Application of a DSS (Fertirrigere) for increasing economic and environmental sustainability of processing tomato cultivated in Mediterranean climate

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Abstract

Aims of the present study were to assess economic and environmental sustainability and promote the use of alternative technologies for crop fertigation management (DSS Fertirrigere). The fertigation management as proposed by Fertirrigere has been compared with the cropping practices of local growers (Tuscany, Italy). Growers carried out irrigation and fertilisation as usual, while a neighbouring field was managed by the DSS Fertirrigere. DSS application increased the mean production albeit without significant statistical effects, while significantly decreased the use of fertilizers and water. Therefore, water and nutrient use efficiency of the crop were significantly improved. The computation of water footprint showed a reduced environmental impact and higher sustainability of crops fertigated with Fertirrigere as compared to the local growers practices. The overall use of water resources and fertilisers resulted more efficient when applying the DSS: nitrogen use efficiency increased up to 102.4%, water use efficiency up to 21.1% and the total crop water footprint decreased of 11.5 m^3 t^{-1} (27.3 %), in the average. Furthermore, DSS management increased the yield value while decreased the cropping costs thus resulting in an higher average net income of about 700 euro ha^{-1}.

INTRODUCTION

Mediterranean countries are historical producers of processing tomato due to their favourable climate conditions that allow both high yield and fruit quality.

Tomato is worldwide more and more representing a significant component of human diet due to its nutritional and nutraceutical properties as it contains vitamins and antioxidant complexes, as lycopene and anthocyans (Giovannucci, 1999). In Mediterranean countries, tomatoes are as well part the local cultural identity, due to its close bond with pasta consumption. In spite of that, the increase of production costs and the constraints set by EU regulations (e.g. EU Nitrate Directive) are affecting the local growers capability to compete on the global market. In this scenario, the optimization of non-renewable inputs becomes a crucial key factor for improving crop environmental sustainability and grower's incomes, supporting local production and market, as well as employment in agriculture and agro-industries.

Local growers irrigation and fertilization scheduling are based on a high degree of empiricisms very often leading to excess or deficit, while increase either environmental impact and cost production or plant stress with reduced yield. A recent study carried out in Italy (RIANPA) on the use of fertilizers revealed that most of growers are using standard doses of fertilizer without duly taking into account soil analyses, crop rotation or the impact of climate on plant growth and nutrient uptake. As a consequence, the overall tendency is to supply more fertilizers than required, following the rule of thumb “more is better than less”.

Fertigation is one of the most valuable agronomical technique for the optimization of plant nutrition management since nutrient and water supply can be tuned on actual plant uptake rates (Bar-Yosef, 1999). Nevertheless, the main difficulty for growers is to estimate in real time plant needs and water/nutrient status in the root zone. It’s well known that changes in the root-soil-water continuum occurs quite fast, in function of environmental variables (i.e. evapotranspiration, air and soil temperature, soil hydrology, root age, etc). Although many DSSs (Decision Support Systems) have been found effective in fertigation control, it is pretty common that growers do not trust in such a “technological approach”.

This project aimed to assess the applicability of a DSS (Fertirrigere; Battilani et al., 2003 and 2006), in two experimental fields, as compared with the standard fertilisation and irrigation techniques widely applied by local growers. Aims of this study were optimize the use of resources, namely water and nutrients, while promoting and disseminating the DSSs among growers, in order to enhance their acceptance and application. The effectiveness of the proposed management has been tested against yield, use of fertilizer and water, economic viability and environmental performances.

MATERIALS AND METHODS

After a thoroughly selection, conducted in collaboration with local agronomists, belonging to farmer’s associations and extension services, two of the most skilled processing tomato growers were selected to carry out the experiment. Farms were located in Val di Cornia (Tuscany, Italy), in a Mediterranean climate and on sandy soil (80% sand, 10% silt and 11% clay).

