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SPACE TECHNOLOGY INPUTS FOR PRECISION FARMING

R. S. Dwivedi[a], S. P. Wani[b], A. Bhattacharya[a] and R. R. Navalgund[a]

[a]National Remote Sensing Agency,
Department of Space, Govt. of India
Balanagar, HYDERABAD – 500 037
India
[b]International Crops Research Institute for
Semi-Arid Tropics (ICRISAT)
PATANCHERU 502 324
India
Commission VII, Working Group-VII/2

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ABSTRACT:

Applications of agricultural inputs at uniform rates across the field without due regard to in-field variations in soil fertility and crop conditions does not yield desirable results in terms of crop yield. The management of in-field variability in soil fertility and crop conditions for improving the crop production and minimizing the environmental impact is the core issue of precision farming. Thus, the information on spatial variability in soil fertility status and crop conditions is a pre-requisite for adoption of precision farming. Space technology including global positioning system (GPS) and GIS holds good promise in deriving information on soil attributes and crop yield, and allows monitoring seasonally- variable soil and crop characteristics, namely soil moisture, crop phenology, growth, evapotranspiration, nutrient deficiency, crop disease, and weed and insect infestation, which, in turn, help in optimizing inputs and maximizing crop yield and income. Though widely adopted in developed countries, the adoption of precision farming in India is yet to take a firm ground primarily due to its unique pattern of land holdings, poor infrastructure, lack of farmers ability to take risk, and socio-economic and demographic conditions. The article introspects the scope of precision farming under Indian conditions and the possible role that space technology can play in this endeavour.

1.0 INTRODUCTION

Green revolution has played a vital role in boosting the agricultural production in India since its inception in 1970. The annual food grain production which was only 109 million tonnes in 1970, had risen to 196.13 million tonnes in 2000-2001. However, while striving for improved agricultural production, due emphasis has not been laid on soil and environmental health. Excessive use of fertilizers, insecticides and pesticides, and lack of organic manure which promote soil biota, has led to pollution of groundwater and depletion of the population of actinomycetes which provide protection to plant against diseases. As a result, crop production though increased initially, has exhibited either stagnation or declining trend after mid-eighties. The improvement in agricultural production on a sustained basis while maintaining soil and environmental health calls for optimal utilization of agricultural inputs based on crops demand.

Hitherto, farmers have been applying fertilizers based on recommendations emanating from research and field trials under specific agro-climatic conditions, which have been extrapolated to a regional level. Since soil nutrient characteristics vary not only between regions and between farms but also from plot to plot (Ladha et al., 2000), and within a field or plot, there is a need to take into account such variability while applying fertilizers to a particular crop. Consideration of in-field/plot variations in soil fertility and crop conditions and matching the agricultural inputs like seed, fertilizer, irrigation, insecticide, pesticide, etc. in order to optimize the input or maximizing the crop yield from a given quantum of input, is referred to as precision farming or precision agriculture or precision crop management.

2.0 THE INDIAN SCENARIO

In India, broadly two types of agriculture viz., high input agriculture characterized by the provision of assured irrigation and other agricultural inputs, and subsistence farming which is confined mostly to rain-fed or dry land regions, are prevalent. Nearly two-third arable land in India are rain-fed. The crop yields are very low ($\approx 1\ t\ ha^{-1}$) and very good potential exists for increasing productivity of rain-fed cropping systems. For instance, soybean is grown in Central India which is considered as heartland of rain-fed agriculture, and its average productivity is $1\ t\ ha^{-1}$. Recent studies at ICRISAT using crop growth simulation model have demonstrated that the potential yield of soybean could be achieved upto $3.05\ t\ ha^{-1}$, and the yield gap of 1.6 to $1.8\ t\ ha^{-1}$ exists which could be minimized and productivity could be increased substantially under rain-fed conditions by adopting improved soil, water, and crop management practices (Singh et al.,2002). In another study which was carried out at Adarsha watershed, Shankarpally *mandal* (an administrative unit) in Ranga Reddy district of Andhra Pradesh, southern India, farmers have increased their farm productivity by 2 to 3 times (maize yield 3.3 to $3.8\ t\ ha^{-1}$) as compared with baseline yields ($1.5t\ ha^{-1}$), increased incomes (3.5 times) with maize/pigeonpea system as compared to the traditional cotton system, reduced runoff (6% vs 12%) and soil loss (0.385 vs. 0.984 t ha-1), improved groundwater levels, increased vegetation cover (200 ha vs. 129 ha) and diversified the system by adopting this approach (Wani et al., 2002).

