NITROGEN UPTAKE EFFECTS ON POTATO YIELD AND QUALITY

A Thesis
Submitted to the Graduate Faculty
of the
North Dakota State University
of Agriculture and Applied Science

By

Enise Ayyildiz

In Partial Fulfillment of the Requirements
for the Degree of
MASTER OF SCIENCE

Major Department:
Plant Sciences

April 2021

Fargo, North Dakota

North Dakota State University
Graduate School

Title

NITROGEN UPTAKE EFFECTS ON POTATO YIELD AND QUALITY

By

Enise Ayyildiz

The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

SUPERVISORY COMMITTEE:

Andrew P. Robinson
Chair

Asunta (Susie) L. Thompson

Gary Secor

Approved:

April 4, 2021
Date

Richard D. Horsley
Department Chair

ABSTRACT

Nitrogen (N) is one of the vital elements for potato production. As well as common synthetic fertilizers, turkey manure compost (TMC) is more commonly used as a source of N for potato production in Minnesota. The aim of this study was to compare traditional N sources and applications (urea broadcast, Environmentally Smart Nitrogen (ESN) broadcast, and ESN banded at hilling) to TMC broadcast prior to planting on yield and quality of Russet Burbank in Minnesota. The TMC treatment resulted in a similar marketable yield compared to the urea and ESN treatments. The TMC also increased the percentage of the >170 g tuber yield. French fry color quality was not affected by N treatment in either year. The TMC was a good nitrogen source that is readily available and provides a good sustainable option for potato production. Further work should examine what benefits conventional fertilizer can have when used with TMC.

ACKNOWLEDGMENTS

I would like to express my sincere gratitude to several people who have supported me during my Master's journey. First, I would like to acknowledge my advisor, Dr. Andrew Robinson, for his time, guidance, and support throughout this project. I would also like to acknowledge my committee members, Dr. Asunta Thompson and Dr. Gary Secor. Their expertise and suggestions were significant factors to the successful completion of this study.

I would also like to thank you, Dr. Jae Ohm, for all your help with my statistical analysis.

For their love and support, I would like to express my appreciation to my family: my parents Huriye and Kemal, and my siblings Yasemin, Nesibe, and Murat. Without their guidance and encouragement, I would not be where I am now.

I want to express my appreciation to my friends for their friendship and support; they were always with me during this journey. Also, I owe many thanks for the help that I received from my colleagues and the staff over my two field seasons.

Lastly, I would like to thank the Turkish Ministry of National Education for their financial and emotional support during my Master's degree.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

DAP	Days after planting.
SG	Specific gravity.
RB	Russet Burbank.
MT	Metric ton.
TMC	Turkey manure compost.

LIST OF SYMBOLS

N	Nitrogen
P	Phosphorus
K	Potassium
NH_4^+	Ammonium
NO_3^-	Nitrate

CHAPTER 1: POTATO HISTORY, PRODUCTION, AND THE IMPORTANCE OF NITROGEN FERTILIZER FORMS AND APPLICATION EFFECTS ON POTATOES

Literature Review

General Introduction

Many factors are important in potato (*Solanum tuberosum* L.) production, including seed quality, fertilization, plant density, crop rotation, soil moisture, storage, amongst others (Blumental et al., 2008). One of the most limiting elements for potato production is nitrogen (N). Nitrogen is essential because it affects vine growth, maturity, tuber size, and dry matter (Salunkhe et al., 1991).

Crops obtain nitrogen from different sources, including the soil via root uptake of nitrate-NO_3^- and ammonium-NH_4^+ (Vos and MacKerron, 2000), plant residues, animal wastes (e.g., manure), irrigation, and fertilization treatments. In soil, NH_4^+ based fertilizers convert to NO_3^-, which is not as tightly bound to soil particles making it more susceptible to movement with water. While reducing environmental damage, N fertilizer management on well-drained sandy soils is needed to maximize N efficiency (Rosen and Eliason 2005). The fertilizer application method, source of N fertilizer, and the timing of application can play an essential role in reducing losses to leaching (Shresta et al., 2010). One of the most commonly used N sources is urea, preferred to use at planting and/or hilling as a starter for potato production. The use of controlled-release or stabilized N sources can reduce NO_3^- losses. These sources may include polymer-coated urea like ESN or products treated with nitrification and/or urease inhibitors (Trenkel, 2010). For the potato crop, total nitrogen requirements generally vary between 100 to 280 kg N ha^{-1} (Stark and Westermann, 2003). However, the requirements for nitrogen are diverse for cultivar, utilization (e.g., fresh consumption, frozen processing, and chip processing), soil type, and yield potential (Vandendriessche et al., 1996; Stark and Westermann, 2003).

