Precision Agriculture for Natural Resource Management and reduction of Green House Gas emissions through Sensor Networks.

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***Abstract*:** This article explores Precision Agriculture (PA) as a means to enhance farm-based and site-specific crop management systems in general, and in the Auroville bioregion, in particular, taking local conditions into account. Of particular interest is the impact of PA on the reduction of Green House Gas (GHG) emissions.

1 Introduction

Precision agriculture (PA) may be defined as a suite of different techniques, primarily related to ICT (Information and Communication Technologies), which can support a farm-based and site-specific crop management system taking into account the temporal and spatial variability of crop-demands in order to attain an optimal goal. If this optimal goal be a precise water application, we call it precision irrigation (PI).

Precision agriculture has long been regarded as a potential agent for large scale agricultural transformation across the world. Although the overall benefits of precision agriculture still remains debatable, recent experiments regarding precision irrigation have been found to yield fruitful results. Furthermore, the environmentally non-intrusive nature of ICT has fuelled the growth of precision agriculture as one of the feasible means for future development in the agricultural sector, particularly in reduction of GHG emissions in agriculture.

2 GHG Emissions in Agriculture

The agriculture sector happens to be a major source of anthropogenic methane and nitrous oxide emissions. Methane (CH_4) contributes 3.3 Gt CO_2 eq/yr and nitrous oxide (N_2O) 2.8 Gt CO_2eq /yr. Of global anthropogenic emissions in 2005, agriculture accounts for about 60% of N_2O and about 50% of CH_4. [6] These emissions stem primarily from:

- Enteric fermentation in livestock (methane)
- Inefficient use of nitrogen in agricultural soils (nitrous oxide)
- the burning of savannas (methane and nitrous oxide)
- Manure management, rice cultivation and the field burning of agricultural residues.
- Over-application of fertilizers and pesticides
- Land use and wetland changes, pipeline losses, and covered vented landfill emissions lead to higher atmospheric methane concentrations. Many of the newer style fully vented septic systems that enhance and target the fermentation process also are major sources of atmospheric methane;

Agricultural soil may also act as a sink for CO_2 but the net flux is small. Agriculture accounts for an estimated emission of 5.1 to 6.1 gigatonnes (Gt) carbon dioxide (CO_2)eq/yr in 2005 (10-12 % of total global anthropogenic emissions of GHGs).

3 Prevalent GHG mitigation techniques

About 90% of the total mitigation arises from sink enhancement (soil carbon sequestration) and about 10% arises from emission reduction. The most prominent mitigation options in agriculture are: (figures in parenthesis below indicate the amount of potential mitigation that is possible in Mt CO_2-eq. yr-1 for carbon prices up to 100 USD t CO_2-eq.$^{-1}$ by the year 2030)

- Restoration of cultivated organic soils (1260),
- Improved cropland management (including agronomy, nutrient management, tillage/residue management and water management (including irrigation and drainage) and set-aside/agro forestry: (1110),
- Improved grazing land management (including grazing intensity, increased productivity, nutrient management, fire management and species introduction: (810), and

- Restoration of degraded lands (using erosion control, organic amendments and nutrient amendments: (690).

Lower, but still substantial mitigation potential is provided by:

- Rice management: (210) and
- Livestock management (including improved feeding practices, dietary additives, breeding and other structural changes, and improved manure management [improved storage and handling and anaerobic digestion]: (260).

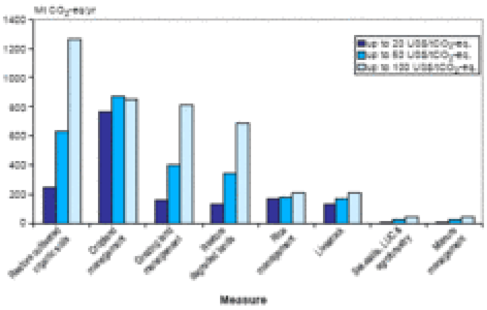

Figure 1. Potential for GHG agricultural mitigation in 2030 at a range of prices of CO_2-equivalent for a SRES B2 baseline.