Assured irrigation (around 96%) with large fields and adequate capital for various agricultural inputs (fertilizer consumption-0.158 t ha^{-1}), and consequent higher productivity (nearly 4 t ha^{-1}) is the characteristic features of agriculture in Punjab, Haryana and Western Uttar Pradesh. Optimization of agricultural inputs and minimizing the cost of production and environmental impact are to be focussed. It is quite evident from the foregoing that in order to improve the agricultural production, to be competitive in the emerging seamless global economy and to maintain environmental health, two strategies, namely adoption of soil and water conservation measures, and minimizing the cost of cultivation need to be addressed. The implicit fact in the strategy is the applications of agricultural inputs based on crop demand, and soil attributes rather than applying at uniform rate across the field.

At national level, information on the nature, extent, spatial distribution, potentials and limitations is available only at regional level (1:500,000 scale), at meso level (1:50,000 scale) only for part of the country, and at micro level no information is available. With respect to soil fertility status, as pointed out earlier, only regional / district-level recommendations based on crop response trials in experimental plots is available, which is used as a base for fertilizer applications. There is, therefore, need to generate at least field-level information on soil fertility. Similarly, for crop production, water resources is equally, if not more, important. Optimal utilization of irrigation water needs due focus. As witnessed in command areas, if not managed properly, it may lead to waterlogging and subsequent development of soil salinity and/or alkalinity.

A beginning towards adoption of precision farming could be made in India by creating awareness amongst farmers about consequences of applying imbalanced doses of farm inputs like irrigation, fertilizers, insecticides and pesticides. The next step would be the evaluation of soil fertility at individual field/plot level and make it available to farmers for fertilizer applications. Once it is achieved, in-field variability in soil fertility need to be looked at and managed by judiciously applying plant nutrients.

3.0 ROLE OF SPACE TECHNOLOGY

As evident from the foregoing, in order to pursue precision farming, baseline information on nature, extent spatial distribution, potentials and limitations of soils is a pre-requisite. Since information on soils at meso-level is available only for part of the country, such information needs to be made available for entire country. Spaceborne multispectral measurements have been operationally used for deriving information on soils (Hilwig, and Karale,1973; Korolyuk and Shcherbenko,1994), and soil limitations like soil erosion (Karale et al., 1989; Dwivedi et al.,1997), soil salinity and/or alkalinity, waterlogging, etc. (Metternicht and Zinck, 1997; Dwivedi et al,2001). The Department of Space, Government of India has already taken initiative to generate soil resources maps at 1:50,000 scale for entire country using the Indian Remote Sensing Satellite (IRS-1C/-1D Linear Imaging Self-scanning Sensor (LISS-III) data.

The next step would be to generate detailed-level information on soil resources addressing potentials and limitations of individual fields since except for states like Punjab, Haryana, Madhya Pradesh and Maharastra where fields size is quite large, practically individual field could be treated as a homogenous management unit for the purpose of precision farming. Currently available high spatial resolution multispectral data from IKONOS-II and Quick Bird-II, and those from planned earth observation missions, namely Resourcesat-1, Cartosat-1 and II would enable generating desired information. Remote sensing has shown encouraging results in providing information on soil fertility. Laboratory and *in situ* spectral measurements have been directly related to variability in soil organic matter (Baumgardner et al., 1970), soil calcium carbonate content (Leone et al., 1995), iron oxide content (Coleman and Montgomery, 1987), and soil nutrients particularly those associated with soil texture and drainage (Thompson and Robert, 1995).

Information on the potential yield that can be achieved from a given piece of land and the likely yield of existing crop is required to bridge the gap by suitably adjusting the agricultural inputs. Crop growth simulation model provide information on potential yield while multispectral measurements made from air and spaceborne platforms have shown immense potentials in crop yield estimation and forecasting using spectral indices (Tucker et al., 1980; Navalgund, 1991; Yang and Anderson, 1996).

