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IRRIGATION OF VEGETABLE CROPS AS A MEANS OF RECYCLING WASTEWATER: APPLIED TO HESBAYE FROST

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ABSTRACT

Since 1991, a food processing plant which freezes a large quantity of locally grown market garden products, has recycled all its wastewater by irrigating 550 hectares of crops located around the factory. Previously, the 700,000 m^3 of wastewater was discharged into a nearby stream apparently devoid of aquatic life. By adopting this solution, the processing plant was able to avoid paying a heavy tax introduced in 1991 to penalize the discharge of industrial effluent. The alternative of building an independent wastewater treatment plant would have required investment costs two to three times higher and would not have achieved the same degree of water purification as the soil. Irrigation guarantees a continuous supply of a vital good quality ingredient, since the short life cycle market garden crops are very susceptible to hydric stress. A 110,000 m^3 capacity storage tank acts as a buffer between continuous water consumption and seasonal requirements; in addition, by mixing the wastewaters, it stabilizes their physico-chemical characteristics which vary according to the vegetables treated. This processing plant offers the regional agricultural industry hit by European restrictions, a source of diversification; it is perfectly integrated in an environment it not only respects but relies on for the auto-purifying capacity of its biological medium.

KEY-WORDS

Market garden crops; purification; wastewater; irrigation; recycling.

INTRODUCTION

As this second millenium draws to a close, we have to search high and low to find the few remaining unspoilt sites often in inaccessible places such as at the foot of glaciers or everlasting snow. It is hardly surprising therefore that even our smallest streams are affected by various degrees of pollution, with often only the slightest breath of aquatic life. These hydrobiological environments are extremely fragile and vulnerable to pollution from industrial, municipal and agricultural wastewater discharge. However, initiatives similar to the one presented here prove that it is possible to reconcile industrial activities with the quality of the environment by relying on the regulating and purifying capacity of the soil.

HISTORICAL CONTEXT

Although market gardening is not as yet well developed in Wallonia, one of the two states in the new Federal Belgium, it does however offer much scope as a source of diversification for an agricultural system faced with the problems of quotas and set-aside, legacy of the famous common European agricultural policy.

Hesbaye-Frost is a deep-freeze firm located in Geer near a stream. The main locally grown crops are spinach, peas, beans, Brussel sprouts, celery, carrots and broad bean. In 1991, a law was passed making it an offence to discharge wastewater into rivers and streams. Non compliance with the law was sanctioned by a tax which would have placed the firm in a difficult situation : around that time it was discharging into the Geer 704 000 m^3 of water used for washing and processing (blanching, cooking, peeling) the vegetables and cleaning the buildings (Xanthoulis, 1993b). A solution had to be found to avoid paying an additional eco tax amounting to some 30 million Belgian francs (+ 1,000,000 US \$). The only viable alternative at the time seemed to be the construction of a water treatment plant costing between 80 and 100 million Belgian francs (+ 3,000,000 US \$); however, the treated water would not have met the 100% purification standard and the firm would have been fined for discharging incompletely purified water into the stream.

Fortunately, the managers hit upon a somewhat revolutionary plan based on a successful irrigation project implemented by the Market Garden Centre of Hesbaye in 1990.Water from an underground aquifer was being pumped from a well to irrigate vegetable crops. This auxiliary system proved both technically feasible and economically viable (Bernaerdt, 1991). Although it might seem surprising in our rainy climate, shallow rooting vegetables quickly suffer from lack of water. If these plants are ensured a sufficient quantity of water to meet the requirements of their short growing cycle, there is a marked increase in yield and product quality (Hauwaert, 1994). The issue raised was therefore whether the wastewater from washing and processing vegetables could be used for irrigating crops growing in the vicinity of the deep-freeze factory. The Research and Teaching Unit of agricultural hydraulics at the Faculty of Agronomy was commissioned to carry out a study.

This feasibility study was presented to the Walloon Region as an original alternative means of treating wastewater. After their initial hesitation and once they had been assured there was no risk to the environment, the Walloon Region gave the go-ahead.

DESCRIPTION OF THE WASTEWATER RECYCLING PROJECT

Land development prior to the implementation of the wastewater project amounts to approximately 40 million Belgian francs (1,300,000 US \$) and comprises two main elements :

Storage Tank

The storage tank with a holding capacity of 110 000 m^3 is lined with a polyethylene film to prevent any infiltration. It plays has a very important function : it acts like a buffer between the continuous production of water and the seasonal and irregular additional water demands; moreover, it cancels out the substantial variations in wastewater composition : reducing the concentration peaks and neutralising the pH peaks.

