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Precision irrigation and harvest management in orchards: an economic assessment

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ABSTRACT

Precision management has become vital in agriculture with possibilities growing alongside developments in information and communication, robotics and sensor technologies. On the other side of expected benefits of precision management in terms of environmental friendliness, yield margin, input efficiency, etc., is the upfront expensiveness of such technologies. There is hence a need to quantitatively assess expected net benefits and provide useful information for farmers and stakeholders to enable informed choice on the potential adoption of precision technologies and management practices. This study presents economic assessment of precision irrigation and harvest management system with integrated use of sensor technologies and Farm Management Information System (FMIS) as compared to conventional practice applying partial budgeting as a tool. Relevant scenarios are defined based on data from an experimental apple orchard field situated in Prangins, Switzerland. The precision management system is found to be economically justifiable in situations of high demand for irrigation characterized by limited rainfall and considerable variabilities in weather conditions. Its economic feasibility is found to be sensitive to changes in fruit price and capital cost.

Keywords: apple orchard, economic assessment, irrigation management, partial budget analysis, precision agriculture

INTRODUCTION

Agriculture is being increasingly challenged by increasing competition, declining availability of key natural resources and growing demand for high quality produce. Farmers are also being increasingly challenged to consider environmental and social impacts of their business besides economic return (Janssen et al., 2010). To survive amidst these challenges, farm businesses need to improve productivity, competitiveness, resource use efficiency and environmental friendliness. Precision farming has been regarded as a means of achieving these multiple objectives (Mondal and Tewari, 2007; Adeyemi et al., 2017).

Nowadays, marketable quality as well as environmental friendliness of production systems has become a competitive edge in the farming business. Fruticulture is a typical area where competition is fierce and there is increasing demand for high quality fruits produced with minimal environmental footprint. In the case of apple orchards, fruit quality along with yield level and production cost is found to be main determinant of economic success (Bravin et al., 2009). Irrigation and harvest management, among other operations, are fundamental to producing high quality fruits.

Given that agriculture is the dominant consumer of water worldwide, efficient application of water is a critical aspect of precision agriculture (Jiang et al., 2011).

It could be possible to save agricultural water use without significant impact on yield (Greaves and Wang, 2017). According to Perea et al. (2017), precision irrigation is particularly important in high value fruits where quality assurance is a major determinant of profitability. In Europe, water availability is expected to drastically decrease because of increased demand, effects of climate change and regulatory requirements (Tarjueloa et al., 2015; Giannakis et al., 2016). There is hence an incessant need to optimally manage water use mainly with irrigation.

Studies show that final fruit quality is also highly influenced by the optimality of harvesting time (Muhtaseb, 2007; Kviklienė and Valiuškaitė, 2009). Management of irrigation coupled with the method and timing of harvest is reported to have an important bearing on final oil quality of olive trees (Dag et al., 2008). Promisingly, developments in Information and Communication Technologies (ICT) including sensors and robotics provide the potential for precise measurement of crop water status for irrigation management and precise estimation of optimal harvest timing, among others. Plant water stress indicators are recognized to having promising potential for irrigation management under water stress conditions (Paço et al., 2013).

To make informed and timely management decisions, Farm Management Information Systems (FMIS) with decision support capabilities are essential tools. In Europe, FMIS are becoming indispensable tools in farm management in the face of increased attention for economic viability and interaction with the surroundings (Sørensen et al., 2010). However, lack of appropriate decision support systems (DSS) customized for farm decision makers has still been a limiting factor against widespread adoption of precision management. FMIS helps improve allocation of managerial time (Vaughan et al., 2013), for example, geo-referenced information and decision aids reduce the burden of field monitoring and spare labor time which can be spent on better planning.

The project "USability of Environmentally sound and Reliable technologies in Precision Agriculture" (USERPA), in the framework of the European Research Area Network Information and Communication Technologies in Agriculture, proposes integration of canopy and fruit sensors with mobile vehicles and wireless sensor networks together with a Farm Management Information System (FMIS) for providing spatial data for high value crops (vineyards and apple orchards). USERPA aims at developing an integrated precision agriculture solution for orchards and vineyards focusing primarily on irrigation and harvest management to produce high quality fruits by optimal input use without jeopardizing environmental sustainability.

It is expected that precision irrigation and harvest management investments that improve yield and fruit quality payoff by receiving higher price in a competitive market. For example, studies show that consumers having concern for health and environmental sustainability reveal positive willingness to pay price premium for eco-friendly apple fruits (Loureiro et al., 2002; Durham et al., 2012). However, such precision technologies are expensive upfront (Giannakis et al., 2016) and involve several uncertainties (Tozer, 2009). To this end, it is crucial to quantitatively assess expected net benefits and provide useful information for farmers and other stakeholders interested in potential adoption of the technologies and management practices. Attempts to quantify economic feasibility of irrigation management systems are mostly based on case studies on small experimental fields and the conclusions tend to reflect that precision irrigation management technologies are not as such economically viable. In a case study on cotton production in Texas High Plains, Seo et al. (2008), concluded that a critical level of output price is required for precision irrigation to be economically justified. As noted in Lu et al. (2005), variable rate application of irrigation would potentially be profitable in the future as many farmers adopt the technologies.