Remote sensing also holds good promise in deriving information on seasonally-variable soil and crop parameters, namely soil moisture status, crop conditions like vigour, infestation of weeds, pests and disease, required for farm management. Spectral measurements in thermal regions have been related with the variations in soil moisture content (Idso et al., 1975). In fact, the combination of long and short wavelengths e.g. Ku-band at 2 cm or x-band at 3 cm, have been used for assessment of within -the- field soil moisture conditions (Prevot et al., 1993).

Various stages of crop development i.e., grain filling in wheat and anthesis of corn have been related to spectral measurements (Railyan and Korobov,1993; Boissard et al.,1993). Likewise, spectral measurements help measuring or monitoring crop growth through empirical correlation of Vegetation Index (VI) with such crop variables as leaf area index (LAI), per cent vegetation cover, vegetation phytomass and fraction of absorbed photosynthetically active radiance (fAPAR) required for calibration and validation of crop growth simulation models (Pinter, 1993). In addition, remotely sensed data could be used for deriving crop co-efficients (the ratio of actual crop evapo-transpiration and that of a reference crop) for estimation of actual, site-specific crop evapo-transpiration rate from readily available meteorological information (Bausch, 1993; Ray and Dadhwal, 2001).

Reflectance measurements in the green (0.545 μm) spectral band have been related to plant nitrogen content and canopy nitrogen deficits (Fernandez et al., 1994). Besides, remote sensing has some potential for detecting and identifying crop diseases (Malthus and Madeira, 1993), weed infestation (Brown et al., 1994) and insect infestation (Yang and Chang, 2001). Furthermore, remote sensing has a variety of roles in determining the cause of spatial and temporal crop and soil variability. The most obvious role is the use of remote sensing information to improve the capacity and accuracy of decision support system (DSS) and agronomic models by providing accurate input information or as a means of model calibration or validation. Another role is the use of hyperspectral images for direct crop diagnosis.

The Geographic Information System (GIS) contributes significantly to precision farming by allowing presentation of spatial data in the form of a map. In addition, GIS forms an ideal platform for the storage and management of model input data and the presentation of model results which process model provides. The Global Positioning System (GPS) technology provides accurate positioning system necessary for field implementation of variable rate technology (VRT). The Internet makes possible the development of a mechanism for effective farm management using remote sensing. The potentials of remote sensing in providing information required for precision farming, in general, have been reviewed by Moran et al.(1997), and for Indian conditions by Ray et al.(2001).

4.0 THE INDIAN INITIATIVE

Realising the potential of space technology in precision farming, the Department of Space, Government of India has initiated eight pilot studies in well-managed agricultural farms of the ICRISAT, the Indian Council of Agricultural Research and the Agricultural Universities, as well as in farmers' fields. The pilot studies aim at delineating homogeneous zones with respect to soil fertility and crop yield, estimation of potential yield, yield gap analysis, monitoring seasonally-variable soil and crop conditions using optical and microwave sensor data, and matching the farm inputs to bridge the gap between potential and actual yield through spatial decision support systems (SDSS). The test sites are spread over a fairly large area across a cross section of agro-climatic zones of the Indian sub-continent, and cover some of the important crops like wheat, rice, sorghum, pigeon pea, chickpea, soybean and groundnut.

5.1 A Case Study

The study was taken up (i) to analyze the gap between potential and existing crop yields using crop growth simulation models, and (ii) to develop a spatial decision support system (SDSS) at ICRISAT farm bound by geo-co-ordinates 17.6^0 to 17.33^0 N and 78.1^0 to 78.4^0 E, and located in Patancheru, Medak district of Andhra Pradesh, southern India (Fig-1). The test site forms part of the pediplain developed over granite-gneiss complex. Both red soils (Alfisols) and black soils (Vertisols) and their intergrades are encountered in the farm. The climate is semi-arid and sub-tropical with around 800 mm of mean annual rainfall, which is received mostly from southwest monsoon. Within the farm, two nano-watersheds-one in the red soils (RW2) and another in black soils (BW7) have been selected. Whereas sorghum and groundnut were taken in RW2, BW7 had two types of cropping system viz., (i) Soybean var. PK72- a 90 to 100 days crop, during *kharif* followed by chickpea during *rabi*, and (ii) Soybean-pigeonpea (ICPL87119- a 210 to 240 days crop) intercrop. In the following section, the work on BW7 nano-watershed will be briefly discussed.