Irrigation Network

Four pumps are used to convey water at a pressure of 4 bars and a rate of 240 m^3/h along an 18 km long subterranean network. 550 ha can be irrigated using 5 gun type sprinklers covering 50 m, with a 6 bar pressure, linked to approximately 200 hydrants positioned regularly every 80m along the edges of the fields. A convention between the farmers and the firm sets out the respective responsibilities of the two parties. Whereby, a farmer involved in the project remains so for a period of at least ten years. All the maintenance costs pertaining to the treatment plant right up to the discharge from the pumping station are covered by the firm. On the other hand, the maintenance costs incurred by the network above the plant are the farmers' responsibility.

Operation and Utilization of the System

The irrigation equipment is composed of several reels of hoses attached to a polyethylene flexible hose. The apparatus is connected to a water hydrant, the gun type sprinkler pointing to the field; a tractor tows the travelling sprinkler across the field. Whilst it is being wound back, it pivots around at an adjustable angle and sprays a strip of land.

THE PURIFYING NATURE OF THE SOIL

The purifying capacity of a soil can be defined as the ability of a soil to prevent the leaching of suspended soluble matter from the effluent. The purifying capacity decreases very quickly below the root zone. This depends on the texture and structure of the soil as well as on the type of vegetative cover and the climate (Fleussu, 1994).

It is vital to spread the effluent evenly in order to prevent the soil from being waterlogged or asphyxiated. Irrigation conducted in this manner constitutes an efficient wastewater treatment process; the amount of wastewater is limited to the quantity evapotranspired by the crop to maintain the soil at field capacity thereby eliminating any percolation or runoff. The soil plays the dual role of physical filter and biological matrix. Organic matter and micro-organisms are trapped in the first cms. Vegetation then fulfills 2 vital functions : firstly, by limiting through evapotranspiration, water percolation in the profile. Secondly, by exporting the mineral elements (N,P,K) found in the wastewater.

ADAPTATIONS MADE TO THE PROJECT

Since the beginning of this experiment, adaptations and technical adjustments have been made to enhance performances or eliminate drawbacks. Prior to the implementation of the project, the volume of water used by the firm was halved to 350.000 m^3 thanks to a new design of the production phases in the flow network. This modification inevitably led to certain problems since halving the volume doubled the concentration of elements in the effluent. Secondly, to reduce the salinity of the water, steam is now being used for peeling instead of soda which was the main source of sodium found in the effluent. Thirdly, to ensure aeration in the tank thereby slowing the formation of sludge and eliminating the occurence of unpleasant smells around the plant, the tank was fitted with 18 aerators. Finally, to reduce the organic matter load of the waters, the mashed peel from potatoes, carrots and other root vegatables are separated from the water, and stocked in an autonomous tank prior to being spread between two crops. Suspended matter gives off unpleasant smells and tends to clog up the plant and the soil.

PROJECT FEASIBILITY STUDY MONITORING DURING OPERATION

Let us consider briefly a posteriori, the feasibility of such a project. Any wastewater reuse project must be designed so as to respect the environment, conserve the production potential of the soil and preserve product quality. The physical, chemical and biological charecteristics which can have detrimental as well as beneficial repercussions on these aspects are outlined below (Xanthoulis, 1993a).

Organic Matter

Their degradation through microorganisms leads to the freeing of mineral nitrogen ; this has a beneficial impact on soil structure since its degradation depends on temperature and soil aeration.

Total salt Concentration

This determines the electric conductivity of water and enables the classification of water according to its irrigation suitability.

Influence of Quality on water Infiltration in Soils

To maintain infiltration conditions, the exchange complexes of soils must have a low sodium load. The S.A.R., sodium absorption coefficient determines the risk of sodicity. The infiltration rate increases with salinity whereas it drops if salinity decreases or if SAR increases. Salinity and SAR therefore simultaneously determine a scale for evaluating the risk of degradation of the infiltration capacity.

Toxicity of Certain Ions

Sodium, chlorine and borum depreciate crop yield.

Toxicity of Heavy Metals

These oligo elements are vital to growth but become phytotoxic above a certain threshold. They are also bioaccumulable : they therefore represent a certain risk for soil microflora, plant growth resulting in yield and quality loss in the food chain and even a health risk.

