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ECONOMIES OF SCALE IN INTEGRATED PEST MANAGEMENT IN VEGETABLE AND FRUIT PRODUCTION

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Abstract

Pest management is achieved directly using a variety of tools, including pesticides, and indirectly through a number of agronomic/cultural practices such as irrigation and fertilizer application; collectively these practices function to positively effect general plant health. Healthier plants are more resistant to or tolerant of pests. This study explores the scale differences that impact the pest management significance and suitability of certain agronomic practices. Scale differences were discussed using literature-based information, direct field observations, and anecdotal information on the relative advantages of drip and sprinkler irrigation systems; organic and conventional cultivation of crops; crop rotation versus mono-cropping systems; precision agriculture, and land tenure effects on the suitability of agronomic practices. It was concluded that, sometimes, scale differences are critical enough to warrant completely different approaches to the achievement of goals of small- and large-scale producers.
Keywords: Economies of Scale, Integrated Pest Management, Agronomic Practices, Vegetable and Fruit Production, Small-Scale Farmers

Introduction

Small-scale and limited resource farmers usually look up to large-scale and well-resourced farmers as good examples of how to become successful in commercial agricultural production. While this is very commendable, certain differences sometimes make adoption of similar practices untenable. The notion that the only difference between a 50,000-acre tomato farm and a 50-acre farm is a thousand-fold difference in certain inputs/resources is an expensive illusion. This view of differences in scale is very misleading because it fails to account for the benefits of economies of scale enjoyed by large-scale producers. The economy of scale refers to the factors that cause a fall in the average production cost of an item as the volume of its output increases (The Economist, 2008; Hindle, 2008). Simply put, if it costs $5,000.00 to produce a certain quantity of southern peas but costs only $6,000 to produce 40 times the original quantity of southern peas, then economies of large scale is likely at play. The cost-saving benefits of economies of scale result in increases in the profit margins which can be invested in recommended pest management technologies and other farm practices that are expensive in the short-term but cost-effective in the long-term. Large-scale farmers are, thus, usually able to reinvest in farm operations that small and/or poorly-resourced farmers are often unable to do.

Direct observation of small- and large-scale farms reveal some differences in the following areas: type of land ownership (nature of land tenure), the cost elements associated with various farm operations/activities, and pest management practices. Pest management (especially with pesticides) is an economic decision which is affected by factors such as total cost of pesticide application, the amount of injury caused by the pest, the amount of damage to the crop as a result of each injury, the amount of crop damage that will be avoided as a result of the application of pesticides, and the market value of the crop (Pedigo and Rice, 2009). Integrated Pest Management (IPM) methods are recommended and employed against pests because they are far more sustainable than the "identify and spray" approach. IPM refers to the use of multiple compatible tactics to manage pest problems in ways that ensure the following: economic viability of the production enterprise; maintenance of good environmental quality; and preservation of beneficial/non-target organisms. IPM does not prohibit the use of pesticides but instead emphasizes the use of other tactics that either make the use of pesticides unnecessary or reduce the amount of pesticides required to keep pest populations below levels that will result in economic damage to the crop production enterprise (Pedigo and Rice, 2009). In other words, pesticides are only viewed as one of the several tools available in the IPM toolbox.

IPM methods also emphasize the need to employ concerted efforts to manage the various types of pests together instead of methods that work well for one type of pest (such as insect pests) but worsen the status of other pests such as weeds and diseases. The method approaches pest management from both a pest reduction perspective and the perspective of improvement in crop tolerance or resistance to pests. It is also important to recognize the "do nothing" option as a viable pest management strategy in IPM. One of the instances in which this option makes sense is when more money will be spent on pest management than the value of crops that are saved as a result of the management action (Pedigo and Rice, 2009). Generally, factors that contribute to better plant health also have significant impact on pest management activities, albeit indirectly. This is because healthy plants are more tolerant of the activity of pests than unhealthy plants. Healthy plants are better able to maintain good yields in spite of the injury caused by pests. This is because each unit of pest injury translates to less economic damage as the health of the plant improves (Pedigo and Rice, 2009; Flint and Gouveia, 2001).

Agronomic practices such as irrigation and application of fertilizers which have positive impacts on plant health, thus, have significant impacts on pest management (Flint and Gouveia, 2001). Even though they are cultural practices that satisfy production goals such as increased crop performance, quality, and yield, they exert bonus pest management effects. The objective of this study is to discuss pest management from the perspective of scale differences between large and small vegetable production enterprises that require either the use of totally different agronomic practices or the use of similar methods with some scale-relevant modifications.

Methodology

Information for this study came from a review of the literature, direct observations, and anecdotal information pertaining to large- and small-scale farms. The use of literature review as a research methodology is particularly important in studies like the current one, in which comparisons are made between different entities across a wide range of categories that cannot be studied directly in a single study. The study compared economic aspects of a range of pest management-relevant crop production practices between small- and large-scale farms. A single study that seeks to comparatively discuss the economic impact of this range of crop production practices will be managerially unwieldy. Therefore, the use of literature review as a methodology is particularly useful in cases, such as the current study, in which the full range of data required to discuss a subject matter cannot be collected directly. Information, including that pertaining to treatment action thresholds, economies of scale, and relative suitability of different cultural practices in pest management, were obtained from a review of the literature.