This study is concerned with assessment of potential economic feasibility of precision irrigation and harvest management system proposed by USERPA compared to conventional practice. A partial budget analysis methodology is employed based on data from

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a demonstration field of apple orchard in Prangins, Switzerland.

MATERIALS AND METHODS

Study site and experiment setup

For testing and demonstrating the USERPA system, field experiments were held on a commercial apple orchard of Gala Brookfield (specie: maus) with 1,357 trees (2,500 trees/ha) in the district of Nyon in the canton of Vaud in Prangins, Switzerland. Description of the study field is given in Table 1 below.

Table 1. Description of USERPA's experimental apple orchard in Switzerland

Feature	Description
Field area	0.6 hectare
Altitude	420 meters
Soil features	Clay 26%, silt 29%, sand 45%; pH 7.5
Precipitation	750 mm (average of 25 years)
Distance between rows	4 m by 2.5 m (inter-row 1m)
Year of tree planting	2007
Expected tree depreciation time	18 ± 2 years
Irrigation system	Drip irrigation
Installed capacity	3.6 liters / tree / hour
Harvest technology	By hand

Conventional irrigation is initiated from mid-May until the end of August or later on a daily basis for two hours. When the rain is believed to be enough to cover the water requirements of the orchard, irrigation is suspended. Though Evapotranspiration (ETP) estimates are provided online and free of charge by the Swiss meteorological agency – Agrometeo, the farmer mentioned that he only considered it for a short while and usually irrigates based on his experience, expectations about weather conditions, tree phenology and perceptions about tree water requirements. The amount of irrigation the farmer applies during rainy, moderate precipitation and dry seasons respectively is 200, 800 and 1,500 m^3/ha (where 10m^3/ha is equivalent to 1 mm of rainfall). In 2014, irrigation was applied on a daily basis from 16 to 30 June while in 2015 it was applied from 27 May until 4 September. Even if the general level of precipitation seems to have been observed in the irrigation decision, the amount and timing of irrigation has been calendar-based without taking full consideration of variabilities in relevant within field features and weather attributes. It could be possible to save more water by precisely managing variabilities. It was also reflected by the case farmer that current practice may not be efficient and better can be done by combining technology and farmer experience.

As for fruit harvest, it is normally done in two rounds one in late August (early September) and a second round in approximately a week or two later. Within two days of harvest, fruits are transported, sorted, stored and marketed by a cooperative called Le'man fruits Fenaco Cooperative Society to which the farmer is a member. The coop classifies apple fruits into three quality groups; namely, premium, first-class, and second-class based mainly on fruit weight, color and sugar content given cultivar (fruit variety). The coop uses several cameras to measure fruit color. Besides, 35 randomly chosen apples are passed through Perenelle to be individually measured for acidity, fruit flesh firmness, and brix and five of them are then smashed and measured for juice content. The cooperative sends out information on expected price of all apple fruit varieties by quality category before harvest (often in August) to all members but price adjustments can be done based on aggregate supply and market conditions.

With the purpose of improving management of irrigation and harvest by integrated use of sensor technologies, USERPA experiment setup was prepared and necessary fixed sensors (on fruits, canopy and in-soil to make real-time measurements throughout the production season) deployed in 2013 whereas measurements with all the sensors were done in 2014 and 2015. The experiment setup consists four irrigation plans with three repetitions (rows) each: no irrigation (0%), half-irrigation (50%), full-irrigation (100%) and ‘farmer practice’ where ‘full-irrigation’ means irrigation amount according to best practice and ‘farmer-practice’ is left for farmer decision that is assumed not to be influenced by the experiment. The idea is to compare the three irrigation levels against farmer-practice in terms of potential economic gains. Despite the original plan, ‘Farmer practice’ and ‘100%’ irrigation zones received the same amount of irrigation throughout the experiment period.

Figure 1 depicts USERPA’s experimental setup of the apple orchard field in Prangins, Switzerland (diagram on the left is the field setup during 2014 experimental season whereas the two diagrams to the right show adjustments made during 2015). To prevent rainfall water from sinking into the soil, plastic cover (rectangular area in Figure 1 with red boundary) was placed on part of the ‘no-irrigation’ zone on 1 June 2015. Half of the cover was removed on 14 July 2015 and then irrigated as the 100% treatment (stage 2 in Figure 1).

