A Survey of Information Systems Reaching Small Producers in Global Agricultural Value Chains

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Abstract— **Smallholder farmers face many challenges competing in the global marketplace. One major constraint is the lack of access to information and communications, which could be used to make decisions and reach new markets. In this paper, drawing from our experiences designing agricultural information systems in India and Central America, we provide a framework for understanding inter-stakeholder communications within agricultural value chains, focusing on the needs of small producers. First, we outline the major types of stakeholders — including farmers, consumers, intermediaries and various supporting organizations. Then, we survey the major categories of information systems supporting communication between stakeholders, focusing on those reaching small farmers. Based on this survey, we provide the following categorization of information flows within agricultural value chains: 1) link-to-link (L2L): those information flows required to coordinate the sale, movement, and distribution of produce along the value chain, 2) peer-to-peer (P2P): communications required to share knowledge and experiences between members of the same stakeholder group, and the expert community serving that stakeholder group and 3) end-to-end (E2E): communications between producers and consumers, for example, to facilitate exchange of non-economic values to be used as external inputs to market pricing (e.g, certification). We outline some reasons why current information systems have had difficulty in reaching small producers, and highlight a few technology trends that could contribute to increasing the fidelity and accessibility of communications, both between producers and consumers, as well as within their respective stakeholder communities.**

I. Introduction

A. Small Producers in the Developing World

Small-scale farming is still the norm rather then the exception in much of the developing world. For example, according to the Mexican Coffee Council, Mexico has almost 500,000 coffee producers — 95% of which are indigenous small holders owning less than 5 hectares of land. In India, over two-thirds of the population are directly dependent of agriculture for their livelihoods, and more than 80% of those are small and marginal landholders with an average of 1.4 hectares of holdings.

Small farmers have increased transaction costs due to poor infrastructure (power, communications, roads) [1]. They are not able to avail the latest technological advances, including many forms of mechanization because of their small scale and low acquisition power. Due to low literacy and low access, small farmers are not able to learn about established best practices and exchange knowledge with their peers, especially beyond their immediate social networks [2].

The lack of scale and access often makes small farmers vulnerable to market actors and forces beyond their control. If they are lacking irrigation, they are also dependent on weather patterns, which are unpredictable and changing globally. Unable to compete with larger competitors, many farmers are left with little choice but to sell (or abandon) their land. Small farmers often end up emigrating to urban regions or wealthier nations in a search for a more stable livelihood, losing their land and their culture.

B. Global Value Chains

In management parlance, a value chain is a series of business activities to create high-worth products and services from the perspective of the end-user at the lowest possible costs [3]. In the last half century, we have seen the emergence of *global value chains*, which highlight "the growing importance of new global buyers (mainly retailers and brand marketers) as key drivers in the formation of globally dispersed and organizationally fragmented production and distribution networks." [4]

In agriculture, value chains extend from farmers to consumers. In between are intermediaries who add value to agri-food products in various ways, including processing, packaging, certifying, transporting, distributing, wholesaling and retailing to the end consumer. In this paper, drawing from our experiences designing agricultural information systems in India and Central America, we survey the information systems that have been implemented to support agricultural value chains, and more specifically the communication and coordination requirements between the various stakeholders.

The rest of the paper is organized as follows. In Section 2, we introduce the key stakeholders in agricultural value chains, including farmers, consumers, intermediaries and various supporting organizations. In Section 3, we survey the major categories of information systems supporting communication between stakeholders, focusing on those reaching small farmers. In Section 4, we categorize these systems according to the inter-stakeholder communication needs that are satisfied: 1) link-to-link (L2L): those information flows

required to coordinate the sale, movement, and distribution of produce along the value chain, 2) peer-to-peer (P2P): communications required to share knowledge and experiences between members of the same stakeholder group, and the expert community serving that stakeholder group and 3) end-to-end (E2E): communications between producers and consumers, for example, to facilitate the exchange of external inputs to market pricing (e.g, certification). In Section 5, we outline some reasons why current information systems have had difficulty in reaching small producers. In Section 6, we highlight a few technology trends that could contribute to increasing the fidelity and accessibility of communications, both between producers and consumers, as well as within their respective stakeholder communities. In Section 7, we conclude by presenting our vision for the future.

II. Stakeholders in Agricultural Value Chains

The structure and organization of food systems vary greatly between developed and developing countries, between local and global food systems, and along a multitude of other dimensions including a particular region's economy, population demographics, geography, and culturally-specific diet requirements. In this paper, we will focus on global value chains, which involve food production and consumption in different countries (or different regions of a large country).

In global commodity chains, the movement of produce from farms to consumers' homes usually involves the coordination of many agents. Each stakeholder has different rights, obligations, interests and information needs with respect to their neighboring links and the chain as a whole. The roles of some of the major stakeholders are described below.