Concentration in Fertilizing Elements

The nitrogen, phosphorous and potassium content in effluents enhance yields except when the concentrations are too high leading to "overgrowth" and affecting quality. The average application rates of mineral elements per plot were respectively 37 kg/ha of available nitrogen, 9kg/ha of P205 and 200kg/ha of K20 in 1993 (Xanthoulis, 1993b). In 1994, different management practices reduced these figures to 17, 10 and 179 kg/ha respectively for these 3 fertilizing elements (Xanthoulis, 1994).

Pathogens

The limit of 1000 faecal coliforms and less than one helminth egg per litre can be stretched somewhat if the plants are cooked prior to consumption. There are no pathogens since the sewage effluent is separated from the industrial wastewaters.

HydrogenCapacity of Water (pH)

The normal range of 6.5 to 8.4 for irrigation water is not often respected but problems of nutrition or toxicity can be overcome through buffering during water storage.

Bicarbonate

Spraying during periods of very low humidity or high evaporation leads to white deposits on plant leaves which is detrimental for their commercial quality. All these parameters were thoroughly analysed and monitored prior to the construction of the irrigation network and are still regularly checked. Stringent restrictions were imposed on the concentrations of sodium and bicarbonates in irrigation water. In the case of sodium, peeling by steam has solved the problem; the theoretical solution to the bicarbonate problem is to irrigate in the morning during dry spells. It should be noted that these two elements in no way present a health hazard to humans or animals. Total salinity and pH are two parameters that need regular monitoring (moderate restriction); the former may affect the infiltration rate of water in the soil and crop yields, the latter, the chemical properties of soils. A drop in sodium content reduces sodium significantly; correction of pH after storage is peformed by adding lime ($CaOH_2$) to attain neutralization of waters.

SOIL MAPPING

Finally, to complete the feasibility study, the Teaching and Research Unit of agricultural hydraulics of the FSAGx has drawn up soil irrigability maps through a GIS system which uses existing spatial and digital data. This data processing system provides topographical, geological and pedological information or more thematic data such as land use. For instance, the underground water table has no affect on the hydric balance since it is situated at a depth of 30m, but along the valleys, it is located less than 125 to 150 cm deep. At the end of the analysis, superposition of these data in a GIS highlights four classes of irrigation potential which determine an irrigation suitability map of the soils in the region.

RESULTS OF CROP PRODUCTION UNDER IRRIGATION

To conclude this project report we will evaluate crop yield response to irrigation. The results after three cropping years are decidedly encouraging. Obviously a certain adjustment period is necessary when modifications are made to the system to overcome or solve any problems which might occur. The next three figures illustrate certain crop responses to increasing rainfall. Summer spinach (Fig. 1) has an increasing response up to 40 mm of additional water (amount of hydric deficit during vegetation period).

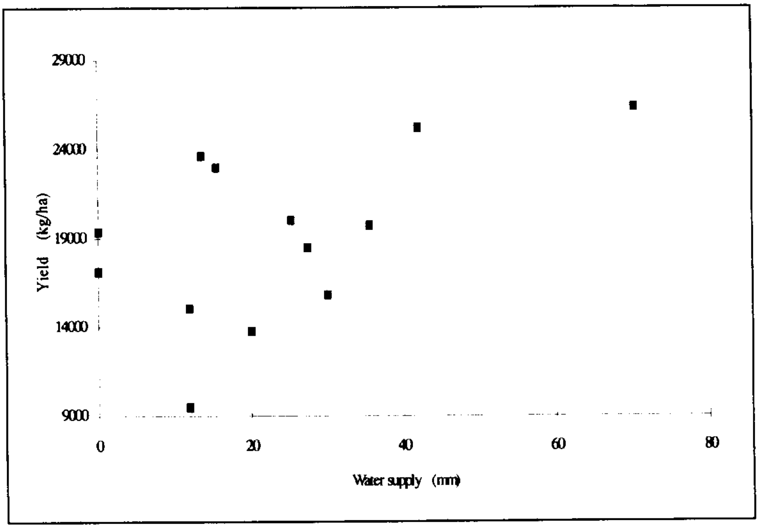

Figure 1. Yields Observed for Summer Spinach depending on Water Supply

Beyond that, the yield remains constant. In autumn spinach (Fig.2), there is an increment in yield response to water according to variety. For haricot beans (Fig. 3), response increases up to maximum yield at around 30-40 mm. The following graphs indicate relative crop yields compared to the general mean observed. The varieties grown in each plot are expressed in the X-axis and the relative yields are given in the Y-axis : they are expressed in percentages of the general mean calculated on the basis of crop results.