Tomato plants were transplanted in the first weeks of May (cv. Reflex; 34000 plants ha^{-1}) and lasted 97 days in Field 1 and 114 days in Field 2. Mean daily temperature, global radiation, relative humidity and wind speed averaged 21.4°C, 153.9 W m^{-2}, 72.5% and 1.9 m s^{-1}, respectively. A large plot was identified in each of the commercial farms involved in the trial, to apply the DSS management (Fert). A neighbouring field has been monitored to compare the grower’s standard management (Std). Each treatment was the main component of a technical itinerary applied in a plot large enough to allow normal crop practices at farm field scale (Sebillotte, 1978; Dumas, 1990; Meynard et al., 1996). A representative area (0.7 ha) in each plot were chosen to undertake the measurements.

The management strategy for applying fertiliser to the Std treatment was determined before the growing season and was based on long-term average fertigation requirements. Std fertigation was determined by growers on the ground of their own experience, with limited knowledge about root zone depth or actual water and nutrients uptake by plants. The fertilisation strategy for the DSS treatment was based on a dynamic approach thus determined day by day during the growing season. Dynamic DSS fertigation was based on daily dry matter (DM) accumulation and partitioning. A root growth model was applied at a daily time-step to determine the root zone volume for irrigation and nutrient balance. Specific growth stage nutrient contents for aboveground and storage organs were used to calculate the daily fertigation requirement (kg kg^{-1} DM). Soil particle size distribution, soil hydraulic parameters, soil organic matter content

(SOM), total and mineral nitrogen and carbon were measured before transplant to calculate nutrient balances. Destructive analyses were carried out four times during the growth season to determine nitrogen uptake and to measure plant's biometric parameters (four replicates during the cultivation and eight replicates at the harvest time per treatment with two plants per replicate). Plant dry matter and leaf area were determined time during the crop growth cycle through destructive analysis Each plant was divided into stems, leaves and fruit; then, fresh and dry weight (72 h in ventilated oven at 72°C), number of fruit and flower were determined. Fruit quality was assessed at harvest: dry matter percentage (%), total soluble solid (°Brix), pH and titratable acidity (expressed as percentage of citric acid), were measured. Tissue mineral content was also assessed, only for total nitrogen, for the plant collected during the last sampling. Nitrogen concentration in root zone soil interstitial water was measured in water extracted by suction cups, then analysed (1:2 vol/vol) for the determination of nitrogen concentration as reported by Sonneveld (2000). Water and nitrogen use efficiency (WUE, NUE) were calculated dividing, respectively, the total amount of supplied irrigation water and nitrogen by the marketable yield.

In Fert treatments, in order to offer a more friendly interface to growers, fertigation schedule was sent as text messages, making use of a widely diffused, well known and cheap method of communication. Simulations were run on a daily base using climate data collected by a meteorological station (Pessl Instruments GmbH, Weiz, Austria) located nearby.

Environmental impact was assessed through the computation of green, blue, grey and total water footprint, only considering the cultivation cycle of the crop, as recommended by Hoekstra et al. (2011). To calculate green and blue water, simulations were run using Fertirrigere. Then, the difference of irrigation water volume between Fert and Std was add, in the computation of blue water footprint, as "*LostReturnFlow*". For the grey water footprint, nitrogen leaching was calculated by Fertirrigere in Fert treatments and by the application of a typical soil nitrogen balance in Std treatments.

RESULTS AND DISCUSSION

Fert treatments started with a pre-planting nitrogen (N) fertilization only in the Field 1 where the initial concentration of total mineral N was deemed insufficient (data not shown), (Fig. 1). Std fertilization schedule started with an abundant pre-planting dose of N (on average, about 70 kg ha^{-1}).

After planting, in the Std treatments, the growers continued to supply N with a nearly constant delivering rate of 14.1 and 9.1 kg ha^{-1} N per application, on average, respectively for Field 1 and 2. DSS calculates soil natural fertility thereby nitrogen supply begun to be significant only around 35-50 days after transplant (DAT) (Fig 1), when plant growth rate increases to reach its maximum; further supplies during the growth cycle were in function of actual plant needs instead of fixed rate.. At harvest, the cumulative supply of nitrogen in Fert treatments was much lower (-43.6%, on average) as compared with Std (Fig. 1).

