Wireless sensor networks for applied research on rain-fed farming in India: an exploratory user experiment

LCA Technical report

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1 Purpose of this document

This document describes a user experiment that was conducted between October 2007 and February 2008 around a wireless sensor network for rain-fed agriculture.

The experiment was organized jointly by UAS, the CK Trust and the EPFL. The participants came from an Indian university of agriculture, an Indian non-governmental organization active in rain-fed farming sustainability, and the Kanrnataka department of agriculture.

2 Description of the experiment

2.1 Objectives of the study

There is a main and a secondary objective to this study:

Main objective: Assess the relevance of Wireless sensor Networks

1. Document the perception of a panel of professionals with regard to the relevance of environmental information for agriculture
2. Document what the participants consider to be relevant parameters and what are the associated constraints (rate, density, margin of error)
3. Derive the relevance of wireless sensor networks in this context
4. List most promising applications

Secondary objective: Test the suitability of the user interface

5. To observe initial reaction of the participants to the user interface
6. To identify problem areas of the user interface through users' feedback
7. To get a feedback from the users regarding the ease of use of the application
8. To get a first level indication of the attractiveness of the application through the number of times the participants access it
9. To get a feedback on the usefulness of graphs by observing which graphs are generated and downloaded.

2.2 Scenario

In a first step, the participants are attending a meeting where we:

1. Present the CommonSense project,
2. Introduce the CKPura context,
3. Give them a tour of the CommonSense Net on-line application.
4. Allow them a first round of hands-on experience with this application

After this first meeting, they can fill up a web-based *general questionnaire*, where they state their opinion concerning environmental information.

Then, they are left two weeks with the on-line application and a scenario as follows:

"As a consultant, you are asked by the local autorities your opinion about the agriculture practiced in the village of Chennakeshava Pura, in Karnataka. In particular your client would like to know:

1. your recommendation for the crops to be cultivated in the area.
2. the constraints to take into account for the cultivation of this crop (such as water stress, pests, diseases, etc.)
3. the environmental parameters to monitor in order to optimize the crop yield (if any)

To help you in your task, you have at your disposal a map of the area, as well as the output of environmental monitoring stations deployed in the area. "

There is a second on-line *detailed questionnaire* that allows the participants to provide their recommendations.

2.3 Context and environmental data

The data used in this study come from a prototype that was deployed in the Chennakeshavapura village in Karnataka. This prototype consists of a wireless network of ground-sensors that record periodically soil moisture, temperature, humidity and atmospheric pressure in the field environment. Sensors record data on a periodic basis and send them in a multi-hop fashion to a base station connected to a centralized server through an 802.11 bridge.

In our case, we had 10 nodes deployed for more than one year (two full cropping seasons) [Panchard07]. They describe the soil moisture conditions in 10 homogenous patches, all rain-fed, with different crop varieties and different soil characteristics. In addition, one sensing node recorded air temperature, humidity and atmospheric pressure over the same period.

About half of the soil moisture sensors had gaps in their readings due to hardware and software problems associated with the development, testing and debugging of the prototype. These gaps were filled using a well-know crop model used for semi-arid conditions: APSIM [APSIM96].

The data can be accessed through the following web interface: http://csn.epfl.ch

2.4 Questionnaires

The on-line questionnaire should allow answering the following questions:

1. What is the percentage of the participants who find environmental monitoring interesting
2. How are the environmental parameters ranked among participants
3. For the relevant parameters, what are their constraints (rate, density, error)
4. What are the envisioned applications for these parameters.

2.4.1 General questionnaire

This is the initial questionnaire that was presented to the participants.

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CommonSense Net User Experiment

Dear Participants,

You are kindly requested to fill up this form in order to assess the usefulness and usability of high density environmental data for agriculture.

[more information...]

* mandatory field

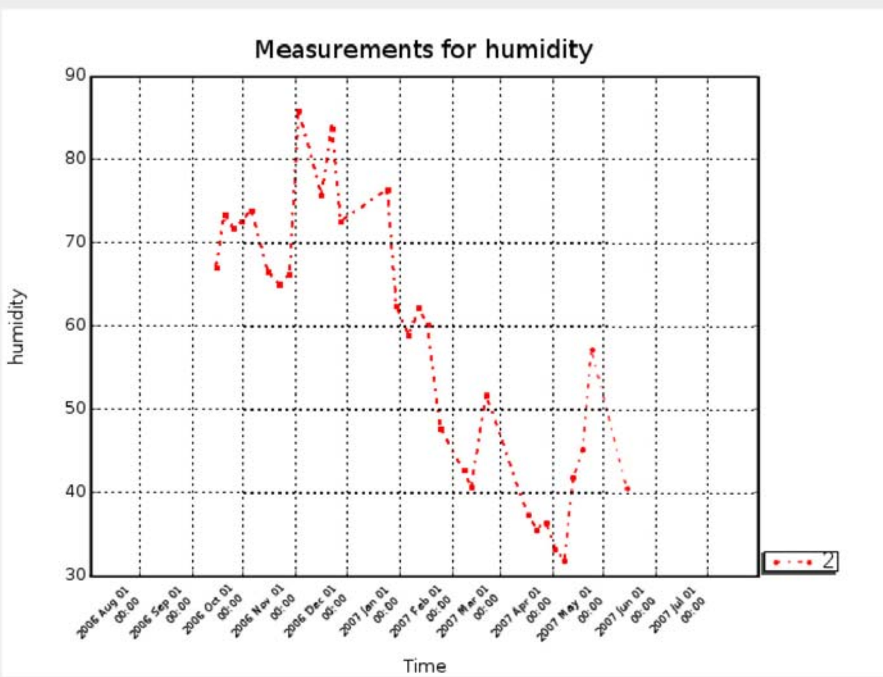
Will monitoring weather parameters help rain-fed agriculture?