Direct observation in research deals with observing the behavior of subjects or items and reporting on them. In this study, direct observation included information that was collected directly by the authors during interactions with selected small farmers in Southern and South Central Alabama. The information comprised the use or popularity of a range of cultural crop production methods employed by the farmers. Specific information on the relative suitability of various pest management methods was obtained from direct observation and anecdotal evidence. Also, some of the information for the study came from observations during farm visits to large-scale producers who supplied Walmart or other large-scale retailers with fruits and vegetables. The observations made during visits to the small farmers were compared to those made during visits the large-scale producers.

Anecdotal information in research focuses on non-statistically generated or tested data. In this research, anecdotal information was derived by interacting with small- and large-scale producers. An example of anecdotal information was the bad experiences of some participating farmers as a result of poor land tenure arrangements. These bad experiences included the premature abrogation of agreements. Another example was a case involving a farmer who leased land and did not know the land had a history of tobacco mosaic virus (TMV). The farmer derived some comfort from the fact that the property had been left fallow for the preceding 5 or 6 years. Inadequate information on land use history; history of pests and their persistence; and the host range of persisting pests, proved to be an expensive information gap. This is because the decision by the farmer to grow a TMV-susceptible tomato variety resulted in a major devastation of the crop. In their quest to increase the production of crops, small-scale producers often resort to leasing land with less than adequate information on previous use and history. Large-scale producers on the contrary usually own their lands or employ experts to carry out a thorough evaluation of land prior to the finalization of lease agreements. Based on the preceding descriptions, it is expected that there will be differences in several factors between small- and large-scale farmers.

Discussion

Bioeconomic Principles Governing Sustainable Pest Management

Cost-benefit analysis undergirding pesticide applications involves consideration of factors relevant to the Economic Injury Level (EIL) concept (Pedigo and Rice, 2009) [Equation 1].

$$EIL = (C/VIDK) + E_0 \qquad (1)$$

Where:

EIL = is the lowest populations of pests that will cause economic damage

C = Cost of pest management action

V = Total market value of crop

I = Injury per pest

D = Damage per unit of injury

K = Proportional reduction in damage due to pest management

E_0 = Tolerant varieties

Healthy plants generally have higher tolerance (E_0) to adverse environmental factors relative to unhealthy plants. Plant health problems are outcomes of the interaction between genetic factors of the plant and environmental factors (which are either living and/or non-living factors). Recommended agronomic practices such as the provision of adequate nutrients and soil moisture create favorable environmental conditions that result in healthier plants. Healthier plants are better able to resist plant damage in spite of injury by pests; that is, they are able to retain a high percentage of their marketable yield in spite of pest injury. Due to the higher E_0 values of healthier plants, they generally have higher EIL values. An increase in the EIL denotes a higher population of pests required to cause economic damage to the crop; this will result in a higher level of tolerance for the pest, and thus, a reduced need for pesticides. Increases in the market value (V) of the crop results in lower EIL values, which denote a reduction in tolerance for the pests; producers, thus, become less tolerant of pest-damage to crops when their market value rises.

The large discounts (and other benefits) of economies of scale put large-scale producers in a position that enables them to be able to invest in preventive pest management practices some of which only make economic sense in the long-term; short-term leases on land and associated short-term planning further make such investments untenable for small-scale producers. Cost-benefit analysis should precede pest management decisions in commercial agricultural production to ensure that management practices are economically beneficial, environmentally sustainable, and result in the production of food that is safe and healthy for consumption.

The Pest Management Benefits of some Agronomic Practices and General Pest Management Methods used in Vegetable Production

The pest management significance of a number of agronomic or cultural practices seems obscured by the prevailing atmosphere of pesticide-based pest management systems that characterize a significant section of the fruits and vegetable production industry. These agronomic or cultural practices have become so traditional that their pest management and other benefits are unknown or taken for granted. The list of agronomic or cultural practices that have pest management significance includes: application of fertilizers, irrigation, deep plowing, ridging, mulching, land rotation, crop rotation, mixed cropping, appropriate inter- and intra-row spacing of crops, timely harvesting of crops, site selection, and sanitation practices. Selecting planting dates that result in asynchrony between peak pest incidence/severity and the most vulnerable stage of crops helps significantly in the management of a number of crop pests. Some agronomic practices that do not affect pest incidence and severity directly are, however, able to exert indirect influences on pest management through effects on crop tolerance of pests. As stated earlier, healthy plants are more tolerant of pests and their activities relative to those that are less healthy. Increased tolerance, in this case, refers to qualities of the crop that cause less of the injury by pests to result in economic damage. The following sections discuss specific scale-based differences in the pest management impact of specific agronomic or cultural practices.