Plant parts (leaves, stems, foliage, and tubers) differ in their N content (Mackerron et al., 1995). Current potato production in the United States relies on sampling petioles of the fourth-youngest leaf to determine nutrient status. Petioles reflect the plant's nutrient status directly and reflect current levels more precisely (Rosen, 2018). However, no data indicates this is a good predictor of yield. In the United Kingdom, the whole plant is sampled to determine plant nutrient status, and the nitrogen concentration is used to determine yield potential. The use of specific gravity can measure the tubers' internal quality. Specific gravity is one of the most widely used factors for estimating internal quality; there is a high correlation between tuber starch content, mealiness, total solids, and specific gravity, and processors use this measurement to determine suitability for processing (Laboski and Kelling, 2007). Increased N applications may cause reductions in specific gravity (Porter and Sisson, 1993; Zebarth et al., 2004). The objectives of this project were to evaluate the effects of different forms of nitrogen (urea, Environmentally Smart Nitrogen, and turkey manure compost) on French fry quality, plant growth, and production by comparing petiole, soil, and whole plant sampling.

History of the Potato

Globally, potato is one of the most vital food sources for humans (Horton and Sawyer, 1985). The history of potato begins between 8,000 and 5,000 BC (Anonymous, 1989). The first domestication was from southern Peru and northern Bolivia (Spooner et al. 2005). *Solanum tuberosum* L. is native to a group of Chilean Islands (Solano et al., 2007). After the Spanish conquest, potato spread through Europe and Africa via Spain (Anonymous, 1989). In the 1600s, potato was introduced to East Asia and became famous with the imperial family in China

(Boomgaard, 2003). Another major potato producer is India who received potatoes in the 18th century from British traders. During the Industrial Revolution, the potato promoted economic growth in Britain (Reader, 2009). However, the Lumper potato variety, with poor resistance to late blight (*Phytophthora infestans* (Mont.) de Bary), was cultivated and consumed intensively by peasant farmers and laborers. Late blight would cause potato tubers to rot, and there was not sufficient food. Because of the shortage, nearly one million deaths occurred by way of starvation in Ireland, and a huge migration to the United States, England, Canada, and other countries resulted (Gráda et al., 2007).

In the 1800s, the potato arrived in North America, and the first continuous potato fields were in New England. These potatoes came from Ireland and spread from New England to mid-Atlantic (Love et al., 2003).

Global Potato Production

After the 18th and 19th centuries, there was a significant increase in the production of potato (Horton and Sawyer, 1985). The total global production was approximately 388 million metric tons in 2017 (FAOSTAT, 2019). There have been significant changes in the countries producing potatoes throughout the world. Potato was mostly produced and consumed in North America, Europe, and the previous Soviet Union until the 1990s. After that time, potato production and demand have seen dramatic growth in Latin America, Asia, and Africa. This shift increased global potato production from 30 million metric tons to 165 million tons between the 1960s and 2007 (FAOSTAT, 2019). In 2019, total potato production was approximately 21 million metric tons. The average yield of 57 metric tons ha^{-1} was down 112 kg from the 2018 yield (NASS, 2020). However, there were increases in the value of all potatoes (about 11%) and the average price received ($116 / ha) in 2019. The largest percentage of potato usage is for the processing market, and the total processing potato production was approximately 14 million metric tons and reduced 5%. Processed potatoes as French fries and other frozen products were 9 million metric tons, down 3%in in 2019 from 2018 (NASS, 2020).

