C21

Food Security with Sustainable Livelihood through *Inte*Gra

C. Pramanik | Tata Consultancy Services Deccan Park | Hyderabad | India
S. Pappula | Tata Consultancy Services Deccan Park | Hyderabad | India
S. Sarangi | Tata Consultancy Services Yantra Park | Mumbai | India
Praneet P. V. | Tata Consultancy Services | Kochi | India
S. Selvan | Tata Consultancy Services Siruseri Campus | Chennai | India

DOI: 10.1481/icasVII.2016.c21

ABSTRACT

In the era of climate change uncertainty, water scarcity, soil fertility degradation and disease-pest dynamics, it is hard for the farmers to obtain the optimized yield and sustain their agri-business. This has led to increased incidents of farmer suicides and has a direct impact on the India's food security. To make agriculture sustainable, an integrated analytically enabled Digital Farming Platform - ***InteGra*** (derived from **Inte**lligent **Gra**m (Village)) – has been proposed. InteGraprovides holistic services, including efficient crop planning, operations scheduling and management by minimizing climate and market risks.The resulting "climate smart" and "market smart" entities called ***SmartPRIDEs*** (Smart Progressive Rural Integrated Digital Enterprises) can transform the lives of millions of farmers across the globe and lead to self-sustaining and economically viable farming. The business model around ***InteGra*** is inclusively designed to bring together agricultural input and output companies, financial and insurance institutions, and policy makers with the appropriate clusters of farmers on the same platform enabling the formation of a mutuallybeneficial and self-sustaining, vibrant ecosystem.

Keywords: Sustainable Food Security, Modelling, Digital Technologies

PAPER

1. Introduction

Agriculture plays a vital role in India's economy. The GDP of Indian agriculture reached US $259.23 billion in FY15 while providing livelihood to nearly 58% of the population and is one of the largest contributor to the Indian GDP [1]. However, all is not well in this sector. India is home to 25 percent of the world's hungry population [2]. India ranks 55 among 63 countries on the Global Hunger Index (2015) and 135 among 187 countries on the UNDP Human Development Index (2014), [3]. Food production has seen only a marginal increase over the past 20 years while there has been an exponential jump in the population. Productivity is extremely low due to unscientific farming practices, fragmented land holdings, lack of agro-climatic focus for crops selection and access to the right farming advice at the right time. Thus food security is a rising question to feed the growing population.

Food security is a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life [4]. Climate change is a fundamental threat to global food security, sustainable development and poverty eradication [5]. Anticipating appropriately the impact of climate change on agriculture requires data, tools and models at the spatial scale of actual production areas [6]. There is an urgent need to organize farming groups which will enable affordability to use modern technologies for sustainable agricultural development.

In order to make Agri business sustainable within the farmers groups, the PRIDE™ (**P**rogressive **R**ural **I**ntegrated **D**igital **E**nterprise) model has been proposed for farmer cooperatives and similar setups [7]. PRIDE™s leverage the power of farmer social networks and ensure that the farmers are able to reassert their place in the agriculture value-chain. To empower PRIDE™s and all associated stakeholders with precision agriculture capabilities obtained from various sensors and other data sources, we propose an integrated digital farming platform –***InteGra***empowered by advanced analytics systems.

PRIDE is digitally enabled a collective group like a cooperative or a farmer producer company is the central channel through which various business and agricultural activities are carried out. This collective group is generally an entity that operates in the field to connect various organizations like agri-input industries, food-processing industries, government organizations, financial institutions, agricultural machinery industries and the stakeholders, i.e. the farmers. In addition, they also trade in large quantities collectively associating with all the farmers.

Through a process of cyclic data optimization involving continuous data collection from the field, data analytics on the backend and directing on-field operations on the basis of intelligence derived from the data, the PRIDE™s are converted into ***SmartPRIDEs. InteGra*** augments the PRIDE™ with precision farming capabilities facilitated through intelligent decision support.**InteGra** is supported by a proprietary, patented scouting application, Intelligent Rural Integrated Sensing (IRIS)which facilitates data collection from the PRIDE™ group of farmers. The regional level agricultural knowledge and data is being stored in an Agriculture Knowledge Base, (AgriKnoBTM), which enables experts to provide recommendations.