Drip Irrigation versus Sprinkler Irrigation Methods

A reliable supply of produce over a given period is very important to large retailers who understandably seek to ensure a constant supply of produce for their customers. Retailers, especially large ones, usually avoid producers with erratic production patterns due to dependence on rain-fed agricultural practices. These large retailers prefer investments in irrigation systems to afford farmers greater control over the quality; duration of supply (Mangala and Chengappa, 2008); time of maturation of crops; and very importantly, the yield of crops. Constant supply of water to plants through irrigation is important for a number of reasons, including the following: water provides the medium for uptake of nutrients from the soil; certain levels of soil moisture present unfavorable conditions for certain soil-dwelling pests; and water serves as a medium for a number of important biochemical reactions in plants. In photosynthesis, it serves as one of the ingredients used in the production of carbohydrates in plants. Decreased photosynthetic activity as a result of water deficiency in plants is well-documented (Lawlor and Cornic, 2002). The fact that adequate soil moisture results in higher (fresh and dry matter) yields of fruits and vegetables can simply not be overemphasized or overlooked. This is partly because water constitutes a large percentage of the weight of fruit and vegetables and partly because it serves as the medium for nutrient uptake from the soil.

Even though it is a universally accepted fact that provision of adequate soil moisture and nutrients has positive impacts on plant health, an important but rarely discussed factor is the effects of the method of water application on its impact on crops. The type of irrigation method employed by crop producers exerts significant effects on crops, pests, and pest management activities. According to (Flint and Gouveia, 2001), poor water management is a major contributor to many pest problems. This is because excess soil moisture results in anaerobic conditions which do not favor the survival of plant roots and is often the cause of many root and crown diseases in plants. In such cases, the pathogens are not introduced via irrigation water; pre-existing fungal population in the environment simply become more damaging due to the excess water and its attendant oxygen deficiency in the soil. According to the authors, excess water and poor drainage in certain areas favor difficult-to-control weeds such as nutsedge. On the other end of the spectrum, are the well-documented effects of drought stress, which include wilting, sunburn, sunscald, and branch cracking. Branch-cracking in turn provides entry routes for pathogens; attract plant-boring insects; and generally stresses plants, thus, making them more susceptible to attack by certain pests (Flint and Gouveia, 2001).

The aforementioned effects present themselves correctly as plant health problems. The plant stress and plant vigor hypotheses (PVH) are usually invoked to explain differential distribution of insect herbivores on host plants (Cornelissen et al., 2008). The authors reported a strong herbivore preference for more vigorous plants. Daane and Williams (2003), in their study on the effects of irrigation amounts on grapevines, also reported higher populations of leafhoppers at higher water application rates. The authors demonstrated that the density suppression of insect herbivores could be achieved via the manipulation of irrigation amounts.

On the issue of the pest management effects of specific irrigation types, Flint and Gouveia (2001) listed both positive and negative attributes of sprinkler and drip irrigation systems. Droplets from sprinkler irrigation systems can dislodge, drown, and drive-off some insects and mite pests; they can also cause a reduction in the severity of powdery mildew on grapes as well as disrupt the mating of moth pests such as the diamondback moth. The downside of this system is the fact that moist plant surfaces can promote some fruit and foliar diseases. Higher incidences of diseases such as bacterial soft rot were reported in experiment fields that had more frequent water applications by the sprinkler method (Ludy et al., 1997). Some other studies reported significant effects of both application frequency and time (morning, afternoon or evening) of application. The sprinkler method also fails to discriminate between crops and weeds in the supply of water which hampers weed management efforts. On the contrary, properly set up drip irrigation systems, deliver water specifically and appropriately to the root zone of crops and not the intervening space occupied by weeds. This irrigation method allows crops to outcompete the weeds and leads to reductions in root diseases.

Research findings based on cost-benefit analyses of drip versus sprinkler irrigation systems generally concur on the existence of a scale-effect on the relative cost-effectiveness of these systems. O'Brien et al. (1998) in their comparison of drip and sprinkler irrigation systems in corn production reported the following: for 65 ha fields, sub-surface drip irrigation had a clear disadvantage in net return of $54/ha. Investment costs per ha increased very significantly as field size decreased, but the costs for the drip irrigation system adjusted proportionally. This caused the net returns of the drip irrigation system to be similar to center pivot sprinkler systems for 25.9 ha fields, but for 13 ha fields, a $28/ha advantage was recorded for the Subsurface Drip Irrigation (SDI) system. According to the researchers, these results were very sensitive to the durability/longevity of the drip irrigation equipment. SDI was unprofitable relative to center pivot sprinklers for an SDI life of less than 10 years. The authors indicated the effects of changes in corn yield and price as well as changes in the cost of driplines on the relative profitability of drip irrigation systems. Generally, for a given crop, the larger the acreage cultivated, the higher the chances that the sprinkler irrigation system will be more cost-effective in the long term; this statement takes into consideration the durability of the irrigation equipment/materials and replacement costs for each irrigation system.

