SMART IRRIGATION FROM SOIL MOISTURE FORECAST USING SATELLITE AND HYDRO –METEOROLOGICAL MODELLING

WP6 - Economic analysis

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Rome, June 12, 2019

Outline

1. Introduction
2. Methods
3. Data
4. Results from the case studies in Italy
5. Conclusions

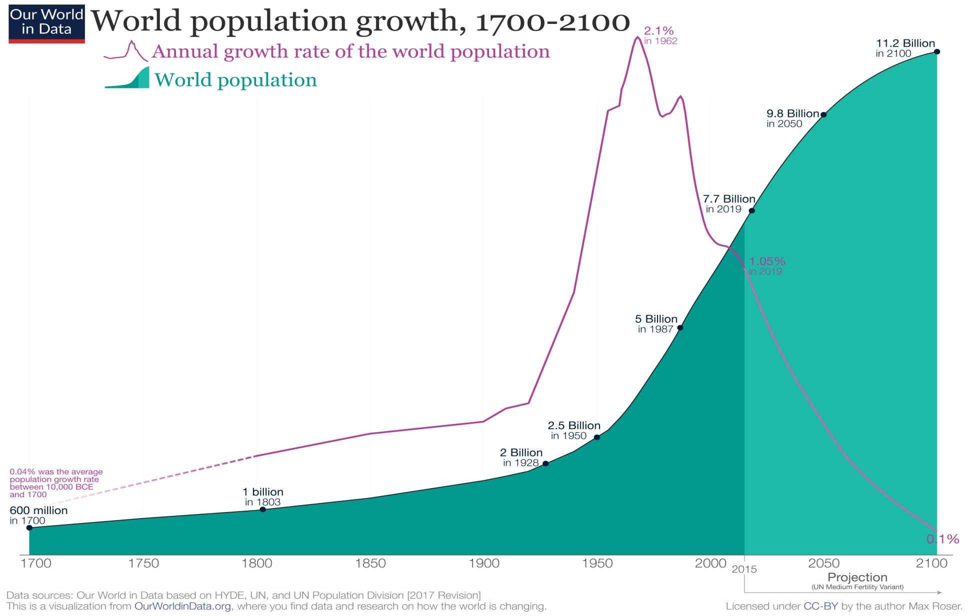
1. Introduction

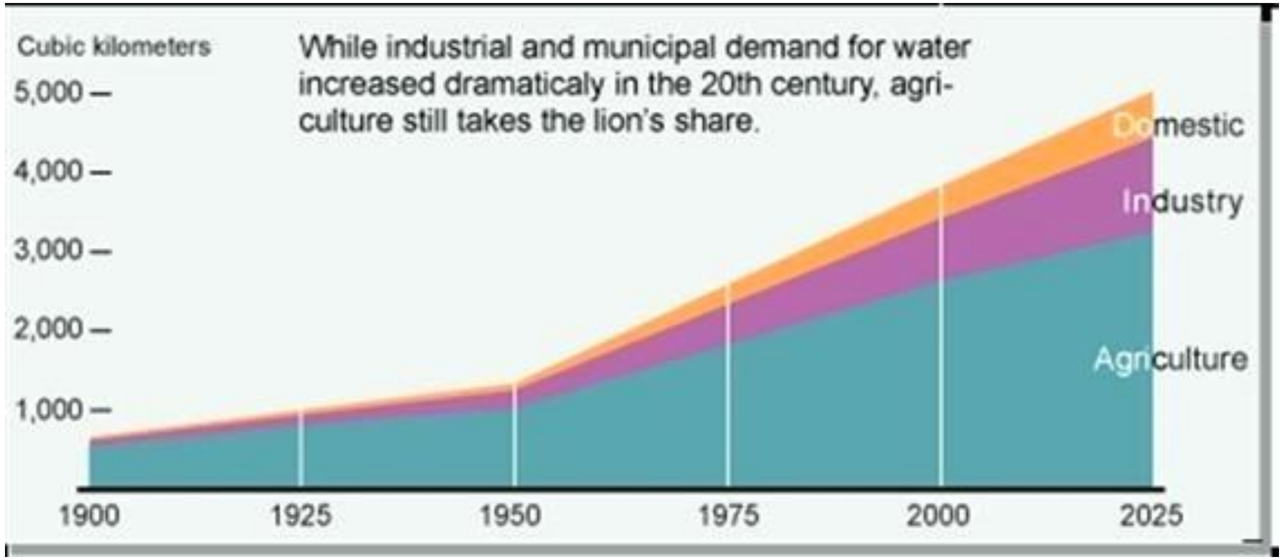
Population growth → increased water demand and increased pressure on water resources

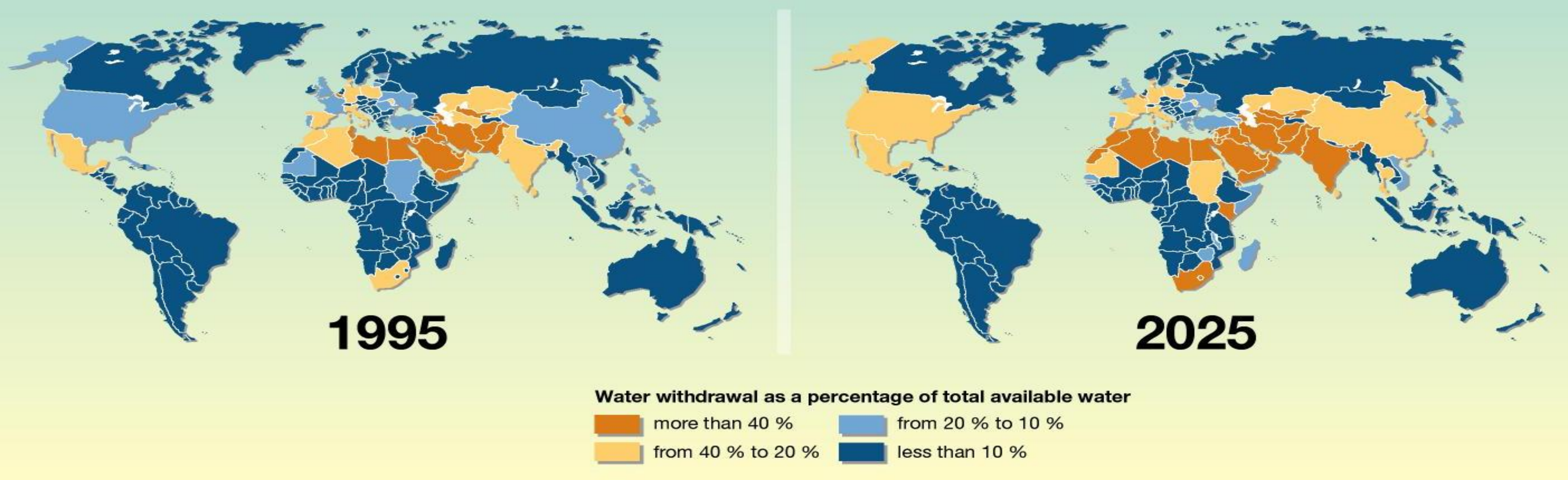
Water supply has become a major challenge → in arid and semi-arid areas but also in humid areas (climate change) and important trade-offs exist in the use of water resources

Efficient agriculture water management through improved water use efficiency/agricultural water productivity is a critical response to growing water scarcity

EU policies aiming at increasing water efficiency and reducing water consumption


Our World in Data
World population growth, 1700-2100
Annual growth rate of the world population
World population
2.1% in 1962
11.2 Billion in 2100
9.8 Billion in 2050
7.7 Billion in 2019
1.05% in 2019
5 Billion in 1987
2.5 Billion in 1950
2 Billion in 1928
1 billion in 1803
600 million in 1700
0.04% was the average population growth rate between 10,000 BCE and 1700
0.1%
1700
1750
1800
1850
1900
1950
2000
2015
2050
2100
Projection
(UN Medium Fertility Variant)
Data sources: Our World in Data based on HYDE, UN, and UN Population Division [2017 Revision]
This is a visualization from OurWorldinData.org, where you find data and research on how the world is changing.
Licensed under CC-BY by the author Max Roser.


Cubic kilometers
While industrial and municipal demand for water increased dramaticaly in the 20th century, agri-culture still takes the lion's share.
5,000
4,000
3,000
2,000
1,000
Domestic
Industry
Agriculture
1900
1925
1950
1975
2000
2025


1995
2025
Water withdrawal as a percentage of total available water
more than 40 %
from 40 % to 20 %
from 20 % to 10 %
less than 10 %

1. Introduction

WP 6 deals with the micro-economic (on-farm) analysis.

