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Precision Agriculture

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Creating Sustainability Through a Broader View of Precision Agriculture

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Abstract

Farmers are looking for the best way to maximize profits and spend the least amount of money due to the constantly changing market in agriculture. Many different options have been explored from limiting herbicide programs to reducing rates on chemicals and trying to use to equipment longer to lower the cost. However, none of these have given results as expected. Precision agriculture is one fast growing industry; from auto guidance to completely autonomous tractors, it has no end in sight. Precision agriculture can be defined as the integration of information and production based farming system to achieve increased productivity while reducing the impact on the environment. Does precision agriculture hold the answer to being able to spend less and produce or make more? Global Positioning System (GPS) guidance systems on farm equipment help farmers save money through reducing labor, fuel, and wear on equipment. GPS guidance also creates opportunities to implement new farming systems that can help increase yield potential while reducing costs, such as strip-till farming, can reduce impact on environment and improve benefits to farmers. On the other side, incorrect implementation of a strip-till program can be detrimental to yields; therefore having the proper correct equipment is necessary to maximizing the benefits of strip-till. Variable rate planting and chemical application results in precise placement of seed and chemicals. It also places exact volume of seed and chemicals needed to maximize yields in all ground conditions. Reducing environmental impact is key to sustainability in agriculture. The scientific advances have allowed for many different farming practices to reduce the environmental impact. Farm planning can help choose exact acreage to be used for certain commodities or farming practices to ensure maximum profits and minimized costs. Planning equipment purchases to ensure maximum trade values and best equipment options is critical to having reliable machinery that gets the job done and continues to make profit for the farmer. With the future of precision agriculture our agriculture can be improved significantly.

Key words: farm planning, linear programing, precision agriculture, sustainability

Precision Agriculture

Creating Sustainability Through a Broader View of Precision Agriculture

Introduction

Precision Agriculture (PA) can be defined many ways and the perspectives of what PA is vary among different groups of people. Some views of PA are electronics and Global Positioning Systems that give tractors auto steer. However, the more complete definition of PA is “An integrated information- and production-based farming system that is designed to increase productivity and profitability while minimizing unintended impacts on wildlife and the environment” (US House of Representatives, 1997). This definition expresses that PA is about maximizing production efficiency, productivity, and profitability through a faming system that is based on information and production. This includes analyzing the amount of feed to provide to dairy cattle to increase milk production while minimizing the amount of feed given, as well as finding the minimal amount of fertilizer to apply to crop to not just maximize yield potential, but profitability as well. Using less inputs and lowering yield to maximize profits per unit can be considered precision agriculture as well because this maximizes profitability and minimizes the impact on the environment and wildlife through the reduction of, possibly, toxic chemicals. Less inputs means less possibility of input loss to the environment, which could pollute water. The US House of Representatives (1977) definition refers to “long-term, site specific, and whole farm production,” which encompasses more than just row crops, or field-by-field planning. Precision Agriculture can be applied to the management of farming operations with multiple sources of income, such as, multiple crops, hogs, cattle, chicken, etc., to increase production and minimizing the impact on the environment.

However, most people think of PA, as “site-specific crop management (SSCM)” (Whelan, et al., 2013). This can also be considered as precision farming, which is a production based farming system to maximize the farms economic potential by recognizing the variability of different fields in the entire farming operation (Grusy, R., 2003). This is a more narrow view on PA is a rapidly growing subject in todays farming industry. The drive behind this SSCM is to increase profits and reduce costs. Through GPS, farmers are able to be more accurate, efficient, and precise when cultivating ground, planting, spraying and harvesting crops. With the ability to be more efficient through out the farming season, farmers are able to use less fuel, seed, labor, and chemicals, and in turn they spend less, thus increasing profits. Along with the reduced chemical use, there will be less environmental impact because less chemical are available to be lost to the atmosphere or water. Increased efficiency mean less equipment usage, less wear on equipment, less maintenance, and greater trade potential, saving farmers money. Also with this added precision, optimal yields are being able to be met due to more exact plant population and greater percent emergence, thus increasing profits. The applications of PA equipment have been seen to be effective in as little as a year’s time, thus providing proof of a wise investment and creating greater sustainability. From a sustainability standpoint reducing the amount of chemical use could lead to increased soil quality thus improving possible yield potentials and profits. The agricultural industry has changed drastically, and it seems it is for the better based on the benefits of PA. Could the integration of PA and whole farm planning be part of the key to sustainability in agriculture through increased economic growth for farming communities, feeding the world, and reducing our carbon foot print? Below is the description of a few technologies and how they contribute to PA applications on a farm scale and the impact they have on the environment.

Global Positioning System Guidance

Efficiency of an operator can either increase or decrease the cost of operation drastically. For example, operator A pulling a 30-foot disk at 5 miles per hour overlapping 3ft each round with out guidance or auto steer is operating at approximately 80 percent efficiency. While operator B pulling the same size disk at the same speed overlapping 4 inches per round with guidance and auto steer is operating at almost 98 percent efficiency. Therefore, operator A covering 30-feet at 5 miles per hr. at 80 percent efficiency is represented as follows: 30ft * 5mph * 5280ft/mile = 792,000ft^2. 792,000ft^2/43560ft^2/acre = 18.2 acres per hr. 18.2ac/hr * 80% efficiency = 14.6 ac/hr, which over an 8 hr day equals 116.8 acres. Operator B at 98% efficiency is represented as follows: 30ft * 5mph * 5280ft/mile = 792,000ft^2. 792,000ft^2/43560ft^2/acre = 18.2 acres per hr. 18.2ac/hr * 98% efficiency = 17.8 ac/hr, which over an 8 hr day equals 142.4 acres. It would take operator A 68.5 hours to cover 1000 acres and at $15 per hour would cost $1027.50. It would take operator B 56.2 hours to cover 1000 acres and at $15 per hour would cost $843, which is a savings of $184.50. Applying that to two passes of pre-plant fertilizer application, one for anhydrous ammonia and one for P and K fertilizers, planting, three rounds of post emergence chemical applications, harvesting, one round of tillage for cover crop, and planting cover crop is nine passes over 1000 acres which equates to $1,660.50 in one year. Over the course of ten years on just 1000 acres is a savings of $16,605, or for someone that farms 10,000 acres over the course of ten years, that is $166,050, in labor cost alone. The fuel savings benefits with the price of farm diesel are as follows; assuming you own a tractor that consumes 9 gallons of fuel per hour, with the same set up as the previous scenario, you will use the tractor for five passes across a 1000 acres farm which takes operator A 68.5 hours per pass across farm or a total of 342.5 hours per year. 342.5 hours * 9 gallons per hour * $2.00 per gallon = $6,165 in fuel cost for one year for a 1000-acre farmer. For that same farmer to operate 10 years, assuming fuel prices stay the same, will cost $66,650, and for a 10,000-acre farmer to farm ten years it would cost $616,500. Operator B, with precision Ag equipment, takes just 281 hours to do the same work. 281 hours * 9 gallons per hour * $2.00 per gallon = $5,058 dollars in fuel cost for one year for a 1000-acre farmer, and $50,580 for ten years of operation for a 1000-acre farmer or $505,800 for a 10,000-acre farmer farming for ten years. The fuel cost savings on 1000 acres for one year is $1,107, for 1000 acres over the course of ten years the savings is $11,070, and farming 10,000 acres for ten years the fuel saving is $110,700. That's a combined labor and fuel savings of $2,767.50 per year for a 1000-acre farmer and a $27,675 savings per year for a 10,000-acre farmer.

Integrating GPS guidance with Real Time Kinematic (RTK) satellite navigation into a strip-till program allows farmers to increase corn yields as well as reduce fertilizer input amounts. Higher yields with lower fertilizer inputs are achievable because RTK makes sub inch repeatability achievable, which means, farmers are able to follow previous lines made through a field and be less that one inch off the previous line taken across a field. Figure 1 shows the difference in a tower-based system, which is comparable to RTK, and a satellite-based system which is your basic GPS.

