Available online at www.sciencedirect.com
ScienceDirect
Progress in Natural Science 19 (2009) 659–666
Progress in Natural Science
www.elsevier.com/locate/pnsc

Review

Adoption of precision agriculture technologies in India and in some developing countries: Scope, present status and strategies

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Received 13 May 2008; received in revised form 20 July 2008; accepted 24 July 2008

Abstract

Rapid socio-economic changes in some developing countries, including India, are creating new scopes for application of precision agriculture (PA). The implications of dramatic shifts for economic development, urbanization and energy consumption in some developing countries are immense. High-tech nature of traditional PA technologies developed in advanced countries created a real challenge for engineers to search suitable PA technologies for developing countries. It is expected that application of balanced soft and hard PA technologies based on the need of specific socio-economic condition of a country will make PA suitable for developing countries also. 'Soft' PA depends mainly on visual observation of crop and soil and management decision based on experience and intuition, rather than on statistical and scientific analysis. 'Hard' PA utilizes all modern technologies such as GPS, RS, and VRT. Three components, namely, 'single PA technology', 'PA technology package' (for the user to select one or combination) and 'integrated PA technology', have been identified as a part of adoption strategies of PA in the developing countries. Therefore, the objective of this paper is to find out the scope, the present status and the strategies for adoption of PA in India and in some developing countries. Application of PA in cash crop, plantation crop, etc. has been discussed. Application of some medium and low-tech PA tools such as chlorophyll meter and leaf colour chart. in small farms has been included. This exhaustive review of the present status of PA in India and in some developing countries is expected to help to find out the adoption trend and direction of future research. Detailed strategy for the adoption of PA in India has also been proposed.

Keywords: Precision agriculture; Indian agriculture; Developing countries; Adoption

1. Introduction

According to the UN data, the world's urban population is poised to surpass the rural total for the first time in history. One UN estimate says that August 16, 2008 will be the day when the shift will happen, with the urban population expected to overtake the estimated rural totals. By that time, more than half of all Africans will live in cities, making up a larger population than the whole of Europe [1]. The major growth of urban population is now taking place in low and middle-income nations such as India, China, and Brazil. China and India have occupied the first and second positions in the list of countries with the fastest growing 100 cities. The implications of such dramatic shifts for economic development, urbanization and energy consumption are immense [2].

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doi:10.1016/j.pnsc.2008.07.020

To meet the huge food grain requirement of 480 million tonnes (Mt) by the year 2050 [3], with the increasing challenge of biotic and abiotic stresses experienced by crops, introduction and adoption of modern technology in Indian agriculture is inevitable. It is true for other developing countries also. Agriculture, like other industries, has made entry into the knowledge-based era, leaving its previous resource-based nature. Future agriculture will be severely competitive, knowledge-intensive and market driven. WTO agreement and liberalization of agricultural trade have created not only new scopes but also new threats to the agriculture of developing countries. Removal of quantitative restrictions on import from 1 April, 2001 in India made quality and cost competitiveness the two most important factors to sustain in the globalized market. The high cost of production and low productivity, even though India produces a large quantity of food grain, will throw Indian farmers out of the economic competition arena of free market [4]. Again poor grasp over cutting-edge technologies, due to the lack of timely start of research on advanced science, is one of the main problems of developing countries. Increasing the productivity on small-scale farms in developing countries is a critical part of a solution to the food insecurity problem. To face all these new challenges, increasing the productivity level of a pollution-free product is inevitable. This can be realized by applying advanced, environmental friendly technology, which can manage and allocate all resources efficiently for sustainable development of agriculture [5]. PA is such a new emerging, highly promising technology, that is spreading rapidly in the developed countries. PA is conceptualized by a system approach to re-organize the total system of agriculture towards a low-input, high-efficiency, and sustainable agriculture [6].

Advancement in space technology (courtesy to Indian Space Research Organization (ISRO)) and IT revolution has changed the Indian environment as well as created new scopes for farm sectors. Under this changed condition, it is necessary to grasp over the new cutting edge technologies in agriculture invented in the developed countries and to make subsequent modification based on the domestic conditions. It is true that the entire Indian farm sector is not ready to accept sophisticated PA technology [7]. But like in all other developing countries, in India too, there are also some relatively developed areas which can act as incubators for new ideas and sophisticated technologies based on the domestic conditions [8].

