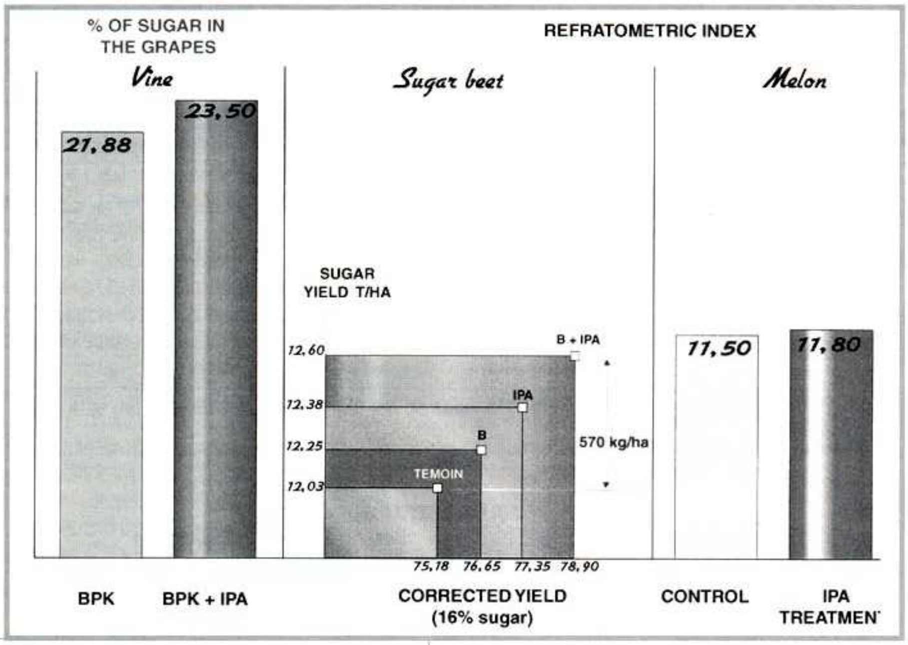


Figure 16 - Effect of IPA on the sugar content or yield

the size of the fruit is maintained or even increased. Therefore, under experimental conditions, IPA treatment tends to be beneficial to the average weight of the fruit which, compared with the reference, is up from 23.7 to 24.7 kg per 100 fruit for pears and from 586 to 663 g per fruit for melon (n>100 melons). This increase in the average weight per melon is particularly the outcome of a reduction of over 57% in the number of small melons less than 10 cm in diameter in spite of a 19% increase in the yield (weight).

A similar expression of IPA is found in potatoes. In fact, the two fertilization programmes using either a 469-micronutrient formula or the combination of a B formula and a MnZn formula generate an increase in yield of between 8 and 27% on Bintje, Bimonda, Sirtema and Estima varieties without affecting the marketable size. The figure thus illustrates that, irrespective of the increase in the yield generated by the various treatments, the percentage of tubers in excess of 50 mm remains constant (Figure 15).

Sugar Content and Firmness

The systemic action of IPA on the nutrients in the raw sap and the nutrients in the elaborated sap (sugar, etc.) combined with the effect on starch synthesis is conveyed in certain tests by an increase of the sugar content, between a BPH formula and the same formula enriched with IPA.

In grapes, the sugar content rises from 21.88% to 23.5%, which corresponds to an increase of 7.4%. This pattern is seen in sugar beet with an increase of 570 kg of sugar per hectare for a Boron-IPA formula compared with the reference. Figure 16 shows the increase in sugar yield between the reference, the Boron fertilizer, IPA and the Boron fertilizer-IPA combination. This increase can be explained by an improvement of roots yields with a retention of the sugar level (18.33% in the reference versus 18.55% with IPA). Similarly, in melons, the refractometric index is up from 11.5 to 11.8 (Figure 16). Regarding the quality field, the tendency of IPA to improve the firmness of the fruit will also be noted. This is the case with pears, whose firmness of which is expressed in kg, is rising from 8.0 to 8.2 kg between the reference and the IPA-treated sample. An identical remark is made in melons, the firmness index is rising from 3.00 to 3.21 (Figure 17).

CONCLUSION

The advantage of IPA resides therefore in its dual control function, both on the transportation mechanism of raw or elaborated nutriments in the plant and on photosynthetic productivity (Figure 18). This discovery therefore introduces a number of applications:

- *In the area of nutrition,* IPA in foliar treatments encourages the active transportation of nutrients not only through the leaf but to the entire plant. Nutriments present in the soil would take advantage as well of this activation of the transportation system.
- *In the area of plant productivity,* this mechanistic action is continued but in this case by promoting the migration of elaborated substances, notably towards areas of growth, developing fruit or grains. This action is all the more favourable as it also benefits from the action of the IPA on the creation of a strong photosynthetic potential.

These new foliar fertilizer formulations therefore generate innovation by introducing the notion of "systemic nutrition" into the area of fertilization. The revelation of the decisive role played by IPA substances marks a new stage in our knowledge of the nutrition and physiology of plants. From a practical viewpoint, as shown by the results of the imposing testing campaign conducted since 1989, this discovery promotes better use of fertilizers both in terms of effectiveness and respect for the environment, thereby raising the quality and quantity of the various types of produce.

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