Yes ○

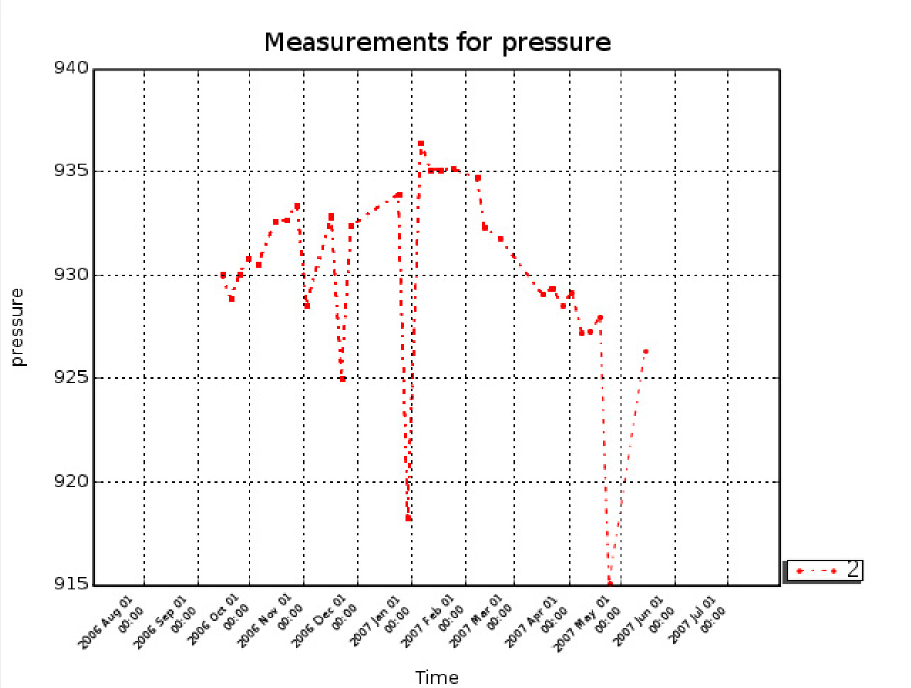
No ○

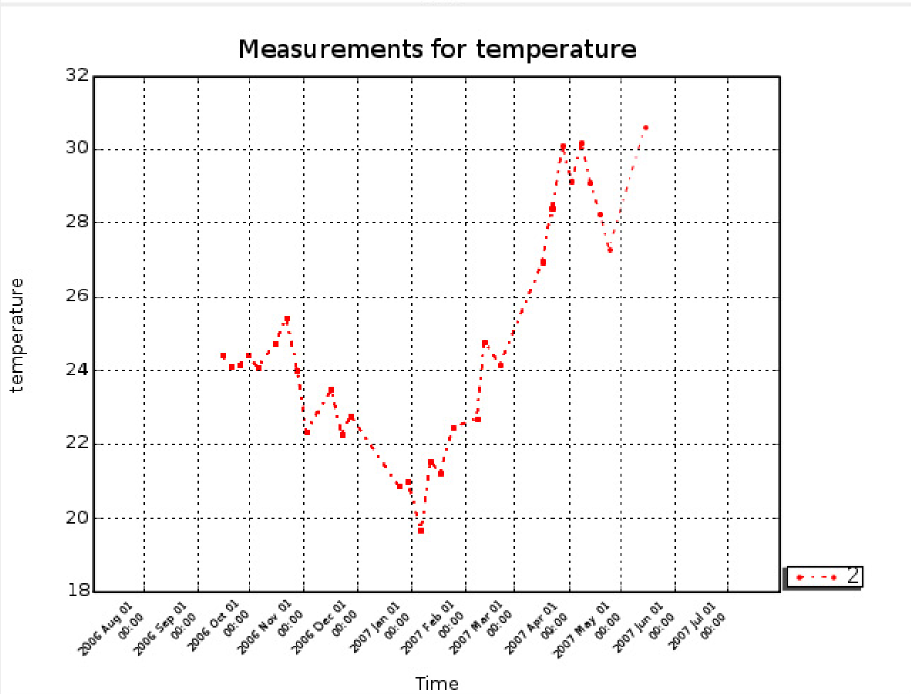
If yes, explain briefly how. If no, explain briefly why.

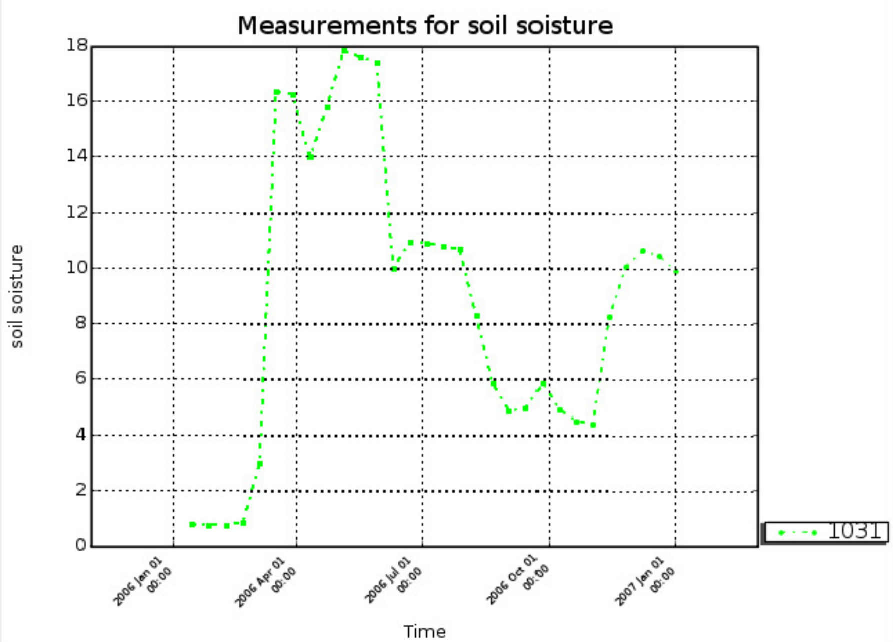
What elements displayed below seem to make sense to you? ☐