4 A New Scientific Approach for GHG reduction

An upcoming new process which holds great promise to reduce GHG emissions in agriculture is Precision Agriculture. By means of precision irrigation through Wireless Sensor Networks it will be possible to:

- ❖ Determine near-exact amount of water necessary for irrigation in a field
- ❖ Predict optimal quantity of fertilizers and pesticides to be applied to prevent over-application
- ❖ Monitor soil mineral contents like soil nitrogen and soil carbon
- ❖ Monitor methane concentrations

Thus the adverse effects of GHG emissions can be curbed effectively with simultaneous increase in agricultural productivity and water savings by using different methods of precision agriculture.

5 Precision Agriculture

PA [7] primarily operates in order to achieve a two-fold objective: (a) to enhance the yield potential of a farm while reducing the costs from inefficiently applied inputs and (b) to reduce the environmental effects due to over-application of fertilizers and pesticides. To fulfill these objectives PA needs to employ:

1. Spatial data collection and processing
2. Precision Irrigation (PI)
3. Variable Rate Technologies (VRTs)
4. Information dissemination to farmers.

Of these 1, 2 and 3 are more of technological problems while 4 has an inherent social and cultural connotation.

6 Spatial Data Collection and Environment monitoring

The essential backbone of precision agriculture is determination of the exact amount of agricultural resources that would be essential for proper development of a crop. The prediction regarding the future inputs requires extensive collection of present crop data through use of a collaboration of various sensors forming a network. A near-exact prediction would mean a significant cut-down on pesticides and fertilizers.

In order to collect data, multiple sensors are essential. The particular sensor which needs to be used depends on the application. The various parameters which have been sensed so far include soil moisture, temperature, mineral content, ambient light, barometric pressure, leaf area index. Some of the commonly used sensors for these purposes include ECH2O probes (soil moisture), Sensiron SHT11(temperature and humidity), TAOS TSL2550D (ambient light), Intersema MS5534AM (barometric pressure). MTS400 weather board is a common platform to integrate these sensors and perform collective monitoring.

Measurement of GHG emissions would necessarily involve including a soil nitrogen and carbon sensor in the sensing suite.

Once the present data is collected, different agricultural simulator tools like DSSAT and APSIM may be employed to predict the future course of action or the accumulated data may be handed over to the farmers so that they can themselves infer the necessary action to be taken based on experience.

7 Soil Health Care

An essential requirement of the project is to determine soil moisture and soil mineral contents. These two factors are going to be constantly monitored through sensors. Furthermore a cut-down on pesticide application is also expected to improve soil health. Thus appropriate soil care can be easily ensured.

8 Precision Irrigation

The problem of water scarcity is an escalating crisis. Besides several environmental hazards, unscientific application of water to crops can lead to crop damage and thus a resultant fall in yield. Groundwater resources are getting depleted, salination of agricultural land due to improper irrigation is increasing, severe droughts are causing more and more famines, further damaging the economy of impoverished nations. The Food and Agriculture Organization (FAO) estimates that some 20 to 30 million ha of the world's 270 million ha of irrigated land have been degraded by salt accumulation.

One of the major tools for precision agriculture is precision irrigation which aims for water savings. Application of PI have been found to be useful where the input costs are high, sub-field spatial and temporal variations in crop parameters are considerable, water resources are limited and where adverse environmental effects need to be curbed.

There are several technological tools for precision irrigation including the prevalent control of nozzle flow during water sprinkling. However, the following principles underline all in-vogue modern technologies:

1. Wireless or wire line communication
2. Integrated irrigation control and monitoring system
3. Decision support system
4. Feedback for irrigation control in Real-time.

In our case, wireless sensor networks installed for precision agriculture are going to suffice for precision irrigation. The decision support system is the deployed network and the analyzing tool. Feedback will be provided in the form of information to be disseminated to the farmers by holding local conventions and meetings. A real-time feedback through variable rate technologies may also be looked upon as a future option. *Such a procedure has already been found to be benefiting in several application scenarios.* Reported water savings have been as high as 30-70% depending on site and crop.

9 Case Study: The CommonSense Project

The CommonSense Project [2,4] (Community Based Management of Natural Resources through Sensor Networks) is a joint collaboration between IISc, Bangalore and EPFL, Switzerland to develop precision agriculture in the village of Tumkur near Bangalore. It was initiated in 2003-04.