Research questions:

1. *how can we measure water economic efficiency?*
2. *how SIM can contribute to changes in efficiency?*

Two case studies, different agro-climatic and socio-economic contexts

- Capitanata Consortium, Apulia (Southern Italy), vegetables and fruits
- Chiese Consortium, Lombardy (Northern Italy), maize

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2. METHODS: Efficiency indicators related to water use in agriculture

a) Physical water productivity (Kg /m^3)

$$PWP = \frac{Crop\ yield}{Water\ used\ for\ irrigation} = \frac{Y}{AWU} = \frac{kg/ha}{m^3/ha}$$

b) Economic water productivity (€ /m^3)

$$EWP = \frac{Crop\ gross\ margin}{Water\ used\ for\ irrigation} = \frac{GM}{AWU} = \frac{€/ha}{m^3/ha}$$

c) Economic water productivity ratio (%)

$$EWPR = \frac{Cost\ of\ irrigation\ water}{Variable\ costs} = \frac{AWEXP}{VC} * 100$$

3. DATA

FADN = Farm Accountancy Data Network (EU) → physical, structural, and economic data for a farm sample. We considered averages:

[1] crop yield (ACY), kg/ha

[2] gross sales production (AGSP), €/ha

[3] variable costs (AVC), €/ha

[4] gross margin (AGM=AGSP-AVC), €/ha

[5] labor costs (ALC), €/ha

[6] machinery costs (AMC), €/ha

[7] operating margin (AOM=AGM – ALC - AMC), €/ha

Period considered: 2011-2016

farms located in the Capitanata consortium (N=45)

farms located in the Chiese consortium (N=100)

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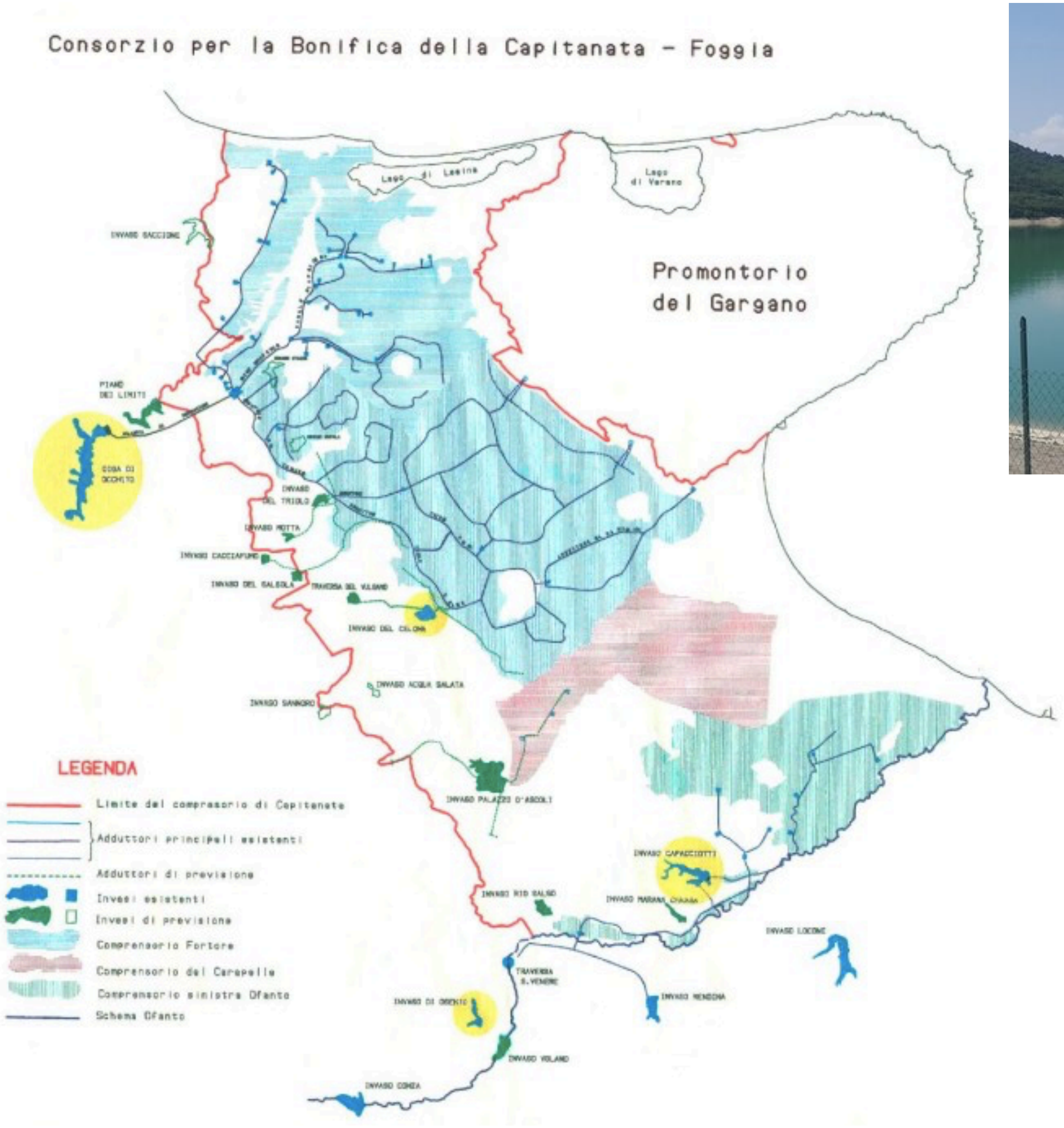
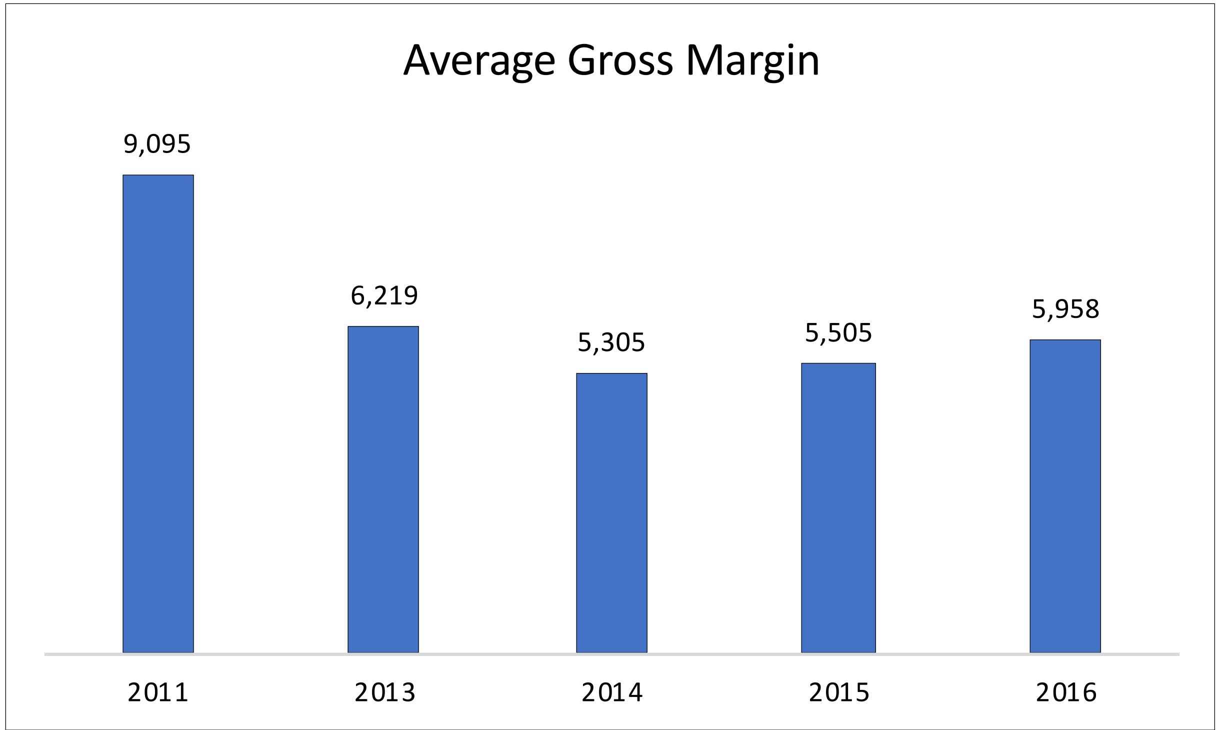
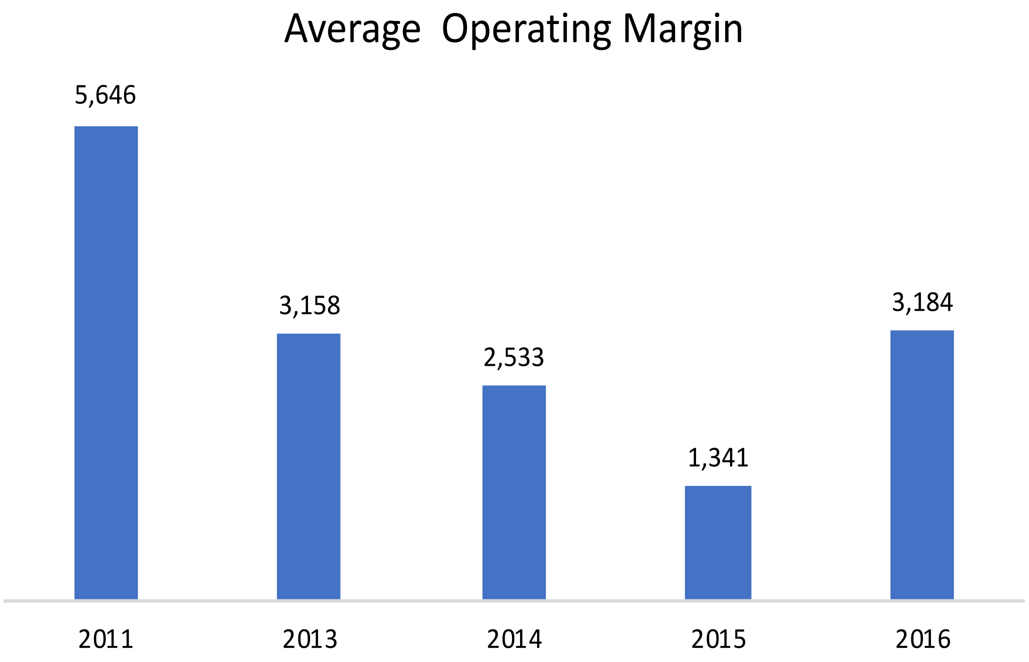
Capitanata Consortium case study, processing tomato