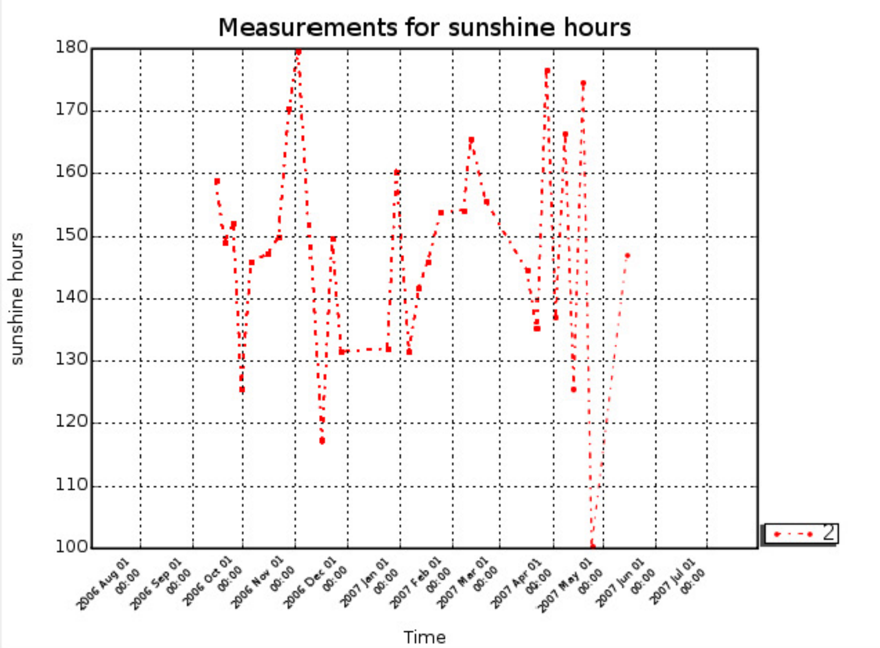


http://inform.epfl.ch/?form=CSN_User_Exp_2007 (1 of 4)05-02-2008 07:01:39


Measurements for pressure
940
935
930
925
920
915
pressure
2006 Aug 01 00:00
2006 Sep 01 00:00
2006 Oct 01 00:00
2006 Nov 01 00:00
2006 Dec 01 00:00
2007 Jan 01 00:00
2007 Feb 01 00:00
2007 Mar 01 00:00
2007 Apr 01 00:00
2007 May 01 00:00
2007 Jun 01 00:00
2007 Jul 01 00:00
Time
2


Measurements for temperature
32
30
28
26
24
22
20
18
temperature
2006 Aug 01 00:00
2006 Sep 01 00:00
2006 Oct 01 00:00
2006 Nov 01 00:00
2006 Dec 01 00:00
2007 Jan 01 00:00
2007 Feb 01 00:00
2007 Mar 01 00:00
2007 Apr 01 00:00
2007 May 01 00:00
2007 Jun 01 00:00
2007 Jul 01 00:00
Time
2


Measurements for soil soisture
soil soisture
18
16
14
12
10
8
6
4
2
0
2006 Jan 01 00:00
2006 Apr 01 00:00
2006 Jul 01 00:00
2006 Oct 01 00:00
2007 Jan 01 00:00
Time
1031


Measurements for sunshine hours
sunshine hours
180
170
160
150
140
130
120
110
100
2006 Aug 01 00:00
2006 Sep 01 00:00
2006 Oct 01 00:00
2006 Nov 01 00:00
2006 Dec 01 00:00
2007 Jan 01 00:00
2007 Feb 01 00:00
2007 Mar 01 00:00
2007 Apr 01 00:00
2007 May 01 00:00
2007 Jun 01 00:00
2007 Jul 01 00:00
Time
2

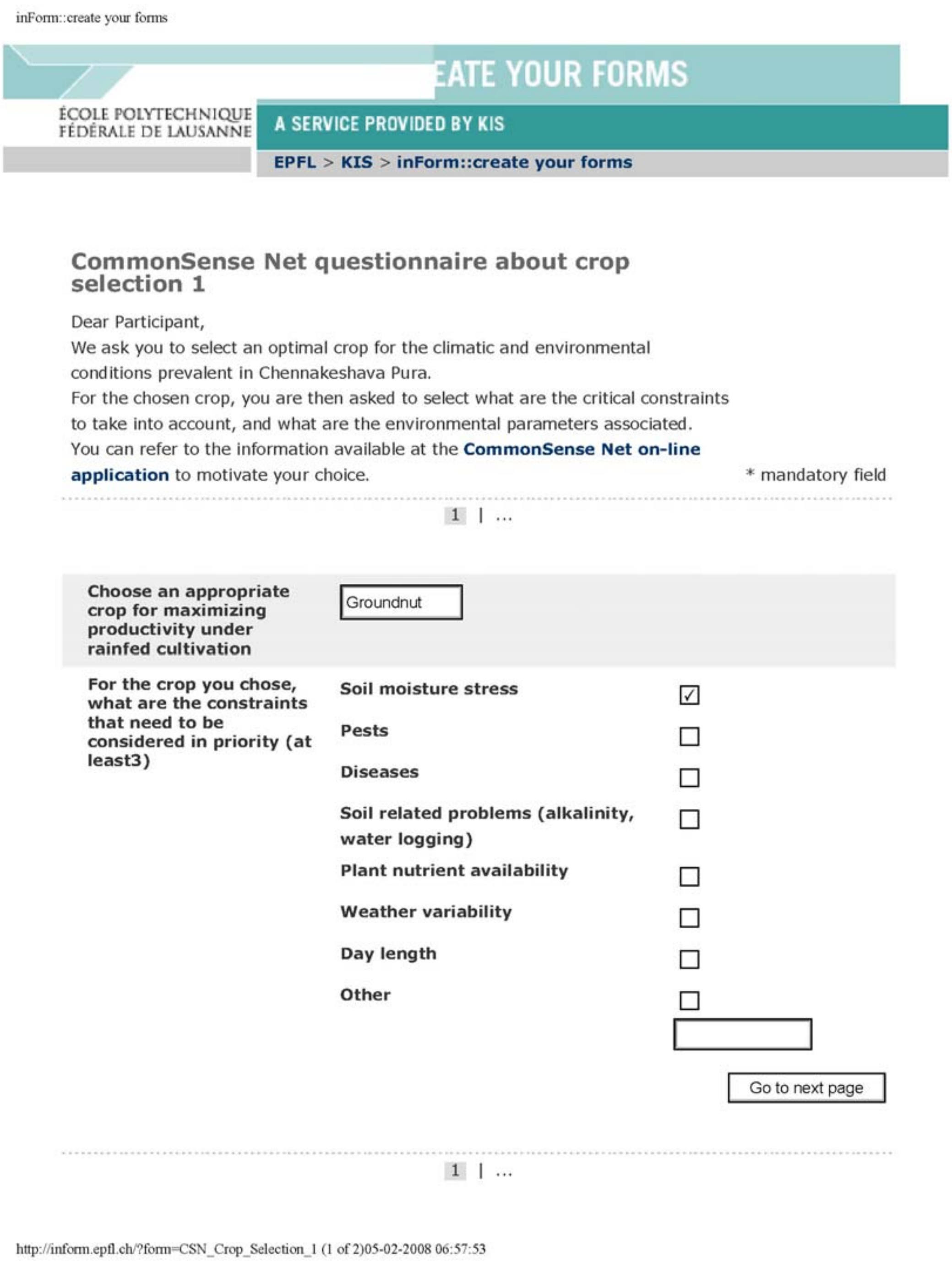
In order to improve crop productivity, what are the 3 most important parameters that need to be monitored, and how?	**First parameter**	Soil Type
	---Desired Data Rate	Monthly
	---Desired Data Density	1 single measurement point
	---Tolerated Error	<1%
	Second parameter	Soil Type
	---Desired Data Rate	Monthly
	---Desired Data Density	1 single measurement point
	---Tolerated Error	<1%
	Third parameter	Soil Type
	---Desired Data Rate	Monthly
	---Desired Data Density	1 single measurement point
	---Tolerated Error	<1%
If you think there is one or several parameters that are important but were not mentioned, please mention them, and develop briefly the associated constraints (rate, density, error, remarks)		
If you have any remarks or suggestions, please write them here.		