High-tech nature of traditional PA technologies developed in advanced countries created a real challenge to search for suitable PA technologies for developing countries. But rapid changes in the socio-economic pattern of some developing countries, such as India, China, and Brazil, created new scope and opportunities for PA to be applied in these countries. So the objective of this paper is to find out the scope, the present status and the strategies for adoption of PA in India and in some developing countries.

2. Scope and status of PA in some developing countries

The status, limitation, and critical parameters of sustainable agricultural development are different for different developing countries. Rapid changes in the socio-economic condition of some developing countries are creating new scopes for PA. The world's urban population multiplied 10-fold during the 20th century and most of this growth is now taking place in low and middle-income nations such as India. For example, the economic growth in India is driving an unprecedented shift in population to urban centres. As many as 11 Indian cities figure among the 100 fastest growing cities in the world. India is second only to China in these lists. And if China and India continue to enjoy economic success, they may have larger urban populations in 2020 than those predicted by the United Nations. Now, Africa has more people living in urban areas than North America. The implications of such dramatic shifts for economic development, poverty reduction and energy consumption are immense [2]. Among the developing countries, Argentina, Brazil, China, India, Malaysia, and others have begun to adopt some PA components, especially on research farms, but the adoption is still very limited [9]. Constant watch on the present status of a technology helps to identify adoption trend and converge research effort in the same direction. Therefore, exhaustive review on the status of PA in developing countries is very important. Some representative examples regarding PA in developing countries have been presented here.

2.1. Application of PA for plantation crops, cash crops, etc.

Tea is one of the most important and highest foreign exchange earning agricultural products of India and of some other developing countries, such as Sri Lanka, China, and Tanzania. To make tea cultivation more profitable, PA can be an ideal solution tool. Tea is a highly structured crop grown in blocks. Once each block is properly surveyed and uniquely identified, positioning systems may be avoided. Yield maps are produced by recording the weight of tea plucked, as well as by recording which block tea was plucked from. Inputs are also applied by hand, and the treatment map is implemented by dividing the workforce into different teams that apply the desired amount in each area. The cost of implementation in this system is very low because of the highly structured fields, and such a recording system is already in place [10]. A GIS Anchored Integrated Plantation Management for tea is under development in India. It consists of the generation of a digital map by using the existing map as well as high resolution satellite image; the development of DEM (digital elevation model); the generation of soil map, land use and land cover map, drainage map; data storage in a centralized location; collection and storage of data into palmtop computers from the field instrumentation sensors, etc. [11]. In Malaysia, site-specific fertilization is being applied to rubber plantations, but not to rice fields. PA technologies have been started to be applied for oil palm in Malaysia [12]. PA is likely to be adopted for plantation agriculture in parts of the tropics as well as for large farms in northern Mexico and perhaps in South Africa [13]. The scope of applications of PA technologies to high-value crops in the tropically controlled environment is wide. The sugarcane production area of the world is about 20.3 million ha of land, 24% of which is located in Brazil. Brazilian sugarcane industry possesses a good scope for large-scale adoption of PA-based tillage and soil erosion control technology, which emphasizes mainly on adjusting the tillage depth depending on the soil texture, thus saving critical inputs [14]. Magalhães and Cerri [15] in Brazil developed a special yield monitoring system specifically designed for the implementation of precision agriculture in sugar cane crops. Their results showed that the output of the sugar cane yield monitor and the harvested load weight present a correlation of 0.66, and the system performance was stable and reliable during tests. PA is being applied to sugar cane in Mauritius also [12]. In the fields of Uruguay, experimental results of site-specific application of Zn proved that the profit level can reach $50 per hectare, which is a benefit of this technology [16]. An experiment was conducted in Costa Rica to apply PA in a banana plantation. The system allows farmers to link to a soil database and to make site-specific decisions on soil fertility- and disease-related problems through yield monitoring. A cable system was used to replace expensive DGPS [17].