As a first step towards transition to ***SmartPRIDEs, InteGra*** offers a variety of services such as crop and variety selection, disease and insect pests' incidence forecasting for selected crops, weather, fertilizer recommendation, irrigation scheduling, market price predictions, and valuation of crops based on consumer pay-off. It is believed that the advanced services for the famer groups in **SmartPRIDE**s will not only lead to a self-sustainable livelihood but also ensure the food security in a collective manner through the formation of an increasing number of intelligent farmer groups.

2. The Analytical Framework of InteGra

The key capabilities of **InteGra** can be captured by the 4As: Acquire, Analyse, Advise, and Actuate. **InteGra**has various components such as *KwikSense, aNutva, ChurnBot, DataPlus, mPush* and CROPS that play a key role in enabling these capabilities.KwikSense can acquire data from personalized sensors installed in farms and can also actuate farm-equipment. aNutva (analytical tool) and *ChurnBot* provide a mechanism to plug in rule-based and statistical algorithms that give useful results from a variety of data sources. Integrated data management is carried out with *DataPlus*. Data is the key driver for the **InteGra** analytical engine to provide intelligence for the farming business. Farming activities depend on multiple phases with inputs from a variety of sources. Hence, data from the corresponding sources is required for better decision making. The cultivation of a crop can be divided into the following four phases.

Table 1 - Cropping phases and Activities

Phases	Present or Upcoming Activities
Phase 1 – Crop Planning	Crop Selection based on Resource estimates, Farmer Constraints, Historical Climatic Conditions and Localized Weather Forecasts, Market demand
Phase 2 – Aggregation and Ordering	Aggregating the Input Requirements across the PRIDE™ and ordering for timely delivery
Phase 3 – Crop Cycle Management	Crop Advisory, Farm Management, Plant Protection, Fertilizer recommendation,Certification, Yield Monitoring & Irrigation scheduling
Phase 4 – Harvest Planning	Crop Valuation and Market Linkages

The core component of InteGra, Crop Rotation, Optimization and Planning System (CROPS™), provides recommendations on the appropriate crops taking into account macro parameters like the historical climatic conditions, market dynamics and micro parameters like the farmer constraints, localized weather conditions, soil fertility and projected market demand. For the selected crops, the revolutionary **InteCrol** (Integrated Crop Protocol) is created by the system. **InteCrol** is the DNA of the platform and has embedded within it a wealth of information which is used by all the downstream phases as well as by various stakeholders in the agricultural value-chain. We discuss in the following sections a variety of analytical techniques that help in critical decisions for the different crop phases:

Crop and Variety Selection: The crop selection is the first and vital step of the entire cropping cycle, which falls under Phase 1- Crop Planning. The selection process is based on two criteria.

Crop Selection: The crops are selected based on the maximum return on investment, considering the resource availability (can be based on quantity orcosts), Agro climate, Soil conditions and market price availability. The Linear – Programming model is used to select the best possible crop and area of cultivation. Following is the Linear Programming model in Matrix form.

$$\text{Maximize } [S_1 \quad S_2 \quad \dots \quad S_n]\begin{bmatrix} x_1 \\ x_2 \\ \dots \\ x_n \end{bmatrix} \tag{1}$$

$$\text{Subject to } \begin{bmatrix} 1 & 1 & \dots & 1 \\ I_{11} & I_{12} & \dots & I_{1n} \\ I_{21} & I_{22} & \dots & I_{2n} \\ \dots & \dots & \dots & \dots \\ I_{m1} & I_{m2} & \dots & I_{mn} \end{bmatrix}\begin{bmatrix} x_1 \\ x_2 \\ \dots \\ x_n \end{bmatrix} \le \begin{bmatrix} L \\ I_1 \\ I_2 \\ \dots \\ I_m \end{bmatrix}, \begin{bmatrix} x_1 \\ x_2 \\ \dots \\ x_n \end{bmatrix} > 0 \tag{2}$$

where,

$S_i = Selling\ price;\ I_{ji} =$
$Inputs\ allocation\ (\text{Fertilizer, Pesticides, Labour etc.})\ with\ respect\ to\ crops;\ I_j =$

$Maximum\ Inputs\ available$, (Fertilizer, Pesticides, Labour etc.), $j = 1,2, \dots, m$; $x_i = Crops, i = 1,2, \dots, n$; $L = Land\ Availability$

Crop-Variety Selection: The crop variety is selected based on the productivity in the available conditions. The crop variety responses are recorded based on prior yield estimates and historical weather information and inputs assisted in yields. The variety selection has been done in following two steps –