A. Farmers

At the base of every food production system are farmers. As discussed in the Introduction, with industrialization and resulting population migration from rural to urban centers, farming has been significantly transformed in recent decades. Increasingly, smallholder farmers have given ground to large, vertically integrated agribusiness operation. In the US, 2% of the population works on farms, accounting for .7% of the country's total GDP [5]. Average land holding has more than doubled in the last 50 years, to over 400 acres per farm. In India, about 70% of the population is engaged in agriculture, accounting for 25% of GDP, with an average family landholding of less than five acres [6]. Despite the variance in the nature of agricultural production between countries, a common trend is the transition to market-driven systems and consolidation, commercialization and privatization of both large and small farms.

As a result, and facing intense competition from sophisticated multinationals in a globalized food market, many small farmers have shifted from subsistence farming to cash cropping. This has led to increased risk for some smallholders, due to the input-intensive nature of commercial agriculture and potential fluctuations in the global commodity markets; and increased damage to the environment, due to a reduction in biodiversity [7].

Cooperatives

To stay competitive, some small farmers have joined *cooperatives*, or other more informal groups, to gain the benefits of scale — including risk mitigation, increased market leverage and access to financial resources for capital investment that can be used to purchase processing equipment, storage space and/or perform other value addition [8]. Cooperative structures also allow for the institution of *internal control systems* for quality assurance and lowered certification costs [9]. In the past, one of the major limitations within cooperative structures — either for agriculture, finance, or other activities, has been the lack of transparency in governance and resource allocation between members [10]. Observers have pointed out that computerization is one way to improve governance and efficiency in agricultural cooperatives [11].

B. Consumers

With higher incomes, improved processing and health technologies, and redefined family structures, the food demands of populations around the world have changed. Consumers have also become better informed and are increasingly demanding assurances about the the inputs and processes that contributed to the food they purchase and consume. Several surveys have shown that between 65-70% of consumers in industrialized countries would choose to pay more for products considered to be beneficial to the environment. Other surveys have shown more than 75% would purchase products that supported healthy working conditions [12]. Clearly, concern for the human and environmental impacts of consumption exists amongst a broad segment of consumers.

However, this concern is not always enough to influence purchasing decisions, even in the developed world. Surveys also show that only between 5-12% of consumers actually follow environmental or ethical principles when purchasing. The actual volume of such transactions is even less — 2% in a UK study [12]. Still, there is enough demand to support a booming niche industry. In 2006, the world market for organic products alone was estimated at nearly US$40 billion (2 percent of food retails), and is expected to reach US$70 billion by 2012 [13]. Two explanations for the disparity between consumer motivations and actions include the lack of information available at the point of sale, and the lack of mechanisms to ensure credibility [14]. Observers have also noted that negative attacks on high-profile brands tend to work much better then messages reinforcing positive efforts [12], [15].

In developing countries, consumers are only now beginning to become educated about their agri-food choices. One study of Indian consumers found that 25% were aware of organic products, and of those only 36% actually used them [16]. Those consumers who were purchasing organic cited health-consciousness as their greatest motivation. This study, and others like it, have shown that the growth in the domestic Indian market will be most effectively driven by health consciousness,

awareness of organic products, marketing techniques and the consistent availability of products year-round [17]. Moreover, economic development, and the growth of the middle class, should increase consumers' purchasing power and ability to afford a price premium.

C. Intermediaries

Between farmers and consumers are a host of intermediary agents that participate in the agricultural value chain. These intermediaries act as procurement, processing, transport, distribution, wholesale and retail agents. The key intermediaries are described below.

Exporters and Importers Exporters and importers facilitate the global market for certified produce. They deal in wholesale, and often operate in sophisticated and high-volume value chains. They have expertise in international standards and regulations and are thus able to negotiate the variations between traceability and certification regulations in different countries. As the global agriculture market is dominated by large producers who can more efficiently deliver bulk shipments with certainty and consistency, importers and exporters tend to have few relationships with small producers. They are market makers, dealing mostly with global trends in supply and demand.

Brokers As mentioned, large buyers lack the time and infrastructure to establish long-term relationships with multiple small producers. Therefore, they often delegate that responsibility to a broker. Brokers facilitate the sale of produce between producers and large-volume buyers. The broker usually works on commission as a percentage of sale, and does not charge unless a transaction takes place. They are in the business of managing trust relationships, meant to be long-term, so they depend on clear communication channels. As we learned in a discussion with a large-volume coffee broker in Mexico City — they often have the latest technology for monitoring production and maintaining a consistent supply of various types and qualities of produce.

Retailers In correspondence to the transition from small-scale farming to agribusiness on the production side, retail sale of agriculture and other food products has similarly become commercialized and consolidated, as firms seek economies of scale in manufacturing, marketing and distribution. Moreover, large retail and manufacturing concerns are increasingly relying on specialized procurement channels and dedicated wholesalers. Food is being "pulled" to retail outlets such as supermarkets, either in-country or abroad, rather than grown for sale in local markets [18].