2.2. PA for small-scale farms

The general perception is that PA cannot be applied for small-scale farms of developing countries. If only 'hard PA' is considered, this concept is true. Searching for the "appropriate PA technology" for small farms is a real challenge faced by scientists and engineers. A number of options for the application of the PA philosophy in these countries have been discussed by Cook et al. [18]. PA can be implemented through improved agronomic decision making on the same spatial scale by increasing the number of decisions per unit time and by using some DSS tool [12]. For example, NUTMON DSS tool has been applied successfully to more than seven projects (http://www.nutmon.org-last accessed on 12 February, 2008) in Africa [12,19].

Some low cost and low technology tools may be proved to be useful for small farms of developing countries. The chlorophyll meter (SPAD) and leaf color chart (LCC) are simple, portable diagnostic tools that can be used for in situ measurement of the crop N status in rice fields to determine the timing of N top dressing, which is very useful for developing countries. On-farm adaptive research is in progress in three countries to adapt the chlorophyll meter technique for transplanted and wet-seeded rice, local cultivar groups, soil, crop, and for environmental conditions. The LCC is not as accurate as the chlorophyll meter in determining the site-specific leaf N status in rice crops [20]. Initial feedbacks on the use of LCC from farmer cooperatives in Philippines, Indonesia, Vietnam, Bangladesh, India, etc. are highly encouraging. A standardized four-panel LCC was produced and more than 250,000 units were distributed in different Asian countries until the end of 2006 [21].

Applications of GIS to small farms have started. The old saying "Better information gives better decisions" is very true for GIS. GIS is currently being adapted for use on small Asian farms, in Japan, the Republic of Korea and in the Taiwan Province of China, where government programs are developing the use of web-based GIS systems. The concept is to encourage farmers to use the Internet and to obtain free information on the soil properties of their farms, including soil fertility and nutrient levels. In Indonesia, GIS is being used to reevaluate appropriate agricultural land use. The system can be used to identify which areas are suitable for arable land, and it is also used to identify the best crop for a particular region [22].

2.3. Adoption of yield monitors

Monitoring of crop yield is the most interesting operation to any farmer. Yield monitors for grain crops have started to be introduced in some developing as well as transitional countries. In Argentina there were about 560 yield monitors in 2001 and about 4% of the grain and oil seed area was harvested with headers equipped with yield monitors [23]. Yield monitors are being used on some larger farm operations in Brazil and Mexico [23,24]. Informal reports indicate that in Australia about 800 yield monitors were used in the 2000 harvest. Some fifteen farmers used the yield monitoring system in South Africa during the 1999–2000 crop season [25].

2.4. General adoption strategies

Formulation of detailed strategies for all developing countries is beyond the scope of this paper. In general, as an outcome of this exhaustive review, some common strategies can be proposed for the application of PA in developing countries (Table 1). The applications of 'single PA technology', 'PA technology package' (for user to select one or combination) and 'integrated PA technology' will be the important compositions of the strategies of PA in the future for developing countries. For small farms, 'single PA technology' may prove to be useful. Therefore, the strategies for small-scale farms are to use single, low cost, low level PA technologies, small machine-based VRT, etc. Virtual land consolidation and cooperative farming can solve smaller land size problems to some extent and can create scope for some selected sophisticated PA techniques ('PA technology package'). 'PA technology package' may be a suitable strategy for the plantation crop, tea, of some developing countries (such as India, Sri Lanka, China, and Tanzania). Organized farming sector for some crops, sugar cane, of some developing countries

Table 1
Proposed common PA adoption strategies for developing countries.

Strategic PA adoption component	Technologies	Target sectors
Single PA technology	Single low level PA technologies, LCC, small machine-based VRT, etc.	Small-scale farms
PA technology package	SPAD, LCC, DSS, GIS, VRT, GPS, etc.	Consolidated plots, plantation crops, cash crops, cooperative farming, etc.
Integrated PA techniques	On-line sensor, image processing, remote sensing (RS), yield monitoring system, VRT, GPS, etc.	Organized farming sector

such as Brazil may adopt some Integrated PA techniques. But harnessing the full power of PA necessitates organized, well-planned long-term "region-specific or area-specific" policy suitable for each developing country.