4. Results. Capitanata Consortium case study, processing tomato

	ACY[1]	AGSP[2]	AVC[3]	AGM[4]	ALC [5]	AMC[6]	AOM[7]
Year	kg/ha	€/ha	€/ha	€/ha	€/ha	€/ha	€/ha
Mean	95,745	10,213	3,796	6,416	1,446	1,798	3,172
Std. Dev	4,698	1,605	298	1,378	105	544	1,406
C.V	5%	16%	8%	21%	7%	30%	44%





Water costs

AWEXP = average water expenses calculated for each hectare of land irrigated = $Q_f + VC_u$

Q_f = fixed contribution → maintenance of the system

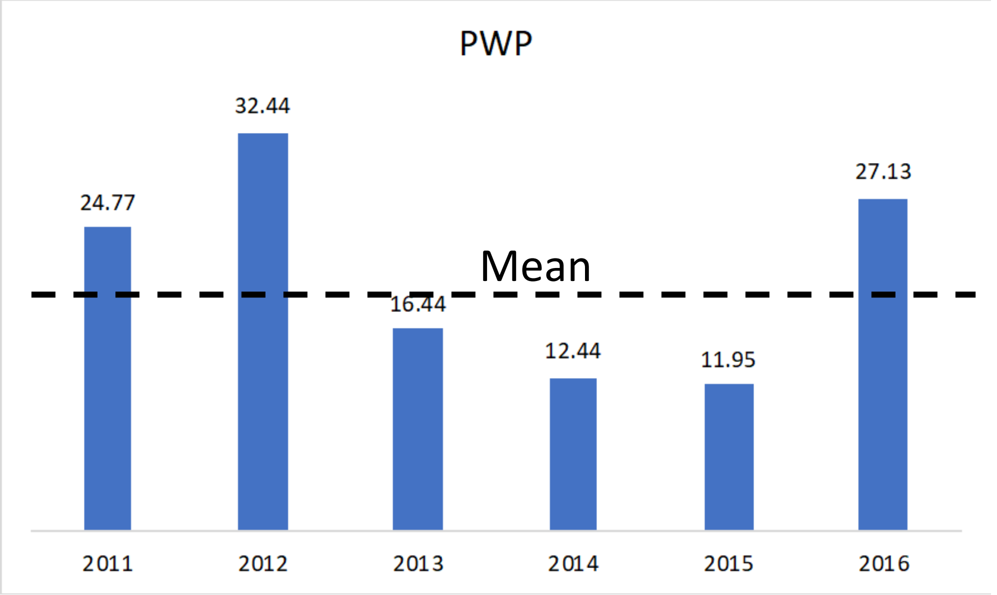
V = volume (m^3) of water distributed

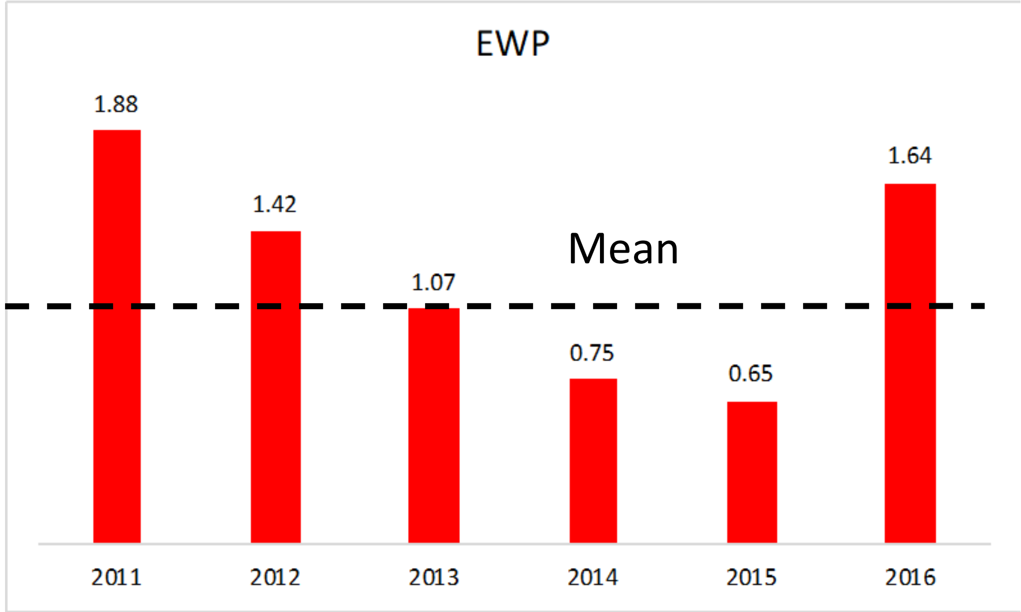
C_u = unit cost of water, i.e. €0,12/m^3 of water consumed up to 2050 m^3/ha; €0,18/m^3 between 2050-4000 m^3/ha; €0,24/m^3 above 4000 m^3/ha.

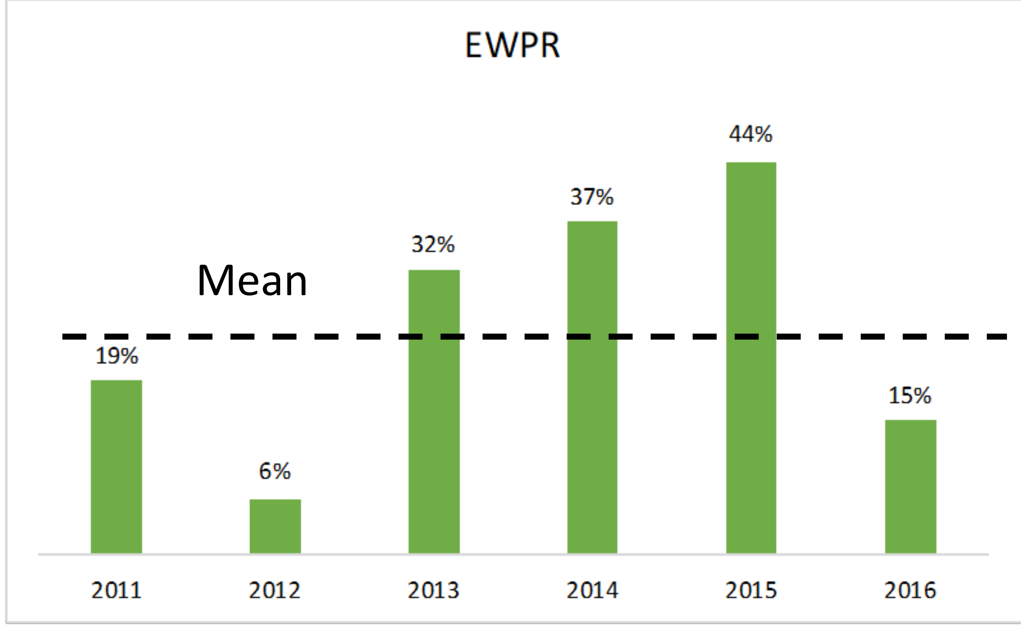
Year	AWU (m^3/ha)	Q_f (€/ha)	m^3	€/ha	$m^3 \cdot ha$	m^3	€/ha	$m^3 \cdot ha$	m^3	€/ha	$m^3 \cdot ha$	AWEXP (€/ha)
2011	4,848	60	2,050	0.12	246	1,950	0.18	351	848	0.24	203.52	831
2013	5,817	60	2,050	0.12	246	1,950	0.18	351	1,817	0.24	436.08	1,063
2014	7,090	60	2,050	0.12	246	1,950	0.18	351	3,090	0.24	741.6	1,369
2015	8,420	60	2,050	0.12	246	1,950	0.18	351	4,420	0.24	1,060.8	1,688
2016	3,630	60	2,050	0.12	246	1,580	0.18	284.4	0	0.24	0	560
Mean	5,918											1027

Water use efficiency indicators

	AWEXP	PWP	EWP	EWPR
Year		Kg/m^3	$€/m^3$	%
Mean	882	19.40	1.10	21%
Std. Dev	443	8.0	0.45	21%
C.V	50%	40%	39%	60%