Drip irrigation systems make more efficient use of water relative to the sprinkler irrigation systems (Shalhevet et al., 1983; Bielorai, 1982). A comparative study of both irrigation systems on the performance of potato in a hot climate revealed similar total maximum yields for both systems, but 8% less water was used in the drip irrigation system (Shalhevet et al., 1983). Wang et al. (2000) reported the use of five times more water in the sprinkler irrigation method relative to the drip irrigation method but found the seed zone water content of the soil to be similar. The researchers also recorded significantly higher soil temperatures in the drip irrigated fields which led to higher seed emergence rates and enhanced growth of seedlings compared to the sprinkler irrigation method. Shalhevet et al. (1983) also found that under drip irrigation, the soil could dry to -40 J/kg without reducing potato yields as long as the water supply is adequate. When the soil water potential in the sprinkler irrigation system changed from -20 to -29 J/kg, potato yield reduced by 12%. The authors ascribed this difference to the higher root concentration of plants grown under drip irrigation relative to those grown under sprinkler irrigation systems.

Some large-scale fruit and vegetable producers find it more cost-effective to engage in certain agronomic practices (such as sprinkler irrigation methods) that are proscribed from a pest management perspective. The availability of resources, however, enables them to put in place measures to avoid the negative consequences of such non-adherence to recommended cultural practices. Mitigation measures include either the adoption of preventive pesticide spray regimen carried out on a calendar basis or the use of other appropriate methods some of which are cost-prohibitive to limited-resource producers. Large-scale producers usually have and exercise more bargaining advantages relative to small-scale producers during price point negotiations with produce buyers and merchants of agricultural inputs. This fact in addition to the economies of scale, in the form of reduced average price of inputs, enables large-scale producers to invest in additional systems to prevent or mitigate pest problems. These advantages result in larger profit margins; higher profits enable large-scale farmers to spray fungicides and other pesticides more often and at concentrations that are closer to the upper application rates on pesticide labels.

The type and market value of crops grown and the prevailing pest and environmental conditions, are other factors that significantly influence the relative suitability of the irrigation systems under discussion. The type of irrigation system used also affects the performance of chemigation systems. Chemigation refers to the irrigation-based application of agricultural fertilizers, soil amendments, and pesticides. Drip irrigation systems are generally more efficient than sprinkler irrigation systems in fertilizer application via irrigation water.

Effects of Fertilizer Application Practices on Pests and their Management

Although the application of fertilizers is not a pest management method, it exerts pest management effects partly through its effect on the health of crops. Fertilizers and soil amendments are capable of influencing pest activity in ways that either favor or harm the crop (Flint and Gouveia, 2001). It must be noted that pest problems are associated with both over-fertilization and under-fertilization. Some of the pest problems associated with excess nitrogen include: increased levels of brown rot and brown patch diseases as well as higher incidences of certain moths, aphids, leafhoppers (Flint and Gouveia, 2001) and flower thrips (Schuch et al., 1998) all of which are attracted to the lush growth of crops due to excess nitrogen (Flint and Gouveia, 2001).

Crop Rotation as a Pest Management Tool

Farmers view crop rotation from a number of perspectives. Some view it rightly as a method of efficiently utilizing soil nutrients by rotating to crops that have different nutrient requirements from the preceding crop. A smaller percentage of farmers seek to select the right sequence of crops, in a rotation schedule, to achieve the aforestated agronomic objectives. Unfortunately, most of the discussions on rotation schedules overly focus on optimum utilization of soil resources (chiefly nutrients) to the neglect of the pest management aspects of crop rotation. The inadequate appreciation of the pest management aspects of crop rotation sometimes results in rotation sequences that perpetuate pest problems. Such mismanagement occurs when preceding and succeeding crops share a common prevailing economic pest. This type of crop rotation from a pest-management perspective is effectively a change in menu for the pests. The corn earworm (*Helicoverpa zea*) is also known as the cotton bollworm and the tomato fruitworm. Any sequential planting involving these crops will result in the perpetuation of this insect pest.

There are some very large-scale vegetable producers who do not practice crop rotation of any kind. Instead, they have in place drip irrigation-based chemigation systems by which water, fertilizers, and pesticides are administered to the area under cultivation. This system is used to fumigate the soil to prevent the persistence of soil-based pests that are favored by mono-cropping practices. Such systems are also used to prevent nutrient deficiency problems. These mitigation measures involve major investments in the installation and maintenance of the required infrastructure. It is also important to note that some of these large-scale farms have research units staffed with scientists such as plant breeders and pathologists; these scientists help in the development of specific crop varieties that are both suitable for the environmental conditions of the production area and also meet the quality requirements of their target market. The aforementioned measures involve large investments which may be cost-prohibitive to some small-scale producers. Mono-cropping, however, has an upside in that it allows practitioners to become very specialized and efficient in the production of a particular crop. The high levels of efficiency, large discounts, and superior bargaining power, enable large-scale producers to comfortably make these investments and still make decent or even huge profits. Again, although mono-cropping is not a recommended agronomic practice, some large-scale producers are set-up to take advantage of its benefits without experiencing the brunt (if any) of the negative consequences associated with the practice. Adoption of such an agronomic practice without the use of relevant preventive measures can lead to major economic losses for small-scale producers.