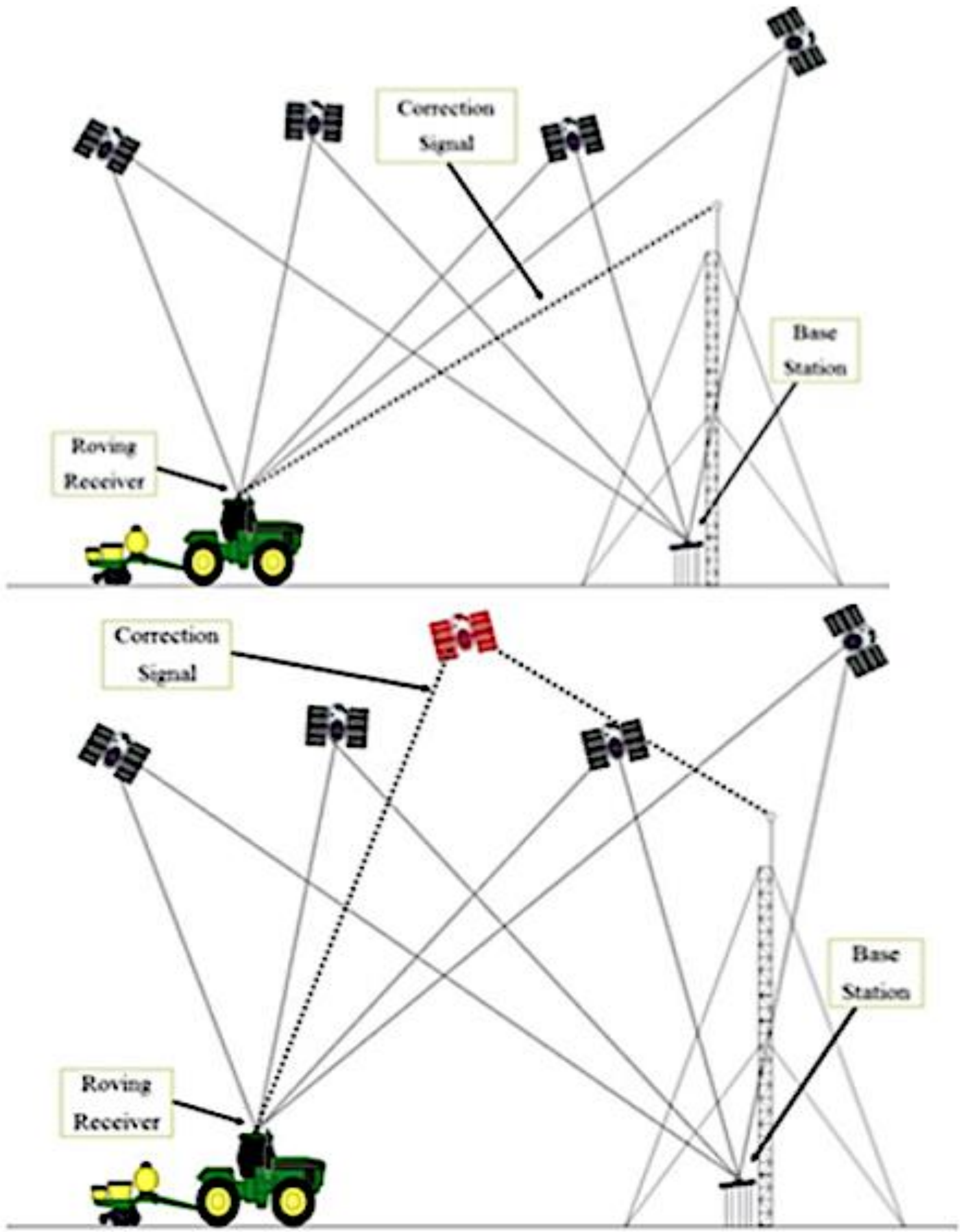


Figure 1. Tower-based signal service (top) vs. satellite-based signal service (bottom)

Tower-based systems allows for more accurate repeatability for cropping practices such as strip-till. Using a strip-till program allows farmers to place the nutrients directly where the farmer needs them, instead of scattering them across the whole field.

Table 1. Results of soil test behind a fertilizer spreader truck covering a 60 ft. swath.

	Swath No.							
	1		2		3		4	
Block	Range	Avg	Range	Avg	Range	Avg	Range	Avg
				pH				
B	5.8-5.9	5.9	5.7-5.8	5.8	5.4-5.9	5.7	5.3-5.8	5.6
C	5.8-6.6	6.2	5.8-6.1	5.9	5.6-5.9	5.8	5.6-5.8	5.7
				Phosphorus				
B	41-59	51	53-90	72	70-140	86	70-122	94
C	99-212	123	45-129	84	29-43	33	35-59	45
				Potassium				
B	284-375	320	261-418	334	368-476	427	388-501	454
C	341-533	420	319-407	368	272-316	292	309-334	332

1/ Av. of 6 composite samples taken across each 60-ft swath
2/ lbs/A
Source: Wells & Dollarhide (1998).

Table 1 shows the variability of fertilization application by a spreader truck with a 60 ft. swath. The fertilizer application had variability from 37 to 157 pounds per acre which can be the difference in a below average crop, average crop or a bumper crop. Strip-till and banded fertilization applications will provide little to no variability due to the direct placement of fertilizer in the needed area.

A strip-till program starts in the fall with a rip-strip cultivation machine, which is found in various brands. In strip-tilling ground dry phosphorous (P) and potassium (K) fertilizers are banded, or placed below the soil surface, so they are readily available to the plants at the proper times. In the spring, strip-till fields are burned down like normal and the same strip-till lines are used for planting. During planting, a liquid row starter solution containing nitrogen and some macronutrients is 2x2 banded, which is 2 inches to one side of the seed and 2 inches below the seeds planting depth, so the corn plant gets the proper nutrients at the exact time. Tony J. Vyn and his colleagues from Purdue University have performed extensive research on strip-till and different fertilizer application methods to determine the different effects on cropping systems. The research includes various soil types, cropping systems, fertilizer application methods, tillage methods, and planting dates to determine how different circumstances have varying results. Below is a picture of fall strip-till from Purdue University (Figure 2.)

Figure 2. Fall strip tillage banding fertilizer, left, and without banding fertilizer, right. Purdue included various soils and planting dates in its strip-till research to determine the different results across multiple soil types and planting times.

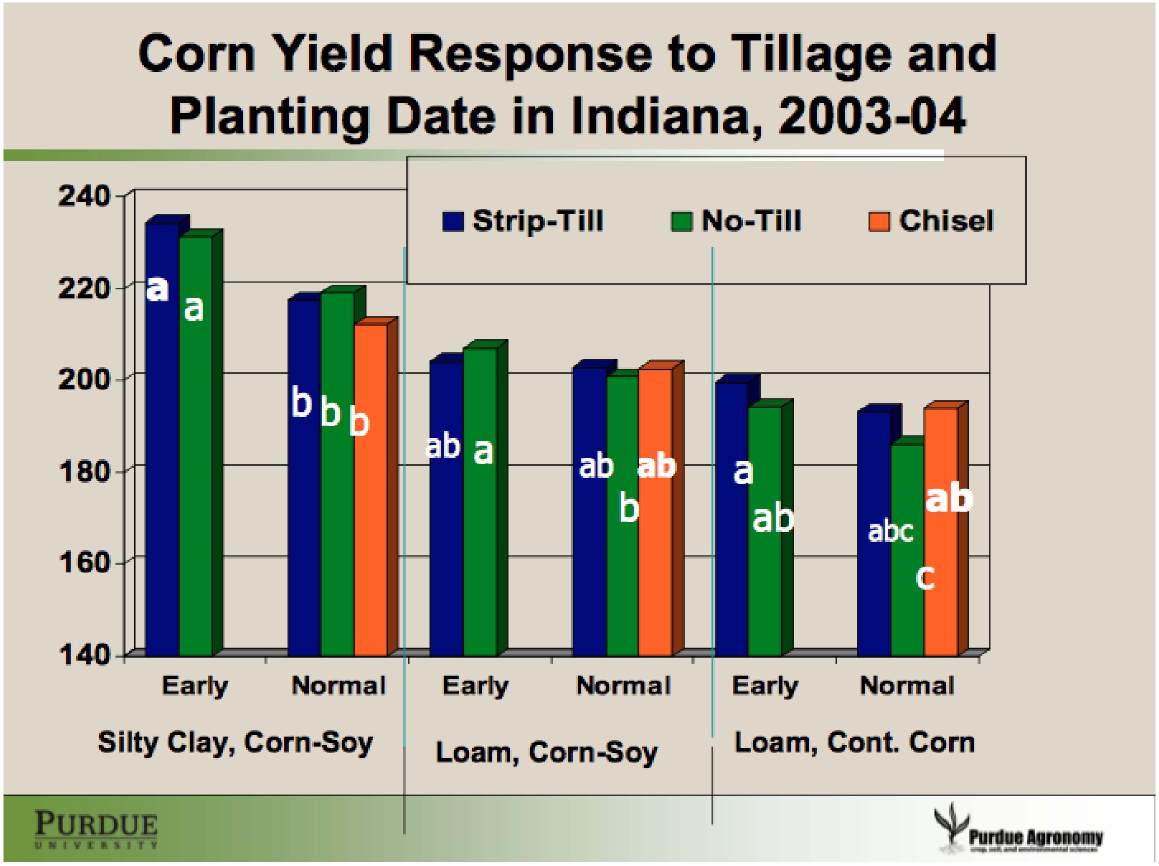


Figure 3. Graph of corn yield response to tillage and different planting dates.

Strip-till systems, (Figure 2), have higher yields than no-till and chisel systems but can have low fertilizer inputs because of the band placement. Having RTK guidance has a huge impact on strip-till results and is greatly needed. Without RTK strip till is not beneficial and is actually worse than many other cropping systems. Seed and nutrient placement is key to making strip-till feasible and effective. Below is a chart that compares RTK strip-till with no RTK strip-till (Figure 4.)