1. Stepwise Regression determining the relation between yield and other independent variables – Stepwise regression equations have been fitted with yield response of the respective crop varieties with respect to weather and input variables (depending upon the available data):

$$Y_{cv} = W_{tf} + I_{uf} \tag{3}$$

where, $Y_{cv} = Yield\ of\ respective\ crop - variety$; $W_{tf} = Weather\ effect$; $t = Weather\ type\ (Temperature, Relative\ Humidity\ etc.)$; $I_{uf} = Inputs\ for\ yield$; $u = Input\ types\ (Fertilizer, Pesticide, etc.)$; $f = Frequency\ (cumulative\ seasonal\ weather, average\ monthly\ weather, etc.)$

2. Forecasting for the upcoming season

The estimated yield responses for the crop-varieties are obtained based on the fitted regression equation (3) with the forecasted weather variables and available input resources for the upcoming season(s). The forecast for the Weather variables are obtained based on time series forecasting, Auto Regressive Integrated Moving Average (ARIMA) model.

A case study has been conducted to select the best Soybean variety with farm level data of Michigan area of United States. The selection is based on the number of trials, average yield and yield differences and their relational responses with respect to weather, irrigation and soil characteristics for 182 Soybean varieties. Five varieties have been selected, which are suitable for recommendation to provide a better yield for the coming season, based on the above mentioned technique.

Plant Protection: Plant Protection is one of the major aspects to increase crop productivity by saving the crop harvests. It is part of Phase 3- Crop Cycle Management. Presently, it has been envisioned for two aspects – a) plant disease-pest forecasting framework and b) plant insect-pest forecasting framework.

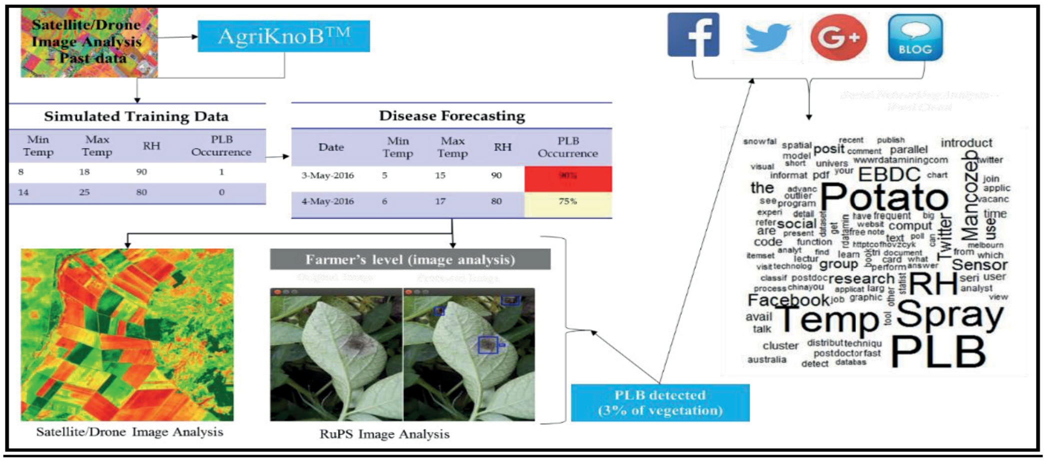
a) *Plant Disease-pest Forecasting Framework*- The framework is designed to accommodate various crops and their diseases. The approach can be initiated having prior knowledge of the disease incidences with the vital causal variables, mostly weather. Having the data of disease occurrences helps to build specific crop-disease models for forecasting and broadcast the alerts. But in the situation where we lack data, disease occurrences data has been simulated based on the weather variability and distributions. The literature thresholds of disease occurrences are mapped with the simulated weather data of the crop growing season with respect to the crop varieties. The historical remote-sensing data (satellite images) can also help in enriching the simulation data. Thus the training data can be used for disease forecasting through Machine Learning algorithms (Logistic Regression, Artificial Neural Network, etc.).

The disease occurrences are broadcast to the farmers at least 7-15 days prior to manage their logistics to protect the crops. The data acquired through the various data sources below the soil, on the soil and above the soil is augmented with geo-tagged, localized field level data obtained from a proprietaryIntelligent Rural Integrated Sensing (IRIS) application. The geo-tagged data is further processed through Image Analysis (Image Enhancement, Region of Interest Segmentation, Feature Extraction and Machine Learning algorithms). Thus we can get the scale of disease severity of different geo-spatial regions, which is posted to the farmers for their region of interests.