The plan with the experiment was to capture stress effects from deficit irrigation treatments (0% and 50%) using the imaging systems and apply 'sensor-based' reaction based on that information during the end of June and the beginning of July. Due to lack of stress effects owing to heavy rainfall especially in the summer of 2014, 'sensor-based' reaction was not accomplished. Table 2 presents description of the sensors involved in the USERPA system.

USERPA intends to provide decision support by FMIS-automated analysis of data from various imaging and bio-physical measurements such as soil conductivity, canopy cover, canopy vigour, chlorophyll content, canopy temperature, leaf/stem water potential, stomatal conductance and maximal daily shrinkage of tree diameter. Within the FMIS, Crop Water Stress Index (CWSI) is calculated both from metrological data and thermal imaging data and statistically associated with leaf/stem water potential measurements taken simultaneously. CSWI based on canopy temperature and metrological conditions was reported as a good indicator of crop water status in the case of potato fields in Israel (Rud et al., 2014). The study claims that CWSI estimated from thermal imagery can be reliably used for precise irrigation management. Decision rules to trigger irrigation can be determined by combining information on CWSI and other bio-physical measurements (e.g. trunk diameter shrinkage, stomatal conductance) and soil water status data.

For improving harvest management, various

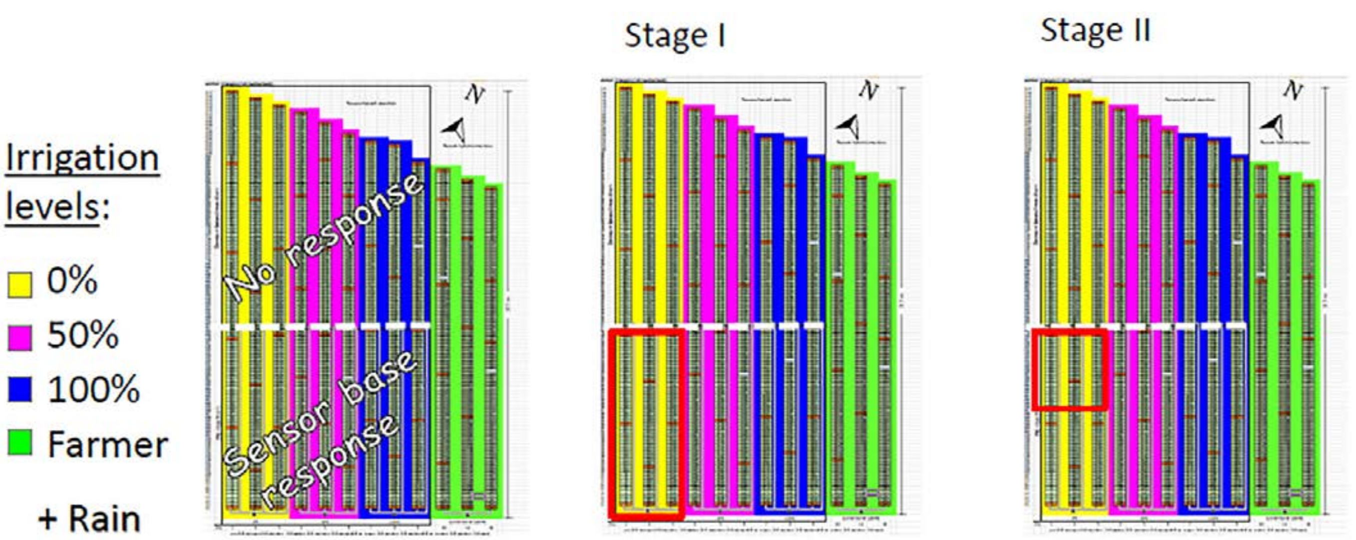

Figure 1. USERPA experimental setup of the field with apple tree rows at the Apple Orchard in Prangins, Switzerland (Source: USERPA project portal, ‘Selected Results’ compiled by ARO, 2016)

Table 2. Description of sensor technologies in USERPA

Sensor name	Sensor type	Measurements	Operation
LIDAR	Mobile	Light absorption & scattering	Harvest
Resistivity meter	Portable	Eca	Irrigation
LAI meter	Handheld	Plant vigor	Irrigation/harvest
Laser scanner	Mobile	Plant biomass	Irrigation/harvest
Multispectral camera (RGB /NDVI)	Mobile	Canopy cover & vigour, chlorophyll content, water potential	Irrigation
Thermal infrared camera	Mobile	Canopy temperature	Irrigation
TRS camera	Mobile	Light absorption & scattering, fruit firmness, chlorophyll	Harvest
Microclimate sensor	Fixed	Temperature, humidity, radiation, wind speed & direction	Irrigation/harvest
Dendrometer	Fixed	Trunk diameter	Irrigation
Optical Spider	Fixed	Chlorophyll & water content	Harvest
Pigment Analyzer	Handheld	Chlorophyll content, anthocyanins, soluble solids content	Harvest
Raman sensor	Handheld	Carotenoids & water content	Irrigation/harvest
Time-Domain Spectrometer	Laboratory	Chlorophyll & carotenoids	Irrigation/harvest
Pressure bomb	Handheld	Leaf/stem/ water potential	Irrigation
Porometer	Handheld	Stomatal conductance	Irrigation
Soil sensor	Fixed	Soil moisture, & temperature, eca	Irrigation