Send

2.4.2 Detailed questionnaire

This questionnaire was to be filled after the 2 weeks duration of the study. The first page allows the participants to choose a crop (up to 3 crops could be selected), then for each crop, to select the relevant constraints.

The subsequent pages are displayed for each chosen constraint.



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CommonSense Net questionnaire about crop selection 1

Dear Participant,
We ask you to select an optimal crop for the climatic and environmental conditions prevalent in Chennakeshava Pura.
For the chosen crop, you are then asked to select what are the critical constraints to take into account, and what are the environmental parameters associated.
You can refer to the information available at the **CommonSense Net on-line application** to motivate your choice.

* mandatory field

1 | ...

Choose an appropriate crop for maximizing productivity under rainfed cultivation	Groundnut	
For the crop you chose, what are the constraints that need to be considered in priority (at least3)	**Soil moisture stress**	☑
	Pests	☐
	Diseases	☐
	Soil related problems (alkalinity, water logging)	☐
	Plant nutrient availability	☐
	Weather variability	☐
	Day length	☐
	Other	☐

Go to next page

1 | ...

http://inform.epfl.ch/?form=CSN_Crop_Selection_1 (1 of 2)05-02-2008 06:57:53

CommonSense Net questionnaire about crop selection 1

Dear Participant,
We ask you to select an optimal crop for the climatic and environmental conditions prevalent in Chennakeshava Pura.
For the chosen crop, you are then asked to select what are the critical constraints to take into account, and what are the environmental parameters associated.
You can refer to the information available at the **CommonSense Net on-line application** to motivate your choice.

* mandatory field

1 | 2 | 3 | 4

For soil moisture stress, what are the 3 main environmental parameters to take into account, and how?	**First parameter**	Atmospheric Pressure
	---Desired Data Rate	Hourly
	---Desired Data Density	1 single measurement point
	---Tolerated Error	<1%
	Second Parameter	Soil Type
	---Desired Data Rate	Monthly
	---Desired Data Density	1 single measurement point
	---Tolerated Error	<1%
	Third Parameter	Soil Type
	---Desired Data Rate	Monthly
	---Desired Data Density	1 single measurement point
	---Tolerated Error	<1%

Go to next page

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CommonSense Net questionnaire about crop selection 1

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For the chosen crop, you are then asked to select what are the critical constraints to take into account, and what are the environmental parameters associated.
You can refer to the information available at the **CommonSense Net on-line application** to motivate your choice.

* mandatory field

1 | **2** | 3 | 4

Justify your answer as to how the environmental parameters measured by the sensors would help you manage these problems. For this kindly provide relevant data, experiences and references (if possible).

Go to next page

1 | **2** | 3 | 4

2.5 *Precise organization of the study*

2.5.1 Introductory meeting

The introductory meetingwas held on October 29th.
Agenda:

1. Presentation of the CommonSense project by Seshagiri Rao
2. Presentation of the on-line application by Seshagiri Rao
   a. How the environmental data can be accessed on-line at http://csn-test.epfl.ch
   b. How the questionnaires can be accessed on-line
3. Presentation of the survey (see next section)
4. Initial discussion among participants

Expected Outcome: the participants understand the context, know how to use the application, and know what task they are supposed to complete.

2.5.2 Survey

The survey was held over 2 weeks, between October 29th and November 11th
Place: Work place of the participants
Agenda:The participants will be asked to fill out one of the on-line form after 5, 10 and 15 days
Prerequisites:

1. Introductory meeting is completed
2. Participants have a working internet access, and a working email address

Outcome: the on-line questionnaires

2.5.3 Debriefing meeting

This meeting was held after the experiment. For organizational reasons, it could not take place before February 2008.

It lasted three days, with individual meetings conducted with all the senior professors that participated to the study.

2.5.4 Participants

The 30 participants come from the following disciplines:

- Soil scientists,
- agronomists,
- crop physiologists,
- entomologists,
- pathologists (plant and animal),
- agriculture meteorologists,
- agricultural communication,

- agricultural department (from State gvt)

We interviewed mostly scientists working at a university of agriculture science (UAS, Bangalore), but also the vice-president of an NGO operating throughout India (BAIF) and an official of the Agriculture Department of Karnataka.

3 Experiment’s results

3.1 Web questionnaires

In the following section, we present the results of the web questionnaires that were submitted to the participants. The terms used in the tables are explained here:

- Parameter: any environmental parameter that the participants considered relevant
- Constraint: Any external element conditioning agriculture practices such as sowing, harvesting, fertilizing, irrigating, etc.
- Number: Number of times the corresponding answer was found in the questionnaire. Some questions containing the possibility of multiple choices as answers, the sum of the “Number” column might exceed the total number of participants

3.1.1 General questionnaire

Parameter	Number
Soil Type	11
Soil Water Content	18
Temperature	14
Humidity	10
Atmospherique Pressure	0
Rain-Fall Pattern	10
Vapor-Pressure Deficit	0

Will Monitoring Weather Parameter help rain-fed agriculture?		
Number Of Yes		21

Statistics on differents parameters

Parameter	Rate	Number	Density	Number	Error	Number
Humidity	Monthly	0	Hectare	4	<1%	4
	Weekly	1	Hundred_meters	0	<5%	6
	Daily	7	Kilometer	3	<10%	0
	Hourly	2	Single	1	<30%	0
	Every 5 minutes	0	Meter	2		

Parameter	Rate	Number	Density	Number	Error	Number
soil water content	Monthly	0	Hectare	6	<1%	11
	Weekly	10	Hundred_meters	5	<5%	5
	Daily	5	Kilometer	3	<10%	2
	Hourly	2	Single	1	<30%	0

	Every 5 minutes	1	Meter	3			

Parameter	Rate	Number	Density	Number	Error	Number
Atmosph pressure	Monthly	0	Hectare	0	<1%	0
	Weekly	0	Hundred_meters	0	<5%	0
	Daily	0	Kilometer	0	<10%	0
	Hourly	0	Single	0	<30%	0
	Every 5 minutes	0	Meter	0		