Today, China is the largest potato producer with an annual production of 99 million metric tons, followed by India at 49 million metric tons. The United States is the fifth largest potato producer at 20 million metric tons (FAOSTAT, 2019; PotatoPro, 2019). In the US, the potato is grown in almost every state; however, 79% of production comes from Idaho, North Dakota, Washington, Minnesota, Wisconsin, Oregon, and Colorado (FAOSTAT, 2019).

The potato cultivar Russet Burbank dominates the US-French Fry processing market accounting for 68% of the hectares processed (NASS, 2020). Russet Burbank (RB), with a late to very late maturation, has medium to high yield potential (CFIA, 2013) and requires about 1000 physiological days (P-days) (Western Potato Council, 2003). Potato is commonly grown on well-drained, coarse-textured, and sandy soils (Rosen and Eliason, 2005), and its tuber yield and quality can be improved with synthetic N fertilizer (Davis et al., 2014).

Nitrogen Fertilization, Sources, and Placement

Nitrogen can come from various inorganic or organic sources, including the air (78% N), soil, plant residues, animal wastes (e.g., manure), irrigation, and fertilization applications (Stark and Westermann, 2003). Examples of common synthetic sources of nitrogen used in North Dakota and Minnesota are urea (46-0-0), anhydrous ammonia (82-0-0), calcium ammonium nitrate (27-0-0-5 Ca), urea ammonium nitrate (28-0-0), ammonium sulfate (20-0-0-24), monoammonium phosphate (11-52-0), and diammonium phosphate (18-46-0). Sources of organic N are livestock manures such as cattle, sheep, chicken, and turkey. The nitrogen content of manures varies and needs to be tested regularly to determine nitrogen concentration (Rosen and Eliason, 2005). Also, plant residues from the previous growing season provide N that can release slowly than other sources (Rosen and Eliason, 2005). Turkey manure is an example of a nitrogen source that varies in dry matter N, phosphorous (P), and potassium (K) concentrations; this is because it is not equally made and mixed with inert ingredients. Turkey manure can vary 55 to 80% dry matter, 15 to 25 kg/ton N, 19 to 29 kg/ton P_2O_5, 8 to 18 kg/ton K_2O, and 3 to 4 kg/ton S; these widely different nutrient contents are due to turkey breed and feeding (Chastain et al., 1999). Waddel et al. (2000) reported that turkey manure did not affect potato tuber quality but reduced nitrogen leaching.

The total nitrogen requirement varies based on yield goal, soil type, environmental conditions, and cultivar. Plants can uptake ammonium nitrate (NH_4^+) directly; however, this N form can change to nitrate (NO_3^-) quickly in moist, well-aerated, and warm (19 to 30 °C) soils (Johnson et al., 2005). As a result, NO_3^- moves easily with water to the lower zone of soil, which can cause N deficiency. The leaching rate depends on rainfall, soil drainage, crop uptake, and the existence of nitrate (Johnson et al., 2005).

A crucial factor affecting N uptake is soil type. Potatoes on sandy soils can take up to 25 to 30% available N, while absorption on sandy loam soil is 30 to 40%, and silt loams may allow 40 to 50% N uptake (Stark and Westermann, 2003). To obtain maximum fertilizer efficiency, splitting nitrogen applications has been demonstrated to be an effective N management practice for potato plant growth. Split applications allow for total N requirements to be provided during the growing season when needed by the plants (Westermann and Kleinkopf 1985; Zebarth et al., 2012; Davis et al., 2014). Fertilizers are applied in various ways, including broadcasting, banding, side dressing, spraying, and irrigation injection (Stark and Westermann, 2003). The application of broadcast fertilizer typically occurs in the spring, prior to planting, or prior to hilling. The fertilizer is applied to the soil surface and tilled into the soil (0 to 10 cm deep) to supply nutrients for the potato roots. Using the banding method, fertilizer is placed near the seed piece approximately 5 cm to the side and 5 cm below in order to prevent root injury. Banding allows easy root access to nutrition (Stark and Westermann, 2003). Fertilizer can also be banded at hilling along the side of the hill when reshaping and enlarging the hill.