measurements such as light absorption and scattering, fruit firmness, water content, chlorophyll content, anthocyanins, soluble solids content (SSC), carotenoids, plant biomass and plant vigor are incorporated. Fruit quality measurements were done on fruits while on tree and harvested using non-destructive sensor technologies (Torricelli et al., 2015). Measurements of fruit quality attributes using mobile and handheld sensors were done three times (end of June, end of July and beginning of September) in a growing season mainly due to a minimum size required to make measurements with the various sensor technologies employed. In 2014, three rounds of field campaigns (June 23-28, July 27-1 August and September 1-5) were made during which measurements on fruit physiology and quality attributes, leaf physiology and water content, microclimate, among others, were taken. Similar measurements were performed in 2015.

With the purpose of providing decision support for the timing of harvest, fruit status estimation was done based on pigments (carotene and chlorophyll) and water sensing using multi-spectral sensors on sampled leaves and fruits. Final fruit quality measurements including local commercial measures for marketing (color, size, sugar content, juice content, etc.) were done on harvest day. Data from vehicle platform, weather station, sensors, farm account data and market data are automatically loaded to the web-based FMIS in a way that enables near-real-time monitoring.

The FMIS has decision support capabilities mainly targeted for irrigation and harvest management where decision rules are generated within the FMIS by automated analysis of field data, market information, agronomic and economic data. The main idea is to assist farmers to answer two basic questions of 'when' and 'where' to take an action to have an optimal irrigation for maximum benefit from yield at harvest time (USERPA, 2013). In this study, the farm manager is regarded as the final decision maker based on suggestions provided by the decision support tools in the FMIS. Handheld and potentially tractor-mountable TRS sensors adapted for fieldwork will provide good potential for the determination of optimal harvest time. Analyses of data acquired during the field measurements is undergoing while some results have been published (Seiferta et al., 2015; Torricelli et al., 2015; Käthner and Zude-Sasse, 2015).

Mobile sensors are mounted on a portable platform (robotic vehicle) that can be remotely guided in the field to make imaging by several sensors such as thermal camera, RGB, hyperspectral camera and laser scanner, simultaneously. During data collection, portable computer and wet reference bath are attached to the mobile platform. A picture of the mobile platform with sensors mounted on it during in-field data collection is shown in Figure 2.

Figure 2. Sensors mounted on robotic platform during field data collection (Source: USERPA project portal)

Assumptions and scenario definition

In this study, the following working assumptions have been made.

1. Yield level and quality of fruits under USERPA is at least as good as conventional practice. Yield amount: presuming that precision management as propounded by USERPA is to improve fruit quality with optimal resource allocation and management than it is to increase yield volume, yield per hectare is assumed to be the same under the two systems.
2. The fruit market is competitive where better quality fruits receive better price premium.
3. Cost of management tasks apart from irrigation and harvest (e.g., thinning, pruning, trimming, etc.) do not change with adoption of USERPA. In reality, as farmers become well aware of the specific needs of their crop through the use of spatially referenced data, it is likely that farmers also adjust their overall management and hence costs and benefits of other management tasks can be changed.
4. Assets of conventional practice including farmer experience and physical assets can be used in USERPA without loss of value.
5. USERPA physical devices bought by a farmer can be used to their full capacity by renting out individually or as a package.

In order to reflect the importance of spatial and temporal variability, precipitation, weather variability and with-in field variability are considered in the scenario definition. In areas of high weather uncertainty and field variability added to generally scarce water resource and scanty precipitation, well-managed irrigation is so crucial. At the experimental field, variability in weather condition is considerable; spatial variation in ground water within the farm and differences in soil thickness and fertility are moderate; the amount of precipitation varies from average to high; and availability and cost of water does not seem to be a constraint.

For the analysis, three scenarios were defined as follows:

LOW scenario: here precipitation is high; no considerable field variability; and weather condition is not as such variable. In such a case, irrigation may not relatively be much of a concern; relatively less number of samples in the field may suffice implying lower capital and operating costs. On the benefit side, marginal improvements can be expected as compared to conventional practice.

MODERATE scenario: characterized by moderate precipitation, moderate field variability and modest weather variability. Cost and potential benefit under this scenario lie between the two boundaries scenarios defined before.

HIGH scenario: is characterized by scanty precipitation with high weather variability and high variability in field features. Under these circumstances, irrigation management according to the specific needs of sub-fields is so crucial. There is greater need for employing precision technologies including farm management information systems with decision support capabilities. However, in economic terms, what matters for farmers is whether the extra benefit would justify such high investment.