The above validation process can also be facilitated through high resolution images either captured by drones or satellites. Thus,remote sensing data analysis for various crop reflectance with respect to the disease helps to generate the disease severity map of the region of interests.

The disease severities evaluated in the validation phase is prompted to the users to post in Social Networking groups. The power of social networking helps to evaluate various factors related to the crop diseases and associated diseases. Additional knowledge is gathered through Social Networking Analysis. This knowledge in turn enhances the knowledge base (AgriKnoBT^M) and thus the training data, which is advantageous for disease forecasting during the next season.

Figure 1 - Disease forecasting framework demonstrated for Potato Late Blight (PLB) disease, Hapur region, Uttar Pradesh, India



Besides the simulated data approach for forecasting disease incidences, proven statistical models have been explored for Rice Blast disease, with some modifications. The EPIBLA model was developed to forecast disease incidences for South India region based on the spore counts of *Pyricularia oryzae*,using Burkard volumetric spore trap [10]. The spores per cubic meter have been estimated with respect to daily temperature and relative humidity, through multiple linear regression. The proportion of disease incidence is modelled through step-wise regression model with respect to minimum, maximum and dew point temperatures and relative humidity.

In our context we have modified the EPIBLA model based on observation of disease occurrences.We took samples from five zones of a rice field (average 1 acre) with an average of 40 tillers inspected under a ring. The count of affected tillers is recorded among the inspected tillers in Chennai Horticulture Produce Producer Company Limited (CHPCL) PRIDETM, Villupuram district of Tamil Nadu. The observations are recorded for every week of rice growing season for twelve farmers with average rice growing area of 1 acre. The disease incidence is calculated with the ratio of infected and observed tillers for each of the observation. The calculated disease incidences are fitted with weather variables following step-wise regression model, as followed in EPIBLA model.

The management practice to control EPIBLA was followed by four farmers during the season.

Following is the developed model –

$$DI = 0.150 - 0.005 \times W_1 + 0.003 \times W_2 + 0.005 \times W_3 + 0.002 \times W_4 \qquad (4)$$

where, DI = Disease Incidence (%); W_1 = Dew Point temperature;

$$W_2 = Minimum\ Temperature; W_3 = Maximum\ Temperature; W_4 = Relative\ Humidity$$

b) Plant Insect-pest Forecasting Framework- The insect-pest framework is another sub-module of ***InteGra*** under Plant protection. The framework is supported by mathematical models, derived from Lotka Volterra, Predator-prey model, with statistical estimates supporting the initial values for the model.

$$\frac{dx}{dt} = ax - \alpha xy + (w_{1x} + w_{2x} - w_{3x})x \qquad (5)$$

$$\frac{dy}{dt} = -cy + \alpha\gamma xy + \left(w_{1y} + w_{2y} - w_{3y}\right)y \qquad (6)$$

where, $x(t) = pest\ population$; $y(t) = predator\ population$;
$a = natural\ growth\ rate\ of\ pest$; $\alpha = predation\ rate$;
$w_{ix} = growth\ of\ pest\ due\ to\ weather\ variables, i = (1 - Max\ Temp; 2 - Min\ Temp, 3 - Rainfall)$; $c = reduction\ rate\ of\ predator\ due\ to\ natural\ death$; $w_{iy} = growth\ of\ predator\ due\ to\ weather\ variables$; $\gamma = increase\ of\ predator\ population\ due\ to\ predation$

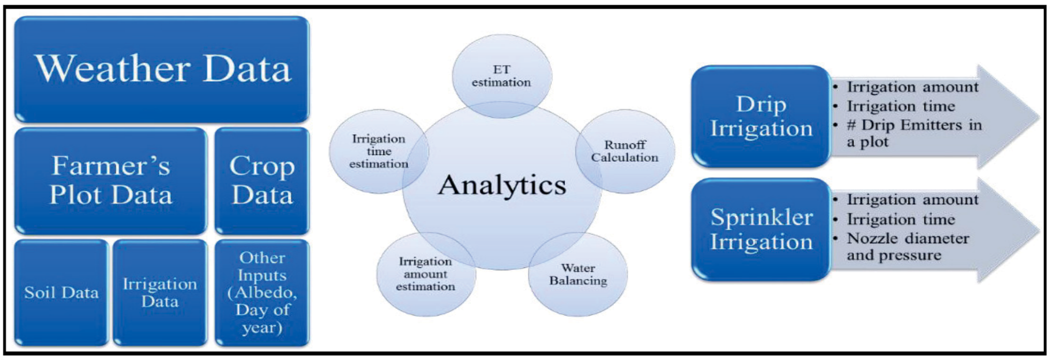
The cultural and biological control measures and its effects on prey and predator are adjusted in the above equations, based on the statistical estimates of population and growth rate. The numerical simultaneous solution of the differential equations 5 and 6 suggest the effective control measures of the pest. The growth rates are estimated based on variety of interactions, preypredator (compound annual growth rate), prey-weather-predator (regression), prey-chemicalpredator (regression) and prey-cultural/biological-predator (regression). The yield component being added in the model will complete the production system, considering growth components of yield.