This is becoming true both for developed and developing country food markets. According to the FAO, supermarkets increased their share of food retailing in Central Europe, South America, and East Asia from 10% in the early 1990s to 50-60% by the end of the decade. The top 30 supermarket chains across the World now control almost one-third of grocery sales [19]. Certified and specialty products (especially organic) have also seen a transition to large-scale retail supermarkets in the United States [20].

D. Supporting Organizations

Another class of intermediary includes third-party providers of complimentary goods and services for the farmers or their crop.

Value-Addition Agents These are businesses which perform processing services to enhance the commercial value of off-the-farm produce. One example is the roasting of coffee beans, which is performed by small and large organizations, both in importing and exporting countries. In the coffee industry, roasters often also act as intermediaries. Some small farmers, especially when organized in cooperative structures, have chosen to engage in their own processing to increase revenues. In India, we have seen that even simple processing of medicinal plant raw materials generates a higher demand and commands a premium that justifies the investment.

Input Providers Input retailers provide products necessary for farming operations — including seeds, fertilizers and pest control agents. Typically, input providers in developing world agriculture chains are medium to large-sized corporations that manage manufacturing and distribution outlets in rural areas. We have observed that input retailers often serve as a de-facto source of expert information for small farmers in the developing world, which predictably leads to over-application of nutrients and pesticides. The shop where inputs can be purchased can also become a local meeting place for local farmers to exchange peer knowledge.

Certifying Agencies Certifying agencies establish standards according to which they grant certification and permission to market products under a specific name and/or label. Some examples of certification efforts include: *Fair Trade*, which seeks to improve the living condition of marginalized producers by creating consumer awareness, promoting change in trading practices and empowering producers to play a larger role in marketing and sales [21]; *Organic*, an attempt to sustain and enhance the health of ecosystems by reducing the use of chemical fertilizers and pesticides [22]; and *Bird-friendly*, which ensures that native shade trees are retained on coffee parcels, preventing sun damage and soil erosion and providing shelter to migratory birds [23]. Certifiers can be for-profit multinational organizations, government agencies to international or grassroots NGOs [24]. As the market demand for certified produce has grown, there has been an almost proportional increase in the number of certifications, and the number of agencies providing certifying services.

In many developing countries, due to their lack of desire (or inability) to purchase inputs and many forms of mechanization, some small landholders are organic by default [17]. However, actually certifying small producers is a challenging task. In India, the main barriers to organic certification of small producers are cost, quality, and the inefficiency of the certification procedure [16]. Besides certification, weak supporting markets for services, infrastructure and coordination make effective distribution and marketing of certified produce difficult [17]. Poor market information for small organic farmers has also been cited as a constraint.

Extension Agencies. Agricultural extension refers to the mechanism by which knowledge and advice is delivered to farmers as an input to their farming practice. Extension agencies serve as a link between the vast body of global agricultural knowledge and the local farming communities they serve. This service can be performed by a government agency, a university or a non-governmental organization (NGO). Some focus on fundamental scientific research (often universities, and large NGOs), while others employ extension agents to work directly with producers. Often farmers themselves, extension agents use scientific knowledge, field observation and their own experience to help farmers grow better quality, higher-yielding crops — contextualizing the information to fit the community's needs. Field agents also serve as a feedback channel to communicate observed best practices and farmers' requests for more knowledge.

NGOs NGOs are local, national or international non-profit organizations that organize, educate, and help create market opportunities for small farmers. Increasingly, NGOs have moved beyond the goals of promoting environmentally and socially-conscious agriculture through extension and policy advocacy to establishing their own value-based certification systems as an alternative to corporate-branded produce. NGO-based certification has been growing rapidly and is perceived to have greater legitimacy because of corporate independence [24]. Today, many of the largest and most recognized certification programs are managed s by NGOs or by NGO-Government partnerships, including Fair Trade (Fairtrade Labeling Organization (FLO) International), Organic (IFOAM / Government), Utz Kapeh (Utz Kapeh) and Bird-Friendly (Smithsonian Migratory Bird Center / Government) [21], [22], [25], [23].

Governments Through trade policies, subsidies and other support — local, state and national governments have considerable impact on the livelihoods of farmers. Governments may choose to promote sustainable agricultural practices by providing incentives to farmers to consider alternative farming practices. In many European countries, the government provides subsidies during the conversion period of land from chemical to organic when yields are reduced [26]. On a lesser scale, the Government of India has recently earmarked about $20 million for the promotion of organic agriculture in the country. This includes the framing of standards, negotiating standards with different countries and establishing a certification system for organic products [27]. Governments also take steps to ensure the livelihoods of small farmers. For example, the national coffee agency in Mexico provides funds supporting community projects in coffee-growing regions, and has started an advertising campaign to promote domestic coffee consumption.

Financial Service Providers Small producers require a variety of financial services to build assets, make investments and mitigate risk. If they have access to a safe savings account (or reasonably cheap credit), and a place to store their harvest, farmers can wait to sell until the market price is highest (due to the glut of supply, this is usually not immediately after harvest). Loans can also be used to make investments in processing equipment or additional land. Weather and health-linked insurance policies can tide over families through times of tragedy, either personal or environmental.