Parameter	Rate	Number	Density	Number	Error	Number
Vapor-pressure-D	Monthly	0	Hectare	0	<1%	0
	Weekly	0	Hundred_meters	0	<5%	0
	Daily	0	Kilometer	0	<10%	0
	Hourly	0	Single	0	<30%	0
	Every 5 minutes	0	Meter	0		

Parameter	Rate	Number	Density	Number	Error	Number
soil type	Monthly	11	Hectare	2	<1%	9
	Weekly	0	Hundred_meters	1	<5%	2
	Daily	0	Kilometer	0	<10%	0
	Hourly	0	Single	7	<30%	0
	Every 5 minutes	0	Meter	1		

Parameter	Rate	Number	Density	Number	Error	Number
Temperature	Monthly	1	Hectare	6	<1%	6
	Weekly	1	Hundred_meters	0	<5%	5
	Daily	11	Kilometer	5	<10%	3
	Hourly	1	Single	3	<30%	0
	Every 5 minutes	0	Meter	0		

Parameter	Rate	Number	Density	Number	Error	Number
Rain-fall pattern	Monthly	1	Hectare	3	<1%	8
	Weekly	5	Hundred_meters	0	<5%	1
	Daily	4	Kilometer	4	<10%	1
	Hourly	0	Single	3	<30%	0
	Every 5 minutes	0	Meter	0		

3.1.2 Detailed questionnaire

Crop_choice	Number
groundnut	13
pigeon pea	4
ragi	4
sorghum	3
cotton	1
sun flower	0
potato	1

Constraint	Number
Sm	27
Pest	16
Disease	18
Soil	12
Nutrient	13
Temperature	9
Day_length	5

Parameter	Number
Soil Type	46
Soil Water Content	59
Temperature	71
Humidity	44
Atmospherique Pressure	5
Rain-Fall Pattern	49
Vapor-Pressure Deficit	0

Figure 1 Participants' choice of crop, agricultural constraints, and environmental parameters

	soil moisture	pest	disease	soil	nutrient	temperature	daylength	custom
groundnut	13	7	10	7	8	5	3	1
Pigeon Pea	4	3	3	1	2	1	1	0
Ragi	4	0	2	2	2	2	1	0
Sorghum	3	3	1	1	1	1	0	0
Cotton	1	1	0	1	0	0	0	0
Sun Flower	0	0	0	0	0	0	0	0
Potato	1	1	1	0	0	0	0	0

Figure 2 Important parameters per crop type

Parameter	Rate	Number	Density	Number	Error	Number
Humidity	Monthly	10	Hectare	10	<1%	22
	Weekly	12	Hundred_meters	4	<5%	13
	Daily	21	kilometer	14	<10%	6
	Hourly	0	Single	15	<30%	3
	Every 5 minutes	0				
Parameter	Rate	Number	Density	Number	Error	Number
soil water content	Monthly	13	Hectare	20	<1%	21
	Weekly	20	Hundred_meters	16	<5%	21
	Daily	21	kilometer	1	<10%	10
	Hourly	2	Single	15	<30%	7
	Every 5 minutes	3				
Parameter	Rate	Number	Density	Number	Error	Number
Atmosph pressure	Monthly	4	Hectare	0	<1%	4
	Weekly	0	Hundred_meters	0	<5%	1
	Daily	1	kilometer	2	<10%	0
	Hourly	0	Single	3	<30%	0
	Every 5 minutes	0				
Parameter	Rate	Number	Density	Number	Error	Number
Vapor-pressure-D	Monthly	0	Hectare	0	<1%	0
	Weekly	0	Hundred_meters	0	<5%	0
	Daily	0	kilometer	0	<10%	0
	Hourly	0	Single	0	<30%	0
	Every 5 minutes	0				
Parameter	Rate	Number	Density	Number	Error	Number
soil type	Monthly	35	Hectare	12	<1%	26
	Weekly	8	Hundred_meters	10	<5%	6
	Daily	3	kilometer	3	<10%	8
	Hourly	0	Single	21	<30%	6
	Every 5 minutes	0				
Parameter	Rate	Number	Density	Number	Error	Number
Temperature	Monthly	16	Hectare	15	<1%	30
	Weekly	14	Hundred_meters	15	<5%	24
	Daily	41	kilometer	13	<10%	9
	Hourly	0	Single	28	<30%	8
	Every 5 minutes	0				
Parameter	Rate	Number	Density	Number	Error	Number
Rain-fall pattern	Monthly	14	Hectare	9	<1%	23
	Weekly	4	Hundred_meters	2	<5%	26
	Daily	31	kilometer	10	<10%	0
	Hourly	0	Single	28	<30%	0
	Every 5 minutes	0				

Figure 3 Statistics on different parameters

3.2 Comments from the web surveys

We reproduce extensively in this section the comments that were made by the participants, including possible abbreviations, typing mistakes or occasional grammar errors. Since these are quite frequent, the usual (sic) was omitted.

3.2.1 General survey

3.2.1.1 Why would monitoring weather parameters help rain-fed agriculture?

Data predicted can be used for forecasting, forewarning and ultimately to increase productivity.

Rainfed agriculture is totally based on rainfall pattern and related weather parameters. If we can motior the weather parameters regularly we can plan the cropping pattern accordingly.

monitoring weather parameters like soil moisture,temperature,humidity etc, will definetly help for precision agriculture. Because as we known rainfed tracts are semiarid tracts which recieve least rainfall and the efficient use of soil moisture will help

would help farmers know the status of soil moisture and related problems he would encounter .   I would like to add that irrespective of the knowledge the rainfed agri farmer is helpless when it comes to implementationof reccomendations and he has no cont

The data will be useful in assessing the crop yield and monitoring the field situation which could help in take corrective measures for best growth and development of the crop in the particular situation.

Definitely yes, because by having weather data one can decide what crop to be taken up, when to irrigate and how much to irrigate, is it worthwhile to irrigate and so on. Similarly, by having other parameters on hand, we can as well predict about the pest

weather forecast is required for knowing seasonal rain fall pattern for suiting suitable crops and also to know the seasonal pest out break and also to know the water status critcal crop growth stages ultimately it will reflect on productivity of particul

Depending on the weather parameters, one can plan for the crop, variety,probable diseases and pest incidence etc and a farmer can really think of solutions weather data help only educated elite farmers to utilize the data in taking up contingency action plans when there are no rains and the moisture level in the soil is depleting.

help in monitoring the crop condition to understand how weather parameters play a role in rainfed agriculture

Proper irrigation, monitoring pest and diseases ultimately for profit

Based on these parameters farmers can decide what measures are to be followed to protect their crops or improve the productivity of the crops.

yes , one should have the weather parameters in order to get good yield by escping the situations

rain fed agriculture mainly depend on rainfal temperature soil moisture , so it is nessesarry to moniter them

since rainfed agriculture depends on the rainfall for water requirement, its of great help to predict the pattern of rainfall and plan for the crop and cropping system

weather parameters such as rainfall, temperature play a crucial role in crop improvement in rainfed situations.