3. Scope, present status and strategy for adoption of PA in India

The adoption and success of PA in India will depend on whether adoption strategies are designed properly or not. A planned number of experiments and analyses are required before application of PA to Indian agriculture. There are three steps to enter the PA age: namely, present stage, intermediate stage and future stage. The present stage involves uniform crop and soil management, development of specialist manpower and institution for PA, and popularization of PA concept by mass media communication, seminar, workshop, etc. The intermediate stage will follow stratified random sampling within zone, delineation of management zone throughout the country, and validation of computer models with zone-specific data. The future stage will involve fine grid sampling and sensing, application of zone-specific computer model to simulate the agronomic input conditions and precise sensing and management.

3.1. Scope of adoption of PA in India

PA can be classified into two categories: namely, 'soft' and 'hard' [26]. It can be commented that balanced use of soft and hard PA will be the deciding factor for its success in India. Land fragmentation is considered to be the main obstacle for large-scale agricultural mechanization in India. But these fragmented lands are cultivated in a family responsibility system, and all small farmers have been following consciously or unconsciously 'soft' PA technology for centuries. Presently, India is producing more than 200 Mt of food grain which makes India self-sufficient in food production. But only quantity cannot meet the need of the globalized agricultural market. Excellent quality as well as high productivity will be the key factor to compete with others, and the huge scope of PA lies here. In production, India holds world-ranks within 10 in most of the crops (wheat-2nd, rice-2nd, pulses-1st, cotton-4th, etc.). However, in the productivity of these crops, the world ranking varies from 32 (wheat) to 118 (Cotton) [27]. Poor scale of mechanization with very small average holding size (1.41 ha in 1995–96) [28] with other reasons augmented the problem. The overall fertilizer consumption rate of India is small (106.5 kg ha^{-1} of agricultural land) in comparison with that of other countries (such as China 271 kg ha^{-1}, Egypt 359.8 kg ha^{-1}, and Netherlands 500.5 kg ha^{-1}) [28]. Studies have already shown that systematic soil testing followed by proper application of NPK fertilizers can increase the productivity level by 2–3 times in most of the states of India [29]. However, high cost of traditional soil sampling is one reason for this improper application of fertilizer. Therefore, in these states cheap dynamic soil sampling technology as well as nutrient status analysis on a large scale by RS and GIS can do a lot of improvement.

Again, some states such as Punjab and Haryana have experienced large-scale mechanization as well as high doses of fertilizers and pesticides. For example, the state of Punjab has 1.5% of the total geographical area of India, but uses 1.41 million tonnes (nearly 7% of all India fertilizer consumption) of NPK fertilizer [28] along with 60% of herbicides used in India [4]. Over exploitation of land and excessive use of agricultural input are typical problems of these areas. The signs of tiredness in the natural resources are already visible, which is the reason for stern concern of the policy-makers and planners [27]. These areas are more or less suitable for 'hard' PA.

3.2. Present status of PA in India

Application of PA technologies is presently at the nascent stage in India. Some discrete initiatives have been started towards the application of this technology. PA has been identified as one of the main thrust areas by the Working Groups (WGs) of India–US Knowledge Initiative on Agriculture (KIA) [30]. It is expected that PA research will be an important part of the recently launched ambitious agricultural research program, National Agricultural Innovation Project (NAIP), which will focus on innovations in agricultural technology with the announced budget of US$ 285 million [31]. Tamil Nadu State Government has sanctioned a scheme named "Tamil Nadu Precision Farming Project" to be implemented in Dharmapuri and Krishnagiri districts covering an area of 400 ha. High value crops such as hybrid tomatoes, capsicum, babycorn, white onion, cabbage, and cauliflower are proposed to be cultivated under this scheme. As a future extension plan, the same scheme will be implemented in six more districts of Tamil Nadu. The scheme will be implemented in an area of 100 ha from each district [32]. With the Project Directorate for Cropping Systems Research (PDCSR), Modipuram and Meerut (Uttar Pradesh state) in collaboration with Central Institute of Agricultural Engineering (CIAE), Bhopal also initiated variable rate input application in different cropping systems. With the Space Application Center (ISRO), Ahmedabad has started experiments in the Central Potato Research Station farm at Jalandhar, Punjab, to study the role of remote sensing in mapping the variability with respect to space and time [27].