Soybean and pigeonpea were sown on June 21,2002 with a row to row spacing of 30cm in case of soybean sole, and 22.5cm for soybean and pigeon pea intercrop. A plant-to-plant distance of 7-10cm was maintained for soybean whereas it was 25cm for pigeonpea. In order to demonstrate the utility of raised-bed system, crops were sown in two types of land configuration- the conventional flat bed, and broad bed and furrow (BBF) system which facilitates free movement of farm machinery apart from maintaining good drainage especially during rainy season. Whereas the distance between the furrows was maintained at 150cm, the furrow width and bed height were kept at 30cm and 20cm, respectively. The raised beds were tending to taper on either side towards the furrow while leaving an effective bed width of 110cm for sowing crops. Due care was taken to keep the crop free from weeds, insects, pests and diseases.

Owing to persistent cloud cover during monsoon (*kharif* season), the microwave data from synthetic aperture radar (SAR) onboard Radarsat-1 in fine resolution beam mode with a spatial resolution of 8m and acquired from three overpasses-one on August14, another on September7 and the third on October1,2002 were utilized. The cloud-free IRS-1D LISS-III and PAN data were also collected. Apart from satellite overpass-synchronous ground truth for soil moisture estimation and for deriving biophysical parameters crops, namely leaf area index (LAI) and phytomass, such observations were also routinely made at biweekly intervals throughout the crop growing season. Soybean crop was harvested on October1 and 2,2002. A 3x3m sample size was selected for harvesting and ultimately for yield estimation and mapping. Samples were taken both from broad bed and furrow (BBF) and flat bed (FB) plots. The locations of each segment was identified with the help of Nikon Total Station model 801.

An attempt was made to correlate the back scattering coefficient as measured by Radarsat-1 SAR and soil moisture, and crop parameters including LAI and phytomass. An analysis of simulated yield using Agriculture Production Systems Simulator (APSIM) model and observed yield data (Table-1) for soybean/pigeonpea crop system for 1999-2000 reveals a seed yield gap of 783kg ha^{-1} (Singh et al.,2002).

Table-1 Simulated and observed yields (t ha^{-1}) of soybean/ pigeonpea intercrop system on a shallow soil during 1999 - 2000 season

	Flat shallow		BBF shallow	
	Soybean	Pigeonpea	Soybean	Pigeonpea
Simulated yield				
Total biomass	7162	1985	7377	1980
Seed yield	2083	325	2145	334
Observed yield				
Total biomass	3286	1861	3781	2107
Seed yield	1300	603	1497	721

Singh et al., 2002 (Unpublished).

Furthermore, a close look at historical yield data for a field within BW7 nanao-watershed, which is based on random sample of 10x4.5m segments, indicates a fairly large in-field heterogeneity (3,756 to 4,556kg/ha) in soybean grain yield (Table-2).

Table-2 Soybean (variety PK472) yield at ICRISAT farm in 1999.

S.No	Weight(kg)*		Yield(kg/ha)	
	Grain	Fodder with pods	Grain	Fodder with pods
1	6.911	16.9	1,536	3,756
2	8.173	19.8	1,816	4,400
3	8.556	20.5	1,901	4,556
4	7.66	18.7	1,702	4,156
5	8.344	19.4	1,854	4,311

*Segment size: 10x4.5m.
Courtesy: Natural Resources Management Group, ICRISAT(Unpublished

6.0 CONCLUSIONS

Precision farming is undoubtedly relevant to Indian agriculture in the context of improving agricultural production and stakeholders' income and minimizing environmental impact. However, the concept and the model of precision farming may be different, and should focus on optimization of farm inputs, reducing cost of cultivation and maintaining good harmony with the environment. Space technology offers immense potential for deriving information on soil fertility, crop conditions and crop yield, crop simulation models enable estimating potential crop yield and the decision support system to facilitate developing appropriate prescription for improving crop production while minimizing the cost of inputs. The major limitations of currently available high spatial resolution multispectral data are the fixed and broad spectral bands, very low repetivity, high cost which most of the Indian farmer could not afford apart from issues like radiometric normalization of multi- temporal spectral measurements for objective change detection, instrument calibration and high turn around time. In order to match the technology with the requirement of precision farming, improvements in corresponding elements needs to be made to address the limitations so as to reap its benefits to fullest extent.