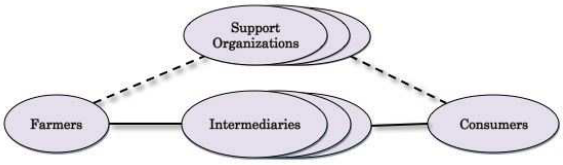

Fig. 1. Stakeholders in agricultural value chains. The dark lines are primary links representing the procurement, transport, distribution and sale of produce. The dotted lines represent supporting activities.

The financial service needs of small producers have been met in the past by government, private and cooperative banks and mostly private insurance providers. More recently, dedicated *microfinance institutions* have emerged to address the specific financial requirements of rural, poor people (many of whom are small producers).

III. Information Systems in Agricultural Value Chains

In this section, we provide a summary of different categories of information systems in agricultural value chains, with an emphasis on those supporting communication and coordination with small farmers.

A. Market Information Systems

Market information is essential for informed decision making — for producers, intermediaries and even for third parties and consumers. In India, it has been demonstrated that access to market information (in this case, via mobile phones) can improve the economic performance of small producers [28]. Web-based initiatives are currently being developed in India, Bangladesh, Central and South America, the Caribbean, Africa, and the United States for information about market prices and access to the latest agricultural practices [29], [30], [31], [32], [33], [34], [35], [36], [37], [38], [39].

Some projects have been able to successfully target rural developing world farmers by allowing them to use either information kiosks or mobile phones to receive information [40], [41]. In Kenya, KACE (Kenya Agricultural Commodity Exchange, ltd.) provides a full market information system plus marketplace, with access through information centers, SMS and voice recordings via a toll-free number. Early results show significant use of the system to match local supply and demand (similar to `www.craigslist.org`) and to learn current market prices, providing leverage with brokers and traders [42]. In India, MCX (Multi-Commodity Exchange) has partnered with rural postal offices to display commodity prices on an electronic ticker [43]. MCX provides the infrastructure, including a computer terminal, Internet access, a printer, a scanner, a fax machine, a webcam and an electronic MCX commodity price ticker. The post office provides a convenient point of access for small farmers.

The Warana Wired Village project was one of the first rural ICT interventions in Asia that succeeded at large scale [44]. Originally intended to provide 70,000 farmers in rural Maharashtra access to market prices, the project transitioned to a remote bookkeeping system for the Warana cooperative, allowing the NGO to keep track of farmer outputs and issue pay stubs, land records, and other documents. Recently, the Warana Unwired initiative successfully migrated all of the functionality of the kiosk-based system to a mobile phone / SMS solution, resulting in significant cost savings and increased system flexibility [45].

B. Procurement and Traceability

One of small farmers' main transaction costs is transportation for their produce. This is exacerbated by the poor condition of roads in developing countries. Providing local access points where farmers can drop off their harvest (and, in an ideal world, collect payment) is a noted best practice, significantly reducing small farmers' risk and expenses.

eChoupal is one such large-scale effort implemented by ITC-IBD, the agri-business division of ITC. By visiting the eChoupal village information kiosk, farmers can find out the current price of soy at various markets and then sell his harvest directly to a nearby ITC-IBD agent — in theory reducing transaction costs and maximizing revenue [46]. Akashganga is a project that automates the local milk collection process for a dairy cooperative in India. A digital scale is connected to a PC that maintains local transaction records and prints payment slips [47]. JAMEX is a network of "chill centers" distributed across Jamaica. Chill centers serve as points of sale and storage locations for farmer-supplied produce. An integrated IT solution coordinates procurement, storage, transport and delivery to customers [48]. Similarly, the Fresh Produce Terminal (FPT) offers fruit exporters cooling and shipping services through four fruit terminals around South Africa [49]. FPT recently invested $5 million on an IT solution that tracks the fruit into the warehouse and onto the shipping vessels. This includes the deployment of 250 vehicle-mounted computers and over 100 mobile computers from Symbol Technologies.

This kind of an integrated solution is required for maintaining *traceability*. Agricultural traceability refers to the "collection, documentation, maintenance, and application of information related to all processes in the supply chain in a manner that provides guarantee to the consumer and other stakeholders on the origin, location and life history of a product as well as assisting in crises management in the event of a safety and quality breach" [50]. Governments often institute traceability requirements for produce being imported into the country.

Utz Kapeh, an independent certifier of ethical and sustainable coffee producers, has developed its own web-based system to track certified coffee through the supply chain from producers to consumers [25]. In Europe, large-scale research initiatives and policy debates have been focused on developing information systems for traceability [51], [52], [53]. These systems rely on technologies such as RFID and GIS to provide farm-to-fork data for agricultural products [52], [54].

C. Extension and Knowledge Systems

Agricultural extension refers to the transfer of agricultural (and other) knowledge to farmers through various communication and learning activities. Many kinds of organizations can be involved in providing extension services - including governments, universities and NGOs. Recent years have seen a trend towards privatization and/or degradation of extension services. To counteract this trend, observers have recommended the increased use of *Information and Communication Technologies*, or ICTs [55].