Different typescripts were chosen for the name of the variety depending on whether the crop was irrigated during the growing season. Upper case letters indicate irrigation with different types of water : usually wastewater used for washing, but also water pumped from underground aquifers or from local streams. Lower case letters mean that the field received no irrigation. Winter spinach (Fig. 4) is rarely irrigated (in our conditions); it can be seen clearly that irrigated fields have a far greater or at least as good a yield (VALETA) as the highest yield of non irrigated winter spinach. In spring spinach (Fig. 5), in 1994, it can be observed that even if production yields of irrigated plots level off, additional water ensures even in the

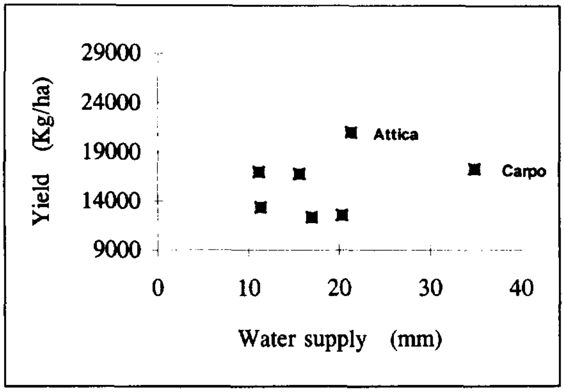

Figure 2. Autumn Spinach Yields depending on Water Supply

least favourable situations a guaranteed minimal yield, except in two cases out of 13 where the results are inferior to 70%.

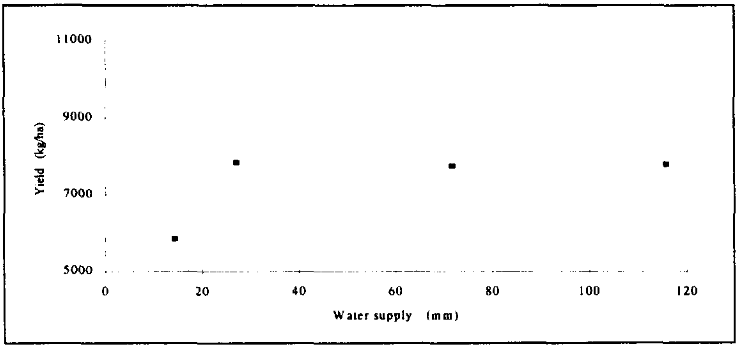

Figure 3. Haricot Bean (Variety Nikki) Yield depending on Water Supply

In 1993, the yields from 6 irrigated plots of broad beans were on the whole higher than those from non irrigated plots (Fig. 6).

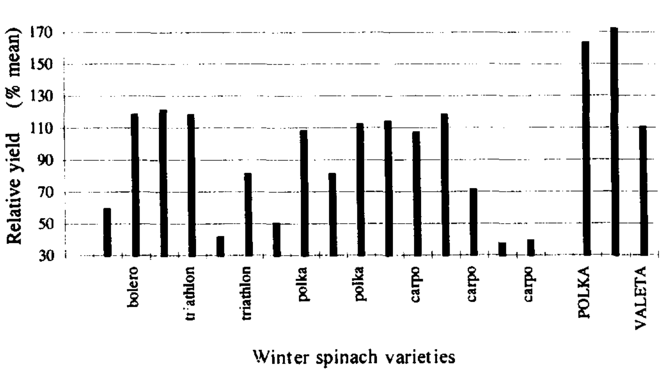

Figure 4. Winter Spinach 92 - 93 : Relative Yields

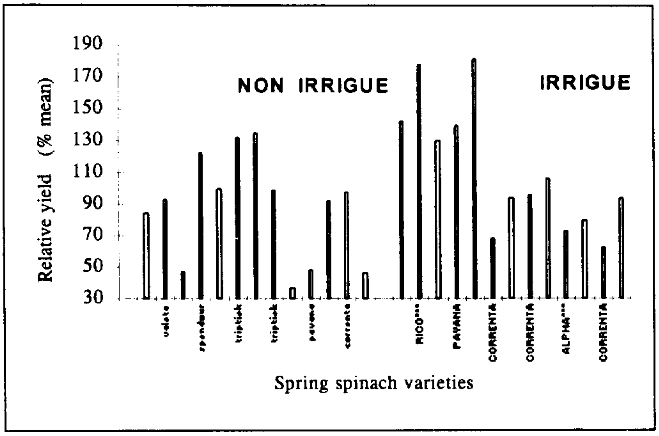

Figure 5. Spring Spinach 94 : Relative Yields

In 1994, all the non irrigated crops of broad beans represented by the variety talia (6 times), showed a production often less than half that of irrigated beans. However, the variety talia which might be considered, in the light of these results as having the poorest performance, was undeniably the champion in 1994 when all the yields were pooled for irrigated plots.