Land Tenure Systems and Implications on Pest Management

Land, the basic resource required for the production of crops and livestock, is the most valuable asset on the balance sheet of most farm businesses (Goeringer et al., 2014). The choice of agronomic and pest management practices to be used in fruit and vegetable production is sometimes impacted by issues about land and its acquisition. The amount of land needed for a farm enterprise and the method of its acquisition are two of the most important decisions that confront farm operators. Acquiring more land than is required may cause financial problems which limit the ability of farm operators to invest in other important farm operations and inputs. Land can be held through ownership, lease arrangements, or various combinations of both methods. The price of land is a significant determinant of whether farm operators opt for lease arrangements or ownership; higher land prices tilt the decision towards lease arrangements.

Each method of land acquisition has its advantages and drawbacks. Lease (especially short lease) arrangements limit farm operators to short-term planning which does not augur well for the long-term growth and financial health of businesses including agricultural ones. However, ownership of land affords farm operators the right to take management decisions such as selection of production enterprises, choice of conservation practices (Goeringer et al., 2014), and installation of chemigation equipment. Lease arrangements are, however, more flexible financial obligations compared to mortgages; these arrangements make more capital available for investment in other farm inputs. Land ownership allows farm operators to invest money, equipment, labor, and other inputs in the land with an assurance of reaping the benefits later.

Full ownership and long leases on farmland, which is characteristic of large-scale fruit and vegetable producers, allow unfettered infrastructural investments to forestall pest problems associated with non-adherence to recommended agronomic practices. Short-term leases put a limitation on investments such as drilling of wells and installation of drip-irrigation-based chemigation systems. Year-by-year leases on land without a formal written agreement are not unheard of among small-scale farmers. Some state laws in the United States, however, do not allow oral agreements on lease terms exceeding three years but do not insist on written leases for shorter terms (Goeringer et al., 2014). Negative effects of verbal lease agreements include termination of leases by landowners before farm operators get the opportunity to benefit fully from their investment in the property. Unless in situations in which farm operators break the terms of a lease agreement, written leases forestall the premature termination of lease agreements after decent investments have been made to make the property more suitable for crop production. The ideal land tenure situation is for farmers to own or have long-term leases on farmland. This helps to justify certain investments on the property that are required to make the production enterprise profitable especially in the long-term. In cases when this is not the case, it is recommended that small-scale farmers refrain from verbal agreements that lack elements of time

frame. Time frame elements are crucial in the financial cost-benefit analysis to determine the prudence of certain investments pertaining to agronomic practices and pest management.
Land ownership, thus, affects the kind of long-term measures that can be put in place to increase the productivity of the land and manage pest problems. Even though a combination of both short- and long-term planning is required for success in business, business entities that depend solely on short-term planning usually fail or perform poorly. Short-term planning, however, is often the only option available in crop production on land leased on a short-term basis.

Conventional Versus Organic Cultivation of Vegetables

Sustainable pest management in a commercial crop production enterprise involves a series of economic decisions that are environmentally sustainable, socially beneficial/responsible and result in the production of food that is safe and healthy for consumption. Even though environmental health and sociological factors are extremely important, farm business enterprises must be financially profitable for the business to thrive. Organic farms satisfy the need for good environmental stewardship, but the financial aspects are what either propel or sink such crop production enterprises. It is a well-documented fact that organic cultivation requires more labor and other production inputs relative to conventional cultivation practices. Preventive practices, early detection, and early pest management actions are even more crucial for organic producers relative to their conventional counterparts. This is partly because organic pesticides are generally not as fast-acting and effective as conventional ones.

IPM practices are, thus, even more important for organic crop producers. Organic farming enterprises must be paid premium prices for their produce to be financially viable. This is because of the additional costs involved, the higher potential of pest-related damage, and aforementioned higher levels of labor required in organic production. Large-scale producers of organic fruits and vegetables are able to enjoy elements of economies of scale, including discounts on inputs bought in bulk; this helps them to have competitive prices that are closer to those for conventionally grown produce. Their small-scale counterparts usually are unable to offer such competitive prices without incurring major losses. Unfortunately, this situation pushes small-scale commercial organic producers out of business prematurely.