Effects of Nitrogen Fertilization

Nitrogen has an essential role in the chemical structure of potato crops. It is the building block of amino acids, affecting nutritional quality, sugar content, and dry matter directly (Blumenthal et al., 2008). Additionally, nitrogen fertilization influences the potato tuber size profile and impacts potato quality and processing ability (Smith and Talburt, 1987). Low nitrogen usually causes low dry matter and sugar levels (Iritani and Weller, 1980), while excessive nitrogen promotes vine growth and delays tuber initiation (Stark and Westermann, 2003). Nitrogen management is critical for building leaf area to harvest sunlight for photosynthesis to maximize yield. Excessive nitrogen results in susceptibility to blackspot bruise and immature skin that is prone to bruising (Dean and Thornton, 1992). In Church's experiment (1980), the annual average N application of 200 kg ha^{-1} to potato provided the greatest tuber yields, while Evans (1975) found a split treatment of 250 kg N ha^{-1} at planting and the tuber initiation stage resulted in the highest yield in England. Further, using excessive amounts of fertilizer (376 kg N ha^{-1}) may reduce yield results (Dyson and Watson, 1971). When potato plants had N applied at rates of 34- 270 kg N ha^{-1}, yield increased. However, with the application of 360 kg, N ha^{-1}, marketable yield declined (Rosen and Bierman, 2008).

Millard and Marshall (1986) reported nitrogen treatment effects on tuber yield depend on harvest timing. Using harvest times of 79, 91, and 112 days after planting (DAP), maximum tuber yield was reached with the latest date in their research. Therefore, fertilization treatments are influenced by potato cultivar, date of fertilization potato growth stage, and harvest timing, and all need to be considered in crop management.

Potato Nitrogen Utilization

Potatoes are utilized for fresh consumption, frozen, and chip processing. Each market has specific quality requirements; thus, producers use many cultivars that are dependent on their end-use. In general, potato plants need approximately 2 to 3.5 kg N ha^{-1} day, depending on cultivar needs and growth stage (Stark and Westermann, 2003). The recommendation for N application can vary significantly. For example, Russet Burbank, the most significant commercial potato cultivar in North America (Love et al., 2003), is used for French fry production and table-stock, while Atlantic is used for chip processing. Russet Burbank requires 280 to 370 kg N ha^{-1}, but Atlantic needs 20% less N than Russet Burbank (Love et al., 2003). Umatilla Russet, the second most grown russet cultivar in North Dakota and Minnesota, is used for frozen processing, while Chieftain, a red-skinned potato, is for fresh consumption. Umatilla has similar N requirements as Russet Burbank; however, Chieftain requires 75% of the N that is used for Russet Burbank in Idaho (Love et al., 2003). Many russet cultivars have similar N needs to Russet Burbank, such as Gem Russet, Russet Norkotah, and Ranger Russet. Other cultivars can require 20 to 40% less N than Russet Burbank because they have lower yield potential or improved nitrogen use efficiency. For example, Shepody, CalWhite, Chipeta, and Alturas require less N than Russet Burbank (Love et al., 2003). Hence, nitrogen requirements can be difficult to determine because of cultivar differences, soil type, and environmental conditions.

Nitrogen Concentration and Uptakes

Nitrogen is stored throughout the plant and accessed when needed. Plant parts have various N concentrations; for example, in leaves, the level of N can vary between 2.5% (deficient) and 7% (ample) (Young et al., 1993). Primarily, for monitoring the current in-season status of nutrients, the fourth leaf from the top of the potato plant is used (Stark and Westermann, 2003). In stems, the N value can be from 0.5 to 6%, and for tubers, between 0.5 to 3.5% (Young et al., 1993). These rates can differ by growth stage. For instance, in stems, tubers, and leaves, the N concentration starts to decrease during tuber initiation; this decrease stabilizes or slightly increases during tuber bulking (Ifenkwe and Allen, 1983).