Correlation between irrigation water use and meteo *information*

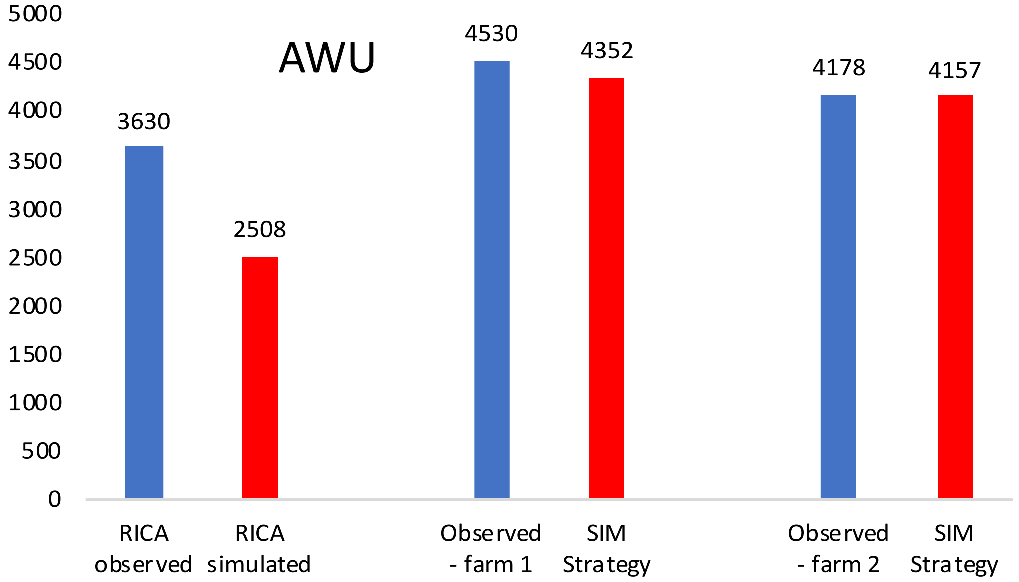
Year	Temperature (°C)	Cumulative precipitation (mm)	AWU m^3/ha
2011	25.3	133.6	4,848
2012	NA	NA	2,800
2013	23.4	90.6	5,817
2014	21.1	214.6	7,090
2015	23.9	113.3	8,420
2016	22.3	150.4	3,630
			5,139

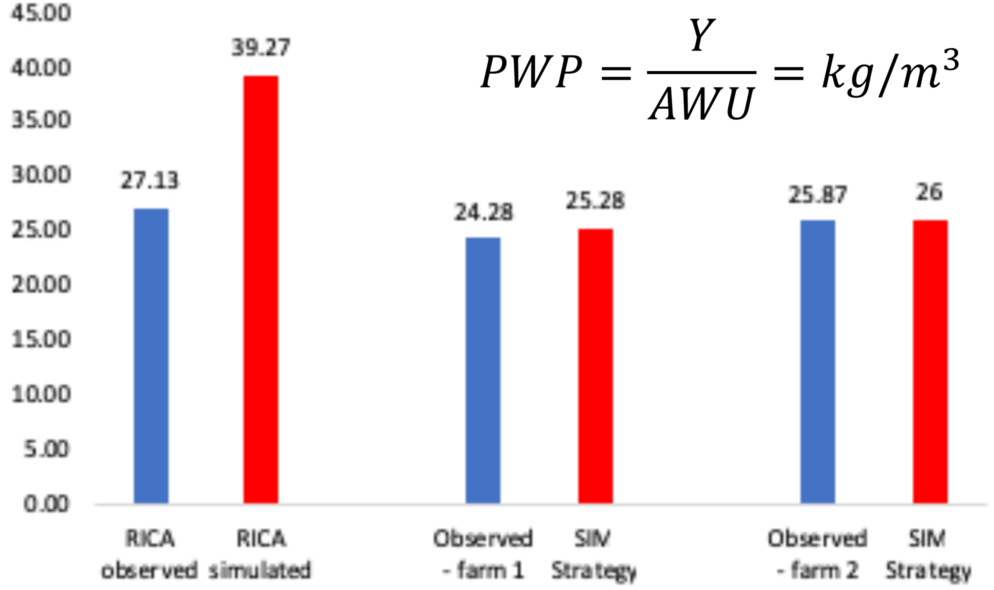
Processing tomato season,
period 15 April - 15 September

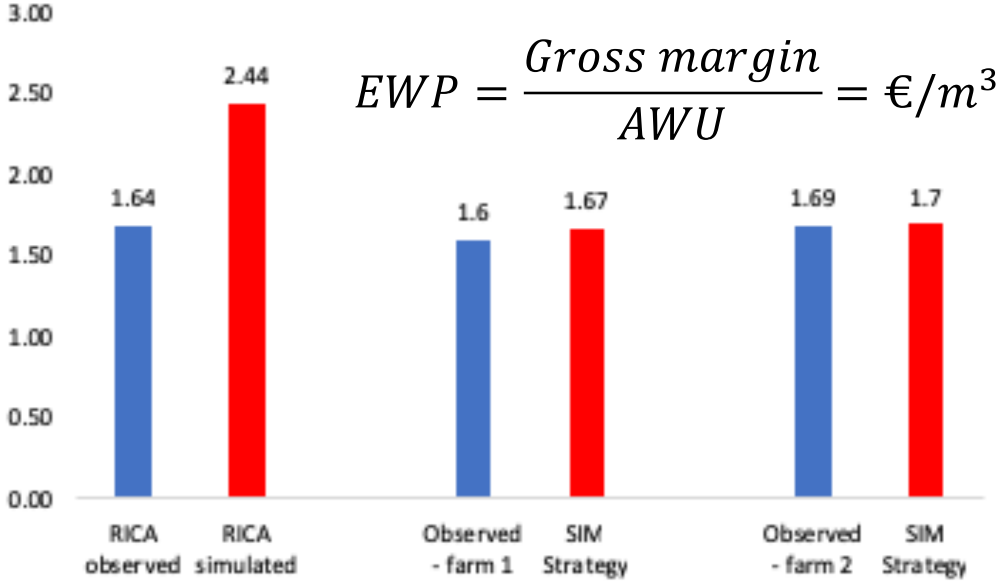
Spearman's rank correlation coefficients

- ρ between average temperature and AWU (FADN data) is: 0.20, indicating a positive correlation
- ρ between cumulative precipitation and AWU (FADN data) is: -0.60, indicating a strong and negative correlation

SIM impact on water efficiency, reference year 2016







SIM implementation increases water use efficiency: saves *up to* 31% of water, increases PWP by 44% and EWP by 45%, and reduces water costs by 36%

…more on efficiency, considering other crops…

Evaluating Input Use (technical) efficiency through a *Stochastic Frontier Production* for cross-sectional data (assumed log-linear form):

$$\ln \boldsymbol{y_i} = \boldsymbol{ln}\, \mathrm{f}(\boldsymbol{x_i}; \boldsymbol{\beta}) + \boldsymbol{v_i} - \boldsymbol{u_i}$$

y_i denotes the output for the *i-th* farm ($i = 1, \ldots, N$).
$f(x_i; \beta)$ = **production function**, $\boldsymbol{x}$ = inputs, $\boldsymbol{\beta}$ = technology parameters
v_i captures the effect of statistical noise
u_i is associated with technical inefficiency

Data: 108 fruit and vegetable farms

Model: Output, water used …… organic agriculture, fertigation, management type

Results

- Most (technically) inefficient crops are pepper and green beans (most water-demanding crops) → inefficiency increases with increased water volumes
- Low elasticity coefficient related to the volume of water → impact on yield is less than proportional compared to the increase of the volume of water
- Processing tomato is most efficient crop: best relationship between water used and yield obtained
- Organic farming is less efficient, fertigation production system is more efficient (i.e. gain output production) than conventional farming

	Coefficient	Std. Err.	P-value
Machinery use (hours)	0.058	0.040	0.488
Human labour (hours)	-0.182	0.032	0.043
Irrigated land (ha)	0.127	0.015	0.020
Volume of water (m^3/ha)	0.127	0.026	0.050
Constant	10.208	0.361	0.000
σ_u	0.211	0.066	0.001
σ_v	0.554	0.043	0.000
λ	0.380	0.075	0.000

Chiese consortium case study, maize

Results:

1. Water costs are a smaller percentage of variable costs

2. But this will change if the volumetric contribution is introduced

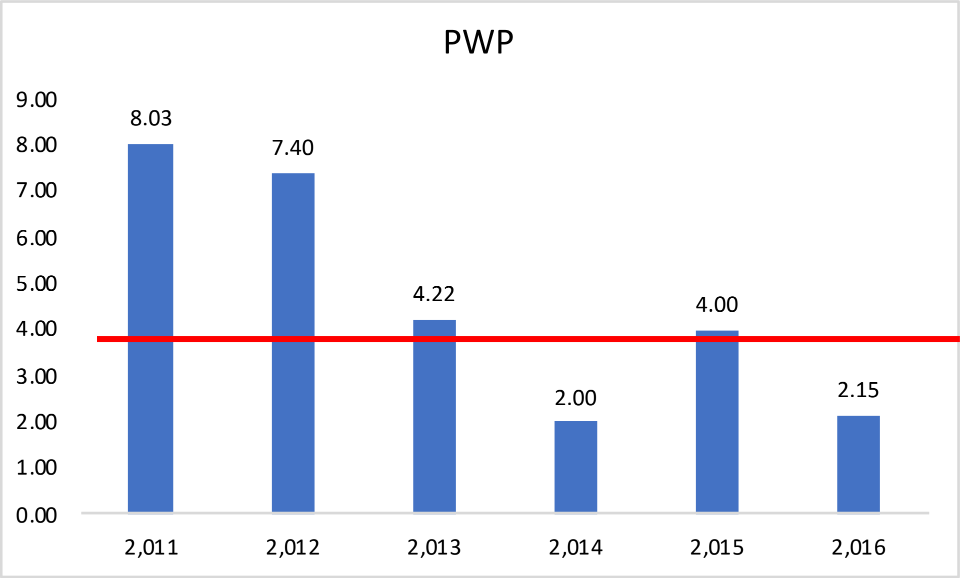
3. SIM can:

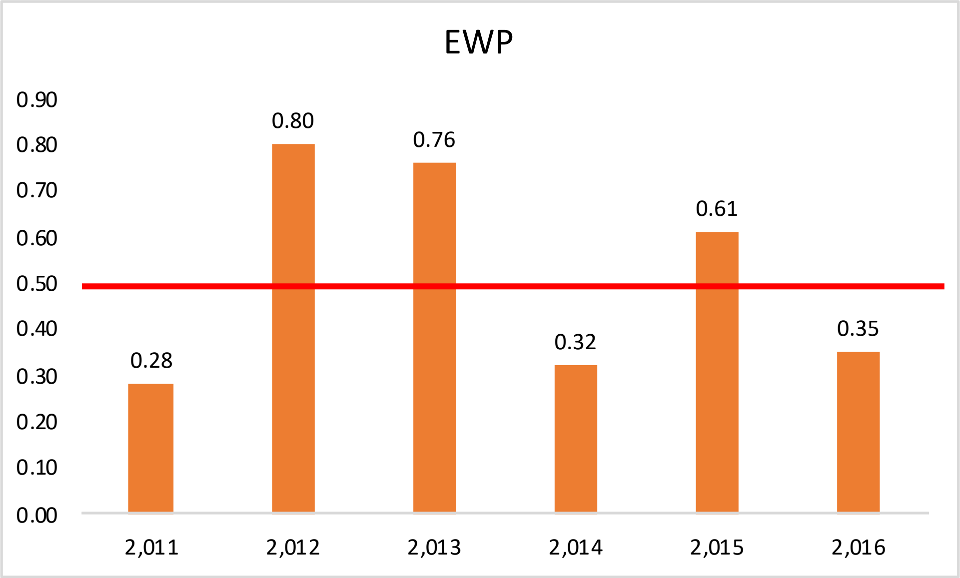
- save up to 40% of water
- increase PWP by 60%
- increase EWP by 20%

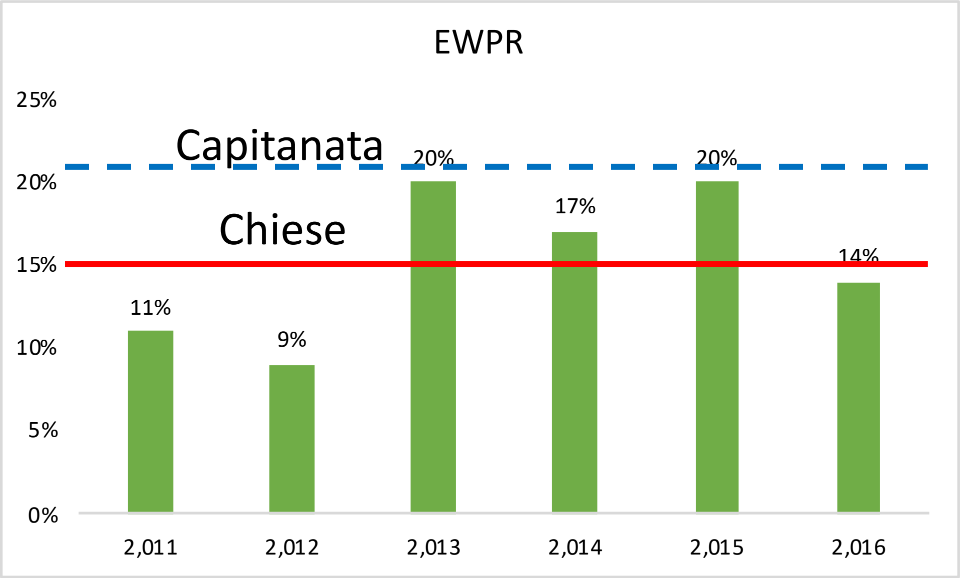
Spearman's rank correlation (with volumes of water used)

- ρ temperature and AWU = 0.77, strongly positive
- ρ precipitation and AWU = -0.03, slightly negative

Chiese consortium: water use efficiency







	AWEXP	PWP	EWP	EWPR
Year	€/ha	kg/m^3	$€/m^3$	%
Mean	141	4.03	0.48	15%

Chiese consortium, maize, hypothesis switching to volumetric contribution

Year	AWU (m^3/ha)	Contrib (€/ha)	Fixed contrib (€/ha)	m^3	€/ha	$m^3 \cdot ha$	m^3	€/ha	$m^3 \cdot ha$	m^3	€/ha	$m^3 \cdot ha$	AWEXP (€/ha)
2,011	3,073	141	30	2,050	0.12	246	1,950	0.18	351	0	0.24	0	627
2,012	2,931	141	30	2,050	0.12	246	881	0.18	159	0	0.24	0	435
2,013	2,245	141	30	2,050	0.12	246	195	0.18	35	0	0.24	0	311
2,014	4,639	141	30	2,050	0.12	246	1,950	0.18	351	639	0.24	153	780
2,015	2,959	141	30	2,050	0.12	246	909	0.18	164	0	0.24	0	440
2,016	5,812	141	30	2,050	0.12	246	1,950	0.18	351	1812	0.24	435	1062
Mean	3,425	141											560

Mean value

Mean value

Costs would increase by 300%

5. Conclusions

@ farm level → SIM can generate economic gains. Different impact in the two case-studies → EWP up by 20% (Chiese) and 45% (Capitanata) → higher impact where water costs are higher

Such gains will increase due to: expected increase in water costs (e.g. switch to volumetric contribution as also asked by CE (see Water Framework art.9); increased water competition due to increased water scarcity and demand (population growth….)

@ Consortium level → SIM could determine contribution reduction (losses for the Consortium) to be compensated by:

(i) expansion of irrigated area (benefits: increased production, incomes, jobs, etc..
(ii) gains in terms of 'behaviour' and compliance with policies aimed at water savings;
(iii) better position to face climatic changes and growing water scarcity

(iv) FADN → valuable data source, the only one existing, yearly collection…. But sample selection is not done at Consortium level → need economic data from the Consortia
(v) Environmental benefits of increased water efficiency use → next future (RET SIF)

Thank you for your attention!

Economics of Sustainable Agri-food Systems Laboratory (ESAS-lab)

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Capitanata Consortium: case study referred to processing tomato crop

Table 1: Characteristics of the consortium area

FADN source

Variables	%	Variables	%
Slope of the land		**Water supply system**	
None	43.1	Consortium	68.0
Flat (less than 5%)	56.9	Lake or river	5.0
Management type		Reservoir	26.0
Direct with extra-family run	58.3	**Type of soil**	
Direct with family run	41.7	Clay and silty	3.0
Dimension of the farm		Sandy soil	97.0
Big	76.4		
Medium	18.1	**Type of irrigation system**	
Small	5.6	Sprinkler irrigation	11.0
Economic dimension of the farm		Micro irrigation	59.0
From 8.000 to 25.000 euro	6.3	Micro Sprinkler irrigation	28.0
From 25.000 to 50.000 euro	12.5	Other system	1.0
From 50.000 to 100.000 euro	6.3		
From 100.000 to 500.000 euro	56.3		
From 500.000 to 1.000.000	18.8		

4. Results. Capitanata Consortium case study, processing tomato

	ACY[1]	AGSP[2]	AVC[3]	AGM[4]	ALC [5]	AMC[6]	AOM[7]
Year	kg/ha	€/ha	€/ha	€/ha	€/ha	€/ha	€/ha
2011	120,086	13,389	4,294	9,095	1,523	1,926	5,646
2012	90,833	10,433	6,455	3,978	2,130	1,667	181
2013	95,649	9,592	3,372	6,219	1,538	1,523	3,158
2014	88,206	9,015	3,710	5,305	1,277	1,495	2,533
2015	100,636	9,378	3,873	5,505	1,368	2,796	1,341
2016	98,489	9,691	3,733	5,958	1,526	1,248	3,184
Mean	94,648	10,157	4,137	5,827	1,539	1,716	1,808
Std. Dev	4,639	1,467	1,028	1,552	272	499	1,700
C.V	5%	14%	24%	26%	17%	28%	64%

- Tomato requires a higher number of labour costs, Machinery costs, it requires significant investments in machinery and technical means.
- The mean of Estimate Gross Sale Production is 10,157 €/ha with a profit of 1,808 €/ha. Yjese values are higher than the observed value on the Capitanata Consortium (GSP is 7,440 €/ha and profit is 2,324 €/ha).