Irrigation depth was similar in both Std and Fert treatment, although water savings of 7.3% and 21.1% were obtained applying the DSS management. An in depth analysis of daily irrigations volume show significant differences between treatments (data not shown) due to the dynamic management at daily step operated by the DSS. As for nutrients, in the Std treatments water was supplied with a nearly constant rate without consideration either of climate parameters or water soil content. Figure 1 reports only N and water supply, while a more complete picture of the fertigation management is given in figure 2 where the cumulative supply of nutrients and water is reported. The use of the DSS reduced drastically the total amount of N and phosphorus (P) supplied to both the experimental fields (43.6% and 84.5% less than Std treatment respectively for N and P, on average). The very large differences in P doses were mainly determined by Field 1 where in the Std treatment the grower distributed a large amount of P (about 150 kg ha^{-1}) although the initial soil analysis showed sufficient P availability in the root zone (data not shown). The use of Fertirrigere reduced potassium (K) doses only in the Field 1 but not in the Field 2 that required an abundant pre-planting fertilization since the initial K availability resulted insufficient for supporting the crop. For this reason, cumulative amount of K resulted higher in Fert treatments as compared with Std treatments (Fig. 2).

Notwithstanding the general lower nutrient and water supply suggested by the DSS (Fig. 1 and 2), Fert treatments did not affect the final plant dry biomass and leaf area index (LAI) (Fig. 3). The only important difference for LAI, in the Field 1, was due to the excessive N fertilization applied to the Std treatment (Fig. 1) by the grower, which stimulated an abundant production of vegetative organs (mainly leaves) as compared to the Fert treatment. However, at harvest, fruit yield and quality (Tab 1.) as well as N tissue content of stems, leaves and fruits (data not shown) were not significantly influenced by the different fertigation regimes. Marketable yield averaged 132.1 t ha^{-1} among treatments and was higher than the regional mean production (+15%). The slight but not significant lower yield reported in table 1 for Std treatments was probably due to the unbalance between vegetative and reproductive sink caused by the abundant N fertilization, which induced excessive vigour thus less fruit setting.

The reduction in water and nutrient supply, but not in yield, in turn improved significantly the use efficiency of nutrient and water in Fert treatments (Tab. 2). Although the total volume of water supplied to the crops was similar for Std and Fert treatments (Fig. 1 and 2), application of fixed rate of fertilisers in Std treatments bought to an important quantity of N leachate, related to overwatering when the soil was water saturated (Vázquez et al. 2006).

The amount of N leached out from the root zone was estimated by N balance computation (Std) and using Fertirrigere (DSS). Then irrigation water volume, N losses and crop yield have been utilised to calculate green and grey water footprint as reported by Hoekstra et al. (2011). The environmental impact, as total water footprint, was significantly reduced by the use of the DSS (-27%, on average) due to the lower grey water use of Fert treatments as compared to Stds (Tab. 2). The values reported in table 2 are in general much lower than those reported by other authors. Nevertheless, literature on this topic is often based on worldwide global data that include third world countries with very low productions and/or not irrigated crops.

To better assess the economic self-sustainability of the applied method, a brief and simple cost-benefit analysis was computed to assess possible economic advantages or extra costs. Fert treatments produced a net economic benefit that on average was 702.1 € ha^{-1} (Tab. 3). It should be highlighted that about 90% of the net benefit showed in table 3 derives from the slight increase in yield of the Fert treatments. This means that among cost production, fertilizers and water remain marginal expenses and for this reasons growers prefer to exceed in their application rather to risk even a slight decrease in yield.

The preliminary results of this project were presented in open days at farm level with very positive feed-back of the audience. A follow up of this study shown that the share of the whole processing tomato fertigated with the support of Fertirrigere in the area is now attaining to 6%.

CONCLUSIONS

This study show the positive effects on production costs and environmental impact of appropriated agronomical practices and criteria. Particularly, computation of nutrient and water balance in the soil, when coupled with soil analysis, resulted in higher crop sustainability from both environmental and economic standpoint. To help farmers to reach that goals DSSs can represent valuable tools to boost knowledge transfer from science to the field.