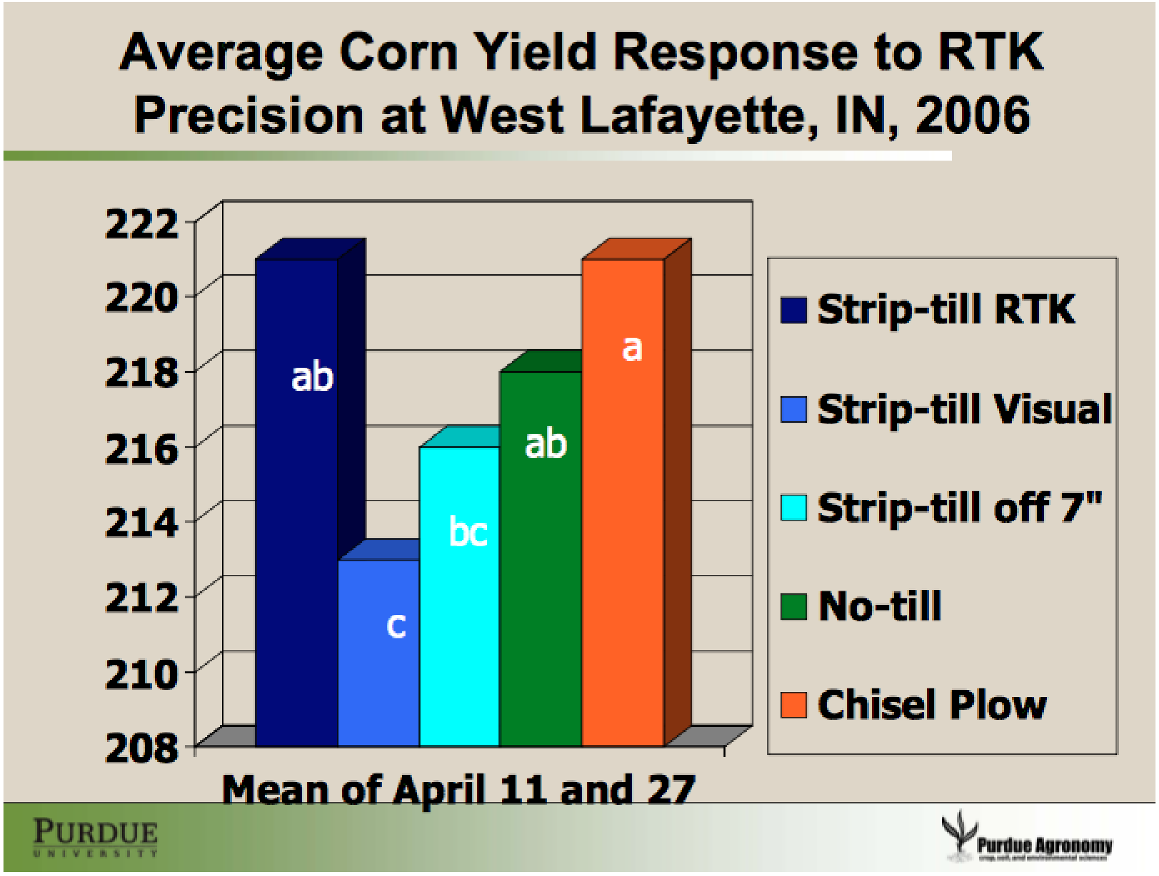


Figure 4. Corn yield responses to RTK precision applications.

Being off only seven inches in a strip-till program cause a 5-bushel per acre yield loss. This shows why sub-inch repeatability with RTK is critical to the strip till program. Strip-till system is a perfect example of integration of information and farm production, as well as technology to achieve maximum yield while reducing costs, and creating more revenue. Therefore, it will fit in the application of PA.

Variable Rate

Variable rate is a continuously changing value or rate at which a farmer is planting or applying fertilizer or chemicals based on various factors and specification of the land. One of the biggest selling points of precision agriculture is the possibility of reducing cost while increasing overall profits. With commodity prices being in continuous flux and input prices remaining close to the same, farmers are trying to find a solution to reduce costs. Several PA implements such as auto guidance, variable rate planting and chemical/fertilizer application, and pneumatic or hydraulic down pressure on planters, are designed to increase operator efficiency, planting and chemical placement accuracy and plant emergence percentages. Implementing these PA applications can reduce operation cost and increase crop production. Various types of mapping systems such as, yield mapping, soil mapping, revenue mapping, weed pressure mapping, and many other forms of mapping data to specific fields help to understand how the strengths and weaknesses of different parts of every field. Figure 5 shows examples of prescription, or recommendation, maps for Urea Ammonium Nitrate (UAN) and yield maps for corn, for variable rate UAN application.

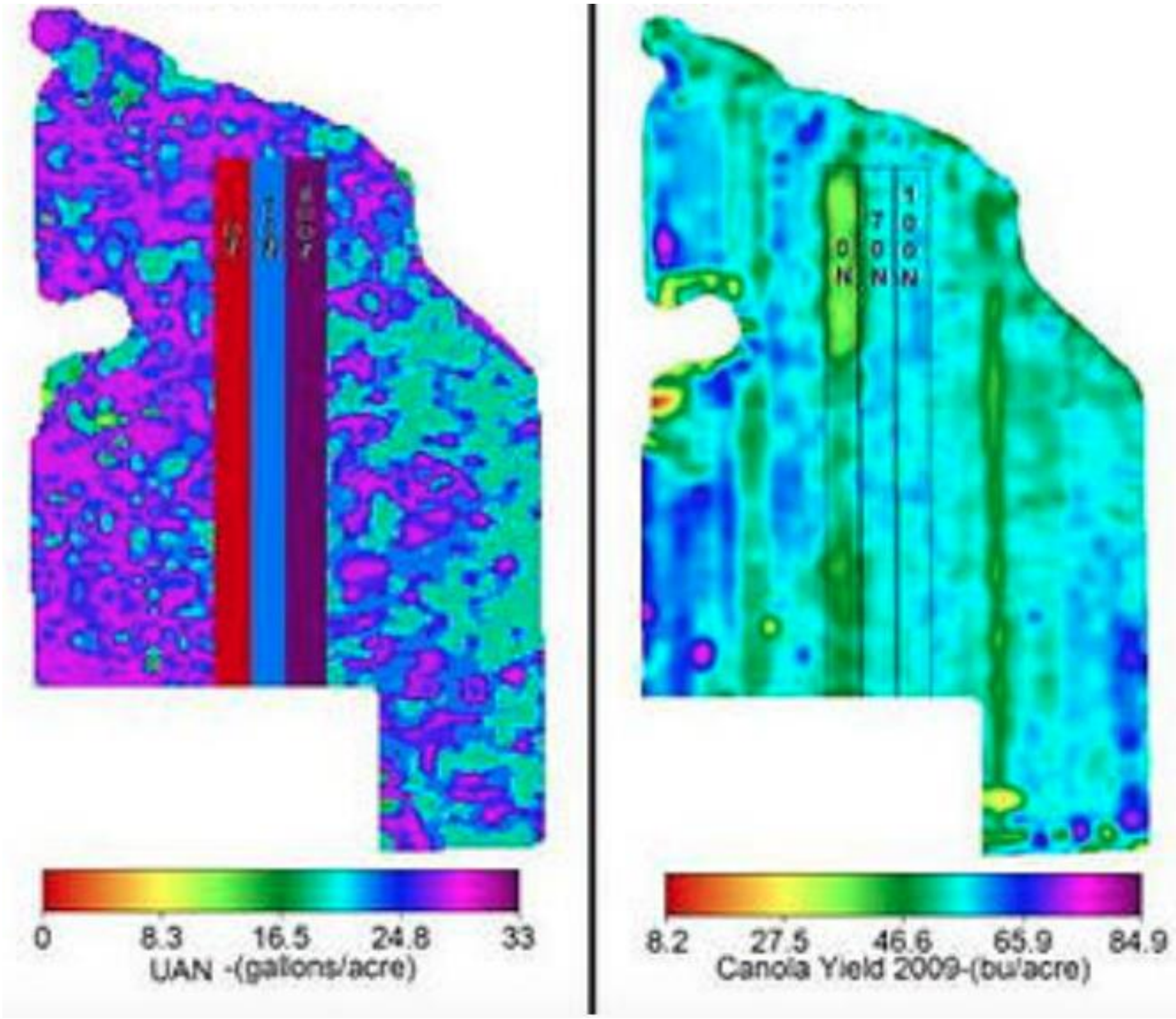


Figure 5. Yield mapping systems, prescription and results,

Image retrieved from: http://www.croppro.ca/maps/on_farm_trial_maps.html

Mapping also allows farmers to target both weak and strong areas to maximize profit potential and minimize costs of inputs. Precision chemical application can be a big factor in economic savings, cases showed there was up to 60 percent pesticide savings and up to 30 percent fertilizer savings due to precision chemical application (Lowenberg-DeBoer and Swinton, 1997; Batte and van Buren, 1999; Pecze, 2006; Rider *et al*., 2006). Hall and Faechner (2005) reported precision chemical application for weed control resulted in 60 percent savings. Precision chemical applications are planned by using mapping technology that determines the amount of weed stress, yield potential, water drainage, disease pressure, and insect pressure. Through mapping farmers are able to do variable rate applications of chemicals. This provides every area with the proper amount of chemical needed, reducing the amount of waste in sections of the farm that may not need as much chemical, but also reducing the amount of under applicated sections of the farm which need more chemical application due to heavier stress. Mapping can be used through the whole planting, growing, and harvesting season and be connected to increase results and understanding of how to maximize profits. Individual maps show a small piece of the puzzle to maximizing yields and minimizing costs, but when soil data maps are used in conjunction with yield data maps, fertilizer prescription maps, and variable rate planting maps, true gains can be accomplished. The integration of all these mapping systems allow for the comparison of larger amounts of data, causing more precise decisions to be made.

