A Historical Analysis of the Environmental Footprint of Peanut Production in the United States from 1980 to 2014

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ABSTRACT

The last half century has seen a significant shift in agricultural practices, affecting productivity, resource use, and ultimately, environmental impacts. These increases have been the result of several developments, including increases in irrigation, the expanded application of fertilizers and pesticides, improved plant genetics, and the development of mechanized operations. Changes in production practices are highlighted here for peanut crops for the years 1980 to 2014. This study uses a resource efficiency methodology from cradle-to-farm gate to examine land use, energy efficiency, soil erosion (water and wind), irrigation water usage, and environmental/greenhouse gas emissions. During the historical period, yields increased from under 2000 kg/ha in the Southwest and an average of 3000 kg/ha in the Southeast and Virginia-Carolina regions to over 4000 kg/ha across all regions. Most of this increase occurred after the year 2000. Overall trends of nitrogen fertilizer applications per planted hectare were increasing; however, chemical protections, fuel use and electricity associated with cultivation, harvest, and drying declined. Energy utilization per hectare and kg of peanut showed steady declines over the last 40 years, particularly in the Southeast and Virginia-Carolina production regions. Results indicated that greenhouse gas (GHG) emissions have been on the decline across all production regions, from greater than 1 kg CO_2e/kg peanut in the early 1980s to less than 0.6 kg CO_2e/kg peanuts in 2013, a 40% decrease in GHG production.

Key Words: Peanut, environmental footprint, sustainability, greenhouse gas

In recent decades, agricultural production practices have undergone pronounced changes that are unique in human history. In the time between the years 1700 and 1960, the human population expanded from roughly 650 million people to approximately 3 billion people worldwide (Land Commodities, 2009). During that same period, the amount of arable land utilized for agriculture kept pace with population expansion, increasing by approximately 400% (Land Commodities, 2009). In modern times, this expansion has slowed, with the world seeing a global population increase of over 114% since 1961, corresponding to an arable land utilization increase of just 10.1% (Johnston, 2013). In spite of the increased demand and the decreased rate of land conversion for agriculture, global agricultural yields have increased dramatically across all sectors in the last half century. These increases have been the result of a number of factors, including increases in irrigated crops, the expanded application of fertilizers and pesticides, the development of mechanized operations, and the use of genetically modified cultivars (Rosegrant et al., 2009; Karlen et al., 2012).

The production of peanuts, which are an important food staple and protein source for the world's population, has also expanded in recent decades. Like other crops, peanut production has seen expanded fertilizer use and increased mechanization that has resulted in increased yields. From 1979 to 1981, approximately 18.55 million metric tons of peanuts were produced worldwide (Singh and Singh, 1991). These values have increased dramatically to over 41 million metric tons of peanuts produced globally from 2013 to 2014 (FAS, 2015). Today, the peanut industry is still evolving, and is seeing a shift in tillage practices from conventional intensive tillage to more sustainable strip tillage methods (Sandefur et al., 2016). The adoption of strip tillage in US operations has increased from 6% to 22.9% between 1997 and 2003 (Monfort et al., 2007). Each of these changes in production practices has corresponded to shifts in environmental impact, which includes water use, soil erosion, and greenhouse gas (GHG) emissions.

Understanding how the sector has evolved is valuable, as peanut producers—and the modern agriculture sector at large—are facing a number of challenges in the coming decades (Johnston et al., 2015). In 2009, approximately one billion people were undernourished or malnourished worldwide (Paoletti et al., 2011). In addition, according to UN projections, the human population is estimated to reach 9.7 billion people by the year 2050 (United Nations, 2015). In order to meet the needs of the

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Table 1. Data sources for peanut production.

Peanut production data sources	Data type
NASS (National Agricultural Statistics Service)	Yields/Fertilizers
USDA ERS (Unites States Divisions of Agriculture Economic Research Service)	Peanut/Hay Economic Value
NRI (Natural Resource Inventory)	USLE Soil Loss Data
ARMS (Agricultural Resource Management Survey)	Fuel Use by Process/Crop Chemicals
Argonne National Laboratory	Chemical to kJ Conversions
Farm and Ranch Irrigation Survey (Census of Agriculture)	Irrigation Data
IPCC (Intergovernmental Panel on Climate Change)	Chemical to GHG Conversions, Nitrous Oxide Emissions Factors

present while expanding to accommodate future increases in demand, experts project that global food production will need to increase by between 70 and 100% by 2050 (Godfray et al., 2010). As a key protein source, demand for peanuts is likely to continue to increase in the coming decades.

Given the shifts that have taken place in modern production practices, and the new challenges posed by future demand, it is important for peanut producers and other stakeholders to understand how the industry has evolved in order to provide context for future planning efforts. To that end, the objectives of this study were to examine changes in yields, land use efficiency, soil erosion, irrigation water use, energy use, and greenhouse gas emissions in the production of peanuts in the United States from the years 1980 to 2014.

Materials and Methods

This study utilized existing data sets that are publicly available, including the National Agricultural Statistics Service (NASS), Natural Resource Inventory (NRI), and many others (Table 1). Specific data sources were defined for each metric. Peanut crop production in the United States were assessed for each year from 1980 through 2014 where data was available. Metrics were produced for three separate regions, Southwest, Southeast, and Virginia-Carolinas. All data and metrics were collected at the state and regional levels. National estimates were built up from the regional values using either regional peanut production area (ha) or production as weights.