The weather data, particularly soil moisture, temperature and humidity is useful to get good crop growth. Farmer can decide the time/period of sowing a crop depending upon the onset of monsoon or in delayed monsoon.

monitoring weather parameters will definetly help in precision agriculture, so by precision agriculture we can harvest good returns in agriculture. Bt monitoring weather parameters we can manage the resources avilability and we can go for suistanable agri

Weather parameters are very important in sustainable agriculture.As we have(India) shortage resources and tremendous growth in population we need to think of the sustainable agriculture. So by knowing the resouces avilability and the planning we can have

Yes monitoring weather parameters is very good idea, because it will ensure good returns.

3.2.1.2 Extra parameters

1.Bio-sensors which can sense the change in the canopy temperature can be installed to monitor to the emergence of pest and disease. (Change in metabolism of plants can be monitor by studying the thermal emission or temperature difference), such sensor sensors for nutrient status are also needed in agriculture. Sensors are needed for Environmental hazardous like land slides, earth quake and sunami also.

1.canopy temperature,
2.leaf temperature.
both of them should be measured hourly.

1 soil nutrient status 2 presence of soil pathogens 3 disease\insects orignating in an area

Plant parameters like canopy temperature and humidity could help in monitoring the pest and disease predictions.

Accurate measurement of water loss from soil will be useful to arrive at water use effciency of the crop. similary, Rate of moisture loss , Relation of soil parameters with microbial activity, soil water content at deeper soil profile, soil compactness, s

crop density, leaf water status, pest and disease infestation, insitu measurement of leaf chrolophyll content based on soil mositure status

Even biological parameters land nutrients like organic carbon,N and P content of soil should be considered. Sensors need to be introduced to analyse available P. Sensors for beneficial microorganisms like Rhizobium, Azotobacter, Mycorrhiza population can

soil physical constraints such as compact layers , depth of soil , and crusts etc also has to be sensed and displayed.

Nutrient status and nutrient movement to the root
Nutrient conversion
weekly basis
per hectare
1%

parameters for measuring soil biomass with reference to biological activity of producing some exudate

-daily Amount of rainfall received for every Hectare.
-Sunshine hours hourly
-Chemicals that are released by the plants in response to pest attack daily for every 1 metre

soil helath, soil nutrient content, FYM content in the soil with the desired data density of 1 point per 100 square meters and the tolerated error of <5%

canopy temperature should be included and it should be taken daily.

3.2.1.3 Remarks, comments, suggestions

Is there a check or control for the sensors? I mean how do we really know that data from the sensors installed are correct. Or to put in simple words how to rely on sensor data.
Is it really going to help farmers? Because usually farmers are lagga

The readings should be measured accurately and pin point.

the programme must include all plant \ crop related parameters this programme seems to only adress soil moisture.

May not be useful to the farm how does have axis to computers

develop sensors to sense leaf moisture status for scheduling of irrigation

This effort in my opinion is more useful to farmers practicing irrigated agriculture. for rainfed farmers with small holdings it may not serve the intended purpose as he has lot of resource constraints

Soil moisture surplus days and deficit days has to be worked for each village and for two to three major soil group

If it is a single crop biosensor for the perticular disease. Including sensor for the wind velosity and direction for spray etc.

The sensors deployment points should be almost uniform and placed equidistance inorder to get the reliable data. placed equi distance

you have mentioned about obtaining desired data every minute, but am not finding any use in it- because there is no use in getting data of soil type every min bz it wont change and also rainfall data,temp of each hour is enough.

as the moisture stress is common in rainfed situation detailed monitoring of weather parameters such as rainfall pattern,soil moisture content,temperature which are interrelated and ultimately determines soil moisture condition of the cropped area is a co

Forestry: The height at which temperature measured should be specified. It usually different below the soil depth, at ground level and varies at different altitudes.

If we have a calibrated sensors with good standard protocol, then its fine.

The data which I gone through has systematic error and it is ok.

As I am breeder, I need to work both on environment and genotype interaction, so by knowing these parameters at least I can have a control on environmental parameters.

3.2.2 Detailed survey

3.2.2.1 Extra constraints to take into account

rainfall pattern, temperature of soil and the atmosphere, soil nutrition

3.2.2.2 Why did you choose day length

Day length is important because the crop is photosensitive

3.2.2.3 Why did you choose weather variability

Weather parameter measurement will help in deciding the irrigation to the crop

Among weather factors soil water content is the most important factor which influences the croop productivity. this is dependent on the rain fall pattern in that area. Humidity also dependent on the rainfall pattern and soil moistrue content. This humidity plat a role in the build of pest and diseases.

most of the crops in india are rainfed only, so sensors are impt to study further on environmental parameter

it helps to predict the changes of weather in the forthcoming days and plan the crop

One of the hurdles in Ragi crop improvement is moisture stress as this crop is predominantly grown by marginal farmers under rainfed conditions. By measuring the environmental parameters such as rainfall pattern,temperature,soil moisture status we can determine how these parameters playing role in this crop.By Knowing soil moisture status we can schedule the irrigation that is at what stage we can give the irrigation,how much irrigation we can provide at critical stages of the crop with which good yield can be obtained. In otherwords we can plan the irrigation properly.

Pigeonpea is mainly dependent on the rainfall pattern in that area. If good rainfall is received in the month of may (premonsoon showers) and sowing of the crop is taken in the month of May itself, the crop can putforth good canopy and we can expect good yield. Good soil moisture content during the crop growth period will enhance the producitvity.

3.2.2.4 Why did you choose nutrient

Nutrient availability and uptake by the plant depends on soil moisture status and temperature

Moisture content is the factor which is going to influence the prevalence of pests and diseases. e.g , Aspergillus infection may take place that finally leads to aflatoxin production Nutrient content of soil decides the nutritional deficiency diseases

Sensors are good enough to give the details of soil moisture content, rainfall pattern and siol temperature. We can shedule the irrigation according to the data obtained from sensors. So we can save water.

Nutrient up take depends on the soil moisture content and rainfall pattern in that area. If there is good moisture content in the soil the nutirient uptake will be high and the crop productivity increses.

Nitrogen fixation by legume plants is reduced by moisture stress due to a reduction in leghemoglobin in nodules,specific nodule activity and number of nodules. In addition dry weight of nodules is significantly reduced by moisture stressed plants and delays nodule formation in legumes.There is considerable evidence to show that N P and K uptake is reduced by moisture stress.