Variable rate planting is effective at increasing yields and is compounded by pneumatic down pressure on planters. Planters can be equipped with row clutches that allow individual rows to increase or decrease population or even shut completely off. They can also be equipped with variable rate down pressure that ensures even planting depth for higher, more even plant emergence, thus increasing yield potentials. A study conducted by Becks on down pressure revealed that down pressure could result in 8-16 bushel per acres increase in corn yields. Quantifying those numbers, on 1000 acres of corn at $3.75 per bushel, results in a $30,000 - $60,000 increases in profits, and on 10,000 acres of corn that’s $300,000 - $600,000 increased profits. Soil mapping and sampling also greatly contributes to the PA industry by providing the information needed to determine more precise plant populations to achieve maximum yield potentials. For example, a more fertile soil that is well drained will produce higher yields at higher plant population, while a less fertile soil that is still well drained but may be on a high spot or hill will produce higher yields with slightly lower plant populations. The reason for this is due to the ability of the soil to sustain the growth of a certain number of plants, higher fertility results in greater ability to provide necessary nutrients to produce healthy plants. The lower fertility areas will not be able to produce the proper foundation for healthy growth with a high plant population resulting in lodging, weak/small stalks, small ear/pod development, or no yield production at all. This is seen a lot in end rows of cornfields where several rows over lap or are double planted and all that is produced in stalk with very little ear corn production. This is combated by variable rate planting and GPS guidance that connect to the planter and individual row clutches that are on the planter. The guidance notifies the planter and clutches that this spot has been planted and to shut off individual rows to prevent double planting. Not only does this increase yield potentials, but it can lower the overall amount of seed used for planting, thus reducing cost while increase production and profits. Figure 6 shows end rows in corn planted using precision technology and individual row clutches.

Figure 6. Picture of corn end rows planted with a planter equipped with row clutches and precision technology. Retrieved from casifarm.files.wordpress.com

Environmental benefits of Precision Agriculture Through No-Till, and Confined Animal Feeding Operations

Not only does PA help the economy and increase profits while reducing costs, it is beneficial to the environment. Traditional farming consisted of disking or some type of conventional tillage at least two to three times before planting, over spraying chemicals due to overlapping passes, and large herds of cattle and hogs moving freely across farms, harming the environment through soil degradation, and water and air pollution. No-Till cropping systems have several benefits for the environment and for farmer's profits. Some of the benefits of no-till farming are: erosion control, higher water infiltration, lower evaporation, organic matter conservation, improved soil structure, higher biological activity, more earthworms, reduced total phosphorus losses, lower labor needs per acre, higher efficiency of farm operations (Duiker & Myers 2005).

Each of these has significant benefits and will be discussed in more detail through the section. Conventional tillage degrades the soils structure, reduces organic matter, and changes both its physical and chemical properties and 70% of all erosion can be accredited to tillage, (Blanco & Lal 2010). Conventional tillage also makes soil more susceptible to erosion and reduces the amount of living organisms in the soil thus reducing it health and fertility. Table 2 shows the impact of tillage systems on soil erosion in various regions.

Table 2. The effect of tillage direction, slope, and tillage method on soil erosion.

Counrty	Tillage Direction	Soil Slope (%)	Tillage Method	Soil Erosion (Mg/ha/yr)
China	Downslope	43	Manual hoeing	48-151
Spain	Downslope	40	Moldboard plow	68
China	Downslope	40	Animal traction	22
Portugal	Downslope	25	Moldboard Plow	35
Philippines	Up- and down-slope	45	Moldboard Plow	456-601
Belgium	Up- and down-slope	14	Moldboard and chisel plow	10
US	Up- and down-slope	14	Moldboard plow	30

Source: Blanco & Lal (2010)

Through scientific and mechanical research, new equipment has been produced which allows farmers to use conservation tillage and no-till farming practices, thus reducing the amount of passes over a field required to put out a crop. This, over time will help rebuild the health of the soil and increase soil fertility. Data from Table 3 shows that no-till management systems reduce the run off and erosion indicating less soil degradation compared to moldboard tillage systems after four years.

Table 3. A 4-year comparison of runoff and erosion on a no-till and moldboard plowed watershed at the North Appalachian Experimental Watershed.

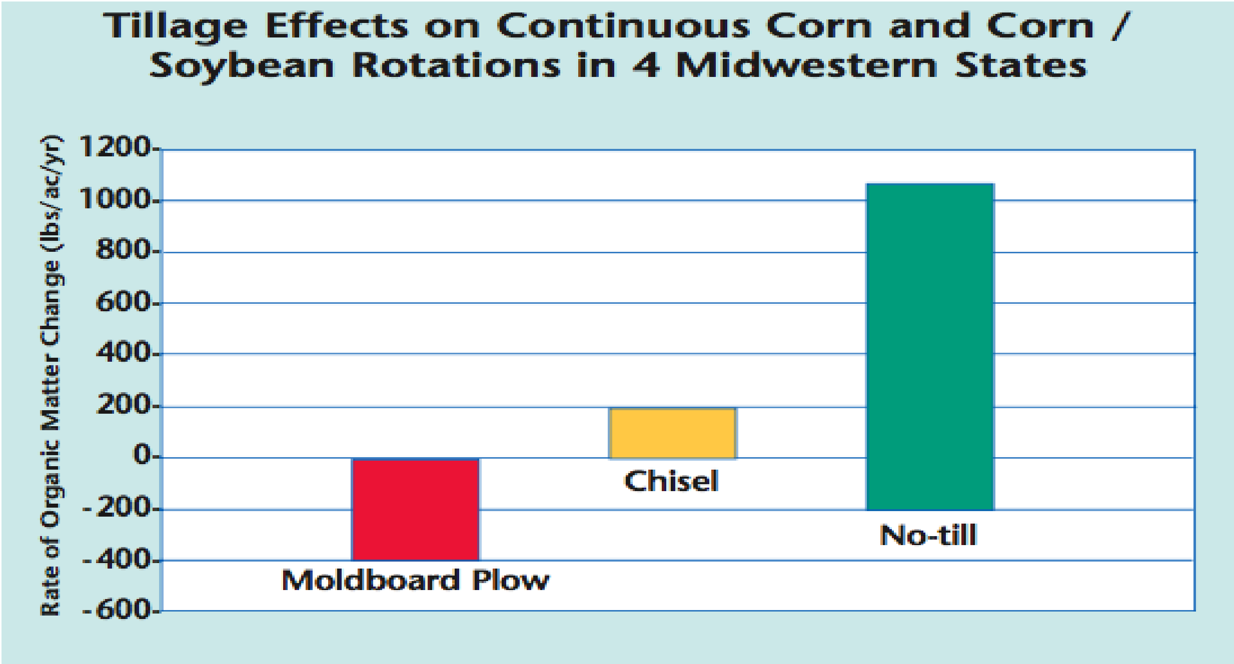
Year	Rainfall (inches)	Runoff (inches)		Erosion (LBS/A)	
		No-Till	Moldboard	No-Till	Moldboard
1979	44	0.14	5.52	8	436
1980	46	0.19	12.47	15	8455
1981	42	0.00	5.60	1	7645
1982	35	0.00	4.46	0	2461
Average		**0.09**	**7.01**	**6**	**4748**

Sjoerd W. Duiker & Joel C. Myers, (2005).

The amount of water and soil that can be conserved in the no-till system is drastically better than that of conventional tillage. This is an example of how the many different facets of PA are beneficial to, both the cropping system and the environment. Figure 7 shows the difference in soil vulnerability under conventionally tilled cropland versus no-till cropland.

Figure 7 – the difference in residue coverage in plow tillage (left) and no-till (right) systems. Blanco, H. & Lal, R., (2010).

The increased soil vulnerability leads to increased erosion and decreased soil fertility as well as the degradation of soil physical and chemical properties, which in turn reduces crop yields and threatens the sustainability of agriculture. Conventional tillage methods reduce the amount of organic matter and living organisms in the soil thus degrading the surrounding ecosystem. Figure 8 shows the effects of tillage on soil organic matter and earthworms.