Tuber nitrogen uptake can range from 170 to 200 kg ha^{-1}; however, N uptake varies by yield potential and cultivar (Stark and Westermann, 2003). Tuber N uptake increases from tuber initiation to maturation (Ifenkwe and Allen, 1983). Before tuber initiation, excessive N availability may delay tuber bulking by up to 2 to 3 weeks (Stark and Westermann, 2003); due to this, the yield of undersized tubers increases, reducing commercial value (Westermann 1993; Errebhi et al., 1998). During tuber initiation, vegetative growth increases due to rapid nitrogen uptake (Zebarth and Rosen, 2007). It is reported that, in Idaho, potatoes generally receive about 40% to 50% of their seasonal N prior to tuber bulking. The rate of nutrient uptake rises during tuber bulking, but at maturation, N uptake stops, plant senescence begins, and nutrients move from the foliage to the tubers (Westermann, 1993; Stark and Westermann, 2003; Zebarth and Rosen, 2007).

Uptake of N throughout the potato growth stages is essential for high-quality tubers and high yield. Potatoes need the ideal level of necessary nutrients from vegetative growth to maturation to supply rapid tuber growth and development.

Objective

The objective of this study was to define the differences between traditional nitrogen sources and turkey manure compost (TMC) on nitrogen uptake, yield, and French fry quality. This evaluation was done using different nitrogen forms: urea, ESN, and turkey manure compost with broadcast and banded placement methods. These N forms' effects were tested by comparing nitrogen levels in tubers, petioles, whole-plant samples, and soil.

An introduction chapter (Chapter 1) describes the importance of N fertilizer forms and application effects on potatoes, concluding with the project objective and thesis structure. Chapter 2 consists of the field study results for potato yield and quality, based on different N sources and placement methods.

Literature Cited

Anonymous. 1989. Lost Crops of the Incas: Little-Known Plants of the Andes with Promise for Worldwide Cultivation, 92-103. Washington, D.C: National Academy Press.

Blumenthal, J., D. Baltensperger, and A. Pavlista. 2008. Importance and effect of nitrogen on crop quality and health. In *Nitrogen in the Environment: Sources, Problems, and Management*, eds. J. L. Hatfield and R. F. Follett, 60-62. Amsterdam: Elsevier.

Boomgaard, P. 2003. In the shadow of rice. *Agricultural History* 77:582-610. https://doi.org/10.1525/ah.2003.77.4.582.

Canadian Food Inspection Agency (CFIA). 2013. Russet Burbank. http://www.inspection.gc.ca/plants/potatoes/potato-varieties/russet-burbank/eng/1312587385873/1312587385874. Accessed February 20, 2019.

Chastain, J. P., James J. Camberato, and Peter Skewes. 1999. Poultry manure production and nutrient content. Chapter 3b, 1-17.

https://www.clemson.edu/extension/camm/manuals/poultry/pch3b_00.pdf. Accessed February 10, 2019.

Church, B. 1980. Use of fertilizers in England and Wales. *Rothamsted Annual Report* 1979, 105-110.

Davis, J.D., R.D. Davidson, and S.Y.C. Essah. 2014. Fertilizing potatoes. https://erams.com/agnutrient/wp-content/uploads/2017/04/00541. Accessed February 17, 2019.

Dean, B.B., and R.E. Thornton. 1992. The specific gravity of potatoes, Washington State University Cooperative Extension Bulletin 1541, Pullman, WA.

Dyson, P.W., and D.J. Watson. 1971. An analysis of the effects of nutrient supply on the growth of potato crops. *Annals of Applied Biology* 69:47–63.

Errebhi, M., C.J. Rosen, S.C. Gupta, and D.E. Birong 1998. Potato yield response and nitrate leaching as influenced by nitrogen management. *Agronomy Journal* 90:10-15.

Evans, S.A. 1975. Maximum potato yield in the United Kingdom. *Outlook on Agriculture* 8:184-187.

Food and Agriculture Organization of the United Nations Statistics (FAOSTAT). 2019. http://www.fao.org/statistics/en/. Accessed February 20, 2019.

Gráda C.Ó., R. Paping and E. Vanhaute. 2007. When the potato failed. Causes and effects of the ‘last’ European subsistence crisis, 1845-1850. In *History of the Potato* - Wikipedia. https://en.wikipedia.org/wiki/History_of_the_potato. Accessed March 30, 2019.