Soil type will tell us about the availability of nutrients in that particular type of soil, while the soil moisture content tells us how much actually the plants could able to get them. In addition, rainfall pattern will again is an indication of soil moisture content and hence monitoring of rainfall pattern will help us to know how much water the plants can get and along with water, the nutrients could also get in.

The environmental sensors woud provide data on Relative humidity and moisture content which would help in disease and pest forcasting. The moisture content could indicate field capacity/ wilting point in turn would influence nutrient availability.

3.2.2.5 Why did you choose soil physics

weather parameters decide leaching loss of nutreints and also bases create the problems like acidity

soil temperature and water content influence the incidence of diseases. So, if sensors can be installed, any deviation in these two can be monitered and can be tried to manipulate the situations.

Except soil type sensors can measure soil water content and soil temperature. So it is very useful.

Soil related parameters like water logging is dependent on soil type,water content,and rainfall pattern.

no experiences as such. it is impt to use sensors to deal with current crop production problems sorghum is mainly grown as rainfed crop so this sensor would help in accordingly manage the crop in order to get a good yield

this would help to know the moisture content in the soil

it is important to have knowlede about rainfall pattern , temperatue and humidity in order to maintain a good crop growth ,yield etc

3.2.2.6 Why did you choose soil moisture stress

Temperature, rainfall, humidity etc. decide the evapotranspiration and also the avialbility soil moisture

with the assistance of sensors data ,one ecan plan well in advance agaginst the rainfall, droght situations

Soil moisture stress will be more if the soil water content is less and inturn the soil moisture content is depends on the rainfall pattern in that area. The moisture content in the soil also depends on the tempture. If more tempture the soil moisture depletion will be fast.

Nitrogen assimilation is affected by water stress due to reduction nitrate reductase activity.In sufficient moisture in pod development zone can depress calcium uptake by developing pods and cause more un filled pods.

(3x)[1] The environmental sensors woud provide data on Relative humidity and moisture content which would help in disease and pest forcasting. The moisture content could indicate field capacity/ wilting point in turn would influence nutrient availability.

(3x) The environmental parameters influence the microbial population in the rhizhosphere,which includes pathogen also. The survival, multiplication and infection are greatly influenced by these parameters.Management strategies can be scheduled based on this data/ information.

Raifall pattern, soil type and water holding capacity are most crucial to know about the moisture stress effects. How much rainfall the area receives, how much water that the soil can hold etc., will determine what crop to be grown in an area/ locality.

Soil moisture stress is dependent on soil type, teperature and rainfall pattern.

The soil moisture stress is dependent on the rail fall pattern of that area. If good amount of rain with fairly equal distribution is obtained the crop growth will be better and it will increase the productivity Soil water conteent and soil moisture stress are inversely

[1] A number in parenthesis at the beginning of a comment indicates the number of duplicates of this comment. This only takes into account word-by-word duplicates, probably from participants holding the same arguments for different contraints.

related. The soil moisture stress is also dependent on the normal weather temperature of that area. Higher the temperature there will be more loss of water from the soil and leads the soil moisture stress.
The environmental sensors woud provide data on Relative humidity and moisture content which would help in disease and pest forcasting. The moisture content could indicate field capacity/ wilting point in turn would influence nutrient availability.

The environmental parameters influence the microbial population in the rhizhosphere,which includes pathogen also. The survival, multiplication and infection are greatly influenced by these parameters.Management strategies can be scheduled based on this data/ information

(2x) The soil moisture stress is dependent on the rainfall and soil water content.

3.2.2.7 Why did you choose pest

Rain fall pattern, temperature and humidity are very important for incidence and build of the pests.

(2x) The environmental sensors woud provide data on Relative humidity and moisture content which would help in disease and pest forcasting. The moisture content could indicate field capacity/ wilting point in turn would influence nutrient availability.

(2x) The environmental parameters influence the microbial population in the rhizhosphere,which includes pathogen also. The survival, multiplication and infection are greatly influenced by these parameters.Management strategies can be scheduled based on this data/ information

Pest problem persist when there is congenial weather condition. Thus, measuerement of environmental/ weather parameters like, temp, humidity and raifall, certaily one can predict the pest incidence

The pest build up is dependent on temperature, humidity and also on rainfall. Prolonged humid weather clubbed with intermittent rainfall leads the high pest build up.

3.2.2.8 Why did you choose disease

for the incidence of the diseases also the rain fall pattern, temperature and humidity are very important.

The degree of insect pest infestation is also affected by drought stress. The leaf minor is densly infected on most drought infected plants.

(3x) The environmental sensors woud provide data on Relative humidity and moisture content which would help in disease and pest forcasting. The moisture content could indicate field capacity/ wilting point in turn would influence nutrient availability.

(3x) The environmental parameters influence the microbial population in the rhizhosphere,which includes pathogen also. The survival, multiplication and infection are greatly influenced by these parameters.Management strategies can be scheduled based on this data/ information

Blast is the predominant disease causing severe yield loss in ragi.Humidity,temperature and soil mosture play crucial role in infestation of disease. Blast is a fungal disease the growth is favoured by humidity and soil moisture. By knowing at what soil moisture level and at what percentage of humidity the growth of fungal spores is more/ less we can again plan our irrigation/crop duration

Disease buildup is also dependent on humidity, temperature and rainfall. Prolonged humid weather result in high disease incidence

Prolonged humid weather with intermittent rainfall will favour the disease incidence.

3.3 Quantitative data

This refers to the interactions with the application that were logged into a database. This part of the experiment led to inconclusive results. Out of the 30 participants, only six actually used the on-line application at some point. All of them were PhD students and post-docs. No senior researcher used spontaneously the on-line application.

The participants who used the application did in average 3 queries to the system, mostly to look at the soil moisture status.

This paradoxical disinterest for the on-line application made the debriefing meetings very important, in order to understand the mismatch between the interest manifested in the survey and the actual usage of the application.

3.4 Individual interviews

One general remark is that people do not spontaneously play with the application.

3.4.1 Prof. Bhaskar Crop Physiology

Prof. Bhaskar (Crop Physiology, UAS) recognized environmental information as useful for post-mortem analysis in case of crop failure - assess crop suitability - evaluate date of planting. The type of data needed is soil moisture (several stations), plus one weather station. A typical type of deployment is nodes scattered in a circular pattern, with typically 200m between the stations. The number of sensors depends on soil type and soil variability. The depth of the sensor placement for particular plants depends on the type of crop.