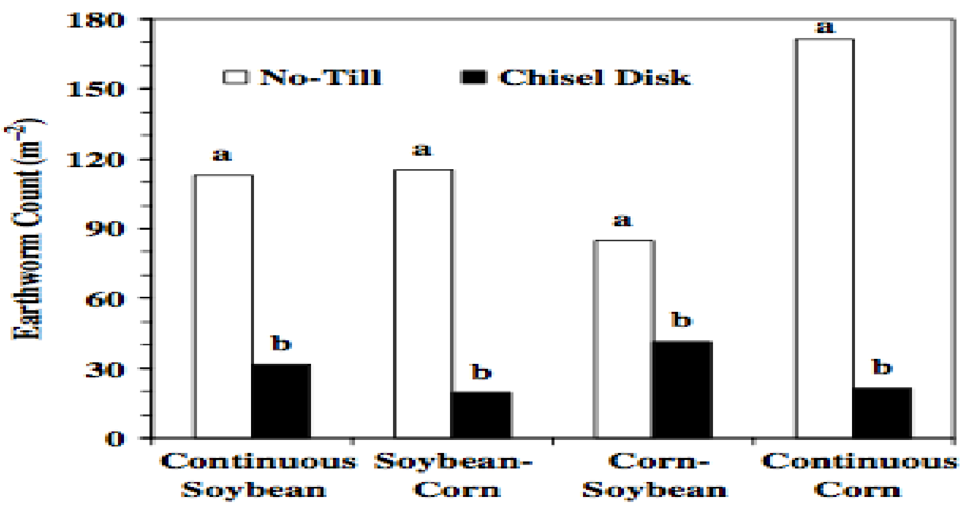


Figure 8. Tillage effects on continuous corn and corn/soybean rotations and comparison of no-till and chisel effects on earthworm counts. Tillage influence earthworm population (After Jordan et al. 1997). Bars followed with different letters within the same cropping system are significantly different ($P<0.05$). Residue left on the soil surface provides an abundant food source and habitat to earthworms responsible for macropore network development. Reduction in surface mulch cover reduces earthworm populations and the number of surface connected macropores. (Blanco, H. & Lal, R., 2010).

Earthworms provide beneficial services to ecosystem such as nutrient cycling, climate regulation, water regulation, development of soil structure, pedogenesis, and pollution remediation (Bertrand et al. 2015). These benefits allow for a better, healthier condition for crops to grow. They reported that, earthworms cause crops to be more resistant or tolerant to diseases and pests and/or could be an effective agent for biological control of soil pathogens. The benefit of higher resistance or tolerance to diseases alone is a huge benefit to farmers because their crops will be at less risk from diseases, and they will not have to spend extra money to prevent or treat diseases. Another benefit of earthworms is increased nutrient use efficiency due to the temporally and spatially synchronized earthworm activity and plant activity or nutrient release. Casts also enrich in mineral nutrients and available for crops. Table 4 shows the many benefits earthworms have on cropping systems.

Table 4 – Lists of agricultural issues that constrain profitable crop production, together with the ways that earthworms could help to solve these problems (Bertrand et al. 2015)

Agricultural issues	Mechanisms through which eaethworms can help
Deterioration of the structure of cultivated soils	Earthworms improve soil aggregation and macro-porosity through their casts and galleries
Low organic matter content in cultivated soils	Earthworms tend to stabalize some soil organic matter within their casts
Cultivated plants require large inputs of mineral nutrients and nutrient losses must be reduced	Earthworms accelerate nutrient mineralization on the short term. Plant growth could be temporally and spatially synchronized with earthworm casting activities, creating of small patches enriched in mineral nutrients and hormone-like effects
Pesticides use should be reduced, seek more sustainable ways to control pests and pathogens	Earthworms may decrease the negative impacts of some pests and pathogens (nematodes,fungi)

One critical factor for soil fertility and most soil functions is soil structure (Bertrand et al. 2015). Stable aggregates are created through the mixing of mineral weathering and humus formation due to the formation of soil and soil structure in which earthworms contribute to. Through their burrowing activities, earthworms also affect the hydraulic and mechanical properties of soil, thus creating macro pores, which significantly effect water infiltration and is extremely important to crops because of the water supply they receive due to less run off. (Bertrand et al. 2015). Overall earthworms are beneficial to the cropping system in many ways. The way to maintain the proper amount of earthworms in soil is to adopt cropping practices that allow earthworm to thrive or repopulate. This can be done through conservation tillage practices, such as the no-till cropping system. It can also be done through reduction of herbicides and pesticides. The increased soil fertility from earthworms through no-till cropping systems allows for higher yield potentials, thus increasing crop production and farmers profits. Also no-till cropping systems allow for less passes across a field, which reduces fuel and labor costs, which in turn also increases farmers profits.

Helping the ecosystem through more conservative farming methods helps the ecosystem to be sustainable. Increasing soil fertility can reduce the amount of passes over the ground. The amount of passes across the ground can also be reduced through no-till farming practices, causing lower amount of fuel consumed, thus reducing air pollution. Limited air pollution helps reduce green house gasses and sulfate deposition from precipitation or acid rain. Figures 9 and 10 show the comparison of sulfate deposition through rain from 1989-1991 and 2007-2009 in the USA.

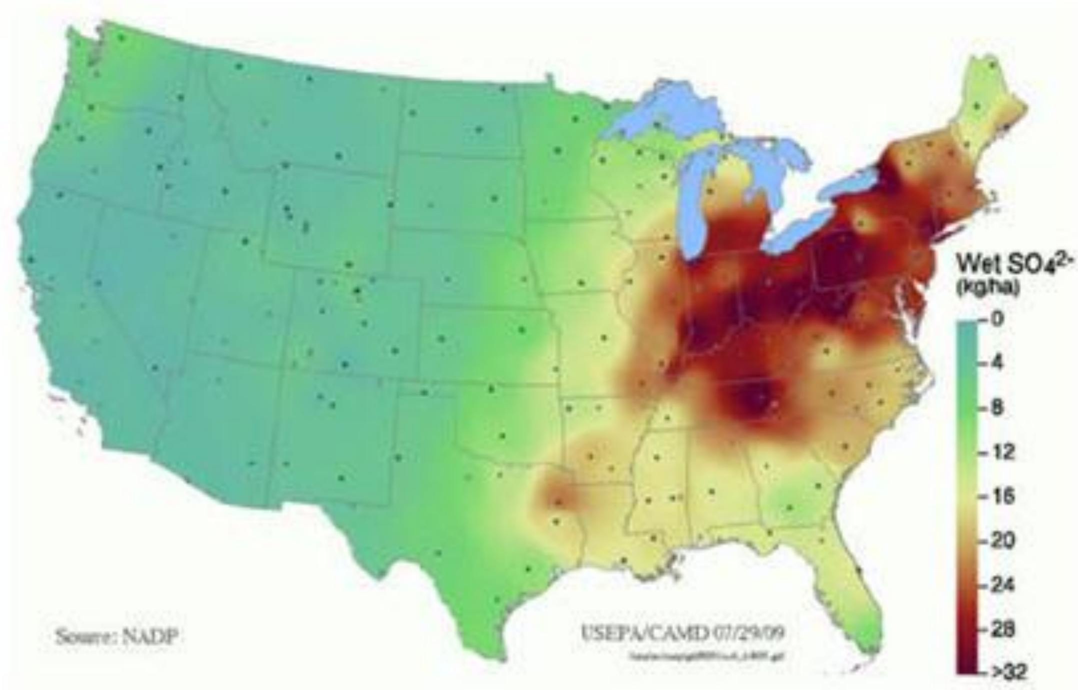


Figure 9. Sulfate deposition through rain from 1989-1991. (DuPont/Pioneer)

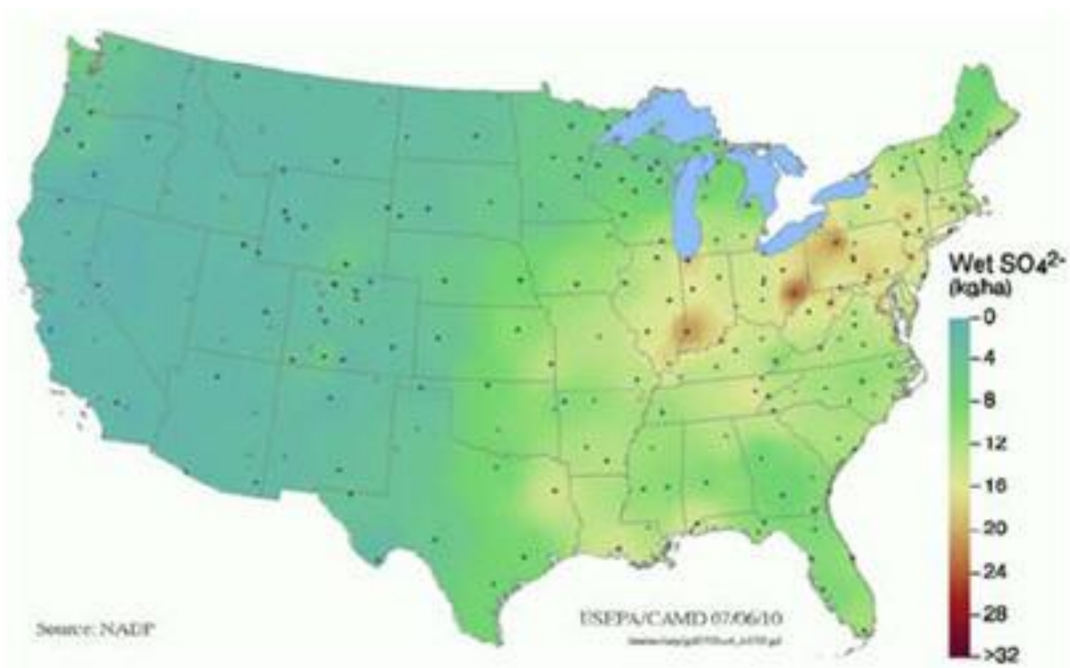


Figure 10. Sulfate deposition through rain from 2007-2009 (DuPont/Pioneer)