In this study, benefits from the USERPA system as compared to conventional practice as characterized by labor and water saving as well as improved quality of fruit.

Yield quality: average proportion of yield on the case farm by fruit quality class is 5-10% premium, about 60% first class and 15-20% second class. In the analysis, for conventional practice 5% premium, 60% first class, 20% second class, and 15% third choice are considered based on data from the case farm (e.g., during 2014 harvest season, about 14% of yield was reported to be 'third-choice' that is generally considered as waste from farmers' point of view). Full potential benefit in terms of fruit quality improvement is assumed to be exploited from year 3 with 50% gain in the first two years of adoption.

Labor saving: semi-automated data collection, management and analysis along with minimum labor hold-up in irrigation reduces labor need. This would bring considerable benefit in high wage countries like Switzerland. Işik et al. (2017) reported that precision irrigation system enables about 60% reduction in labor force.

Table 3 shows assumed potential labor cost by task under conventional versus USERPA systems.

Table 3. Labor hours by task per hectare per year: conventional versus MODERATE USERPA scenario

Task	Conventional	USERPA
Testing and calibration	0	1
Advisory cost	15	30
Platform integration	0	1
Staff training	0	30
Manual data collection	15	11.25
Hold-up labor in irrigation	15	11.25
Manual data organization	5	3.25
Manual data analysis	5	3.25
Laboratory analysis	0	3.42
Interpret DSS results and decide on management plan	0	10

Water saving: in dry areas, in farms of significant within-field variability and with much variability in weather conditions, precision management of water would entail tremendous value. In the case of Switzerland where precipitation is generally plenty, a 50% reduction in irrigation water would ideally produce the same level of yield without impairing quality (personal communication with Reynald Pasche and Ronit Rud). Table 4 presents fruit quality gain and water saving assumptions by scenario. Other precision irrigation projects also show up to 50% water saving (https://www.youtube.com/watch?v=7QUSg0hmqOk). Sadler et al. (2005) reported water conservation potential of from marginal up to nearly 50% with the use of precision irrigation. Hence, '50% water saving' assumption by use of precision techniques appears reasonable.

Table 4. Water saving and fruit quality gain assumptions by scenarios relative to conventional practice

Benefit item	LOW	MODERATE	HIGH
Water saving	10%	25%	50 %
Fruit quality improvement	2%	4%	6 %

Analysis method

For the purpose of the present study (to make economic assessment of the USERPA system), Partial Budget Analysis (PBA) appears a suitable tool as it enables the evaluation of the effect of change in farm technology on net income without knowing all the cost structures of the farm (Horton, 1982). PBA involves identifying costs and benefits, converting identified quantities into costs and returns, and then calculating the change in cost and revenue between the technologies in question to get the net effect on income.

To evaluate economic rationality of the USERPA system, relevant performance indicators; namely, Net Present Value (NPV), Internal Rate of Return (IRR) and Benefit-Cost Ratio (B/C) are presented. Present value of P_i amount of monetary investment at period n is calculated as follows:

$$PV_{Pi}^{(n)} = \left(\frac{1}{1 + I_R}\right)^n P_i$$

where P_i is the amount of money outlay at period *i*; $PV^{(n)}_{Pi}$ = present value of P_i at period *n*; and I_R = real interest rate. NPV is the difference between present value of revenue and present value of cost. IRR represents the rate of return required for an investment to break-even (i.e., NPV becomes zero) whereas B/C is ratio of benefit to cost. Besides, NPV estimates are annualized applying the standard annuity factor payment formula:

$$ANB = NPV * r\,(1 + R)^{-T}$$

where *ANB* stands for annualized net benefit, NPV is the estimated net present value, r is discount factor, and T is the project life over which the NPV calculation is done. In this case, ANB represents estimated net value per hectare per year from USERPA system relative to conventional practice.

Data on the following variables has been collected: capital and operating costs, quantities and prices of inputs that vary between the two systems (labor, water and energy), fruit price, and yield data from the technologies in comparison. Even if it is challenging to assign monetary value to inputs and outputs from a trial as noted in (Ehui and Rey) an attempt has been made to calculate relevant benefits and costs.

RESULTS

The first part of this section presents estimated cost of the USERPA system along with price and yield data. The second part presents result from partial budget analysis of USERPA drawing from data on the experimental field of apple orchard in Switzerland.

Cost and revenue estimation

To be able to use the full functionality of USERPA FMIS requires several sensors (Tsiropoulos and Fountas, 2016). Cost estimates based on data for the experimental site based on measurements taken in 2014 are provided in Table 5 below. Purchase cost information for the sensors as well as hardware, software and rental cost of FMIS are provided by USERPA project partners. The price of data logger, soil sensor and porometer are price quotes provided by INVERVA Aps of Denmark on behalf of Decagon and for LAI meter is provided by Li-COR of UK (email correspondence on 5 January 2016). As Raman sensor, optical spider and TRS camera are not yet available in the market for agricultural use; their costs are estimates by project partners in USERPA.