Organic pesticides are more expensive than their conventional counterparts and can require more frequent applications either because of their short residual activity and/or instability when exposed to environmental conditions. All of these make it imperative that farmers have a ready market made up of consumers who understand the health benefits of organic produce and have the financial resources to pay the premium prices that make the enterprise financially viable and rewarding. Lack of these conditions results in poor financial profiles and limited growth (if any). Consequently, such production enterprises are unable to attain the large sizes that will enable them to enjoy economies of scale. In this regard, small-scale organic producers are even more challenged than comparably sized conventional producers. It typically takes varying lengths of time for businesses (including agro-businesses) to break even and eventually start making profits. Financial constraints that characterize some small-scale farm operations make the period between initial investment and accrual of decent profits an unaffordable luxury, especially for small-scale organic producers who fit the aforestated profile. Typically, such enterprises are driven out of business because of inability to muster the financial patience to go through the growth process, from small- to large-scale enterprises, with the associated incremental acquisition of managerial skills.

Commercial producers will reject, outright or eventually, any pest management recommendations that emphasize environmental and social factors at the expense of economic factors in ways that result in economic losses. A better approach will be to make environmentally-friendly and socially-responsible production methods, economically attractive or vice-versa. At the other end of the spectrum in conventional crop production, there is sometimes a tendency for pesticide-based economic approaches to crop production to get into overdrive mode. This approach happens when killing of pests replaces crop protection as the goal of pest management efforts, and moves pest management outside the realms of financial, environmental, and social prudence, resulting in unsustainable crop production practices.

Scales in Agricultural Production

Farm-scales can be delineated (based on total annual sales) into the following categories: very large farms (>$500,000); large farms ($250,000 to $499,999); small farms (< $250,000 to $100,000), and low-sale farms (< $100,000) (Hoppe and Banker, 2010). Direct pest management activities and agronomic practices that have pest management effects have cost elements associated with them, which tie into farm-scale categories. Given the fact that economic sustainability/viability is an integral aspect of IPM, every pest management step must be evaluated on a cost-benefit basis. According to Pedigo and Rice (2009), an evaluation of the cost of pesticide application needs to include the cost to the environment. This type of cost reflects environmental aspects of sustainability which is a critical element of IPM. The bioeconomic principles provide the decision guidelines that aid farmers to optimize returns on pest management activities (or at least) avoid financial losses while paying due attention to social effects and maintenance of environmental quality.

As previously stated, agronomic and other crop production practices usually provide far more benefits beyond the ones that are immediately apparent to a number of crop producers. The objective of recommended agronomic or cultural practices is to make plants more healthy and productive through the creation of favorable and unfavorable conditions for crops and pests, respectively. Each agronomic practice can be achieved using a range of specific methods. A good example of this is the fact that irrigation and weed management can be achieved using a range of specific methods such as drip and sprinkler methods (for irrigation) and use of herbicides, mechanical weed control, and use of plastic mulches for weeds. The managers of individual farm enterprises, thus, have to opt for combinations of methods that make economic sense for the scale at which they operate instead of selecting methods solely based on the fact that they are used by successful large-scale farms. In some instances, the use of same but scale-appropriate practices as large-scale producers makes economic sense, but in some other cases, the recommendation for small-scale producers is completely different. This is because sometimes large-scale producers are able to get away with certain practices that are normally proscribed; they are, however, able (partly due to economies of scale) to put in place systems to forestall or mitigate the negative effects of such practices.

The willingness and ability of large-scale, well-resourced farm enterprises to invest in research and development activities (such as the development and use of crop varieties that are suitable for their specific production environments) make them different from a number of their small-scale counterparts. Adoption of some of their practices without access to some of the resources can lead to disastrous results. As mentioned earlier, the discounts and other benefits afford large-scale producers additional financial resources which can be plowed back into the production enterprise in the form of preventive pest management methods. Even though such benefits are normally not available to small-scale producers, a number of options exist to satisfy the quest for similar benefits. Individual small-scale producers can opt to organize themselves into clusters/cooperatives and/or enter into purchasing arrangements with large-scale producers. Contract farming, specifically variants of the Nucleus Estate Model (NEM) described by Eaton and Shepherd (2001), provide another viable avenue for the achievement of this objective. The authors described NEM as a type of contract farming involving an arrangement between a central estate/plantation and a large number of small farmers to achieve required production targets. The central estate in traditional NEMs, serve as sponsors of the small farms and also guarantee the availability of produce to markets/processing plants. Sponsorship involves a significant provision of materials and management inputs to the small farms. Variants of NEM are used in a number of countries, including the type currently used in the production of Jatropha in Tanzania for the global biofuel chain (Balkema and Romijn, 2015).

Relationship between Farm Scale and Record-Keeping Practices

Very large-scale farms typically have more “moving parts” that need to be tracked in order to help coordinate the various parts to perform as a functional unit. In studies on the farm record-keeping practices of pig farmers in Venezuela, Viloria Carrillo (2010) reported that farmers with a higher number of sows were more likely to keep physical records of their operations. Thus, the more complex the production scale is, the better the required managerial skills. The author also reported that farmers with higher capital investments were more likely to engage in physical record-keeping due to better commitment to take care of the investment. Viloria Carrillo (2010) also observed the existence of a robust scale effect on financial record-keeping among farmers; farmer operators with larger farm sizes were more likely to keep financial records compared to operators with smaller sizes.