The reduction of acid rain is due to EPA regulations on exhaust system in motorized vehicles and equipment, as well as reduced use of equipment. Although farmers have to find other ways to introduce sulfate to their crops the overall benefits of the regulations and reduced usage are far greater than the inconvenience of reduced atmospheric sulfate. By reduced equipment use, there is less cost to operate and less wear on machinery giving the machinery a longer life span and reducing costs exponentially. This increases profitability through reducing fuel costs, labor, and maintenance as well as reducing the impact on wildlife and environment through reduced pollution. Also new varieties of crops have been produced that are resistant to certain chemical, pests, and various types of stress, allowing farmers to use less amounts of chemicals. By using less chemicals farmers are able to reduce cost as well as pollution through chemical loss. These new crop varieties, such as BT corn that is genetically modified to create a protein that kills Lepidoptera larvae, specifically, European corn borer. According to the NRCS (2007) precise nutrient applications can provide significant economic and environmental benefits. Appling only the nutrients that the plants needs and can use reduces excess chemical that leads to runoff pollution. Application rates will vary within the field based on existing fertility levels, soil types, and environmental sensitivity. Some soils in a field simply do not have the yield potential to justify maximum rates of nutrient application. Other areas may require reduced rates because of environmental sensitivity. Using fewer amounts of chemicals results in reduction of water pollution du to runoff and leaching, as well as reduces air pollution from volatilization. Blanco and Lal (2010) reported that “Discriminate use of inorganic fertilizers and other agrichemicals through precision farming and choice of appropriate cropping systems are useful strategies to minimize environmental pollution.”

Along with reduced passes over the ground, the precision spraying application of chemicals with swath or section control reduces the amount of over application of chemicals. Over application of chemicals leads to run off, volatilization, seepage, or leaching of chemicals which causes pollution to the ecosystem, particularly water. Table 5 shows samples of groundwater near rice fields tested for chemicals.

Table 5. Pesticides found in groundwater samples collected from shallow tub wells near rice fields. Data taken from Varca (2010).

Pesticides	No. samples	% samples contaminated	Mean concentration (ppb)	
			all samples	contaminated samples
Chlorpyrifos	150	7	0.002	0.026
Butachlor	270	24	0.039	0.163
Endosulfan	207	79	0.089	0.113
Carbofuran	270	6	0.011	0.202
Methyl parathion	270	24	0.006	0.026
Monocrotophos	150	54	0.209	0.386
Total			0.356	0.916

Source: Castaneda 1996

Polluted ground water can be detrimental to the ecosystem. It can cause abnormal algae growth in water systems, kills fish and other animals, and if at high enough concentration can be harmful to humans. According to the United States Geological Survey (USGS) the inorganic nitrogen, nitrate, can pollute water system at high concentrations. The USGS states:

> "Excessive concentrations of nitrate in lakes and streams greater than about 5 milligrams per liter (measured as nitrogen), depending on the water body, can cause excessive growth of algae and other plants, leading to accelerated eutrophication or 'aging' of lakes, and occasional loss of dissolved oxygen. Animals and humans cannot use inorganic forms of nitrogen, so nitrate is not a nutrient for us. If nitrate-nitrogen exceeds 10 milligrams per liter in drinking water, it can cause a condition called methemoglobinemia or "blue baby syndrome" in infants. Some recent studies have indicated a possible connection between elevated nitrate concentrations and cancer."

There are many ways nitrate can enter water systems, but the most common is over application of the chemicals, which leads to direct pollution through run off. Through PA technology over application of chemical can be minimized, thus reducing the amount of pollution and the impact on wildlife, which coincides.

Other pollution occurs when cattle, hogs, chickens, and other animals raised for human consumption in large numbers that are able to roam free and pose a threat to the environment through over grazing and water pollution. According to Florea (2016), There is a great deal of natural carbon in the water that comes from vegetation, but the high concentration of carbon may result from nearby farms, mostly cattle, and confined animal feeding operations (CAFOs), mostly poultry. In fact, south central Kentucky has scores of these poultry farms, and their waste may go from the operations and into the groundwater. In addition the soil and rock will absorb some of the pollutant as the waste flows through it, but a lot of it ends up in the unground rivers and streams. In this use it is also important to know where the pollutants are originating (Florea, personal communication, 2016). This testing showed how high concentrations of animals, even CAFOs when not managed properly, can cause water pollution.

Over grazing land can result in increased erosion due the severe reduction in living plant matter protecting the soil. Pollution of water of natural water sources such and creeks, streams, rivers, and ground water can be a result of large number of cattle roaming freely as well because of the amount of manure. Confined Animal Feeding Operations can reduce the amount of environmental degradation if managed properly. According to The Department of Natural Resources of Missouri, modern agriculture systems can help in the reduction of the overall environmental impact of poultry and livestock production, this includes CAFOs. There is increased environmental risk with the increased animal concentration in barns on each farm. The large amounts of manure that each of these barns produce must be managed properly to reduce the risk of pollution of the environment. Famers will have a safe, reliable, and sustainable fertilizer source for their farming operation once proper waste management is accomplished. When proper waste management is not achieved CAFOs can have impact the environment negatively. Manure can be contained and disposed of properly, and overgrazing of land can be regulated. Missouri has put in place regulations and laws that minimize risk of pollution due to improper waste management. Confined Animal Feeding Operations can be considered precision agriculture because of the production based information that is incorporated into their design. Planning and deciding the number of animals one CAFO building can accommodate to maximize the amount produces while minimizing the amount of inputs takes time and precise analysis of information. Finally, Confined Animal Feeding Operations require the analysis of vast amounts of data to determine profit points and input cost points to maximize production, thus minimizing input costs and reducing environmental impact.

Farm Planning

Farm planning plays an enormous role, if not the largest role, in precision agriculture based on the U.S. House of Representatives Definition. Gathering information and using it to create budgets and preparing crop plans for the upcoming year. Planning the precise amount of each crop, animal, or forage a farmer is going to produce in a given year is crucial to the farming operation to increase profits. One of the greatest tools for whole farm planning is linear programing. Linear programing is a mathematical procedure that uses systematic techniques to find the most profitable combination of enterprises. Also linear programing models have linear objective functions that are maximized, or minimized, subject to the resources available. The notation for a linear programing model are as follows; $C_n X_n$, Max/Min, objective function, what you are trying to maximize or minimize, $A_n X_n \leq B_n$ where A is the resource requirement and B is the resource limit, and $X \geq 0$ which is the non-negative constraint. A sample blank notation would be as follows:

$C_1 X_1 + C_2 X_2$ Max or Objective function

$A_{11} X_1 + A_{12} X_2 \leq B_1$ First resource limit or constraint

$A_{21} X_1 + A_{22} X_2 \leq B_2$ Second resource limit or constraint

The following is an example of a linear model for whole farm planning: A Farmer has 2000 acres of class A cropland, 1000 acres of class B cropland, and 1400 acres of permanent pasture and the farmer is limited to a total of 10000 hours of labor. Class A cropland can grow corn, soybean, and milo, class B cropland can grow soybeans and milo, and to keep crop rotation the farm decides to grow a maximum of 1000 acres of corn. The livestock enterprise consists of beef cattle and stocker cattle and beef cattle require part of class B cropland for hay. The resource requirements for the whole farm linear model are as follows:

- One acre of corn produces $180 profit and requires 4 hours of labor on class A cropland.
- One acre of soybeans produces $135 profit and requires 3 hours of labor on class A cropland.
- One acre of milo produces $120 profit and requires 2.5 hours of labor on class A cropland.
- One acre of soybeans produces $90 profit and requires 3 hours of labor on class B cropland.
- One acre of milo produces $75 profit and requires 2.5 hours of labor on class B cropland.
- Beef cattle produce $220 profit per head and require 1 acre of class B cropland, 5 acres of pasture and 5 hours of labor.
- Stocker cattle produce $75 profit and require 3 acres of pasture and 1 hour of labor.

C will represent corn, S will represent soybeans, M will represent milo, F will represent beef cattle, and T will represent stocker cattle. The subscript A, B, and C will represent the classes of land. The first step is to set up the profit maximization function, which in this case is $180C_A + 135S_A + 120M_A + 90S_B + 75M_B + 210F + 75T$. The first constraint is for class A land and the function is $1C + 1S_A + 1M_A \leq 2000$. The second constraint is for class B land and the function is $1S_B + 1M_B + 1F_B \leq 1000$. The third constraint is for class C land and the function is $5F_C + 3T_C \leq 1400$. The forth constraint is labor $4C_A + 3S_A + 2.5M_A + 3S_B + 2.5M_B + 5F + 1T \leq 10000$. The last constraint is maximum corn acres and the function is $1C_A \leq 1000$. Once the functions are set u they can be integrated into an excel spreadsheet as shown in Figure 11.