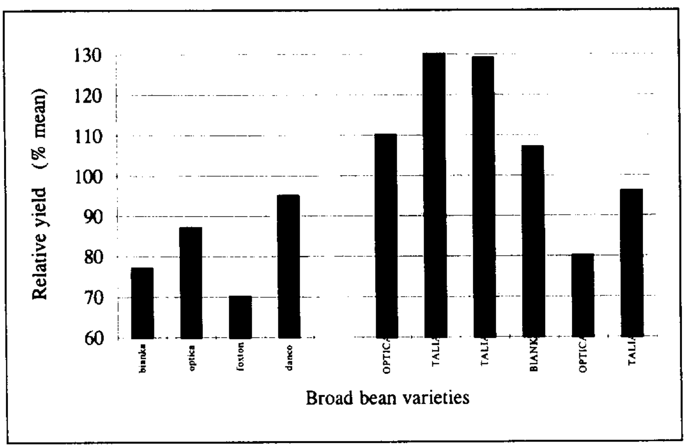

Figure 6. Broad Beans 93 : Relative Yields

The figures pertaining to the haricot bean (Fig. 8) give less distinct results. Non irrigated crops are not systematically less prolific than the others. Irrigation does however guarantee a minimum yield.The poor performances of two early varieties, mirel and odessa, compared to the others can be explained. They are the first to be sown in the firm's schedule and not having benefitted from irrigation during the intense July heat which coincided with their flowering, they were particularly affected by lack of water as shown by the results.

Experience Gained

Except in one or two cases, irrigation offers enhanced phytotechnical potential which is expressed by substantial yield gains and financial returns. This guarantee of a readily available source of water represents an undeniable advantage for agriculture. However, one must remain cautious: although irrigation can save yields threatened by insufficient rainfall, it can not compensate for initial shortages nor

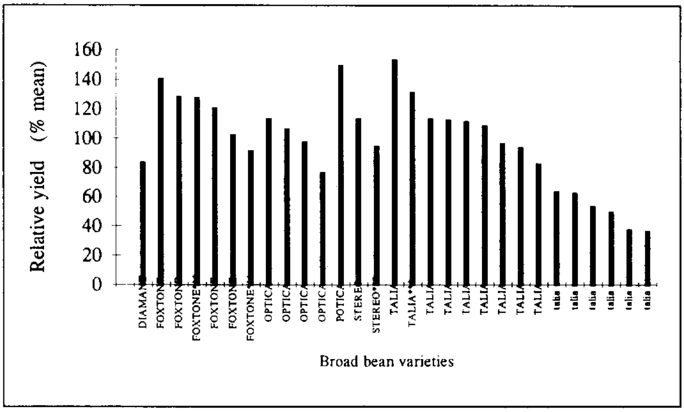

Figure 7. Broad Beans 94 : Relative Yields

for cropping systems which were unfavourable from the start. The findings from studies on beans clearly highlights this point.

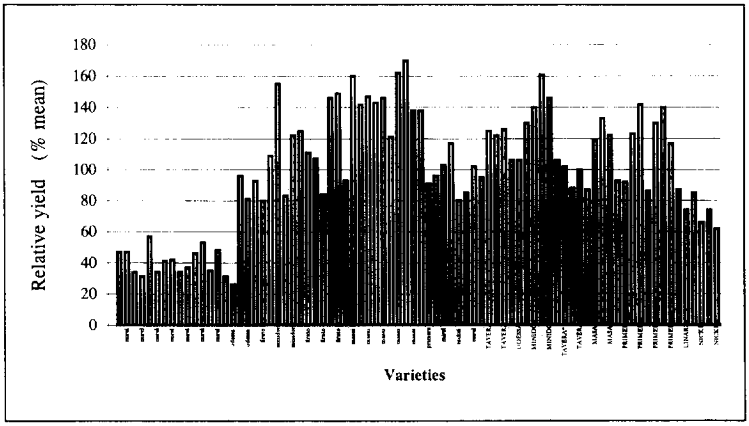

Figure 8. Haricot 94 : Relative Yields

TECHNICAL APPRAISAL OF SPRAYING: UNIFORMITY OF SPRAYING

In addition to the traditional monitoring of the project, different field studies aim at improving the performances and quality of this form of irrigation (Fleussu, 1994).