System boundaries for the resource efficiency assessment were from cradle to farm gate (Figure 1). The scope of the metrics was intended to include the products and activities needed to produce the crop and get it to its first point of storage after harvest; most times this will be the buying station. The metrics are intended to capture the energy used to produce and dry the crop as well as the embodied energy in crop protection products, fertilizer, and seed. No allowance was made for general farm overhead activities or capital expenses such a machinery depreciation. Peanut production is defined on an in-shell basis unless otherwise noted.

This analysis was conducted for the average of all peanuts produced in the U.S. Since peanut hay has economic value, an economic allocation was made to differentiate between the impacts of peanut and peanut hay production. All measures are corrected for the practice of harvesting peanut hay using the economic value assigned to the hay by the U.S. Department of Agriculture Economic Research Service (USDA ERS). For example, if the gross market returns from all sources are $1000 per planted hectare and $50 was attributed to peanut hay, then peanuts themselves would bear 95% of the burden of all resource indicators. This discounting process is based on annual data by region. Peanut hay had the greatest economic value in the Southwest approaching 5% in recent years but in other regions, the value was typically about 2% (USDA ERS, 2015).

Metrics

Yield. Yield is the measure of production per unit area, and measured over time, yield indicates trends in overall efficiency of production. Changes in yield can be a function of several different factors such as weather, genetics, climate, and production practices. Yields of agricultural products are the most significant indicator of agricultural performance, as such, yield deserves a place in any benchmarking process that concerns agriculture. Yield values in this study are for planted hectares available from the USDA ERS (USDA ERS, 2015). A three year centered moving average was used to reduce the amount of volatility in yields from one-year weather events such as drought and flooding.

Land use efficiency. Land use efficiency is the inverse of yield and puts the focus on the area required to produce a unit of crop. This measure is the yield per planted hectare inverted such that the units are planted hectares per unit of peanut production. As such, the smaller the value for the

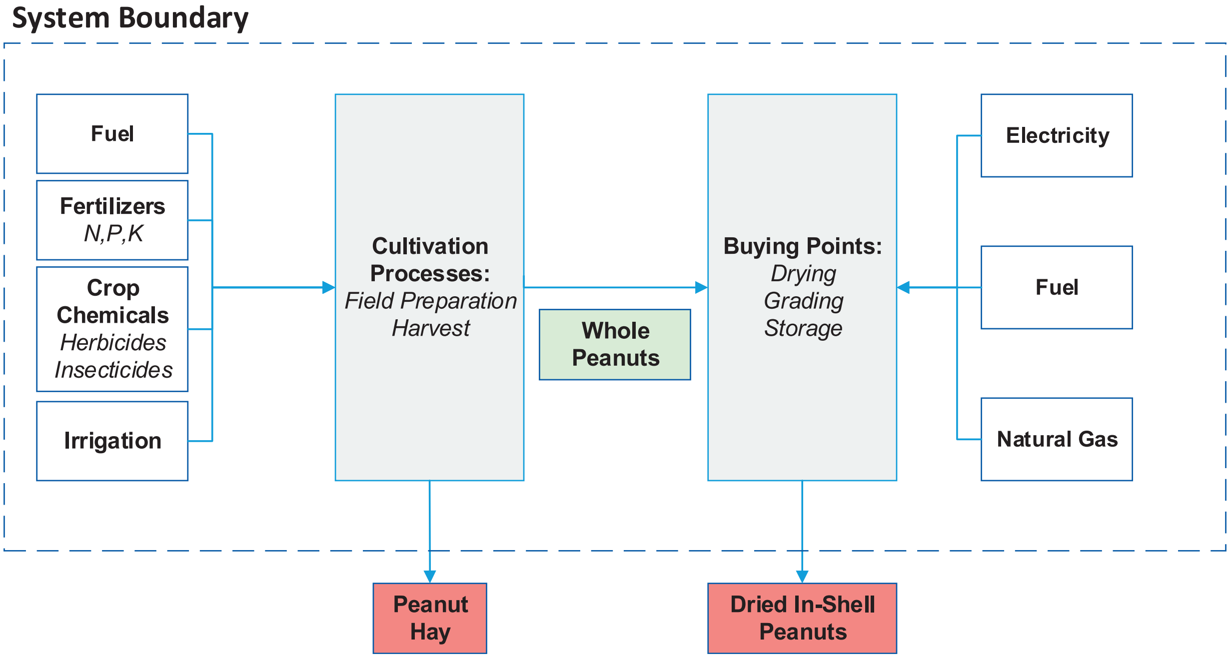

Fig. 1. System boundary and processes for the resource efficiency assessment of peanut production.

metric, the greater the efficiency. The three year centered moving average was also used for the land use efficiency metric.

Soil erosion. Soil erosion data were provided through customized runs of the USLE (Universal Soil Loss Equation) conducted by the staff at the National Resources Inventory (NRI). Reported soil erosion was the combination of water (sheet and rill) and wind erosion and represented the area weighted erosion for a given region. Soil erosion values were made available from NRI in five-year increments. Linear interpolation was used to calculate soil erosion on an annual basis.

Irrigated yield. Applied water, irrigated and non-irrigated yields were provided through the Farm and Ranch Irrigation survey (USDA, 2015). This survey is part of the census of agriculture and is conducted the year after the original census. The most current data were for the 2013 production year. Irrigated hectares and applied water is only available for the years in which agricultural census data is available, which is roughly every five years. Linear interpolation was used to estimate irrigated hectares and applied water on an annual basis.