	A	B	C	D	E	F	G	H	I	J
1			Class A			Class B				
2										
3		Corn	Sbean	Milo	Sbean	Milo	Beef	Stocker		
4	Max	180	135	120	90	75	220	75	0	
5	Class A	1	1	1	0	0	0	0	0	2000
6	Class B	0	0	0	1	1	1	0	0	1000
7	Class C	0	0	0	0	0	5	3	0	1400
8	Labor	4	3	2.5	3	2.5	5	1	0	10000
9	Corn	1	0	0	0	0	0	0	0	1000

Figure 11. Set up of linear program in Excel

The Max row is the profit maximization objective while the other rows are the constraints respective to their name. The column represents each crop or cattle type and how they relate to each constraint, and the yellow represent the amount of each commodity raised. Column 9 contains the formulas for profit maximization and each constraint and are entered as follows:

Max - =B4*B2+C4*C2+D4*D2+E4*E2+F4*F2+G4*G2+H4*H2

Class A - =B5*B2+C5*C2+D5*D2+E5*E2+F5*F2+G5*G2+H5*H2

Class B - =B6*B2+C6*C2+D6*D2+E6*E2+F6*F2+G6*G2+H6*H2

Class C - =B7*B2+C7*C2+D7*D2+E7*E2+F7*F2+G7*G2+H7*H2

Labor - =B8*B2+C8*C2+D8*D2+E8*E2+F8*F2+G8*G2+H8*H2

Corn - =B9*B2+C9*C2+D9*D2+E9*E2+F9*F2+G9*G2+H9*H2

Once all the data and formulas are entered into the spreadsheet use the solver, sown in Figure 12 to solve for the most profitable combination.

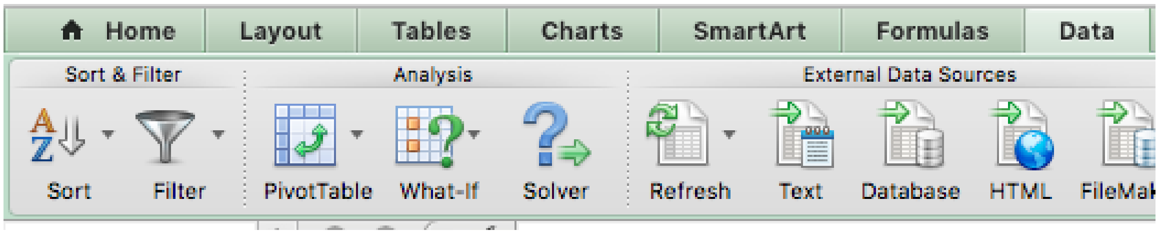


Figure 12. Solver for Excel

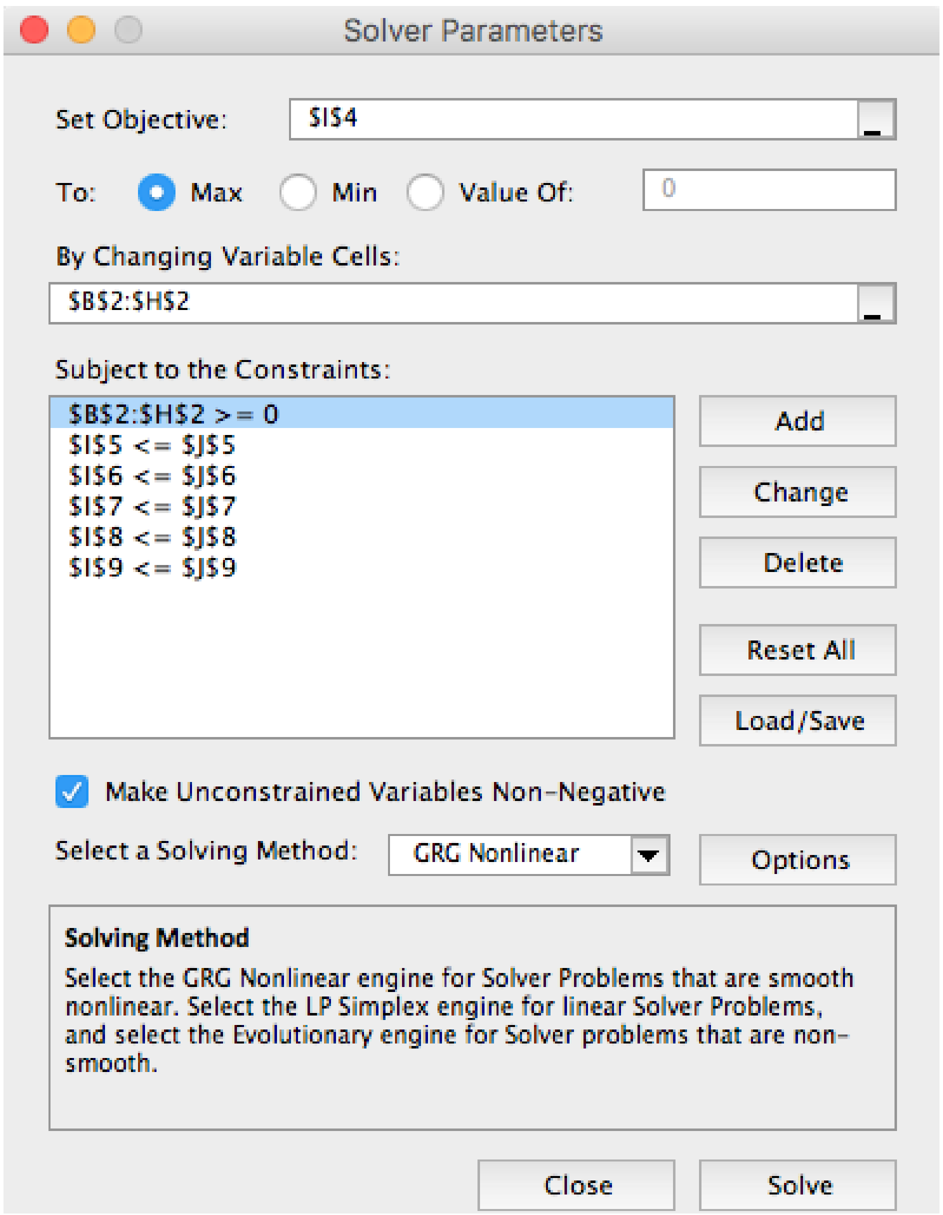


Figure 13. Solver parameters in Excel

Figure 13 shows how the solver needs to be set up in order to get the results desired. Once all the data for the objective function and constraints are entered into the solver, click solve for the results. The results are shown in Figure 14.

	A	B	C	D	E	F	G	H	I	J
1		Class A			Class B					
2		1000	436	564	631	369	0	467		
3		Corn	Sbean	Milo	Sbean	Milo	Beef	Stocker		
4	Max	180	135	120	90	75	220	75	426000	
5	Class A	1	1	1	0	0	0	0	2000	2000
6	Class B	0	0	0	1	1	1	0	1000	1000
7	Class C	0	0	0	0	0	5	3	1400	1400
8	Labor	4	3	2.5	3	2.5	5	1	10000	10000
9	Corn	1	0	0	0	0	0	0	1000	1000

Figure 14. Linear program solver results.

Figure 14 cell I4 shows the maximum profit possible in the given scenario is $426,000 by producing 1000 acres of corn, 436 acres of soybeans, and 564 acres of milo on class A land, 631 acres of soybeans, and 369 acres of milo on class B land, as well as zero beef cattle and 497 stocker cattle. Every acre of land and hour of labor available was used and the most profitable solution was found. Taking farm planning a step further after using solver to get the most profitable combination use the answer sensitivity report in the solver results screen. Figure 15 shows how to get the shadow prices (lagrange multiplier) and the reduced costs (reduced gradient)

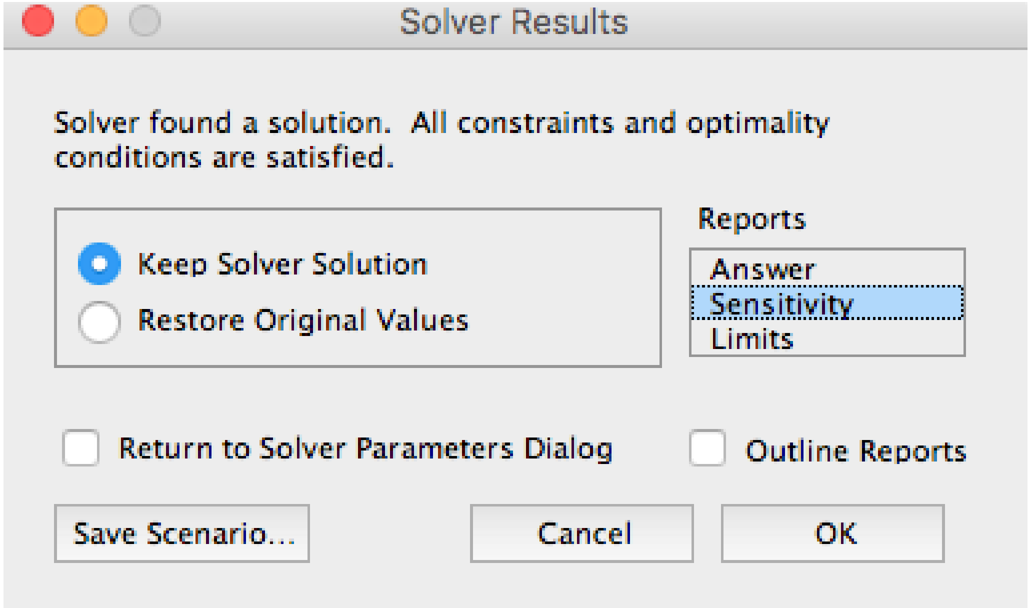


Figure 15. Sensitivity analysis for shadow prices and reduced costs in Excel

Shadow prices are defined as the change in the objective function when one unit of the resource (constraint) is changed. Reduced Costs are defined as the change in the objective function when one unit of a variable that is not in the optimal solution is forced into the solutions. Shadow prices and reduced costs for the previous example are show in Figure 16