The insect-pest model is being tested and explored for controlling the devastating Tea looper (*Hyposidra talaca*) of north-east region of India.

Fertilizer recommendation: The fertilizer recommendation module for other crops has been explored through Monte Carlo Markov Chain (MCMC) model. The MCMC process considers a set of states. After initiation from one state it flows to the successive states following the transition probabilities. The probability does not depend upon which states the chain was in before the current state. The depletion rate of fertilizers due to natural erosions and plant uptakes have been considered to determine the available nutrients in soil on periodic basis. Initial soil sample tests have been done to determine the nutrient status. The fertilizers are recommended when the nutrient status get depleted as per plant requirements. The fertilizer recommendation has also been explored through a software (named as Nutrient Expert) developed by International Plant Nutrition Institute (IPNI) for rice.The Nutrient Expert is presently available for Rice, Wheat and Maize. The fertilizer recommendation and irrigation scheduling are important modules under Crop Cycle Management of Phase 3.

Irrigation scheduling: The water requirement is one of the major inputs for the plants to grow. In the era of climate change, precision in irrigation is needed to have "per drop more crop". A novel framework has been designed comprising the modern methods of estimations for irrigation scheduling (Figure 2). The irrigation scheduling is believed to be more efficient having sensors installed in the field, through which precise information on temperature and moisture levels is obtained.

Figure 2 - Irrigation framework



The Evapotranspiration (ET) has been estimated through Penman Monteith Model.

Crop Valuation: The market price forecasting for the crop and variety is one of the most advantageous attributes of the **InteGra**, under Phase 4 – Harvest Planning. It has been noted that the seasonal variation of the crop prices is pretty much predictable, except for some unpredictable occurrences caused by Nature and/or policy makers (which are reported more often). In this scenario, the price prediction models (through ARIMA) fail. There is a need to develop a methodology to evaluate value of crops based on the amount paidby end consumers. The crop valuation has been mathematically structured by solving three partial differential equations considering demand of crop products due to population growth, urban growth and cost of production and products and productivity, respectively.Let c(t), p(t) and u(t) be three dependent variables representing crop valuation, population and urbanization, all depending on time t. The crop valuation includes the crop productivity, costs related to crop production and processing and valuation of crop products in market.

Thus, $$\frac{dc}{dt} = \frac{\gamma}{n}c + \delta c - \rho c + \frac{\varphi}{q_1}cu + \frac{\theta}{q_2}cp \qquad (7)$$

where, γ = % of growth of c per unit of μ per unit time; n = crop units processed to produce a product; δ = % of growth of c per unit of μ per unit time; ρ = % of loss of c per unit of μ per unit time; φ = % of growth of c per unit of u per unit time; q_1 = unit of products of crop available in urban space; θ = % of growth of c per unit of p per unit time; q_2 = unit of products of crop available; μ =the units of products processedin unit time

$$\frac{dc}{dt} = \{(\frac{\gamma}{n} + \delta - \rho) + \eta p\}c \qquad (8)$$

where, $\eta = (\frac{\varphi}{q_1}\lambda + \frac{\theta}{q_2})$, $u = \lambda p$, $\lambda = growth\ of\ Population$ (9)

$$\frac{c}{c_0} = e^{F(t)},\ F(t) = \left(\frac{\gamma}{n} + \delta - \rho\right)t + \frac{K\eta}{\alpha} ln\left\{\frac{1+\beta e^{\alpha t}}{1+\beta}\right\} + b.\eta(1 - e^{-mt}) \qquad (10)$$

The numerical analysis of the model through statistical estimates for various crops, crop-products for different geographies need to be evaluated.