Development of specialized centers and scientific databank is a well-known pre-requisite for PA. The PA technology is started to be developed and disseminated in a regionally differentiated manner through 17 Precision Farming Development Centers (PFDCs) located in different parts of India [33]. PFDCs are working for the popularization of PA and hi-tech applications to achieve increased production in addition to imparting training to a large number of farmers. But all these PFDCs mainly concentrate on precision irrigation water management. As an example of collaborative effort of private and Govt. agencies, a new precision farming centre has been established by MSSRF (M.S. Swaminathan Research Foundation – a non-profit trust) at Kannivadi in Tamil Nadu with financial support from the National Bank for Agriculture and Rural Development (NABARD). This Precision Farming Centre receives the help of Arava R&D Centre of Israel [34] and works with an objective of poverty alleviation by applying PA technologies.

To explore the potential of application of IT in the agro-sector, Tata Chemicals Ltd., a private sector, has been started with an objective of providing the farmers with infrastructure support, operational support, coordination and control of farming activities and strategic support. Tata Kisan Kendra has been replicated successfully in the states of Uttar Pradesh, Haryana and Punjab. The project has been claimed to be scalable and replicable [35]. Private sectors such as Indian Tobacco Company (ITC) have established 'e-choupals', which are village internet kiosks that enable access to information on weather, market prices and scientific farm practices, crop disease forecasting system and expert crop advice system. Nearly 1200 'e-choupals' have already been developed across four states of India. Region-specific and crop-specific (such as soybean, coffee, wheat, pulses, and rice) 'e-choupals' are under development to provide more specific information to the poor farmers of all remote areas of the country [36].

A good amount of research has been initiated on plant-need-based real-time N management for rice. LCC is becoming an effective low-technology PA tool for the need-based N management of rice grown in small farms of India. In 107 on-farm experiments conducted on rice, the average yield recorded in LCC-based real-time N management and that obtained by following farmer's practice were identical. On average, about 40 kg N ha^{-1} less fertilizer was applied following the need-based fertilizer management as compared with the farmer's practice. In 48 on-farm experiments conducted at different locations in north-western India, LCC-based N management was tested on rice varieties commonly grown by small farmers. Savings of 16–43 kg N ha^{-1} were observed for seven different rice cultivars by applying N using LCC rather than by following the farmer's practice [37]. The popularity of LCC for rice grown in small farms has been documented in many literatures. Islam et al. [38] reported that about 47% and 28% of farmers of the intervention and control villages, respectively, adopted LCC during a farmer-participatory experiment in West Bengal, India. They also found that the first time adopters experimented with LCC on about half of their rice lands, which rapidly increased with experience, and reached 97% in the third year. Adoption of LCC saved N by 19.4–21.0%. They predicted that the combined effects of reduced N and insecticide use on the environment protection might be enormous, provided large areas were adopted. IRRI, Philippines, reported that more than 5000 pieces of low-cost LCC were distributed or sold to Indian rice farmers [39,40]. This is an example of the fact that PA has started to find its own way of penetrating small Indian farms.

Experience of field level experiments is an indispensable part of PA. Laser land leveling was used as a tool of PA to increase the input-use-efficiency. After precise leveling of fields, the irrigation efficiencies increased significantly. The average application efficiency of 65%, storage efficiency of 70% and water distribution efficiency of 80% were achieved after laser leveling. The yield of rice crop also increased by 15–20% in laser-leveled fields [41]. Precision land leveling increased the production of pigeonpea crop by 32% [42].

The development of a computer model, DSS, a region-specific expert system, for agriculture can be indirectly helpful to depict the path of PA revolution in India. A computer-aided software named 'CROP9 -DSS' has been developed, which will aid as a DSS for calibrating water and fertilizer requirement, crop protection and identification of implements for the leading crops of the state of Kerala [43]. Agro-Climatic Planning and Information Bank (APIB) is under development, which is a concept-demonstration project executed by ISRO and the Planning Commission towards establishment of a single window access to all agriculture-related information and decision support to users of agricultural and allied sectors [44].