Horton, D., and R.L. Sawyer. 1985. The potato as a world food crop, with special reference to developing areas. In *Potato Physiology*, ed. P.H. Li, 1-34, Orlando, Florida: Academic Press, Inc.

Ifenkwe, O., and E. Allen. 1983. Nitrogen and potassium uptake by high-yielding potato crops. *Journal of Agricultural Science* 101:103-111.

Iritani, W.M., and L.D. Weller. 1980. Sugar development in potatoes. Washington State University Cooperative Extension Bulletin 0717, Pullman, WA.

Johnson, C., G. Albrecht, Q. Ketterings, J. Beckman, and K. Stockin. 2005. Nitrogen basics- the nitrogen cycle. http://nmsp.cals.cornell.edu/publications/factsheets/factsheet2.pdf. Accessed February 10, 2019.

Laboski, C. A. M. and K. A. Kelling. 2007. Influence of fertilizer management and soil fertility on tuber specific gravity: A review. *American Journal of Potato Research* 84:283-290.

Love, S.L., J.C. Stark, and J.F. Guenthner. 2003. The origin of potato production systems. In *Potato Production Systems*, eds. J. Stark and S. Love, 1-6. USA: University of Idaho Agricultural Communications.

Love, S.L., R. Novy, D.L. Corsini, and P. Bain. 2003. Variety selection and management. In *Potato Production Systems*, eds. J. Stark and S. Love, 21-47. USA: University of Idaho Agricultural Communications.

Mackerron, D. K. L., M. W. Young, and H. V. Davies. 1995. A critical assessment of the value of petiole sap analysis in optimizing the nitrogen nutrition of the potato crop. *Plant Soil* 172:247-260.

Millard, P., and B. Marshall. 1986. Growth, nitrogen uptake, and partitioning within the potato (*Solanum tuberosum* L.) crop in relation to nitrogen application. *Journal of Agricultural Science* 107:421-429.

National Agricultural Statistics Service (NASS). 2020. Potatoes 2019 Summary. Nass.usda.gov. https://www.nass.usda.gov/Publications/Todays_Reports/reports/pots0920.pdf. Accessed February 13, 2021.

Porter, G. A. and J. A. Sisson. 1993. Yield, market quality, and petiole nitrate concentration of non-irrigated Russet Burbank and Shepody potatoes in response to side dressed nitrogen. *American Potato Journal* 70:101-116.

PotatoPro. 2019. World PotatoPro. https://www.potatopro.com/world/potato-statistics. Accessed February 20, 2019.

Reader, J. 2009. Potato: A History of the Propitious Esculent. New Haven: Yale University Press.

Rosen, C., and P. Bierman. 2008. Best management practices for nitrogen use: Irrigated potatoes. University of Minnesota Extension Publication 08559. https://conservancy.umn.edu/handle/11299/198232. Accessed February 11, 2019.

Rosen, C., and R. Eliason. 2005. Nutrient management for commercial fruit and vegetable crops in Minnesota. https://conservancy.umn.edu/handle/11299/197955. Accessed February 13, 2019.

Rosen, C. 2018. Potato fertilization on irrigated soils. Extension.umn.edu. https://extension.umn.edu/crop-specific-needs/potato-fertilization-irrigated-soils. Accessed May 2, 2021.

Salunkhe, D.K., S.S. Kadam, and S.J. Jadhav. 1991. *Potato: Production, Processing, and Products*, 36-150. Boca Raton, Fla.: CRC Press.

Shresta, R. K., L. R. Cooperband, and A. E. MacGuidwin. 2010. Strategies to reduce nitrate leaching into groundwater in potato grown in sandy soils: Case study from north-central USA. *American Journal of Potato Research* 87:229-244.

Smith, O., and W. Talburt. 1987. *Potato Processing*. Westport, Conn.: AVI Pub. Co.

Solano Solis, J., D. Morales Ulloa, and L. Anabalón Rodríguez. 2007. Molecular description and similarity relationships among native germplasm potatoes (*Solanum tuberosum* ssp. *tuberosum* L.) using morphological data and AFLP markers. *Journal of Biotechnology*. https://doi: 10.2225/vol10-issue3-fulltext-14. Accessed February 20, 2019.