REFERENCES

Baumgardner, M. F., Kristof, S. J., Johannsen, C. J., and Zachary, A. L., 1970. Effect of organic matter on multispectral properties of soils. Proc. Indiana Acad. Sci. 79:413-422.

Bausch, W. C.,1993. Soil background effects on reflectance based crop coefficients for corn. Remote Sens. Env. 46:213-222.

Boissard, P., Pointel, J.-C., and Huet, P., 1993. Reflectance green leaf area index and ear hydric status of wheat from anthesis until maturity. Int.J. Remote Sens. 14:2713-2729.

Brown, R. B., Steckler, J.-P. G. A., and Anderson, G. W. R., 1994. Remote sensing for identification of weeds in no-till corn. Trans. ASAE 37:297-30-2.

Coleman, T. L., and Montgomery 0. L., 1987. Soil moisture, organic matter and iron content effect on spectral Characteristics of selected Vertisolsand Alfisols in Alabama. Photogramm. Engg. Remote Sens. 12:1659-1663.

Dwivedi,R.S., Ravi Sankar,T.; Venkataratnam,L.; Karale,R.L.; Gawande, S. P.; Rao,K.V.S.; Senchuandhary,S.; Bhaumik, K.R. 1997. The inventory and monitoring of eroded lands using remote sensing data. International Journal of Remote Sensing. 18(1): 107-119.

Dwivedi, R. S., K.V. Ramana, S.S. Thammappa and A. N. Singh.2001. Mapping salt-affected soils from IRS-1C LISS-III and PAN data. *Photogrmmetric Engineering and Remote Sensing.67(10):1167-1175.*

Fernandez, S. Vidal, D., Simon, E., and Sole-Sugrafies, L. 1994. Radiometric characteristics of *Triticum aestivum* cv. Astral under water and nitrogen stress. Int. J. Remote Sense. 15:1867-1884.

Hilwig,F.W. and Karale, R.L., 1973. Physiographic systems and elements of photo-interpretation as applied to soil survey in Ganges plain. . *Journal of the Indian Society of Remote Sensing.* **21(2)**:205-212.

Idso, S.B., Schmugge, T.J., Jackson, R.D., and Reginato.R.J., 1975. The utility of surface temperature measurements for the remote sensing of surface soil water status. J. Geophys. Res. 80:3044-3049.

Karale, R.L., K.K. Narula, V. Dayal and K.M. Saini.1989. Database management system for erossivity values. Journal of Indian Society of Remote Sensing**77 (1)**: 23.

Korolyuk, T.V., and Shcherbenko, H.V., 1994. Compiling soil maps on the basis of remotely-sensed data digital processing: soil interpretation. Int. J. Remote Sens. 15:1379-1400.

Ladha, J. K., Fischer, A. K. ,Hossain, M., Hobbs, P. R., Hardy, B., editors. 2000. Improving the productivity and sustainability of rice-wheat systems of the Indo-Gangetic plains: a systematic synthesis of NARS-IRRI partnership research. IRRI Discussion Paper Series No. 40.Makati City (Philippines): International Rice research Institute.31p.

Leone, A.P., Wright, G.G., and Corves, C., 1995. The application of satellite remote sensing for soil studies in upland areas of Southern Italy. Int. J. Remote Sens. 16:1087-1105.

Malthus, T.J., and Madeira, A. C., 1993. High resolution spectroradiometry: spectral reflectance of field bean leaves infected by Botrytis fabae. Remote Sens. Environ. 45:107-116.

Metternicht, G and Zinck, J. A., 1997. Spatial discrimination of salt and sodium affected soil , soil surfaces. *International Journal of Remote Sensing* **18 (12)**: 2571 – 2586

Moran, M.S., Inoue, Y., and Mitchell, T., 1997. Opportunities and limitations for image-based remote sensing in precision crop management. Remote Sensing of Environment.61:319-346.