Since the goal of the current project that is to be initiated at Auroville tallies closely with the CommonSense Project, with an additional objective to reduce GHG emissions, it will be worthwhile to investigate further the CommonSense project in order to understand the deliverables in a precision irrigation project.

9.1. Technical Description

The initial phase was an extensive user survey to determine and educate the small and marginal farmers of the region and have an in-depth understanding of the needs of the farming community of the region. For data collection, Shockfish node manufactured by Semtec was utilized. It had a MSP430 µC and Zemix Radio operating in the 868 MHz ISM band with a transmission range of 1.5-2 Km. Presently 3-4 square Kilometers are being monitored with 40 Berkley Mica2 Motes in 3 clusters. For communication purposes 4m. high GI tubes with Linx antenna and RG-58 SMA connectors are being utilized. Solar powered nodes are a future option of the project.

9.2. Initial Phase-User Requirements

Chennakeshava Trust (CT), a local NGO active in Pavagada, a semi-arid region of the Tumkur district in Karnataka was responsible for conducting the user survey.

The area of interest was a cluster of villages consisting of mostly marginal and small farmers in a 25 Km radius. Relevant facts about the community living in that area include the following items:

- The proposed project area (radius of 25km) encompassed approximately 25 villages, out of which three were identified as benchmark locations. Those were equipped with basic weather stations for manual data collection.
- The water table in the concerned area had dramatically gone down in the last decade. Traditional open wells had dried up, except for a brief period following good monsoon rains. Farmers who could afford it had resorted to bore wells. But with the depletion of the water table, even those wells had to be deepened. The cost of bore wells was prohibitive for marginal farmers.
- The whole project area was very well covered by a traditional system of tanks to retain rain-

water. However, marginal farmers possess land on the higher reaches, without any access to such water resources by gravitation.

- The cost of powered irrigation is such that marginal farmers cannot envisage using such methods for their crops. They fully depend on rain.
- All farmers have to take critical decision regarding seed density, best time to sow, to apply fertilizers, to apply pesticides, to irrigate, etc. Those decisions are based on a variety of data and on traditional knowledge applied to those data.
- Since application of fertilizers and water were completely based on the farmers experiences, excess amount of water utilization and soil mineral degradation were common features of the region.

Fig. 2. Meeting with local farmers at Tumkur

9.3. Crops grown and monitored

Rain-fed: Ground nut, Pigeon Pea, Cereals, trees: Areca Nut, Coconut

Irrigated: Rice, Ground Nut, Trees: Areca Nut, Coconut

9.4. Rainfall in the region

It was a semi –arid region with average annual rainfall around 56.1 cms. and a standard deviation of about 19 cms.

9.5. Field Deployment of sensors

Around 40 sensor arrays deployed in 3 clusters record data on a periodical basis, and send them in a multi-hop fashion to a centralized processing unit, which uses simple statistical computations and correlates them with meteorological and ground-water data to assess the optimal cropping, irrigation and harvesting strategy. The centralized processing unit can be linked to external meteorological servers to help in its decision process. This can be done, depending on the environment, through a wired or wireless connection, or a satellite link.

Fig. 3. Deployed sensors and GI poles

The pilot application deployed in Pavagada consists of wireless sensors are deployed in geographical clusters corresponding to the assignment to one base station, which is connected to a centralized server via an 802.11 (wi-fi) link. The sensors are also organized in groups, each group corresponding to a particular application, be it crop modeling, water conservation measures assessment or deficit irrigation management. From then on, the data are sent periodically to a centralized database. Sensors from different groups can collaborate for data relaying.

9.6. Outcomes

The results of the first year point to a significant increase in yield. It was such a success that other farmers were willing to pay a significant fee to become members of the association (first clear sign of sustainability). Considerable water savings have been achieved on crops like groundnuts, cereals and finger-millets, rice and pulses like pigeon-pea and horse gram. Recently a suite has been developed for pesticide control and pest infestation prediction.