Several web-based applications are being implemented in Uganda, North Africa, Egypt and India, for creating information-sharing networks between farmers and agricultural researchers [56], [57], [58], [59], [60], [61], [62]. These portals have some combination of online resources, multimedia (usually in the local language), and question and answer services with experts. eSagu is a system developed at IIIT Hyderabad [63]. Extension workers are equipped with a digital camera to document farm conditions and current problems. Using a PC-based kiosk, they can submit text and image-based reports to agricultural experts at a central location. Later, they download advice and feedback to be conveyed back to farmers.

Fintrac implemented a system in Honduras where extension agents were equipped with a mobile office consisting of a GPS device, laptop, digital camera, portable printer, cell phone, portable weather station and a floppy disk drive. This allowed extension field agents to access location-specific agricultural information, provide immediate technical advice to farmers and track their extension activities [64]. AGIS is a PC-based system in South Africa that allows extension agents to access a geo-referenced database with physical, social and economic information essential to agricultural planning and decision making. AGIS is also developing an electronic question and answer system to allow extensionists to communicate with agricultural scientists and researchers [65].

Radio provides a very practical means of communication with farmers in remote areas, overcoming geographic, economic and literacy barriers [66]. The Developing Countries Farm Radio Network (DCFRN) has been working with broadcasters in Africa to meet the needs of local small-scale farmers and their families. The organization maintains direct relationships with 300 radio broadcasters in 39 countries in Africa [67]. By gathering agriculture, health, and other content relevant to rural development information, which are then shared through the partner broadcasters, DCFRN maximizes both outreach and impact. Some initiatives have found that radio broadcasts are most effective when farmers hear local voices instead of radio personalities [68]

The richness of video offers even greater possibilities for the sharing of complex information. Several projects have allowed grassroots "filmmakers" to produce videos documenting organic farming practices, useful for demonstrating the practice to other farmers [69], [70], [71], [61]. Interestingly, the Digital

Green project also found that farmers prefer watching demonstrations from other farmers they know, rather then strangers. Video has also proven to be an effective channel for reaching groups previously underserved by agricultural extension, such as women farmers [72], [73].

D. Inspection and Certification Systems

Maintaining certification requires constant follow-up to ensure that requirements are being met. For fair trade, certifying agencies must ensure that farmers received the minimum price, and the social premium was spent on appropriate activities. Organic and bird-friendly certification imply monitoring at the parcel level.

There have been several tools developed to help in the inspection process. e-Cert is a commercial monitoring and certification system that uses a Tablet PC to perform field inspections. A separate database application provides for the creation of inspection templates, scheduling of inspections and managing of inspection data [74]. A group of UK food retailers developed the Social and Economic Development Exchange (SEDEX), a web-based data management tool to track labor standards along the wine, fruit and cut-flower supply chain [75]. ACTRES is another web-based system that allows flower growers to share information about their water and energy consumption, use of fertilizers and waste generation. This is used to check compliance with certification requirements, and for growers to track their own use of natural resources [76]. QualCheck captures quality assurance data during the processing, packaging, storage, distribution and serving of food and agricultural products [77].

As mentioned earlier, cooperatives often institute *internal control systems*, conducting their own internal inspections and monitoring activities, to provide advance warning of possible breaches of certification requirements, and to reduce the potential of a revoked certification. RANDI is a system that supports the internal inspection process [78]. Inspectors are equipped with a mobile phone to capture the current status of each farm parcel, including multimedia data documenting potential infractions (images), and explanations from the farmers themselves (audio). This data is aggregated in an online database, browsable and searchable by the cooperative's head agricultural expert, who can provide advice to farmers and follow up on potential trouble spots.

IV. Categories of Information Flows

In this section, we provide a categorization of information flows in agricultural value chains, according to the inter-stakeholder communication needs satisfied.

We divide flows into three categories: 1) link-to-link (L2L): those information flows required to coordinate the sale, movement, and distribution of produce along the value chain, 2) peer-to-peer (P2P): communications required to share knowledge and experiences between members of the same stakeholder group, and the expert community serving that group and 3) end-to-end (E2E): communications between producers and consumers, to facilitate exchange of non-economic values as external inputs to market pricing (e.g, certification).

A. Link-to-Link (L2L)

L2L information flows are based around business processes such as procurement, distribution and retail. Depending on the industry, these links can consist of inter-company (or inter-division) communications within highly integrated vertical processes; or open markets with many actors on either side [4]. Examples of the latter are the farmer-broker and supplier-retailer links [17]. In general, these links can be many-to-many — each farmer can sell to several brokers, and each broker deals with many farmers. These information flows are usually well-supported because they are part of some organization's every day business processes. Moreover, most intermediaries can achieve the scale and market leverage to be able to afford significant infrastructure, including information technologies (IT). However, farmers and consumers often do not have the same access, limiting their ability to plan and make decisions. Due to remoteness and lack of literacy, it is hard to even achieve regular communications. As noted in the previous section, recent advances in technology (particularly mobile phones) have in some cases improved farmers' access. However, farmers must pursue their own value addition (such as processing, transportation and marketing) to avail the best opportunities.