Navalgund R. R., 1991.Remote sensing applications in agriculture: Indian experience. In Space and agriculture management. Special Current Event Session. International Astronautical Federation. 42nd IAF Congress, Montreal, Canada.pp31-50.

Prevot, L., Champion,I.,,and Guyot, G.,1993. Estimating surface soil moisture and leaf area index of a wheat canopy using a duel frequency (C and X bands) scatterometer. Remote Sensing of Environment..46:331-339.

Pinter, P.J., Jr., 1993. Solar angle independence in the relationship between absorbed PAR and remotely sensed data for alfalfa. Remote Sens. Environ. 46:19-25.

Railyan, V. Ya., and Korobov, R.M., 1993. Red edge structure of canopy reflectance spectra of Triticale. Remote Sens. Environ. 46:173-182.

Ray, S. S., Panigrahy, S. and Parihar, J. S., 2001. Role of remote sensing for precision farming with special reference to Indian situation. Scientific note, SAC/RESA/ARG/AMD/SN/01/2001,SAC, Amedabad.

Ray, S. S., Dadhwal, V. K.,2001. Estimation of crop evapotranspiration of irrigation command area using remote sensing and GIS. Agricultural Water Management.49(2001): 239-249.

Singh, P., Vijaya, D., Chin, N.T., Arun Pongkanjana, Prasad, K.S., Srinivas, K., and Wani, S.P., 2001. Potential productivity and yield gap of selected crops in the rain-fed regions of India, Thailand, and Vietnam. Natural Resource Management Program Report No. 5, Patancheru 502 324, Andhra Pradesh, India : International Crops Research Institute for the Semi-arid Tropics.

Singh, P. et al., 2002, Improving measurement of natural resources sustainable rainfed agriculture. Unpublished.

Thompson, W., and Robert, P.C.,1995. Valuation of mapping strategies for variable rate applications. In Proc. Site-Specific Mgmt. for Agric. Sys., 27-30 March 1994, Minneapolis, MN, ASA-CSA-SSSA, Madison, WI, pp. 303-323.

Tucker, C.J., Holben, B.N., Elgin, J.H., Jr., and McMurtrey, J.E., III, 1980. Relationship of spectral data to grain yield variations. Photogramm. Eng. Remote Sens. 46:657-666.

Wani, S. P. Pathak, P., Tam, H. M. A. Ramakrishna, A., Singh,P. and Sreeedevi,T. K. ,2002. Integrated watershed management for minimizing land degradation and sustaining productivity in Asia. Proceedings of a Joint UNU-CAS International Workshop, Beijing China – 8-13 September 2001. Paper published in Integrated Land Management in Dry Areas. pp. 207-230.

Yang, C., and Anderson, G. L., 1996. Determining within-field management zones for grain sorghum using aerial videography, in 26th Int. Symp. on Remote Sens. Environ. 25-29 March, Vancouver, BC, Canada, pp. 606-611.

Yang, C. and Chang, C., 2001. Spectral characteristics of rice plant infested by brown plant hoppers. Proc. Nat. Sci. Counc. ROC(B), 25(3)2001 PP 180-186.

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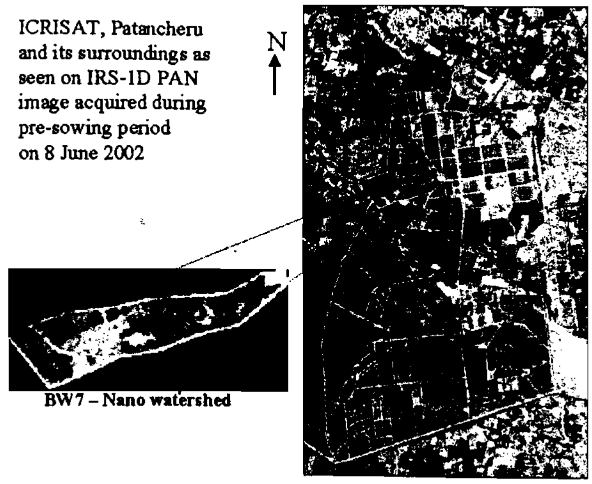

ICRISAT, Patancheru and its surroundings as seen on IRS-1D PAN image acquired during pre-sowing period on 8 June 2002