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Tables

Table 1. Marketable yield and fruit quality parameters determined at harvest. One-way ANOVA was used to test statistical differences between treatments; different letters show differences at 95% of significance (LSD test).

Treatment	Marketable yield ($t\ ha^{-1}$)	Fruit weight ($g\ fruit^{-1}$)	Dry matter (%)	Soluble solids (°Brix)
		Field 1		
Std	121.1 a	46.7 a	5.7 a	4.5 a
Fert	128.6 a	49.4 a	6.0 a	4.8 a
		Field 2		
Std	135.8 a	51.0 a	5.1 a	4.2 a
Fert	142.9 a	53.2 a	5.0 a	4.5 a

Table 2. Use efficiency of nitrogen and water (NUE and WUE), green, blue, grey and total water footprint (WFP_{green}, WFP_{blue}, WFP_{grey} and WFP_{blue},). One-way ANOVA was used to test statistical differences between treatments; different letters show differences at 95% of significance (LSD test).

Treatment	NUE ($t\ kg^{-1}$)	WUE ($t\ m^{-3}\ 10^3$)	WFP_{green} ($m^3\ t^{-1}$)	WFP_{blue} ($m^3\ t^{-1}$)	WFP_{grey} ($m^3\ t^{-1}$)	WFP_{tot} ($m^3\ t^{-1}$)
			Field 1			
Std	0.41 b	43.6 a	1.5 a	23.3 a	21.1 a	45.9 a
Fert	0.83 a	46.8 a	1.4 a	21.2 a	9.1 b	31.7 b
			Field 2			
Std	0.64 b	40.2 b	2.5 a	25.4 a	10.4 a	38.3 a
Fert	1.09 a	48.7 a	2.5 a	23.1 a	3.9 b	29.5 b

Table 3. Cost-benefit analysis carried out on the basis of current average prices of fertilizers.

	Field1 (€ ha^{-1})			Field 2 (€ ha^{-1})		
	Std	Fert	Fert-Std	Std	Fert	Fert-Std
Gross production[1]	10656.8	11316.8	660.0	11950.4	12575.2	624.8
Cost of fertilizer (N)	294.6	154.5	-140.1	211.8	131.0	-80.7
Cost of fertilizer (P)	118.0	60.0	-58.0	346.0	12.0	-334.0
Cost of fertilizer (K)	297.6	184.0	-113.6	212.8	400.8	188.0
Cost of water	417.1	412.4	-4.8	506.6	440.4	-66.2
Cost of soil analysis	0.0	70.0	70.0	0.0	70.0	70.0
Cost of climate data[2]	0.0	15.0	15.0	0.0	15.0	15.0
Cost for extra manual labour[3]	0.0	60.0	60.0	0.0	60.0	60.0
Cost for intellectual labour[4]	0.0	100.0	100.0	0.0	100.0	100.0
Net economic benefit[5]			731.5			672.7

1 Calculated on the basis of the average price of processing tomato in 2011 (Italy) without corrections for quality parameters (°Brix).
2 Calculated as the depreciation value of a meteorological station (covering 200 ha, for the period of cultivation).
3 Calculated on the basis of the extra cost of the labour required by Fert treatment, in terms of applications (hours of extra labour), as compared to Std treatment.
4 Calculated as a fixed performance for intellectual work.