Large-scale producers typically have assured markets for their produce; a decent and a steadily increasing portion of such “assured markets” require food safety certification of their produce suppliers. Food safety certification and the attendant record-keeping practices are going to become the norm among agricultural producers. The FDA’s Food Safety Modernization Act which was signed into law by President Obama on January 4, 2011 (Sellers, 2012) provides an additional impetus for this change. The Act does not only aim to ensure that the U.S. food supply is safe, but also does so by shifting the focus from reactive to preventive measures against contamination of food. When large-scale enterprises fail to keep accurate records (especially financial records), inefficient aspects of the operation cannot be identified promptly until financial losses become huge enough to be very obvious at which stage their impact on the business jeopardizes its very existence. At the risk of sounding over-simplistic, the authors will use the following example to explain the concept:

A poor decision to use the best pesticide (95% efficacy) that costs $600 per gallon instead of the second best pesticide (94% efficacy) that costs $100 per gallon against a major pest results in larger financial losses or reduction in profit margin of a farmer with a 20,000 acre farm than it does for a farmer with a 5 acre farm. The marginal returns (regarding the amount of crop loss prevented) may not justify the marginal cost of using a pesticide that is slightly (and maybe imperceptibly) more effective.

The quantum of financial implications of everyday decisions made by large-scale farmers makes them more inclined to engage in data-based decision-making. This fact does not mean all small-scale farmers engage in poor record-keeping practices or fail to engage in data-based decision-making in the operation of their farm enterprises. However, they are more likely to keep poor or unwritten records relative to their large-scale counterparts. Irrespective of size, many farmers encountered by the authors in South and South Central Alabama employ good record-keeping practices in their operations. The food safety requirement and its attendant record-keeping practices have contributed significantly to this culture.

There are farmers who view their farms as business enterprises even though the adoption of good financial record-keeping practices will easily help re-classify such enterprises as either non-commercial activities or expensive hobbies. Even though there is absolutely nothing wrong with engaging in farming as a hobby, there is everything wrong with the operator being under the illusion that it is profitable. Adoption of good financial record-keeping practices sometimes reveals the fact that a number of such farms are kept running only because of funds from other sources such as full-time employment (for part-time farmers) and retirement funds (for retirees who engage in farming). Such non-profitable farm operations are even more difficult to detect when all (personal and business) incomes are kept together in one account without proper tracking of the inflows and outflows of each.

The small farmers encountered in this study, offered IPM specialists a unique opportunity to explain and encourage the use of area-specific action thresholds for various pests relevant to the crops under cultivation. These action thresholds governed the decision on whether and when to apply pesticides to pests as an appropriate pest management and economic decision. Various pieces of data informed the determination of these action thresholds. Accurate information and records helped to calculate relevant action thresholds for various economic pests.

The Suitability of Precision Agriculture for Different Farm Scales and its Impact on Pest Management

As indicated previously, improvement in plant health impacts tolerance of crops to pests, which in turn, impacts pest management activities. There are major cost elements associated with improvement of plant health through cultural practices such as the application of fertilizers and irrigation. Precision Agriculture (PA) is a method that helps to optimize the use of such inputs by using site-specific information to target rates of fertilizer, seed, and chemicals for soil and other conditions (Bongiovanni and Lowenberg-DeBoer, 2004). According to the authors, PA can contribute to the long-term sustainability of production agriculture via reductions in the application of fertilizers and pesticides. This is because the technology ensures that the right amounts of applications are made only when and where they are needed. Other benefits of PA include reduction of economic losses that stem from nutrient imbalances, excessive application of fertilizers, and less efficient management of weeds and insects.

According to Whelan and McBratney (2000), PA should be considered as a philosophical shift in the management of differences within agricultural industries. Its objective must be the improvement of the profitability and/or environmental impact in both the short- and long-terms. The authors specifically defined Site-Specific Crop Management (SSCM) as a system of matching resource application and agronomic practices with soil and crop requirements as they vary in space and time within the field. In other words, the use of SSCM in fertilizer application does not involve the uniform application of fertilizer on entire fields. It involves the application of specific amounts of fertilizers to different areas of the field based on specific amount of nutrients required to attain the nutrient requirements of the specific crop under cultivation.

Whelan and McBratney (2000) also differentiated variability in crop performance at different times (temporal variability) and variability in crop performance at various locations within a field (spatial variability). SSCM is more useful in fields that show a lot of variability relative to those that are uniform. Uniform application of fertilizers may be more cost-effective on fields which have a high level of uniformity. Even in uniform fields which exhibit a high level of variation in performance over time or in different seasons, SSCM can exert a positive influence by helping to provide crops with their requirements irrespective of the season. Generally, the larger a field is, the higher the probability of the existence of significant within-field differences in factors (such as soil nutrients, soil type, soil moisture, and slope of land).This is exactly how farm-scale begins to feature prominently in the discussion of SSCM. Scale becomes a major factor to consider in the discussion on whether it is financially prudent for small-scale producers to use the technology without first increasing the scale of their production to the point that justifies the use of the technology. PA, thus, appears to be a better fit for large-scale farms because of the short-term costs which many small operations are ill-equipped to accommodate for considerable lengths of time. A minimum farm-scale and financial performance are required to justify investment in precision-agriculture technology. Given the range of benefits of SSCM which generally result in optimal use of a number of agricultural inputs and the ability of the technology to reduce temporal variation in crop performance, crop producers irrespective of size will benefit from the technology. The question for small-scale producers is whether it makes financial sense for their businesses to opt for the long-incubation periods associated with such large investments. This can be particularly unattractive when the piece-meal nature of the benefits takes a long time to become significant because of the size of these operations.