Study of Spraying Uniformity

Optimal uniformity corresponds of course to spray the whole irrigated plot with the same depth of water. This uniformity is expressed by the Christiansen coefficient which characterises the spatial distribution of rainfall. Figure 9 illustrates an example of uniformity measurements represented in graphic form on the basis of sampling performed on 4 lines of 23 pluviometers placed perpendicularly to the forward direction of the travelling sprinkler gun (traveller). Each graph represents the distribution pattern of water sprayed for each of the 4 lines of pluviometers in function of the distance from the centre of the traveller.

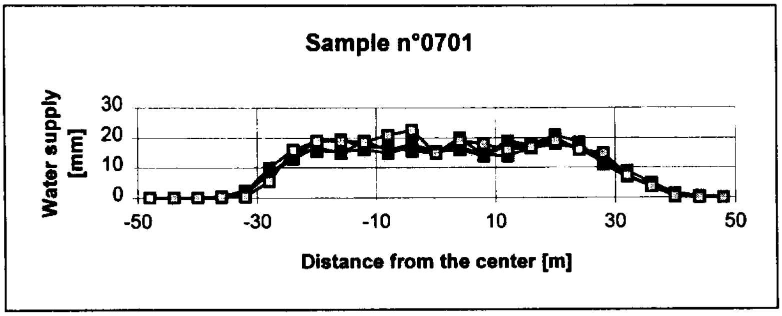

Figure 9. Example of Uniformity Measurement

The evolution of the uniformity coefficient can also be expressed in function of the distance between the passages of the traveller (Fig. 10). The curve obtained is characterised either by a threshold, or by a local maximum. The value which maximizes uniformity is precisely this value or the highest threshold value between distances. These should correspond to a multiple of spray boom length of the farmer. This is far from simple as each farmer does not use the same type of boom for his phytosanitory treatments.

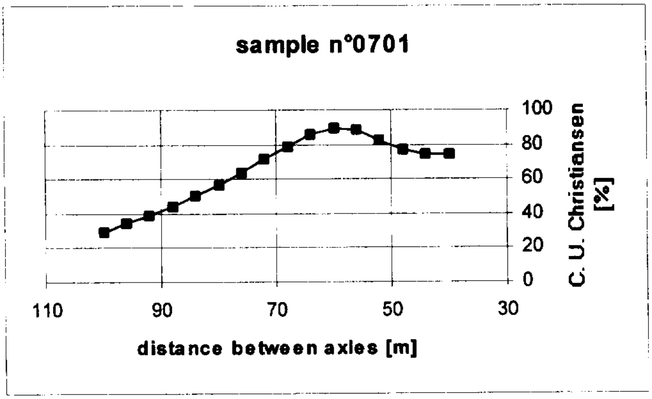

Figure 10. Evolution of the Unifomity Coefficient in Function of the Distance between Passages of the Traveller

Influence of Dry Matter on Spraying

The greater the dry matter content of the effluent which leads to an increase in the viscosity of water, the greater the loss of power from the nozzle. For a given pressure, one would expect the flow rate and the range to decrease progressively depending on the dry matter content of the water. However, the flow rate remains constant whatever the dry matter content. This can be explained by the fact that with increased dry matter, the accompanying increase in the number of condensation spots in the effluent causes a reduction in the spray of the water jet, reducing the range (Fleussu, 1994). In other words, the decrease in spray range due to the increase in dry matter content is at least as important as the reduction in flow rate caused by an increased pressure loss. Increased dry matter content of water is associated with rainfall distribution which develops into a more and more distinct bell shape.

What's the Outcome ?

Water with the least possible dry matter content will optimize distribution uniformity. A greater load, leads to a reduction of irrigation range even though the flow rate remains unchanged. The depth of water sprayed therefore increases depending on the dry matter content of the effluent.

CONCLUSIONS

To conclude, and after 3 years of operation, this pilot project is now attracting attention from many industries faced with ecological constraints. Needless to say, this experiment will lead to others. This original and attractive project ensures 5 fundamental functions in this context. It respects the environment, maintains the production potential of soils, preserves the quality of products, guarantees a regular supply to the firm, recycles nutritive elements and water in a natural cycle. No other process however sophisticated can compare with the natural purification capacity of the soil which can attain 100% in a well controlled system. Finally, and most importantly, it ensures the aquatic environment all the conditions crucial to ecological rehabilitation and biotic balance by the absence of any trace of effluent from industrial activity which is reconciled with the surrounding environment.

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