A large amount of already done work on GIS and remote sensing application, such as the use of GIS for soil data analysis [45], crop discrimination in salt-affected soils by IRS IA LISS II satellite data [46], performance evaluation of an irrigation project using IRS 1A LISS II and IRS – 1C/1D LISS III data, GIS and GPS [47], can be extremely helpful to develop trained manpower pool for PA. A study has been carried out with 28.7 thousand ha of potato growing area of Bardhaman district of West Bengal state by using IRS 1C WiFS (188 m resolution) and IRS 1C

LISS -III (23 m resolution) data. The GIS map helped in finding the optimized locations of future cold storages to meet the needs of small and marginal farmers also [48].

All the works mentioned above will help PA revolution in India directly or most probably indirectly. These activities will help to prepare the platform of PA revolution in India. No example of adoption of hard PA technologies has been reported to date. But soft PA techniques based on visual observation of crop and soil and management decision established on experience and intuition have been used by Indian farmers for centuries. The need-based nutrient application for paddy and application of IT in Indian agriculture have been initiated in some places. But to harvest the full benefit of PA, an organized, well-planned, long-term policy suitable for Indian farming sector is required.

3.3. Strategy for adoption of PA in India

Future strategy for the adoption of PA in India should consider the problems of land fragmentation, lack of highly sophisticated technical centers for PA, specific software for PA and poor economic condition of general Indian farmers. Strategically proportionating back up from the public and private sectors is essential to promote its rapid adoption.

'Virtual land consolidation' while keeping ownership structure intact can be a solution for land fragmentation problem of India and can create new roads for PA. Initial analyses of the existing 'transborder farming system' show a saving of 15–25% in the required head land, 20–30% in the required work time and a large amount of total operational cost savings [49]. So when we consider contiguous field with the same crop (mostly under similar management practices), the field (rather simulated field) sizes are large. Analysis of aerial data has revealed that in the Patiala district of Punjab, more than 50% of the contiguous field sizes are larger than 15 ha. This trend is more or less common throughout the country. These contiguous fields can be considered to be a single field for the purpose of the implementation of PA [27].

A total of 107.08 million farms of the 115.6 million of total farms have an area of less than 4 ha [28]. So for these huge numbers of farms, some measures are expected from the government to organize dynamic soil sampling and to create nutrient maps with the help of the already developed Information Technology. Using the precisely validated zone-specific computer simulation model can increase the span between the two subsequent soil samplings by predicting the intermediate conditions. These nutrient maps along with the easy to understand fertilizer recommendation for each management zone within the field can be distributed from 'Panchayets' (Village regulatory body).

Another possibility of the introduction of PA in small farms is that individual farms will be treated as management zones within a field, and that some centralized entities will provide information to the individual farmers on a cooperative basis [50]. The problem of high cost of positioning system for small fields can be solved by the 'dead reckoning system'. The dead reckoning system, suitable for small regularly shaped fields, relies on in-field markers, such as foam, to maintain consistent application [51].

A nationwide Agricultural Advanced Technology (AAT) program should be started immediately for the next 10 years. The scope of application of the already developed information technology and satellite-based technology in the agricultural field should be studied. Trial farm projects for PA should be started region-wise. The nature of crop and weed vary from zone to zone, and country to country. Therefore, developing software and hardware for crops and weeds of India should be started and this IT package will be used for remote sensing technology of PA, and zone-specific computer simulation model dedicated for only PA application should be developed and properly validated. Two-hundred Agricultural Advanced Technology Parks (AATPs) should be developed in each region throughout the country, which will gather experience and develop methodology to apply PA precisely in region-wise format within the country (for example, China has already developed 153 such parks [8]). These AATPs must attempt to answer the grower's needs and accentuate the operational execution of technology and complete analysis of the costs and savings involved. Records of AATPs would assist in analyzing the operational impuissance and identification of corrective actions. These AATPs can be used to train progressive farmers and early adopters, expose the neighboring nonparticipating farmers to the new technologies, and show the usefulness of the technology for short and long-term management [27]. In brief, these AATPs can work as an embryo of the new region-wise PA technology as well as an incubator of mature technology that have already been developed in developed countries.