B. Peer-to-Peer (P2P)

Agriculture typically requires substantial knowledge transfer between farmers, including spreading successful farming practices, learning about new technologies or methods, and troubleshooting disease or pest problems. This is particularly true for organic farming, where "knowledge" is not readily available with the input provider, and top-down agricultural extension programs struggle to make knowledge transfer demand-driven and locally appropriate [17]. In India, we found that organic farming was not being adopted in remote communities because farmers were hesitant to change their practices without seeing the benefits of the change firsthand. Efforts in Africa have found it equally difficult to spread the appropriate use of chemical fertilizer beyond farmers' immediate social networks [2]. In these cases it is clear that small farmers lack the needed access, tools, resources, education and confidence to be able to establish their own knowledge systems.

Support agents, particularly NGOs and cooperatives, are critical entities in facilitating farmer-to-farmer and farmer-to-expert linkages. By organizing farmers into groups, they create de-facto knowledge societies within which to exchange information and resources. Also, in the case of agricultural extension, by serving as a liaison between the ivory tower of academic science and the applied world of the grassroots, NGOs serve an essential role in translating the latest science and technologies into locally appropriated knowledge. Essentially, NGOs and other extension agencies serve a "proxy" role, because farmers are not able to establish their own mechanisms for accessing and aggregating knowledge.

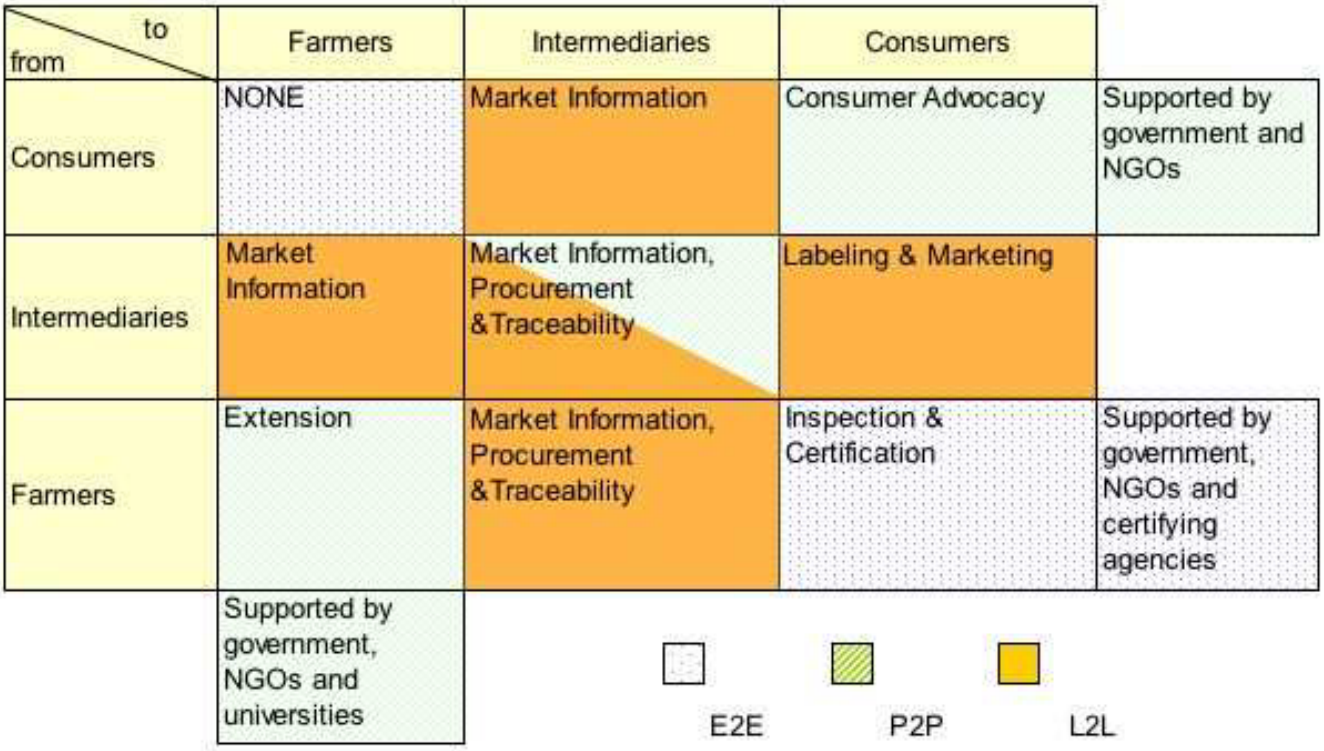

Fig. 2. The communication needs satisfied by the various categories of agricultural information systems. The matrix cells represent specific pairwise communication links. L2L links are indicated in orange, P2P in green and E2E in white.