Capitanata Consortium: case study referred to processing tomato crop

Table 3: water use and water expenses indicators for processing tomato (FADN data)

Year	AWU FADN	fixed contribution (€/ha)	m^3	€/ha	$m^3 \cdot ha$	m^3	€/ha	$m^3 \cdot ha$	m^3	€/ha	$m^3 \cdot ha$	AWEXP (€/ha)
2011	4,848	30	2,050	0.12	246	1,950	0.18	351	848	0.24	203.52	831
2012	2,800	30	2,050	0.12	246	750	0.18	135	0	0.24	0	411
2013	5,817	30	2,050	0.12	246	1,950	0.18	351	1817	0.24	436.08	1,063
2014	7,090	30	2,050	0.12	246	1,950	0.18	351	3090	0.24	741.6	1,369
2015	8,420	30	2,050	0.12	246	1,950	0.18	351	4420	0.24	1060.8	1,688
2016	3,630	30	2,050	0.12	246	1,580	0.18	284.4	0	0.24	0	560
	5,139											882

Mean value

Mean value

- The AWU observed for processing tomato on the Capitanata Consortium range from 3.000 to 6.000 m^3/ha (source: Consorzio per la Bonifica della Capitanata FOGGIA, L.Nardella, N. Noviello);
- The AWEXP range from 600 €/ha to 1010 €/ha on the Capitanata Consortium, with a medium value equal to 840 €/ha (source: Consorzio per la Bonifica della Capitanata FOGGIA).

Table 4: characteristic of the farms located in the Chiese consortium area

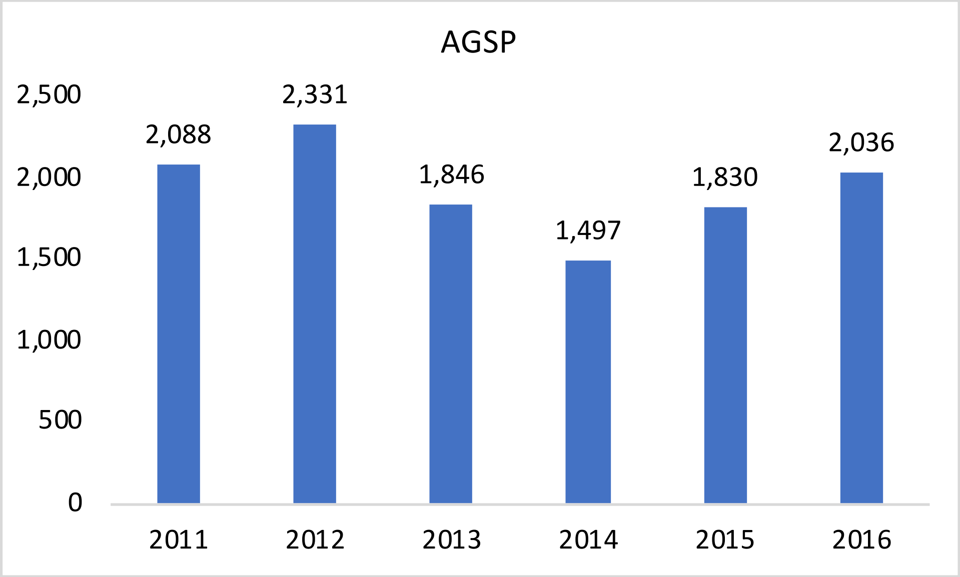
Variables	%	Variables	%
Slope of the land		**Water supply system**	
None	6	Consortium	93
Flat (less than 5%)	83	Lake or river	0.5
Sloping terrain	12	Reservoir	5.5
Management type		**Type of soil**	
Direct with extra-family run	19	No information	6
Direct with family run	75	Sandy soil	8
Indirect	6	Clay and silty soil	86
Dimension of the farm			
Big	55.26	**Type of irrigation system**	
Medium	36.84	Sprinkler irrigation	6
Small	7.89	Micro irrigation	93
Economic dimension of the farm		Micro Sprinkler irrigation	1
From 8.000 to 25.000 euro	7.89		
From 25.000 to 50.000 euro	21.05		
From 50.000 to 100.000 euro	15.79		
From 100.000 to 500.000 euro	13.16		
From 500.000 to 1.000.000	5.26		
More than 1.000.000	36.84		

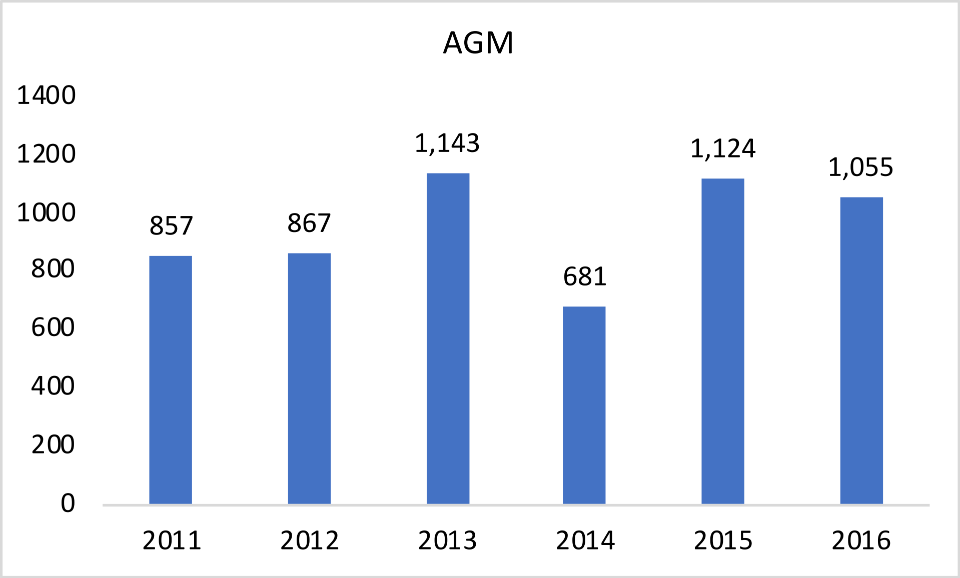
Table 5: Economic indicators for Maize crop production

	ACY[1]	AGSP[2]	AVC[3]	AGM[4]	ALC [5]	AMC[6]	AOM[7]
Year	kg/ha	€/ha	€/ha	€/ha	€/ha	€/ha	€/ha
2011	24,669	2,088	1,231	857	490	485	-118
2012	21,826	2,331	1,464	867	811	715	-659
2013	10,319	1,846	703	1,143	315	701	126
2014	8,583	1,497	816	681	375	205	100
2015	11,091	1,830	706	1,124	417	29	679
2016	12,469	2,036	999	1,055	426	230	398
Mean	12,173	1,920	949	939	450	263	88
Std. Dev.	4,657	259	282	166	160	259	418
C.V.	38%	13%	30%	18%	36%	98%	477%

[1]average crop yield (ACY) expressed in term of kilograms per hectare (kg/ha), [2]average gross sales production (AGSP) expressed as €/ha, [3]average variable costs (AVC) expressed as euro per hectare (€/ha), [4]average gross margin (AGM=AGSP-AVC); [5]Average labor costs (ALC) expressed as euro per hectare (€/ha), [6]Average machinery costs (AMC) expressed as €/ha, [7]Aaverage operating margin (AOM=AGM – ALC - AMC) expressed as €/ha;

The Chiese consortium: case study of the maize crop





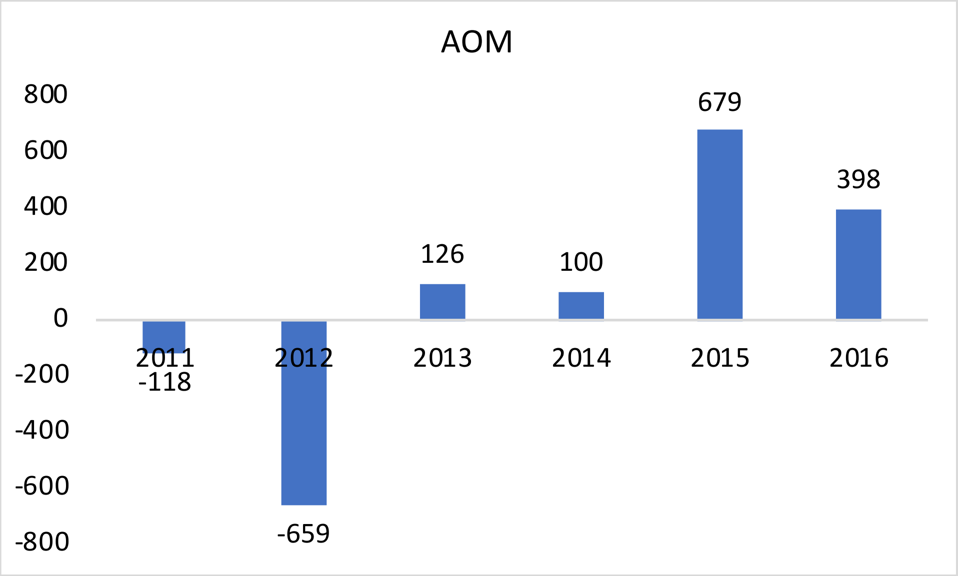


Table 7: water indicators for MAIZE crop (FADN data)