Estimation of per hectare cost of devices presented in Table 5 is based on measurement repetitions needed and estimated use potential of the respective devices. For the estimation of use potential, reasonable measurement repetition needed for typical apple orchard per production season of mobile, handheld and laboratory sensors is set to be approximately 14, 7, and 5 per season respectively in accordance with recommendations by project partners. Tractor turning time is set twice the driving time at normal driving speed for the maximum turning distance

Table 5. USERPA System Investment Cost

Device	Year of purchase	Purchase price in € per unit	Annual fixed cost in € per unit**	Estimated use capacity in hectare	Fixed cost in €/ha/yr. at EUC
LiDAR	2015	5,324.63	93.20	82.00	1.14
Resistivity meter	2004	15,000	262.50	42.00	6.25
Multispectral camera (RGB/NDVI)	2016	4,000	70.00	82.00	0.85
Data logger		1,466	25.70	500.00	0.05
LAI meter	2016	8,903	155.80	42.00	3.71
Soil sensor	2016	298	5.20	0.50	10.40
Thermal infrared camera		18,000	315.00	82.00	3.84
Porometer	2016	3,429	60.00	42.00	1.43
Pressure bomb		2,000	35.00	42.00	0.83
Optical spider		4,000	70.00	0.50	140.00
Pigment analyzer	2009	8,000	140.00	42.00	3.33
Raman spectroscopy		30,000	525.00	42.00	12.50
TRS cameras		50,000	875.00	203.00	4.31
Dendrometer	2011	1,000	17.50	0.50	35.00
Microclimate sensor	2011	200	3.50	0.50	7.00
Mobile platform		25,000	568.80	82.00	6.94
Office computer	Assumed	400	7.00	500.00	0.01
Task computer	Assumed	500	8.80	82.00	0.11
Tablet	Assumed	350	6.10	82.00	0.07
Irrigation system installation	2014	3,150	55.10	1.00	55.10

producing maximum turning distance of 16 meters and a total of 9 turnings per hectare. For simplicity, time for turning around one row and between nearby sampled rows is assumed to be the same.

Use potential of the tractor and the sensors to be mounted on it is estimated for 25 rows with 4m distance between each row at a sampling rate of 20% (5 rows as one block and the middle row sampled in each block). Assuming 6 hours per day and 5 days per week suitable for imaging, mobile (imaging) sensors mounted on semi-autonomous vehicle with driving speed of 5 km/hour and use efficiency of 70% can be used on 82 hectares of orchard. Suppose, in a commercial farm, representative measurement with handheld devices can be done in one hour per hectare and measuring once in two weeks would be enough. With the same assumptions on use efficiency and suitable hours and days in a week, a unit of handheld sensor is estimated to suffice for about 42 hectares of orchard. With 10 hours per day and 5 days a week available for lab measurements, a unit of lab sensor is estimated to be enough for about 203 hectares of orchard at 90% use efficiency.

From the reported purchase price of the physical technologies in USERPA, a 30% reduction is assumed in the analysis based on project partners' reflection that the price of those devices will decline in the future with wide market penetration. Useful lifetime of the technologies is assumed to be 10 years. Cost per hectare is estimated combining information on actual/expected/ cost of devices, literature, intuition and assumptions. In the analysis, relevant operating costs are also included. Following the guidelines in (Kime et al., 2016), ownership (fixed) cost items of insurance, housing, and repair and maintenance are estimated as 0.5%, 1% and 5% of average value of investment. Housing and insurance costs are added only for the mobile platform. Staff training cost and changes in energy consumption in relation to data collection, irrigation and harvest due to the proposed system are also considered. In Table 5, fixed cost includes repair and maintenance, insurance and housing cost.

For the revenue estimation, price data obtained from the case farm owner and yield assumption based on information provided by project partners are used. In 2013 the price of premium, first and second choice apple fruits was 1.134, 1.044, 0.378 €/kg (equivalent of 1.26, 1.16 and 0.42 CHF/kg at an exchange rate of 0.9 €/CHF) respectively. According to Dominique Fluery, on average per hectare apple yield in Switzerland is 45 hectares (email correspondence on 1 July 2015). In the analysis, a conservative estimate of 35 kg per hectare is used.

Results from partial budget analysis

Chosen performance indicators to evaluate the economic viability of the proposed technology as compared to farmer practice are NPV, IRR and Benefit-Cost Ratio. Annualized net benefit estimates (ANB) are also presented where necessary. USERPA under the MODERATE scenario is estimated to have an IRR of 6.12 % and generate a net benefit of €843 in present value over a period of ten years equivalent to 69 € per hectare per year in annualized terms.