Intermediaries, on the other hand, have no such limitations. Gereffi uses the term "buyer-driven global commodity chain" to denote how "global buyers used explicit coordination to help create a highly competent supply-base upon which global-scale production and distribution systems could be built without direct ownership" [4]. As a result, when there is a strong enough economic incentive, intermediaries are able to build systems to match supply and demand and establish prices, even between agents that don't have a direct L2L linkage.

Especially in the developed world, consumers are often able to access and contribute to global and regional sources of knowledge. However, the development or intervention of supporting organizations (such as NGOs) is required to aggregate this knowledge, and to use it for concerted action [12]. For example, NGOs as certifying agencies can be seen as one example of how savvy consumers can aggregate demand to create alternate value chains for agricultural commodities. Researchers have noted the following factors that are important for the potential success of such consumer-led movements: the perception of success, the size and nature of the social network supporting it, and the framing of communications between NGOs and consumers [15].

C. End-to-End (E2E)

Information flows from producers to consumers are often about the communication of non-economic values of production (as opposed to purely economic value, which is captured in the price). We call the synergy of non-economic values between producers and consumers *value coherence*. Intermediaries sometimes themselves convey this information within their brand. However, this creates obvious conflicts of interest. For example, in recent years, many multi-national corporations have acquired niche, socially and environmentally-conscious brands, without similarly updating their own production methods. This has led consumers to question the credibility of the now subsidiary brands [79].

An alternative is third-party certification, which attempts to convey actual production values through marketing and specialized brand labels. Because direct communication between producers and consumers is difficult to achieve in global value chains with many intermediaries, this requires the intervention of a third party, in this case the certifying agency. The certifying agency 1) establishes value standards that both producers and consumers agree to, 2) monitors the producer for adherence, and 3) conveys information about the conformance (or non-conformance) of produce with these established standards.

However, the use of a certifying agency to facilitate farmer to consumer value coherence is also a proxy approach. This can lead to cases where the values espoused in a label (or perceived by the consumer), do not actually match the realities on the ground. One example can be found in organic certification, where by following the requirements farmers may actually use more energy and resources (for example, by having to transport their produce to a faraway organic processing center). Another case is Fair Trade. As we observed

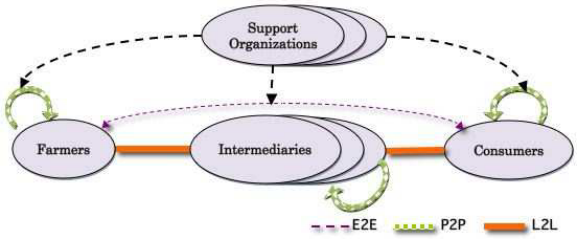

Fig. 3. Categories of information flows in agricultural value chains. Black thick arrows are link-to-link, green dotted arrows are peer-to-peer and the purple dashed line denotes edge-to-edge information flows. Black dotted lines again represent supporting activities.

in Guatemala, the "floor price" of Fair Trade coffee is roughly equal to the local market price, making it irrelevant for local farmers, except for the extra paperwork.

Consumers can also have trouble identifying the meaning of a certification label — what standards it represents and how they are enforced. There is ambiguity about what is being certified, whether the label covers a farmer, a piece of land, a particular product, the processors and distributors who handled the product, or some combination. Producers that we have interviewed have also shown a lack of trust in certifications, expressing that they feel they are being "watched". They feel certain certifying agencies are "in it for the money", lowering their certification requirements to beat the competition.

Interestingly, of all of the information systems that we surveyed, we did not find any that addressed communication from *producers to consumers*. During our discussions with producers, one request that came up repeatedly was that farmers wanted to know more about the value added at each stage of the value chain, and the resulting markup in price. We call this *value transparency*, in this case, referring to economic value. Interestingly, Fair Trade certification provides transparency for the consumer, by communicating the minimum price that was paid to the farmer, but not for the farmer, for example, by knowing the final retail price (a fact that several farmers that we surveyed expressed interest in knowing).

V. Challenges in Reaching Small Producers

Why has it been difficult to reach small producers, particularly within E2E and P2P information flows? Here, we list some potential reasons.

Not aligned with the flow of goods and money E2E and P2P communications are, by definition, not aligned with the flow of goods and money. This may lead some to consider them "optional" — without them, the world will go on, food will still be produced and consumed. In a media world dominated by messages from intermediaries, it is not hard to understand why the trend has been towards increased consumption and production. However, one doesn't have to be a climatologist to realize that increased consumption has to be tempered by a human understanding of the environmental costs of production. Moreover, especially for small farmers, the only way to compete is to aggregate knowledge and resources with their peers.

No institutional base Producers and consumers are geographically, culturally and linguistically dispersed — both from each other, also often within themselves. This limits their ability to organize and aggregate resources, required to implement robust and effective information systems for their needs. As a result, supporting institutions are required for both extension and certification. In both cases, this is often delegated to NGOs.