Research, development and subsequent popularization of inexpensive electronic gadgets, which can increase the profit of small farmers, can be instrumental in preparing the platform of PA adoption by softening the farmer's attitude towards modern technologies. Some examples are given as follows: digital throttle gear optimizer (DTGO) for better fuel economy of tractors can be an attractive and inexpensive solution for farmers [52]. A digital slipmeter has been developed, which can help to operate the tractor in the most productive slip zone and can be a popular choice of farmers [53].

To create professionals and extension workers/consultants, capable of using ITs in sustainable crop production, profit-maximization and natural resource management, the educational institutions need to modify their curricula, teaching and training methods. High-speed data/information connectivity systems (computers/Internet) need to be developed in rural areas. To realize this, close collaborative efforts are needed among farmers, farm associations, community groups, NGOs, machinery manufacturers, research and extension agencies and other public and private agencies [54].

The indirect benefits of adoption of PA should be carefully calculated and sufficiently highlighted. Business opportunities for PA technologies, including GIS, GPS, and RS, are immense in India. The scope for funding new hardware, software and consulting industries related to PA is gradually widening. In Japan, the market is estimated to be about US$ 100 billion for GIS and about US$ 50 billion for GPS and RS. Commercial banks, as well as other sources of funding, have to be educated regarding the potential of PA. It may be worthwhile to develop a program of subsidized credit to enable R&D activities on PA at the initial stage. Like in most developing countries, the lack of penalties for pollutant generation has partly contributed to an excessive use of toxic inputs in India. Proper determination of environmental benefits, effective canvassing, and pollution taxes can indirectly help in PA adoption [27].

Adoption of PA in India is likely to follow the classical S curve pattern (Fig. 1) [55]. Attitudes of confidence toward using the PA technologies, perceptions of net benefit, farm size and farmer educational levels positively influence the intention of farmers to adopt PA technologies [56].

Therefore, with all these virtual land consolidation, cooperative system introduction, AAT program, specific software development, and AATP development, the first segment of S curve will be constituted which should be completed by 2014 (A segment of S curve). By 2015 the second steep segment of S curve, i. e. rapid adoption and application of suitable PA technologies, should be started (B segment of S curve). It is expected that the adoption rate of suitable PA techniques will slow down gradually, and after 2030 the adoption rate will be stabilized in most potential application areas (C segment of S curve).

4. Conclusions and perspectives

The scope, status and strategies for the adoption of PA in India and in some developing countries have been reviewed. Different diversified application sectors, such as small farms, cash crops, and plantation crops, have been discussed. Three components, namely, 'single PA technology', 'PA technology package' and 'integrated PA technology', have been identified as part of the general adoption strategies of PA in developing countries. Suitable application sectors of these strategic components have been highlighted. As a case study, the specific status review for PA and adoption strategies in India are also discussed. This review is expected to help in finding out the adoption trend of PA suitable for developing countries.

PA has created scope of transforming the traditional agriculture, through proper resource utilization and management, to an environmentally friendly sustainable agriculture. The basic goal of PA to optimize yield with minimum input and reduced environmental pollution is highly required for developing countries to face the challenge of sustainability, even if it is used in a different form from that available in Europe or North America. Rapid socio-economic changes in some developing countries are creating new scopes for the application of PA. The implications of dramatic shifts for economic development, poverty reduction and energy consumption, and urbanization in some developing countries are immense. Application of the balanced soft and hard PA technologies based on the need of specific socio-economic condition of a country will make PA suitable not only for developed countries but also for developing countries and can work as a tool to reduce the gap between the developed world and the rest.

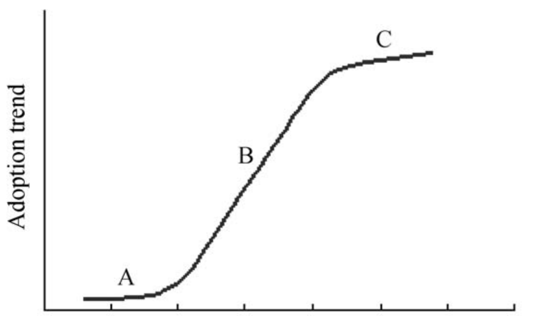

Fig. 1. Proposed PA adoption trend in India.

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