It was assumed in this study that non-irrigated yields for a particular state were achieved universally throughout the state and that the application of irrigation improved non-irrigated yields. The authors recognize that this is not always the reason irrigation is applied; some lands may not achieve a marketable crop without the use of irrigation. The irrigated yield metric developed in this paper is loosely based on the inverse of the Irrigated Water Use Efficiency metric (Payero et al., 2008). Applied water was divided by the difference in yields for irrigated and non-irrigated peanut yields. For instance, if applied water was 500 m^3, irrigated yields were 2000 kg, and non-irrigated yields were 1500 kg, the irrigated water use would be 500/(2000-1500) or 1.0 m^3 per kg peanuts. Correcting for hay would result in approximately 0.95 m^3 per kg peanuts, assuming hay represented 5% of the total economic value.

Total energy use. Energy embodied in the production of peanuts comes from the application of fertilizers, crop chemicals such as herbicides, energy from peanut seeds, and energy from cultivation that includes fuels, lubricants, and electricity. Energy from each of these processes were calculated in a different way depending upon the available data. Energy values were reported in kJ/ha and were converted to kJ/kg peanuts using the three year centered moving average yield. Total energy use is the sum of energy calculated for the production practices described below. All energy values were corrected for hay.

Fuel, lubricants, electricity, and drying energy. Fuel, lubricants, electricity, and drying dollar values were reported in historical USDA ERS cost budgets that date back to 1975. These values are on a cost basis, therefore, they needed to be converted into an energy basis (kJ). With inflation and variability in the price of energy related products this is a difficult task. The year 1995 was used as a

Table 2. Fertilizer energy density.

Fertilizer	kJ/kg
Nitrogen*	51225
Phosphate	14005
Potash	9003
Lime	8003

*Assumes 50/50 Ammonia Urea

benchmark year using fuel, lubricants, electricity, and drying data from USDA farm costs and returns survey (FCRS) reports for peanuts. The combination of fuel, lubricants, electricity, and drying energy for peanuts in 1995 was 11.6×10^6 kJ/ha according to USDA ERS (1997). A fuel and energy product weighted price index was created by multiplying the producer price index (PPI) for fuels and electricity by the percentage of that energy sources share within peanut cultivation, as determined using the 1995 USDA FCRS data (USDA ERS, 1997). The fuel and energy product weighted price index was the sum of the energy weighted PPIs.

Next, a year 2000 rebased index was created by dividing the fuel and energy product weighted price index by the year 2000 fuel and energy product weighted price index. Using these indices, the dollar amount spent on fuels, electricity, and drying was converted to year 2000 dollars by dividing it by the year 2000 rebased index. Finally, kJ/ha were approximated by assuming a proportional relationship between the year 2000 fuel and energy dollars and the benchmark kJ/ha from the 1995 USDA FCRS data (USDA ERS, 1997).

Fertilizers. The National Agricultural Statistics Service (NASS) historical datasets were used to determine average fertilizer application per hectare for peanuts by state. State data were available for the years 1991, 1999, 2004, and 2013. State data were averaged for each region. The average application amount per year between published data was determined by linear interpolation. Energy embodied within each of the nutrients, presented in Table 2, was used to convert from kg applied per ha to kJ per ha (Wang and Elgowainy, 2007). Further, yield was used to determine the energy associated with a kg of peanuts.

Crop chemicals. Crop chemicals (herbicides, fungicides, and insecticides) and their applications per hectare were also available by state from NASS for the same years as fertilizers. Chemicals were reported as pounds applied per acre within the NASS dataset, which were then converted to kg active ingredient per hectare. Active ingredients were converted to kJ based on Audsley et al., 2009. Total energy embodied in crop chemicals was calculated by summing the energy in kJ from each of the chemical treatments.

Seed energy. In peanut cultivation, seeding rates are approximately 100 kg per ha, and peanut yields in the U.S. average around 3400 kg per ha. A rough estimate of seed use then equates to about three percent of the harvested crop. Based on conversation with industry seed experts, a safety factor of two was used, indicating that around 6% of the previous year's harvest is used to seed the following year's crops (personal communication). Seed energy for a given year was calculated by multiplying the previous year's total energy (fertilizer, crop chemicals, and fuels) by 6%. This accounted for the energy embodied in the sown peanut seeds.

GHG impact. Calculated energy per unit area of production for fuel, electricity, and drying energy were converted to GHG values using conversion factors found in the Argonne National Laboratory GREET model version 1.7 (Wang and Elgowainy, 2007). Similarly, applied fertilizer per unit area was converted to GHG equivalents using the GREET model. Direct nitrous oxide emissions from nitrogen fertilizer applications were calculated using the recommendation of Bouwman (1996). N_2O-N was converted to CO_2e using the conversion factor 298 kg CO_2e/kg N_2O-N provided by EPA (2015). GHG from crop chemicals was calculated by converting the total energy for crop chemicals to diesel kJ equivalents and then to GHG for diesel. GHG associated with seed production was assumed to be 6% of the total energy used from the previous year and similar to crop chemicals, was converted to diesel equivalents and then to GHG. Total GHG was summed from the previous processes. All reported GHG values were corrected for hay production.

Results and Discussion

Yield. In the United States, peanut production yields have not doubled like many cereal grains; however, significant increases have been recorded (Figure 2). Analysis revealed that yields remained mainly steady throughout the 25-year period between 1975 and 2000. During that period yields in the Southeast and Virginia-Carolina Region averaged around 3000 kg/ha, while the SW averaged 2000 kg/ha.