	AWEXP	PWP	EWP	EWPR
Year	€/ha	$\frac{kg/ha}{m^3/ha}$	$\frac{€/ha}{m^3/ha}$	$\frac{AWEXP}{Variable\ costs}$ %
2,011	141	8.03	0.28	11%
2,012	141	7.40	0.80	9%
2,013	141	4.22	0.76	20%
2,014	141	2.00	0.32	17%
2,015	141	4.00	0.61	20%
2,016	141	2.15	0.35	14%
Mean	141	4.03	0.48	15%

Table 8: Water use and metereological information for the Capitanata consortium

Year	Average Temperature [1] (°C)	Average Temperature [2] (°C)	Precipitation [1] (mm)	Precipitation [2] (mm)	AWU[2] m3/ha
2011	14.8	17.1	787.8	74.7	3,073
2012	14.6	17.2	856.2	94.1	2,931
2013	14.1	15.8	1145.8	112.7	2,245
2014	15.1	16.4	1319.5	107.7	4,639
2015	15	16.8	651.4	58.0	2,959
2016	15.7	16.9	735.5	278.6	5812
Mean	14.88		887.48		3424
Std. Dev	0.49		237.43		1220
C.V.	3%		27%		36%

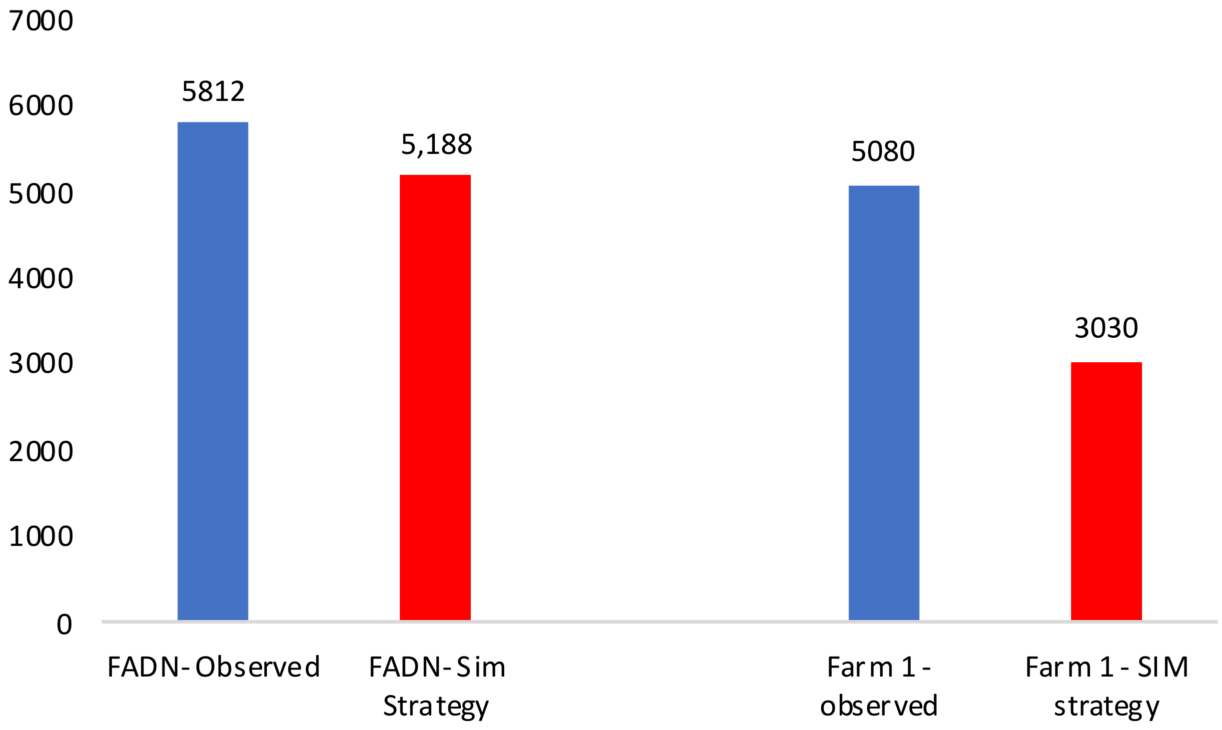
Source: [1] and [2] data estimation from POLIMI, [1] refer to the period 15° April, 15° September, [2] refer to the period 1° March-30° November

Spearman's rank correlation coefficients

- ρ between average temperature and AWU estimated on the basis of FADN data is reported as 0.77, indicating a strong positive correlation;
- ρ between cumulative precipitation and AWU estimated on the basis of FADN data is reported as -0.03, indicating a stlight and negative correlation.

The Chiese consortium: case study of the maize crop

Figure: AWU for observed and simulated data for the year 2016



FADN: -23% of water

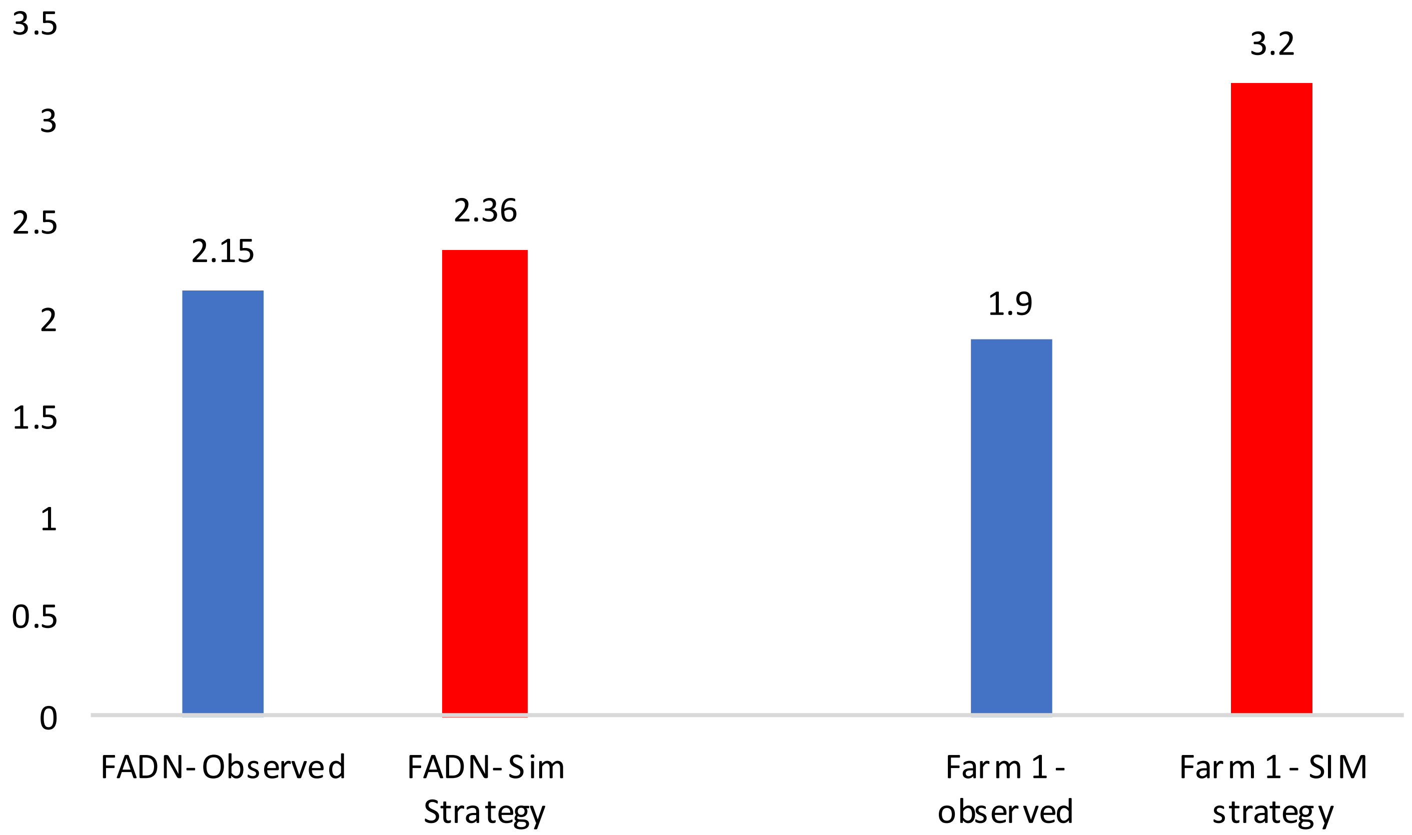
FARM 1: -40% of water

For the FADN dataset, when we move from observed data and simulated data, it is possible to.