Variable Cells

Cell	Name	Final Value	Reduced Gradient
\$B\$2	Corn A	1000	0
\$C\$2	Sbean A	435.5303167	0
\$D\$2	Milo A	564.4696833	0
\$E\$2	Sbean B	631.1363499	0
\$F\$2	Milo B	368.8636501	0
\$G\$2	Beef	0	-5.000065083
\$H\$2	Stocker	466.6666667	0

Constraints

Cell	Name	Final Value	Lagrange Multiplier
\$I\$5	Class A	2000	44.99991546
\$I\$6	Class B	1000	-9.55397E-05
\$I\$7	Class C	1400	14.99998944
\$I\$8	Labor	10000	30.00003071
\$I\$9	Corn	1000	14.99995972

Figure 16. Shadow prices and reduced cost results from Excel

The shadow prices can be interpreted as follows:

For every additional acre of class A land that can be acquired, one can increase profits by approximately \$45. For every additional acre of class C land that can be acquired, one can increase profits by approximately \$15. For every additional hour of labor that can be acquired, one can increase profits by approximately \$30. For every additional acre of corn that can be grown, one can increase profits by approximately \$15.

The reduced costs can be interpreted as follows:

For every additional beef cow raised profits will decrease by approximately $5. Since all other variables were grown they do not have reduced costs. This form of farm planning assures that the most profitable outcome, as well as informs farmers of the most profitable areas are to increase production in.

Taking farm planning a step further into equipment purchase planning can determine if an equipment purchase is feasible or not, or can help reduces cost by maximizing trade value, therefore decreasing the total amount spent on equipment. Integrating strip-till into equipment purchase planning, strip-till equipment has to be justifiable and feasible. Therefore, it has to be determined how beneficial is a strip-till system, and how much do I have to invest in this system. Assuming, as shown below, a complete strip-till rig with dry fertilizer banding capabilities, full RTK guidance, and a hydraulic hitch to keep implements from drifting cost $140,000. With a 20% down payment and a 5 year equal payment not at 5%APR the payments would be as shown in Figure 17.

Strip Till Equipment Investment

Strip Till Rig	$120,000
Guidance upgrades	$10,000
Other	$10,000
Total Investment	$140,000

Annual Debt service (20%down-5 equal annual

Down Payment	$28,000.0
1st	$25,926
2nd	$25,926
3rd	$25,926
4th	$25,926
5th	$25,926

Figure 17. Strip-till investment cost.

Also assuming the average amount spent on N, P, and K fertilizer is $115 per acre and a strip-till system can reduce your fertilizer inputs by 30%, that a savings of $34.50 as shown in Figure 18.

Input Reduction	
N, P & K average input cost/acre (normal)	$115
Percent reduction to utilize strip till placement	30%
Input cost reduction per corn acre	$34.50

Figure 18. Reduction of N, P, and K fertilizer input costs.

In addition to the savings a proposed 15-bushel per acre yield bump is a result of using a strip-till system and corn prices are at $4.00. This results in an increased profit of $ 60.00 as shown.

Yield Increase	
Proposed Yield Increase (bushels per acre)	15
Sale price per bushel	4
Increased revenue per acre	$60.00

Figure 19. Proposed yield and profit increase from implementation of strip-till cropping system.

This results in an overall savings of $94.50 per acre and if incorporated over 1000 acres results in an increased bottom line or revenue of $94,500 are shown in Figure 20.

Overall revenue increase per acre	$94.50
Total strip till acres	1000
Overall bottom line increase per year	$94,500.00

Figure 20. Over all increase in annual profits.

In the given scenario the equipment purchased for $140, 000 can essentially be paid for in two years, making it a good purchase decision. This type of equipment purchase planning qualifies as precision agriculture based off the fact that it takes information and integrates it into a production based farming system to determine the feasibility of the purchase.

Maximizing trade value on current equipment owned takes a vast amount of research to determine where the market stands at the current time and what the historical value of the piece of equipment owned. For example, a combine that is 5 years old and has less than 1000 separator hours is worth significantly more than a combine that is 6 years old and has more than 1000 separator hours, but not much less than a combine that is 4 year old and has 800 separator hours, at what point should the combine be traded? To get the most use out of the current combine and the maximum trade value, the combine need to be traded at 5 years old before it reaches 1000 separator hours. Using the information found on values of equipment throughout different stages of its life span all equipment purchases can be planned in advance to be sure to get the best deal possible. Waiting till the last minute to make an equipment purchase or trade can be difficult because many of the desired pieces of equipment may not be available and making a rushed decision may result in a bad purchase that could cost more down the road.

The Future of Precision Agriculture

With all the new innovations in GPS guidance, telematics, and computer-controlled systems, autonomous tractors are being able to be developed. CASE IH Agriculture, one of the leading equipment manufactures unveiled their first concept autonomous tractor in Racine, Wisconsin on August 30, 2016 at the progress farm show in Boone, Iowa. The autonomous tractor can operate a wide variety of implements and can operate its self or be controlled remotely. This autonomous tractor can help farmers overcome the obstacle of finding qualified operators that are able to operate machinery as disused in a interview with Case IH's Brand President Andreas Klauser;

> In many parts of the world, finding skilled labor during peak use seasons is a constant challenge for our customers," said Case IH Brand President Andreas Klauser. "While we offer auto-steering and telematics on our equipment today for remote management of farm machinery and employees, this autonomous tractor concept demonstrates how our customers and their employees could remotely monitor and control machines directly. This technology will offer our customers greater operational efficiencies for tasks such as tillage, planting, spraying and harvesting." Case IH (2016)

With this innovation, struggling to find labor when will be eliminated and efficiency will increase due to reduction in operator error. The autonomous tractor uses a combination of "radar, lidar (light imaging, detection, and ranging) and onboard video cameras" to navigate and sense moving and stationary objects. The autonomous tractor will stop if an object is obstructing its path, and will not resume until the operator assigns a new path, as well as stop if GPS signal is lost to avoid incidences. Along with autonomous tractors, various telematics systems are being developed so the owner of the farming operation, the agronomists, or whoever makes decisions can send out prescriptions to operators for variable rate applications or planting. Mattern (2010) said that "Telematics is a technology that captures data from farm equipment operating in a field and transfers the data to the Internet in real time." Figure 21 and Figure 22 show telematics systems JDlink by John Deer and AGCOMMAND by AGCO.

Figure 21 - JDLink by John Deer (2017), different screes that send prescription chemical aplications and prescription variable rate planting applications, as well as yield monitoring, system monitoring, and efficiency monitoring.
Source: Strom

Figure 22 - AGCOMMAND yield monitoring system. (AGCO 2013)
Source: AGCO

The rapidly growing technology of telematics is allowing farmers to increase efficiency enormously. Telematics is able to replace hand written notes that need to be picked up every morning so an operator know when, where, and how much to plant or apply/spray. This allows operator to start earlier and finish sooner, which in turn leads to needing a smaller window of time for planting as well as chemical and fertilizer application. The future of PA technologies seems endless and will continue to grow. Farmers will have to decide if the new technologies will be beneficial to them in their specific farming operation. These technologies are great innovations but will have to be justifiable and have a return on investment. If there is not a return on investment then farmers will not be able to continue to be sustainable. Farmer will have to continue to collect data and evaluate farm plans, purchase decisions, and return on investments to maximize profits. Precision agriculture can be the future of farming.

Conclusion

Precision agriculture is much more than site-specific management of crops. Precision agriculture encompasses whole farms with various operations. Precision agriculture is takes date and incorporates it into farming operations to minimize economic risk while increasing economic potential. Farming is an ever-changing operation that is difficult to predict or control. Through PA farmers are able to have more control over the potential profits and inputs. Farmers are able to do this in many ways such as, precision chemical, fertilizer, and seed placement to maximize yield potentials; variable rate chemical, fertilizer, and seed application to minimize input cost; GPS guidance to increase operator efficiency; and using innovations in conventional, no-till, and strip-till cropping systems to maximize yield potentials for different types of soils. All these PA applications benefit farmers and allow the to become more sustainable and reduce their impact on the environment. Furthermore PA can also be a part of farm planning for crops and animal production. Through PA farmers are able to become more profitable, sustainable, and reduce their negative effect on the environment. They are able to be more profitable because of reduced costs and increased profits. Farmers are able to be more sustainable because of the increased profits and their reduced negative effects on the environment. They are able to reduce their negative effect on their environment through reduced chemical use because of variable rate application. As PA continues to evolve agriculture will continue to evolve and become more sustainable.

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