Starting around the year 2000, peanut yields began to climb due to a range of factors. Prior to the 2002 U.S. Farm Bill, peanut quotas were assigned in order to protect the price of the crop. This system had been in place since the 1940s. Current growers were assigned a percentage of the

Fig. 2. Three year centered average of historic yield values (1975-2014) for peanuts produced in Southeast (SE), Southwest (SW), and Virginia-Carolina (VC) regions of the U.S.

total US peanut demand based on their previous growing record. Quotas were re-evaluated every 5-10 years. Any additional peanuts grown had to be sold in the export market. The export market brought a lower price, thus lowering the incentive to increase peanut yields on quota lands. The quota was also tied to the land, which is important in terms of crop yield. A farmer wanting to grow peanuts would have to purchase/lease quota land from another farmer. Peanuts had to be grown on the same land year after year while excluding more productive lands (Hoffman et al., 2004).

In the 2002 U.S. Farm Bill, the government purchased all of the peanut quotas from existing farmers and ended the quota system. The direct result was that farmers nationwide were now free to grow peanuts on any land of their choosing. This led to peanuts being optimized for growth on improved lands, whereas under the quota system, peanuts were locked into potentially underperforming land per the quota. Under a free market system, growers were incentivized to produce higher yields.

Several other factors likely contributed to changes in yields during that time. The 1979 EPA ban on 1,2-dibromo-3-chloropropane (Nemagon or Fumazone) nematicide likely reduced yields (Germani et al., 1980) and the 1989 EPA ban on succinic acid 2,2-dimethylhydrazide (Alar) growth regulator had variable impact on yields (Mitchem et al., 1996). Prior to its ban, Daminozide was used on approximately 30% of the peanut crop in North Carolina and Virginia (Mitchem et al., 1996). The introduction of Tebuconazole (Folicur) fungicide in 1994 was useful for improving yields (Bowen et al., 1997). In addition, over the last two decades, researchers have been working to develop peanuts with aflatoxin and disease resistance, as well as, drought and salinity tolerance (Pasupuleti et al., 2013; Nigam et al., 1992). Improvements have been made to seed quality and oleic to linoleic fatty acid ratios. While peanuts have benefited from improved breeding for most of the 20th century, the most significant advancements have occurred in the last two decades (Nalini, 2014).

Land use efficiency. Land use efficiency experienced the most change in the Southwest region where, in the late seventies, roughly 0.6 ha were required to produce one kg of peanuts (Figure 3). By 2014, this value was cut in half to roughly 0.3 ha/kg peanuts. This is predominantly related to yield improvements observed in the Southwest during that period. Southeast and Virginia-Carolina land efficiency also improved dropping from around 0.3 to 0.2 ha/kg peanuts. As land use efficiency is simply in the inverse of yield, the same reasons for its improvement apply.

Soil erosion. Soil loss remains a challenge in peanut production systems with the southwest region having the greatest levels. Soil erosion

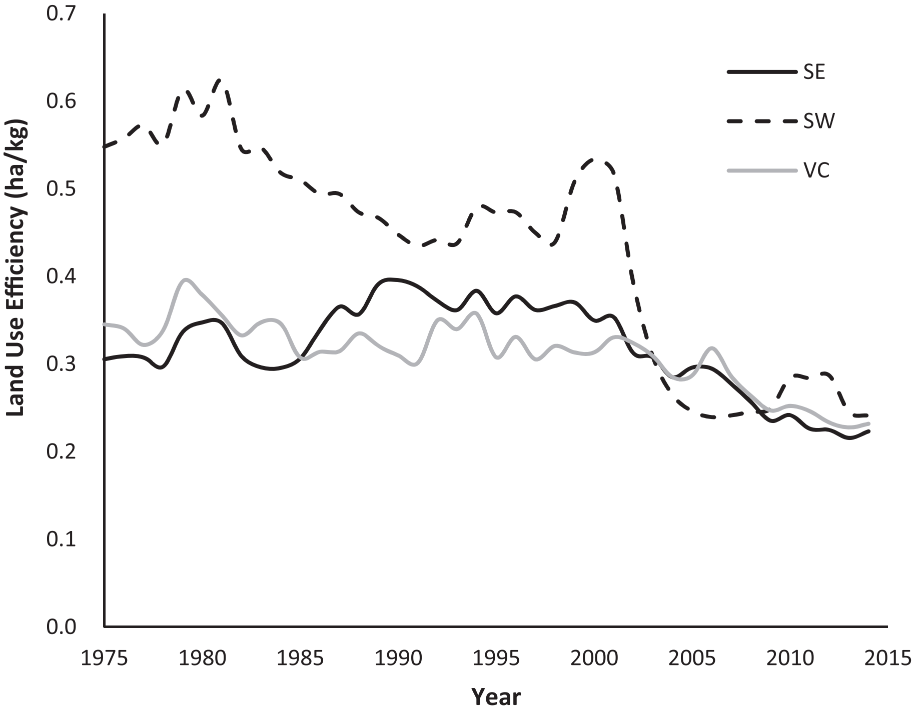

Fig. 3. Historic land use efficiency (1975-2014) for peanuts produced in Southeast (SE), Southwest (SW), and Virginia-Carolina (VC) regions of the U.S. Calculated from the three year centered average yield.