Qualitative exchanges of data As described, E2E information flows are often about communicating human values, and P2P flows are often about communicating learning and knowledge. Both of these activities require rich, qualitative exchanges of data, which are best suited to multimedia formats, such as audio and video. Traditional enterprise information systems usually do not address the storage, indexing and transfer of this kind of data.

Differences in culture and language Producers and consumers often can be separated by great distances — physically, culturally and linguistically. While producers in the same locality may talk frequently, this often does not extend beyond a narrow social network. This makes it difficult to disseminate and collect information, especially rich, qualitative information — for example, the values behind production, and descriptions of new farming practices.

Lack of access and/or literacy For both producers and consumers, lack of access to information sources, and the literacy to use them, can present significant limitations to knowledge acquisition and aggregation. As a result, they are at the mercy of more empowered stakeholders.

Lack of economic and social empowerment Unfortunately, primary producers are most often at the bottom of the socio-economic pyramid. Even if they are able to access information and communicate their brand message, they are less likely to benefit or be heard. This is particularly true for women, and for discriminated communities.

VI. Some Promising Technology Trends

On a more optimistic note, the declining cost of access to many *Information and Communication Technologies*, or ICTs, and their ability to provide *on-demand* information and services, has the potential to erode this information asymmetry.

The tools for content creation and dissemination — including video and still cameras, TVs, MP3 / VCD / DVD players, radios, mobile phones, and increasingly, PCs, are now accessible to more of the world's population than at any other time before. In this paper we have described projects that have leveraged each of these technologies for the benefit of small producers.

Coinciding with cheaper devices, the price of digital storage has also plummeted in recent years. Inexpensive media such as CDs, DVD and USB-compatible Flash Memory, combined with a "sneakernet" that leverages existing physical communications (such as the postal network), provide a low-cost, high-bandwidth, high-latency connection to rural areas [80], [81].

Given the nature of communications in extension and certification, latency is not a constraint. This means that significant content and services can be provided to small producers *now*, without waiting for the deployment of ubiquitous wireless access. The high bandwidth of this approach allows for the capture and dissemination of rich, multimedia data, improving accessibility to all classes of stakeholder. Video has been found to be particularly effective, both for demonstrating new practices (extension), as well as documenting farm conditions (certification) [69], [78].

For real-time information, such as market prices and meteorology — recent developments in the long-distance adaptation of low-cost 802.11 hardware (operating in unlicensed spectrum) mean that the increased availability and quality of wireless access are not far off [82]. In the interim, for providing services such as market information to farmers, the notable role of mobile phones and cellular networks has already been described.

However, thus far the closed nature of cellular data networks has limited the scope for innovation by small market actors. Implementing low-cost, highly available mobile services often requires partnership with a mobile service provider. Similarly, state control over the radio airwaves in India has limited local production and appreciation for radio content [83]. As mentioned, several projects have observed that farmers prefer receiving information from people whom they know, trust and that are familiar with the local farming conditions [69], [68].

The Internet, if one can access it, provides an open platform and a cornucopia of tools for user-generated content. Discussion fora and mailing lists have already been successfully applied for connecting farmers to agricultural experts in many countries [56], [57], [58], [59], [60], [61], [62]. Blogs and Wikis are two canonical examples of establishing (sometimes) trusted information sources based on contributions from the user community. In many cases, these can become virtual sources of institutional authority (for example, `wikipedia.com`). More recently, with the ubiquitous availability of video cameras, and the growing reach of broadband, video and image sharing sites have become very popular [84], [85]. Recommender systems have emerged in e-commerce as a way for consumers to implicitly learn from their past behavior, or the actions of other consumers in similar positions [86]. While to our knowledge there are no existing recommender systems for agricultural products, it is an approach that has been proposed to have potential for the future [87].

VII. Conclusion

Historically, government-run developing country extension and certification programs have had a poor track record in reaching small farmers. Now, with the transition of many of these functions to non-governmental organizations, the outlook is even more bleak for the long-term funding, scale and institutional basis of such efforts [55]. Commercial intermediaries are (and should be) motivated by profit, so can not be expected to uphold the values of other stakeholders [79].

We agree that improved access to information and communication technologies (ICTs) is one way to address the needs of small producers. More specifically, the plummeting cost of many technologies (video and still cameras, radios, TVs, video players, mobile phones, PCs) is putting the means to access and create knowledge in the hands of billions. Combined with the open network platform provided by the Web, the underlying Internet, and overlying collaborative applications, including recommender systems, wikis and blogs; we may really see a paradigm shift in the near future.

As the population noose grows tighter, and the world's natural systems are stretched to the extent of their production capabilities, the application of the latest technology and science is required to keep pace. We hope that by increasing the fidelity and accessibility of communications — both between producers and consumers, as well as within their respective expert communities — we can foster the development of a true knowledge society. A society where the actions of all stakeholders are informed by the latest in scientific understanding, and where all stakeholders have the ability to communicate their own knowledge and experiences — amongst themselves, and again back to the scientific community for validation and wider dissemination.

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