This water saving is more marked when we compare the observed and simulated values for the experimental farm: during the 2016, with the SIM strategy, farm 1 could save up to 40% of water.

The Chiese consortium: case study of the maize crop

Figure : PWP for observed and simulated data for the year 2016



$$PWP = \frac{Ya}{AWU} = \frac{kg/ha}{m^3/ha}$$

FADN: PWP would increase by 30%

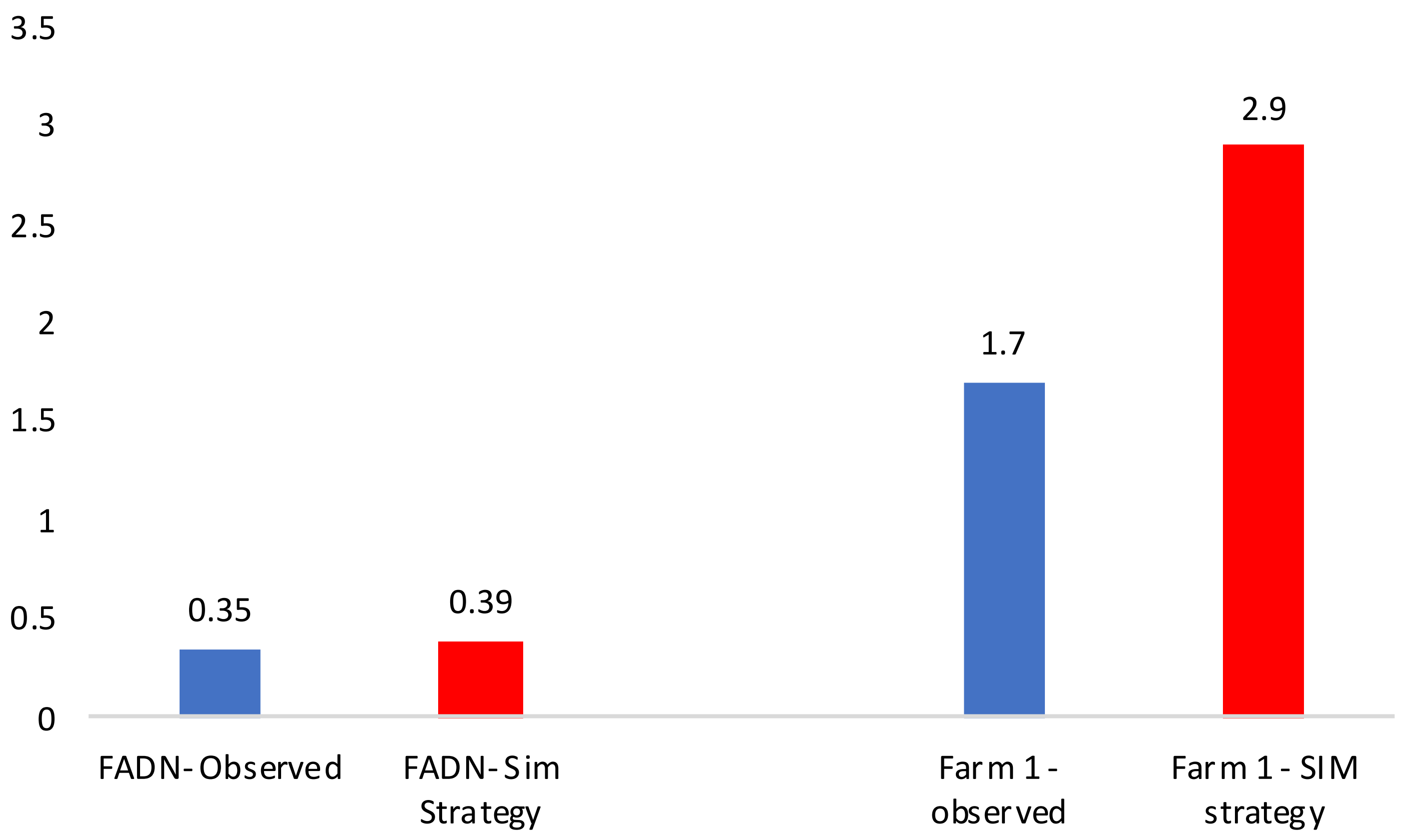
FARM 1: PWP would increase by 60%

For the farms included in the FADN dataset, when we move from observed data and simulated data, it is possible to increase the PWP to 30%.

This increase in PWP is more marked when we compare the observed and simulated values for the experimental farm: during the 2016, during the 2016, with the SIM strategy, farm 1 could increase the PWP of 60%.

The Chiese consortium: case study of the maize crop

Figure: PWP for observed and simulated data for the year 2016



$$EWP = \frac{Gross\ margin}{AWU} = \frac{€/ha}{m^3/ha}$$

FADN: EWP would increase by 25%

FARM 1: EWP would increase by 60%

For the farms included in the FADN dataset, when we move from observed data and simulated data, it is possible to increase the PWP to 25%.

This increase in PWP is more marked when we compare the observed and simulated values for the experimental farm: during the 2016, during the 2016, with the SIM strategy, farm 1 could increase the EWP of 60%.

Classical Stochastic frontier model (SFM)

These components are assumed to have a normal distribution with zero mean and constant variance, $iid \sim N(0; \sigma_v^2)$.

The second term u_i is assumed to be independently distributed of v_i and non-negative random variables, $u_i \geq 0$.

The one-sided components u_i are assumed to be **heteroscedastic and to follow a half-normal distribution**, with the following probability density function:

$$f(u_i) = \frac{2}{\sqrt{2\pi\sigma_{u_i}^2}} exp\left\{-\frac{u_i^2}{2\sigma_{u_i}^2}\right\}$$

For each production unit, inefficiency could derive by an incorrect allocation of inputs and by the effects of other factors $\boldsymbol{z_i}$ which are **exogenous** to the production process but influence the efficiency level.

Results: descriptive statistics

Table 1: input, output and Water use indicator

		IWU	Yield	Irrigated Land	Labour	Machinery	WUE
		m^3/ha	kg/ha	ha	Hours/ha	Hours/ha	Yield/IWU
Crop	n	mean	mean	mean	mean	mean	kg/ m^3
Broccoli	18	15,547.0	12,960	11.6	270.3	43.8	0.83
Cucumber	4	30,260.0	41,621	3.2	1,886.9	67.7	1.38
Chicory	10	12,381.9	18,308	7.3	346.8	25.2	1.48
Green beans	4	57,159.8	12,799	2.8	3,770.4	137.5	0.22
Fennel	7	6,795.1	15,589	8.7	275.5	24.8	2.29
Aubergine	4	46,420.0	31,950	2.1	523.8	59.7	0.69
Potato	7	10,755.3	26,638	25.7	262.9	43.1	2.48
Pepper	6	62,345.8	27,250	5.2	408.9	47.4	0.44
Processing Tomato	21	18,387.7	93,239	21.0	213.9	68.8	5.07
Table tomato	17	19,276.2	29,164	5.5	621.3	61.8	1.51
Zucchini	10	19,660.5	34,313	2.7	429.2	63.1	1.75
	108	27,180.8	31,257	8.7	819.1	58.4	1.65

Results: Stochastic frontier approach (SFA)

Table 3: Estimates of marginal effects on inefficiency

	Coefficient	Std. Err.	P-value	Marginal effect on E(ui)
Crop type				
Ref. processing tomato				
Broccoli	1.915	0.408	0.000	1.035
Cucumber	-0.102	1.034	0.921	-0.055
Chicory	1.421	0.430	0.001	0.768
Green beans	1.640	0.531	0.002	0.886
Aubergine	0.827	0.572	0.148	0.447
Potato	1.270	0.480	0.008	0.687
Pepper	1.255	0.512	0.014	0.678
Table tomato	0.970	0.436	0.026	0.524
Fertigation				
Ref. no	-0.321	0.174	0.065	-0.174
Organic production				
Ref. no	0.420	0.379	0.067	0.227
Management Type				
Ref. direct with prevalence of family extras	0.004	0.183	0.983	0.002
Constant	-0.430	0.396	0.278	

Results: Stochastic frontier approach (SFA)

Table 4: Technical efficiency for the factors influencing the optimal output

	Mean	s.d.	p25	p75
Crop type				
Broccoli	0.261	0.045	0.235	0.288
Cucumber	0.946	0.014	0.933	0.961
Chicory	0.440	0.092	0.379	0.532
Green beans	0.390	0.037	0.363	0.418
Fennel	0.994	0.000	0.994	0.994
Aubergine	0.798	0.153	0.678	0.917
Potato	0.602	0.008	0.598	0.609
Pepper	0.629	0.218	0.497	0.665
Processing tomato	0.940	0.018	0.933	0.952
Table tomato	0.753	0.176	0.598	0.992
Zucchini	0.992	0.000	0.991	0.992
Total	0.692	0.285	0.403	0.956
Use of Fertigation (yes)	0.743	0.251	0.563	0.958
Adoption of Organic farming (yes)	0.644	0.372	0.343	0.923