5 Calculated as the difference between gross production and total costs.

Figures

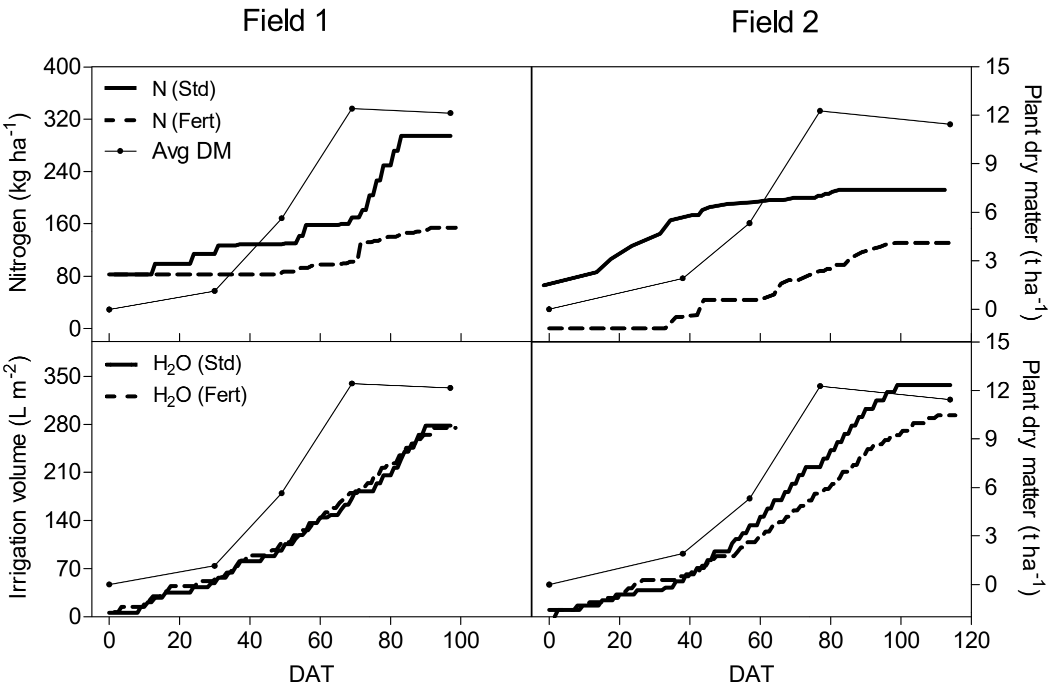

Figure 1. Cumulative nitrogen (N) and water supply (H_20) are plotted versus days after transplanting (DAT). Total plant matter evolution (Avg DM) is also reported to follow plant growth; values represent the average of the two treatments.

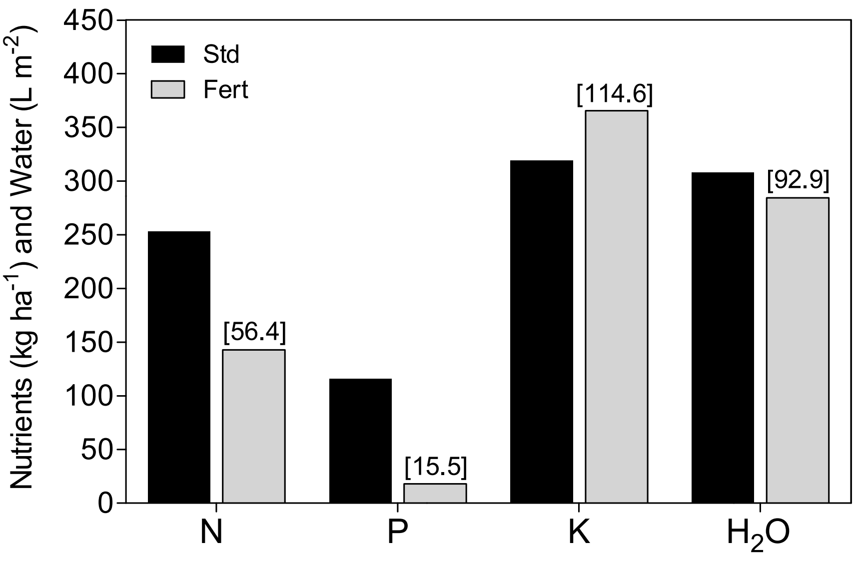

Figure 2. Cumulative amounts of fertilizers (N, P, K) and water (H_20) are reported in the figure for the different treatments. Values represent the average of the two experimental fields. Percentage of Fert treatment with respect to Std treatment is reported within brackets.