10 Promote Awareness amongst farmers

One major advantage of using wireless sensor networks for precision agriculture is that the entire process is highly interactive and involves active participation of the farmers in the development process. This involves holding meetings with farmers periodically, setting up data distribution and collection centers and educating the farmers with modern agricultural techniques. Previous attempts in this direction have also reportedly resulted in cooperative formation amongst villagers.

11 Auroville's needs for precision agriculture

Certain prevalent features hint that precision agriculture may be a rejuvenating tool for the agricultural development of the Auroville region[5]:

1. Rainfall in bursts around 1200 mm/yr. (see Table 1 below)
2. Uncertain crop yields
3. Water problem persists as due to sloping land water drains away towards the sea in the coastal regions.
4. Groundwater is sometimes misutilized due to unscientific methods of farming in villages surrounding the city.
5. At places water table is 30m. below the surface.
6. Salination has started in Pondicherry at certain locales
7. Some coastal strips south of the city have already become infertile
8. Soil is red loamy mainly
9. Soil nature is acidic (except Annapurna farm) in city and alkaline in villages
10. Soil Nitrogen is low and organic carbon is depleted in villages.

Table 1: Rainfall distribution in Auroville [8]

Month	Precipitation Average Year	Precipitation Wet Year	Precipitation Dry Year
	[mm]	[mm]	[mm]
January	36	88	25
February	18	48	18
March	19	0	0
April	22	47	0
May	45	1098	38
June	45	67	17
July	68	28	26
August	118	157	56
September	145	139	5
October	263	367	202
November	350	234	25
December	162	331	214
Annual	**1.293**	**2.604**	**626**

12 Outline of Project Plan

The proposed project at Auroville will involve the following activities:

1. Gathering of available soil data at Auroville and identifying the potential regions of development.
2. Meeting with farmers at the village community center (VIC 'B' of TRD project [1]) to discuss the issues
3. Carrying out of user survey to determine information needs of the farmers
4. Education of farmers at the educational hubs and IT Centers in the villages (VIC 'A' and 'F' of the TRD Project [1])
5. Procurement of essential sensors and associated devices with particular emphasis on GHG reduction (VIC 'D' and 'F' of TRD [1])
6. Deployment of sensors
7. System development
8. Prediction of water required for irrigation and pesticide control
9. Dissipating analyzed information through village farming centers (VIC 'B' of TRD Project [1])

We hope to implement these activities in the course of the 'Total Rural Development' project that has recently been initiated with the Planning Commission of India, also in December 2007.

13. Conclusion

The concept of precision agriculture through sensor networks being scalable and replicable, the model used in Tumkur can easily be replicated in Auroville on the broader scale of the TRD project. Another major objective would be simultaneous reduction of GHG emissions in agriculture and this would probably be the first endeavor in these lines in the field of precision agriculture. The next measure in this direction would be to involve people having agricultural and networking background to collaborate on this project to implement precision agriculture with an aim to reduce GHG emissions.

References:

[1] TRD Project Implementation Proposal: Rural Convergence Program (RCP); Submitted to the Knowledge Commission of India; 1st December, 2007.

[2] "CommonSense Net: Improved Water Management for Resource Poor Farmers via Sensor Networks", Jacques Panchard, Seshagiri Rao, Prabhakar T.V.,

H.S.Jamadagni and Jean Pierre Hubaux, in Proceedings of ICTD 2006.

[3] "Investing in Irrigation: Achieving efficiency and sustainability", National Water Commission, Australian Government

[4] www.commonsense.epfl.ch

[5] www.earth-auroville.com

[6] "Greenhouse gas mitigation in agriculture.", Smith, Pete ; Marco Bertaglia, In: Encyclopedia of Earth. Eds. Cutler J. Cleveland (Washington, D.C.: Environmental Information Coalition, National Council for Science and the Environment). [Published in the Encyclopedia of Earth June 26, 2007].

[7] "Wireless Sensor in Agriculture and Food industry- Recent Development and Future Perspective", Ning Wang, Naiqian Zhang, Maohua Wang, in Computer and Electronics in Agriculture (Elsevier), pp. 1-14, 21st September 2005.

[8] EU-ASIA URBS: Pre-Feasibility Study on Water Supply, Stormwater and Wastewater Management, 2003

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