remained relatively steady during the historic period for the Southeast and Virginia-Carolina regions averaging 14 and 10 metric tons/ha respectively (Figure 4). The Southwest region experienced much more variability peaking at 74 mt/ha in 2007. Trends seen in soil erosion were highly dependent upon the resolution of data, which was available for the years 1982, 1987, 1992, 1997, 2002, 2007, and 2010. Linear interpolation between these data points produced straight lines

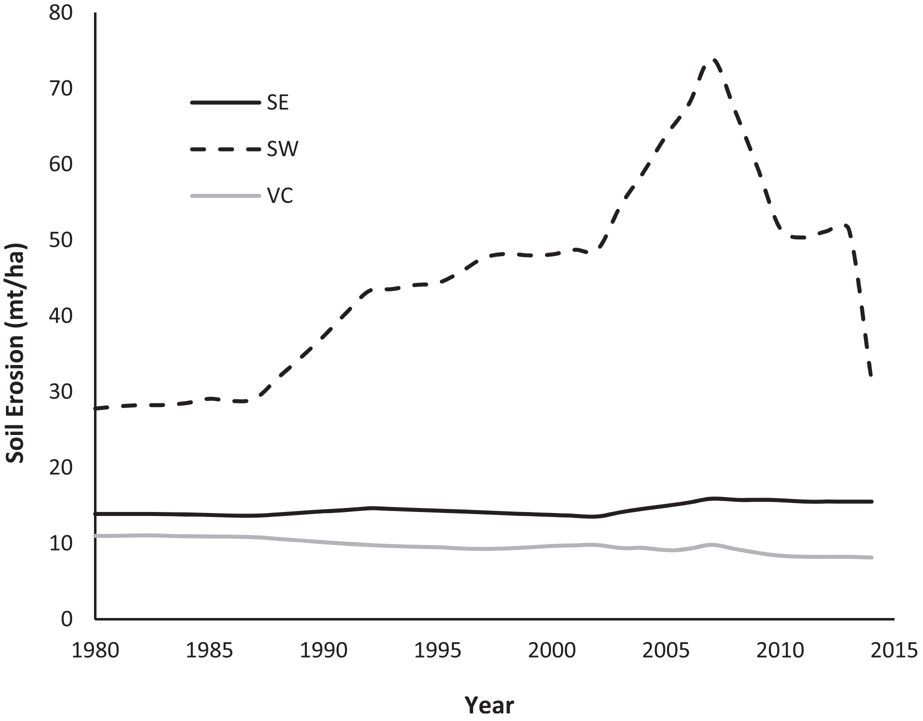

Fig. 4. Soil erosion per unit area (mt/ha) calculated from the Universal Soil Loss Equation for peanuts produced in Southeast (SE), Southwest (SW), and Virginia-Carolina (VC) regions of the U.S.

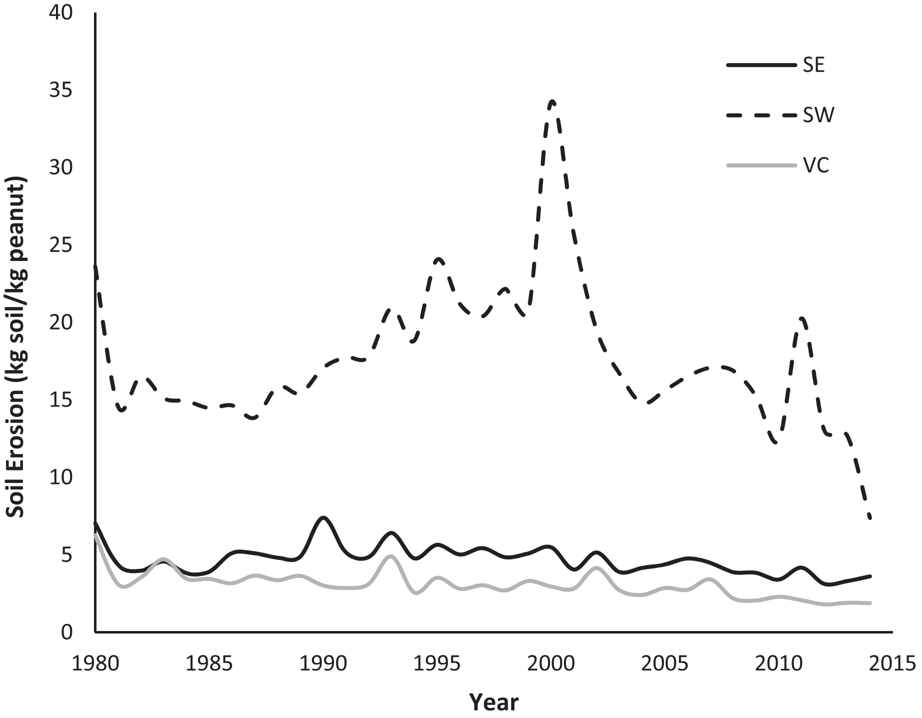

Fig. 5. Soil erosion normalized by yield (kg soil/kg peanut) calculated from the Universal Soil Loss Equation for peanuts produced in Southeast (SE), Southwest (SW), and Virginia-Carolina (VC) regions of the U.S.

where little about the actual erosion rates of these particular years was known.