In Table 6, comparison of results for selected use capacity of non-fixed sensors is provided.

The PBA results from estimated use capacity by sensor type and that of 75 ha for all portable devices alike are comparable. Comparison of results by scenario for a hypothetical 75 ha farm is presented in Table 7 as an example. To break-even under the MODERATE scenario, a unit of portable sensor needs to be used for a minimum of about 53 hectares of orchard. USERPA is not economically justifiable under the LOW scenario as reflected by the negative net present value and an IRR less than the discount rate.

Sensitivity of the PBA results (MODERATE scenario) to key parameters of interest, i.e., wage rate, water price, fruit price and cost of sensor devices was assessed.

Table 6. Comparison of PBA results by non-fixed sensor use capacity in hectare: MODERATE scenario

Farm size	Capital cost (€/ha)	Labor cost (€/ha)	Total cost (€/ha)	Revenue (€/ha)	NPV (€/ha)	ANB (€/ha/yr.)	IRR (%)
EUC*	14,214	1,411	15,895	17,116	1,221	99	6.59
50 ha	15,025	1,966	17,261	17,116	-145	-12	4.82
75 ha	14,038	1,966	16,273	17,116	843	69	6.12
100 ha	13,544	1,966	15,779	17,116	1,337	109	6.81
150 ha	13,050	1,966	15,286	17,116	1,830	149	7.53

* Figures on this row are based on estimated use capacity (in hectare) of sensors.

Table 7. Comparison of results by scenario

Criteria	Unit	LOW	MODERATE	HIGH
Capital cost	€/ha	8,423	14,038	19,653
Operating costs	€/ha	641	1,069	1,496
Water cost	€/ha	-139	-799	-2,481
Labor cost	€/ha	1,179	1,966	2,752
Total cost	€/ha	10,104	16,273	21,420
Revenue	€/ha	9,729	17,116	29,188
NPV	€/ha	-375	843	7,768
ANB	€/ha/yr.	-31	69	633
Gross B/C	Ratio	0.963	1.052	1.363
NET B/C	Ratio	0.955	1.06	1.395
IRR	Percent	4.05	6.12	12.74

Figure 3 depicts estimated change in NPV due to specified percentage changes in three parameters, i.e., water price, sensor cost and fruit price. A small change in the use capacity of fixed sensors results in a considerably big effect on the economic feasibility of the proposed system. A 1% increase (decrease) in wage rate resulted in about 2.3% decrease (increase) in net present value of adopting USERPA relative to conventional practice. The negative sign for the effect of wage is because the estimated present value of labor cost in USERPA is positive unlike that of water cost. On the other hand, marginal changes in the cost of sensors and price of fruit are found to have an important bearing on the PBA results. A 1% increase in sensor cost reduces NPV by about 16%. This big impact of change in sensor cost on the NPV reflects that the USER-PA system is capital-intensive in relation to other costs. High capital cost is of course a main issue in economic feasibility of irrigation systems (DeJonge et al., 2007).

Under MODERATE scenario, the proposed technology is only marginally economically justified if the cost of sensors considered is higher by 1% than the

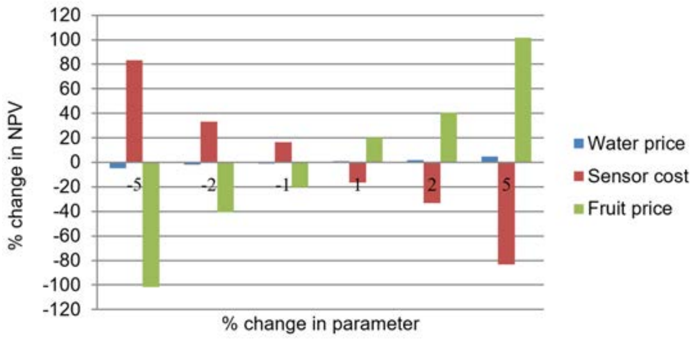

Figure 3. Sensitivity of NPV for change in parameters of interest

values included in the PBA analysis. Conversely, a small reduction in the cost of the technology, improves the potential net benefit of the proposed system. As for the effect of change in fruit price, a 1% change brings about 20% change in NPV. Given that a quality differentiated price regime instead of an average price is used, the effect of change in price needs to be closely considered in relation to assumptions on quality gain while making comparisons across scenarios.

DISCUSSION

Some encouraging results have been observed from the project particularly in increasing awareness on the potential of FMIS to improve farm management. Results from a survey intended to elicit user satisfaction of the USERPA FMIS show promising potential for commercial adoption of the project's FMIS (Tsiropoulos and Fountas, 2016). The owner and manager of the experimental farm also adjusted his irrigation with 20% up and down from ETP recommendations provided by local metrological agency in the 2015 production season after having stopped except trying with it for a while. Though the optimality of this adjustment is still questionable, it is encouraging that the farmer combined decision support with own perception and experience in his irrigation management. This change in management behavior is more likely triggered by increased awareness through repeated discussions with the USERPA project partners about the potential benefit of decision support tools.