However, no precise use case emerged during this meeting. Prof. Bhaskar was not convinced that the time variability of the environmental parameters would justify the deployment of a wireless sensor network.

3.4.2 Prof Ramakrishna Parama: Soil Science

Provided we can adapt nutrient sensors to the wireless nodes, there is research to be conducted in the response at the root zone to different strategies of nutrient application and irrigation. The main objective would be to observe the variation in: nitrogen , phosphorus and potassium content, in the context of nutrient dynamics under a system of multiple crops and trees.

Appropriate sensors are of interest in order to understand the dynamics of nutrients and soil moisture, soil PH, etc. under a system of multiple crops and trees. Experiment would be meaningful if conducted in the following way:

- 4 ha divided in 4 plots, 10 sensors per plot.
- Sensors placed at 2 different depths
- Experiment should last 2-3 years minimum
- Bi-weekly measurements

For research purposes, having multiple measures per day would be useful, but that would not give meaningful results from an agriculture point-of-view, because the time-scale of farming operations is much larger.

Prof.Bhaskar is willing to undertake such an experiment, and encouraged us to contact him when we have identified the proper sensors for nutrient concentration.

3.4.3 Suvarna V.C, Micro-biology

Ms. Suvarna V.C. is a junior collaborator, who exposed two research activities where environmental information can be useful in micro-biology:

- Effect of microbial activity on soil nutrition. Environmental parameters have effect on the evolution of nutrients in the soil
- Disease-causing organisms: Observe the conditions in which these organisms (typically aerial micro-flora) develop. Environmental parameters may condition the outbreak of an epidemic.

Typically, research in this area is done in micro-plots. The granularity is one-reading per week The parameters of primary interest are soil and air temperature, soil moisture and humidity. When prompted, the interviewee mentioned other parameters of possible interest, such as wind direction/intensity, sun radiance and precipitation.

The interviewee never seemed to think sensor networks could be useful in this context. When prompted, she acknowledged that the size of the experiments was constrained by the difficulty to obtain parameters at a satisfying rate, but did not really consider the use of WSNs in this framework.

We could not obtain a meeting with a more senior professor in this department. However, Ms. Suvarna gave us a tentative list of other persons to talk to:

- Dr. G.P. Brahmaprakash
- Dr. A. Manjunath
- Dr. Radhakrishna
- Dr. Balakrishna
- Dr. Mallesha
- Dr. Shivaprakash

3.4.4 Prof. Bhaskar, Forestry Department

He showed no interest in the application.
He has published a paper that has an experiment of monitoring soil moisture levels in a crop and tree interaction. For measurements they used neutron probes. He understands the utility of sensors, but, not interested to work further.

3.4.5 Prof. Kumar[2], Entomologist

Observation of white grubs: Their activity depends on the weather, especially rain fall soil moisture, soil temperature. There is a clear correlation between the rain patterns and the emergence of adults of the insects from the soil. This happens in a fixed time of the year between the last week of April and the end of June. If there is rain before April 20th, then there is no emergence. Moreover, after October all the larvae enter pupation and emerge as adults after 20 days. If the soil moisture conditions are not favorable to them until the end of June, a large percentage of the population might die.

The hypothesis that Prof. K. would like to verify is whether the insect's activity depends on soil moisture evolution and accumulation of soil temperature in the weeks prior to emergence.

Another pest, Red Hairy Caterpillar has a similar biology but 2 months later than the white grubs. Emergence happens in two cycles, one in early July and the second in late September.

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[2] Email: arv_k02@yahoo.com, prabhuganiger@gmail.com

Soil moisture, temperature sensors in specific regions of endemic populations of these pests (sampling various soil texture typologies) will help to investigate, understand their biology . This would enable to provide advance information on intensity of pest damage to farmers.

Prof. Kumar expressed keen interest on the usage of WSNs, also to try the technology.

3.4.6 Prof. Narayana Gowda

Prof. Narayana Gowda is conducting applied studies on the productivity increase through appropriate agricultural management techniques. His work spans 72 villages in the Bangalore greater area. The project uses one automatic weather station. Before using sensors, he wants to understand a profitable use case of information using sensors.

3.4.7 Prof. Shrinivasa Murthi

Soil moisture sensors can help in certain special cases. For instance, soils with hard crust formation will have much lower percolation than predicted by science. In such cases the sensors may measure actual percolation and benefits of appropriate measures to break the crust.

3.4.8 Prof. Sheshshayee (Crop Physiology)

His interest is about evapotranspiration assessment. The goal is to assess precisely the ratio between the water that is transpired by the plant and what gets evaporated.

The goal is to test plants with different genotypes obtained by cross-breeding and to assess which one has the best ratio of biomass production per water used. Prof. S. is looking for water efficiency.

The method used for this test today is gravimetric method. For this, micro-plots in pots are used. They are filled daily with water up to field capacity. The next day, they are weighted to assess the water lost in evapotranspiration. Bare plots are used to assess the effect of pure evaporation.

The goal is to replace the gravimetric method with soil moisture sensors that would give directly the volumetric content of water of the soil. The tedious weighting procedure could then be avoided.

A typical experience contains 120-200 pots. Each pot should contain 1-4 probes (ECH2O) connected to one wireless sensor. The experiment duration is typically 80 days from plant sowing (out of which 50 days of measures) The number of measures should be at least 4 per day, the more the merrier.

His expressed interest is high. Prof. S. would like to conduct as soon as possible a first experiment with 30 pots.

The impact on rain-fed farming is the possibility to achieve crop improvement through selection.

3.4.9 Dr. Reddy (Veterinarian, BAIF)

In the framework of their upcoming BIRD-K program, BAIF is conducting applied research.

In this context, wireless sensor networks are perceived by Dr. R. as a promising validation tool. Two experiments are envisioned:

1. the possibility to increase soil retention capacity through different measures, such as fertilizer, mulching, etc.
2. assessing the efficiency of underground drip irrigation. Here, the goal is to bring the water directly to the root zone of the plant.

For both experiments, soil moisture is the ultimate measure of success or failure.

A second use case is about information sharing in rural kiosks. BAIF has implemented a network of internet kiosks in the Tumkur region. At the central server in Tumkur, ext. specialists are analyzing data they receive from local kiosks in the villages. This data consists in questions and environmental information. Then, they redistribute the information they analyzed to the kiosks.

Obtaining live data about soil moisture content for different types of soil would be an interesting complementary source.

The sensors useful for this application are soil moisture sensors and nutrient sensors.

Dr. R. expressed keen interest. In a first phase, BAIF is interested in 100 sensors minimum.

In his words, funding seems to be a solvable problem.

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