Erosion rates calculated by NRI are based upon climate data, site characteristics, and production practices. According to NRI (2007), soil erosion on cropland in the U.S. declined 43% from 1982 to 2007. However, this takes into consideration all cropland and not those specific to peanuts. Regardless of crop and cultivation type, soils in the Southern Plains have the highest combined water and wind erosion in the nation, with the majority of that coming from wind (NRI, 2007).

Results from the conversion of per hectare soil erosion using peanut yield were similar to the per hectare soil erosion results (Figure 5). The Southeast and Virginia-Carolina regions remained steady at under 5 kg soil/kg peanut while the Southwest region was variable. Fluctuations in yield tended to play a greater role in this region. While the values that are shown from the USLE model at five-year intervals does not indicate a significant reduction in soil erosion, there is evidence that changes in production practices for peanuts have had an impact on the industry.

Practices such as conservation tillage, which reduce soil disturbance and increase crop residue, have been shown to reduce erosion by 68% (Holland, 2004). Conservation tillage has been responsible for a reduction in the number of tillage passes used to establish the peanut crop from 4.8 passes on average in 1999, to just 3.3 passes in 2013 resulting in an increase in crop residue from 3.9 to 16.7% over the same period (USDA ARMS, 2016). Additionally, growers in the Virginia-Carolina region have widened their rotation interval between peanuts and have cut soil loss levels significantly.

Irrigation water use. Irrigation water use remained relatively steady at around 2 m^3/kg peanuts produced regardless of the region (Figure 6). One significant anomaly seen in 2003 has the irrigated water use increased to over 6 m^3/kg. This is largely due to lower irrigation amounts used that year with irrigated yields being only slightly higher than non-irrigated yields. Trends seen in irrigated water use were highly dependent upon the resolution of data, which was available every five years with the earliest data available in 1988 for Southeast and Southwest regions, and 1998 for Virginia-Carolina peanuts. Lack of variability within the irrigated yield trend lines is a direct result of the lack of data and need for linear interpolation between points. There is certainly more to be said concerning irrigation trends in peanuts during the last forty years; however, currently available data does not lend itself to this end.

The irrigation and soil erosion data used for this study highlight the importance of increasing the resolution of data that is available to researchers. It

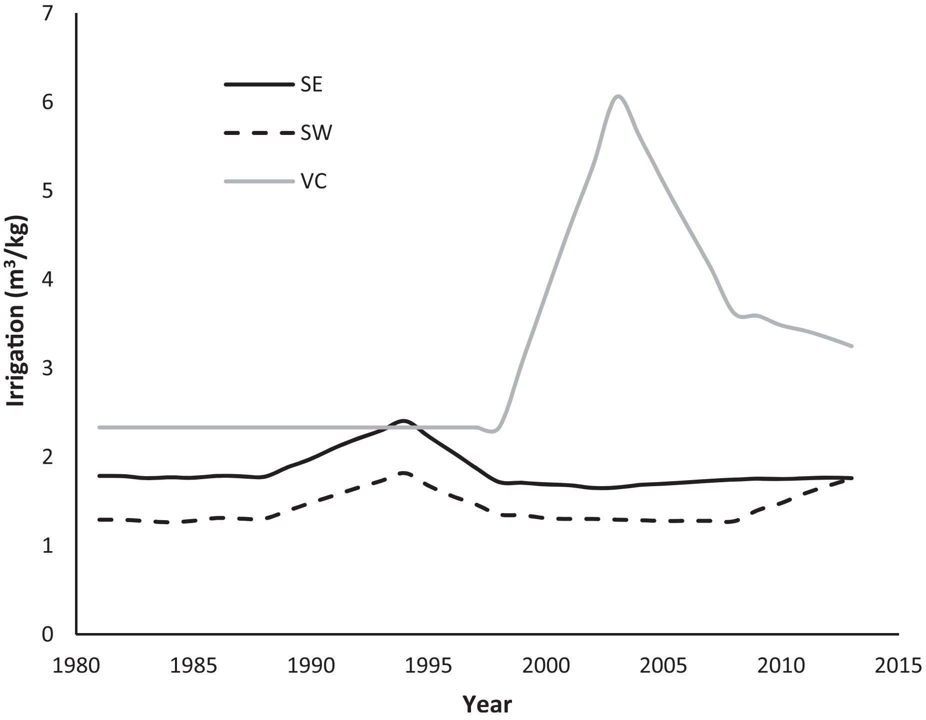

Fig. 6. Irrigation water applied per kg of peanuts produced above non-irrigated yields in Southeast (SE), Southwest (SW), and Virginia-Carolina (VC) regions of the U.S.

is difficult to ascertain any meaningful trends from the data due to the amount of interpolation that was required between available data points. We know that there are best management practices (BMP) available to reduce soil erosion and applied water, however, without data to support these transitions, it is difficult to make the connection between industry wide soil and irrigation trends and industry BMP adoption practices.

Total energy use. The Southeast and Virginia-Carolina regions experienced a large reduction in the total energy per hectare required to produce peanuts. In the Southeast, values fell from a high in 1982 of 42 GJ/ha to a low of 22 GJ/ha in 2013 (Figure 7). The Virginia-Carolina region saw a high of 50 GJ/ha in 1982 that fell to 19 in 2002 and subsequently leveled off at around 22 GJ/ha between 2005 and 2013. Total energy values for the Southwest region were fairly constant and average 18 GJ/ha. The largest portion of energy use was taken up by crop protection and in equipment operation, drying, and transport. Consequently, the largest declines seen during the period were also experienced by those two categories.