The production of scale-appropriate PA equipment/technology will make them more affordable, and thus, increase adoption by small-scale producers. In their paper on farm operator characteristics affecting awareness and adoption of PA, Daberkow and McBride (2003) reported that farm operators who were educated, computer-literate, farmed full-time, and had larger farms were more likely to be more aware of PA; they also reported that older farmers were less likely to be aware of PA. Geographical location and type of crops cultivated also impacted PA awareness in that study. McBratney et al. (2005) stated that, even though PA was advancing, it was not doing so as fast as was predicted five years earlier. The authors listed several causal factors including inadequate development of proper-decision-support systems for farmers. Daberkow and McBride (2003) stated that adoption rates were not affected by awareness rates; instead, they found that farmers whose farms were of the required scale and structure for profitable use of PA were already aware of the technology.

Anecdotal Evidence in Support of Scale-Specific Decision Making In Crop Production

Several examples of anecdotal evidence were encountered by the authors regarding pest management situations and land tenure arrangements. A few are discussed in this section. During a farm visit in 2016, the authors received a request from a small farmer for recommendations on the best way to protect peaches from squirrels. If this request had come from a large-scale farmer, say with a 20,000 acre farm, the recommendations would have been totally different from the one given in this particular case where the farmer had about three peach trees near her house. The farmer was advised to either use a sticky topical application or install metal collars around the trunk of the peach trees. Similarly, a recommendation, in 2016, to deal with tomato hornworm by picking the worms and dropping them in a bucket of soapy water is a perfect solution in a small backyard garden but will not be feasible on large farms. Time and labor costs involved may be more cost-prohibitive relative to other management methods, including the use of pesticides.

Also, a farm visit to a very large-scale vegetable production enterprise in 2016 revealed that it practiced mono-cropping. This company has been engaged in this practice for several years, but was able to afford to put in place the necessary measures (e.g., fumigation equipment and research center) to forestall negative consequences such as pest outbreaks and poor yield due to inadequate soil nutrients. The amount of capital investment needed for the installation and maintenance of fumigation equipment, running a research center, and keeping full-time research scientists on staff, make this a cost-prohibitive practice for small and resource-challenged farmers.

Still, in 2016, short (yearly) lease arrangements by some small-scale farmers resulted in bad outcomes, because the landowners gave notices of their intentions to use their properties in the subsequent year (2017). This occurred despite the major investments that the tenant farmers had made in 2015 and 2016 to make the land more suitable for crop production activities. The lack of adequate resources by these farmers to own or obtain land on long-term leases resulted in poor financial returns on the investments made.

Conclusion

Commercial farming as the name suggests should have maximization of profits and minimization of costs as paramount goals. Pest management decisions in commercial agricultural production should, therefore, be based primarily on economic factors with due attention to environmental, social, and food safety/public health factors. Scale considerations must also feature in the economic calculations. Differences in cost-structure between small and large-scale producers sometimes require the use of completely different agronomic and pest management practices. Scale differences result in certain advantages to large-scale producers that small-scale producers do not experience. Such differences necessitate great circumspection in the adoption of some of the production and pest management practices used by large-scale producers. Sometimes, scaling down is appropriate, but other times the use of completely different production methods are more financially prudent and suitable for use by small-scale producers.

The ideal land tenure situation is for farmers to own or have long leases on farmland. This helps to justify certain investments on the property that are required to make the production enterprise profitable especially in the long-term. In cases when this is not the case, it is recommended that small-scale farmers refrain from verbal agreements that lack time frame elements. Also, it is easier to get a business to look good on paper (in the form of feasibility studies and business plans) than it is to make the business perform well in practice. The reality on the ground makes it financially obvious in instances when bad business decisions are taken; good record-keeping (especially financial record-keeping) will help detect or avoid bad business decision earlier. The use of information-based recommended action thresholds for various pests will help optimize resources and maximize profits in crop production.

Furthermore, individual small-scale producers can benefit from economies of scale by either forming clusters/cooperatives or entering into purchasing arrangements with large-scale producers. It is recommended that small-scale producers employ variants of NEM that replace the "sponsorship" aspects with "purchasing agreements." This will make it possible for small-scale producers to purchase materials and/or equipment through the large nucleus estates at discounted prices; the resulting savings can be plowed back into the enterprise in the form of preventive pest management methods.

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