Population theory

Verhulst [8] suggested the famous logistic growth model for population,

$$\frac{dp}{dt} = \propto p\left(1 - \frac{p}{K}\right) where, K = \frac{\propto}{a}, \text{ at } t = 0,\ p = p_0 \qquad (11)$$

Solving equation (11) we get

$$p\ (t) = \frac{Me^{\propto t}}{1+\frac{M}{K}e^{\propto t}} \quad \text{where, } M = \frac{p_0}{1-\frac{p_0}{K}},\ \lim_{t\to\infty} p(t) = K \qquad (12)$$

The law of entropy in Informatics suggests that as the population grows a census of a nation will miss some number of people which is likely to be caused mostly by the dynamics of the very system of recording the census. So let us assume,

$$p(t) = P(t) + \varepsilon(t) \qquad (13)$$

where, $P(t)$ is recorded by the census and $\varepsilon(t)$ is the error in the record.

Thus, $$\frac{dp}{dt} = \frac{dP}{dt} + \frac{d\varepsilon}{dt} = \frac{K\beta e^{\alpha t}}{1+\beta e^{\alpha t}} + \varepsilon_0 e^{-mt}, \text{ where,if } \beta = \frac{M}{K}, \text{ then } \beta = \frac{\frac{p_0}{K}}{1-\frac{p_0}{K}} \qquad (14)$$

This gives,

$$\frac{P_0}{K} = \frac{\beta}{1+\beta}\ and\ \frac{d\varepsilon}{dt} = \varepsilon_0 e^{-mt}\ , m > 0 \tag{15}$$

$$\text{Urbanization, } \frac{du}{dt} = \lambda \frac{dp}{dt}\text{, att} = 0,\ u = u_0 = \lambda p_0 \tag{16}$$

The developed mathematical model is developed considering the cost involved in producing the crop based products, productivity of the crop and the demand of the crop products due to urban tastes and population growth. The model framework is expected to provide the farmers the valuation of the crops before cultivation, which will enable the farmer to choose themost profitable crop. It also provides the farmers betterbargaining power and encourages building food processing enterprises to reach the consumers through the least possible channels. This helps famers to createsuccessful business groups and organize profitable farming business units.

3. Conclusion

The Digital Farming Initiatives of Tata Consultancy Services [7] is empowering the farmers, especially the small and marginal agrarians to combat against all the uncertainties such as weather risk, water and soil degradation, pest and disease attacks and market price fluctuations. The farmers are facilitated through a collaborative network called **SmartPRIDEs** supported with an advanced analytical platform **InteGra**. A Smart Ecosystem is enabled for farmers to collaborate and produce optimized yield with appropriate inputs overcoming major risks associated with climate & pest/disease and to market their produce to obtain maximum profit. In addition, the real time data driven framework ensures operational efficiency and resource optimization at every stage of crop cycle, thus making Agribusiness systems more productive, profitable and competitive to ensure food security across the globe.

References

IBEF (2016) Indian Agriculture Industry: an overview, (http://www.ibef.org/industry/agriculture-india.aspx , 26April, 2016). [1]

Food Security Portal, (http://www.foodsecurityportal.org/india/resources , 26April, 2016). [2]

WFP India | Brief (2015), (http://documents.wfp.org/stellent/groups/public/documents/ep/wfp273244.pdf, last visited 26 April, 2016). [3]

FAO (2002) The State of Food Insecurity in the World 2001, Rome. [4]

World Bank (2015) A real-time food security information system is a Big Data reality, (http://blogs.worldbank.org/ic4d/real-time-food-security-information-system-big-data-reality, 26 April, 2016). [5]

FAO's work on Climate Change, (http://www.fao.org/climate-change/en/, 26 April, 2016). [6]

Pappula S. (2015) The revolutionary PRIDE™ model by mKRISHI® – empowering farmers to live with dignity, Success Stories on Information and Communication Technologies for Agriculture and Rural Development, FAO, 55- 68 (http://www.fao.org/3/a-i4622e.pdf, 22May, 2016). [7]

Murray J.D. (2002) Mathematical Biology, Springer 17 1-510. [8]

Dey S. K., Pramanik C., Dey C. (2010) Mathematical modeling of effects of urbanization and population growth on agricultural economics, Intellectual Economics, 2(8) 7-20. [9]

Manibhushanrao K., Krishnan P., (1990), Epidemiology of blast (EBIPLA): a simulation model and forecasting system for tropical rice in India, Rice Blast Modelling and Forecasting, International Rice Research Institute, 31 – 38. [10]