When normalized by yield, total energy per kg peanut fell across all three regions. Increases in yields affected energy per unit product most in the Southwest where a sharp decline in energy is observed corresponding to yield increases (Figure 7). While energy decreases are tied to yield increases, energy use was on the decline in the Southeast and Virginia-Carolina regions, long before significant increases in yields were achieved. This is likely due to a number of factors including changes in recommended crop protection amounts, as well as improvements in efficiency of mechanization and drying operations. Recommended fungicide active ingredient applications decreased across all three regions. Total reported costs for fuel electricity and drying increased on an annual basis across all regions, however, when we normalized costs based on a year 2000 index and took into consideration fuel and electricity price indices, actual consumption as represented by GJ/ha and MJ/kg peanut decreased over time.

GHG impact. In this study, GHG was highly correlated with energy use in peanut production; therefore, all of the same trends observed in total energy apply here as well. Greenhouses gases per hectare declined in the Southeast and Virginia-Carolina regions from greater than 3500 kg CO_2e/ha in 1982 to under 2500 kg CO_2e/ha in 2013 (Figure 8). Values were constant for the Southwest and averaged around 2000 kg CO_2e/ha. Energy products were the most variable of contributors to total GHG.

Similar to total energy, when normalized by yield, total GHG fell across all three regions. The

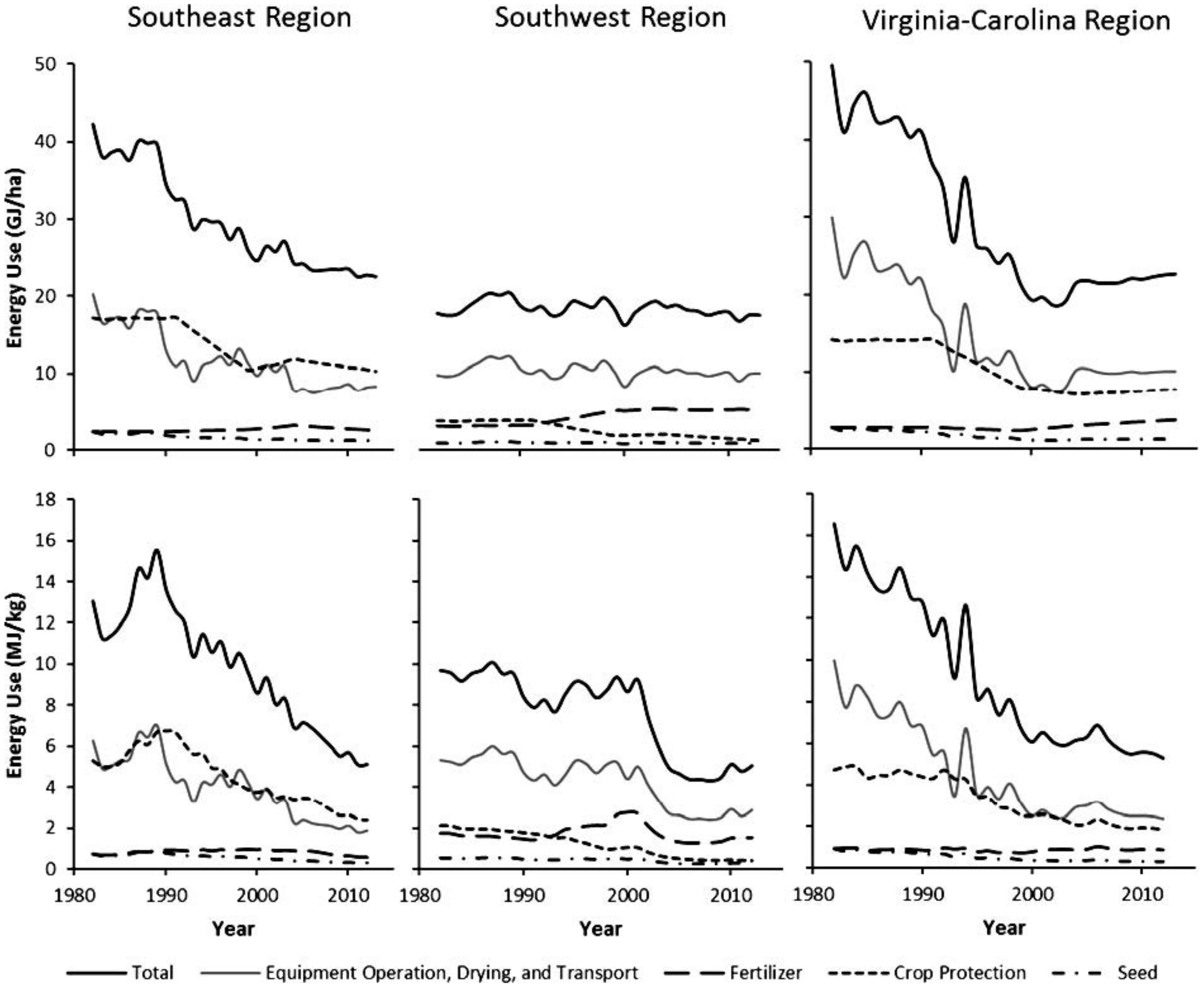

Fig. 7. Energy use for the production of peanuts (kJ/ha and kJ/kg peanuts) produced in Southeast, Southwest, and Virginia-Carolina regions of the U.S.

largest contributors to this decline were energy products and crop protection products. GHG per kg peanut fell over the study period from over 1 kg CO_2e/kg peanut to under 0.6 kg CO_2e/kg peanut. This is in line with the results of McCarty et al. (2014) which found that GHG contributions from the farm for 1 kg of peanut butter were roughly 0.4 kg CO_2e.