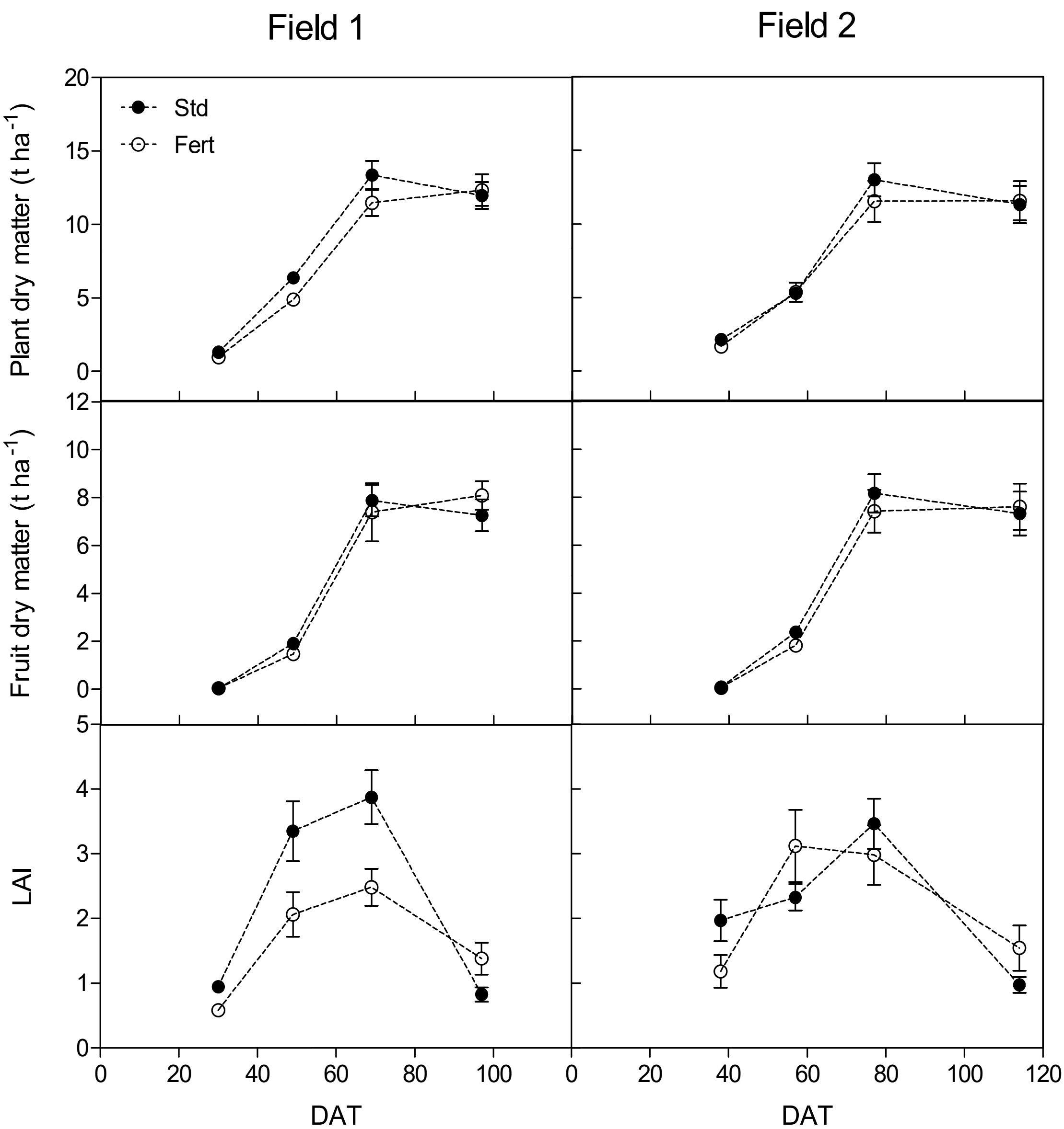

Figure 3. Dry matter evolution of the whole plant and fruits (top) are showed in the figure with leaf area index (LAI; on the bottom) as a function of days after transplanting (DAT). Values represent the average of (four replicates during the cultivation cycle and eight replicates at end of the crop; two plants per replicate) ± SE.