In this study it is expected that precise data analyzed with adaptive decision support tools enables precise management which can be inferred mainly from yield quality and optimal resource use. Based on evidence for organic farming (Bravin et al., 2009), it could reasonably be expected that for a given quality level, apple fruits produced in a precision management framework would receive higher prices than those by conventional system partly for environmental friendliness of their production and partly for perceived 'healthiness of the fruits' by optimum input use. In Switzerland, the existing considerable difference in price across quality grades could be an incentive for farmers to hit the margin and get their produce in a desired quality regime. From the cost side, optimal resource use contributes to minimizing cost.

In the case of Switzerland, where farmers tend to over-irrigate possibly due to relatively plenty rainfall added to availability of cheap and easily accessible water, direct economic value from water cost saving may not be considerable to an individual farmer. However, in temperate and humid climates where irrigation is supplemental to rainfall, precision irrigation can offer other benefits such as scope for more effective use of rainfall, help reduce the non-beneficial losses associated with irrigation (deep drainage, nitrate leaching) and provide farmers with evidence to demonstrate environmentally sustainable practices to processors and retailer (Daccache et al., 2015). On the other hand, in dry areas like Turkey and Israel, stringent deficit treatment may not be feasible but a marginal saving in water use could bring considerable economic and also environmental value and help release scarce water for other uses or other farms.

Major share of the cost of the USERPA system is initial investment cost required to buy the sensors and the robotic (mobile) platform and establish the FMIS. Lab sensors and mobile sensors could be used for larger farm size. Some of the handheld devices such as porometer and pressure-bomb are mainly meant for calibration and augmenting measurements done by other sensors and hence may be excluded from the package. As commented in the data section, some of the sensors are yet to be adapted for agricultural use and they are likely to be cheaper. Net reduction in labor cost could also be possible from using the proposed management system. Furthermore, as many of the operating costs (e.g., platform integration, testing and calibration, data management and data analysis time) are less dependent on the size of the farm in question, much benefit can be expected from big farm sizes. Potential net benefits from the USERPA system are likely higher than estimated in this study. However, effectiveness of management decision in improving yield and quality also depends on other behavioral and weather factors that have not been accounted for in this study.

The sensitivity analysis shows that economic viability of the proposed change from conventional practice is strongly sensitive to change in fruit price and sensor cost but less sensitive to wage rate and water price. The relatively low sensitivity of the PBA results to change in wage rate could be due to low share of labor cost. In a discussion with the farmer, however, it was learnt that labor is a main consideration given that wage rate is generally high in the Swiss market.

A couple of remarks on the prospect of the new system are of interest to mention here. With further refined sensor integration and decision rules, sensor-triggered (automated) irrigation which helps to save considerable labor time while at the same time minimizing crop stress (e.g., labor time hold-up in field irrigation, manual data collection, manual data analysis, interpreting DSS results and making decision) will be possible. In addition, the system may be adapted to use in other crops (e.g., grapes, peers, peach, lemon, potato), other areas, and include other management operations like fertilizer management, pest and weed management.

CONCLUSION

This study reports economic assessment of an integrated sensor-based technology and farm management information system for irrigation and harvest management in apple orchard. The main drive is to optimize resource use by precise application in a way that produces the highest possible yield quality and return to farmers while being environmentally friendly.

To quantify the changes in benefit and cost associated with the USERPA technology as compared to conventional practice, partial budget analysis in a standard discounted cash flow framework is adopted. The analysis considers only private economic benefit accruing to the farmer. At a large scale, environmental benefits and peer-learning effects among farmers would generate extra social benefits which have not been accounted for in this study.

Mainly focusing on irrigation management, relevant scenarios were developed considering precipitation, weather variability and within field variabilities. Under the assumptions maintained and based on data from the experimental field, the proposed technology is found to produce a positive and considerable net benefit under MODERATE and HIGH scenarios. Hence, decisions to adopt the system should account for particular features of the farm and the weather condition assuming same cost of capital investment. Besides, given that the net economic benefit of the proposed system is very sensitive to fruit price and capital cost of investment, target market conditions need be closely considered in the decision to adopt this system.

The fact that initial investment cost occurs at the beginning of the adoption of a technology or change in practice whereas benefits are distributed across project life makes it difficult to precisely estimate the net benefit from going for a proposed change. An effort has been made to incorporate important aspects in the analysis making working assumptions where necessary. The results provide important insight into what on average can be expected of from using the technology and how it compares with conventional practice. The authors wish to remind the reader that the results are dependent on the working assumptions made behind the estimation. Therefore, the results presented need be treated with care and within the context analyzed.

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