Conclusions

A resource efficiency methodology was used to determine the environmental impacts from the production of peanuts cradle-to-farm gate for the period between 1980 and 2014. Significant improvements in yield and land use efficiency were seen across all production regions during the past 20 years. Soil erosion remained steady for the Southeast and Virginia-Carolina regions and variable for the Southwest. Irrigation was steady for the Southwest and Southeast, while variable for the Virginia-Carolinas.

The most important results from this study center around total energy use and greenhouse gas metrics. Yield increases were the key drivers of much of the energy and GHG reductions on a per kg of production basis. Significant differences in total energy use and GHG emissions were observed between growing regions. The greatest gains for each of these metrics were achieved through improvements in efficiency of equipment operation, drying, and transport, and reductions of crop protection chemicals. While significant reductions in energy use and GHG were achieved, the categories of equipment operations, drying, and transport, as well as the use of crop protection chemicals have a higher proportion of energy use and GHG than the other categories. The greatest opportunity for continued increases in the efficiency of production and reduction of emissions is with the categories of equipment operations, drying, and transport, as well as crop protection.

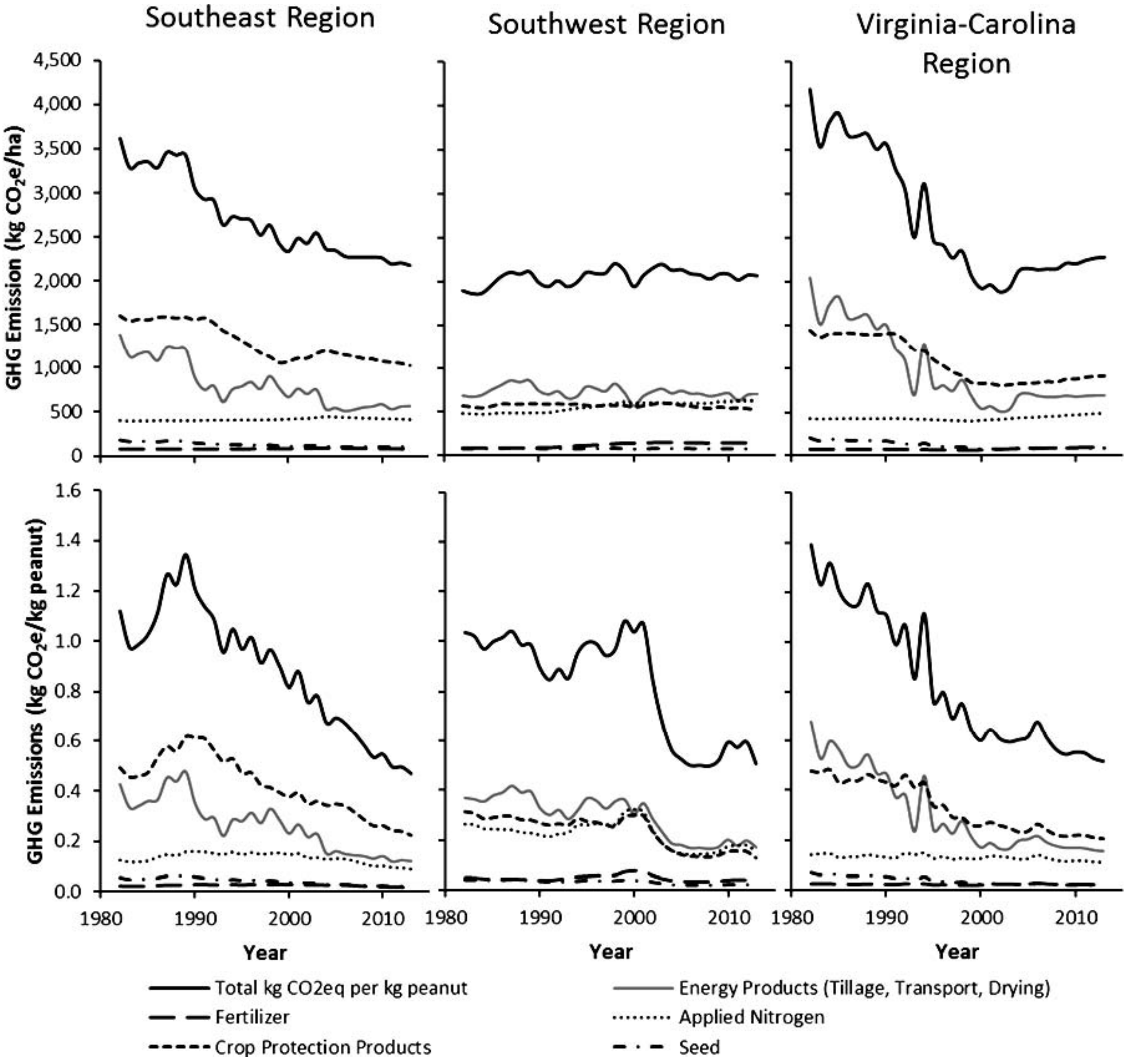

Fig. 8. Greenhouse gas production for the production of peanuts (kg CO$_2$e/ha and kg CO$_2$e/kg peanuts) produced in Southeast, Southwest, and Virginia-Carolina regions of the U.S.

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