Spooner, D., K. McLean, G. Ramsay, R. Waugh, and G. Bryan. 2005. A single domestication for potato based on multilocus amplified fragment length polymorphism genotyping. *Proceedings of the National Academy of Sciences* 102:14694-14699. https://www.pnas.org/content/102/41/14694.

Stark, J. and D.T. Westernmann. 2003. Nutrient management. In P*otato Production Systems,* eds. J. Stark and S. Love, 115-130. USA: University of Idaho Agricultural Communications.

Trenkel, M. E. 2010. Slow- and controlled-release and stabilized fertilizers. An option for enhancing nutrient use efficiency in agriculture. International Fertilizer Industry Association. Paris, France.

Vandendriessche, H., J. Bries, and M. Geypens. 1996. Experience with fertilizer expert systems for balanced fertilizer recommendations. *Communications in Soil Science and Plant Analysis* 27:1199-1209.

Vos, J. and D. MacKerron. 2000. Basic concepts of the management of supply of nitrogen and water in potato production. In *Management of Nitrogen and Water in Potato Production*, eds. A.J. Haverkort and D. MacKerron, 16. Wangeningen: Wangeningen Academic Pers.

Waddell, J., S. Gupta, J. Moncrief, C. Rosen, and D. Steele. 2000. Irrigation- and nitrogen-management impacts on nitrate leaching under potato. *Journal of Environment Quality* 29: 251.

Westermann, D., and G. Kleinkopf. 1985. Nitrogen requirements of potatoes. *Agronomy Journal* 77: 616-621.

Westermann D.T. 1993. Fertility management. In *Potato Health Management*, ed. R.C. Rowe, 77-86. St. Paul: The American Phytopathological Society, APS Press.

Western Potato Council. 2003. Guide to commercial potato production on the Canadian Prairies. Chapter 1, 1-3. https://www.gov.mb.ca/agriculture/crops/crop-management/pubs/guide-to-commercial-potato-production.pdf. Accessed March 2, 2019.

Young M., H. Davies, and D. MacKeron. 1993. Basic concepts of the management of supply of nitrogen and water in potato production. In *Management of Nitrogen and Water in Potato Production*, eds. A.J. Haverkort and D. MacKerron, 16. Wangeningen: Wangeningen Academic Pers.

Zebarth, B. J., Y. Leclerc, G. Moreau, and E. Botha. 2004. Rate and timing of nitrogen fertilization of Russet Burbank potato: Yield and processing quality. *Canadian Journal of Plant Science* 84:855–863.

Zebarth, B., and C. Rosen. 2007. Research perspective on nitrogen bmp development for potato. *American Journal of Potato Research* 84:3-18.

Zebarth, B.J., G. Bélanger, A.N. Cambouris, and N. Ziadi. 2012. Nitrogen fertilization strategies in relation to potato tuber yield, quality, and crop N recovery. In *Sustainable Potato Production: Global Case Studies*, eds. Z. He, R. Larkin, and W. Honeycutt, 165-186. Netherlands: Springer.

CHAPTER 2: FIELD EVALUATION OF NITROGEN SOURCES EFFECTS FOR RUSSET BURBANK POTATO

Abstract

Nitrogen (N) is one of the vital elements for potato production. It is available as organic and inorganic sources. However, nitrogen must be transformed into the inorganic forms of nitrate (NO_3^-) or ammonium (NH_4^+) to be utilized by plants. As well as common synthetic fertilizers, turkey manure is commonly being used as a N source in potato production in Minnesota. Little information exists comparing traditional N sources and placement to turkey manure in Minnesota potato production. This study aimed to compare traditional N sources and applications (urea broadcast, Environmentally Smart Nitrogen (ESN) broadcast, and ESN banded at hilling) to turkey manure compost (TMC) broadcast prior to planting, on yield and quality of Russet Burbank potatoes in Minnesota in 2019 and 2020.

Results showed that TMC improved the total marketable yield (51 MT ha^{-1} in 2019 and 60 MT ha^{-1} in 2020) and the >170 g (%) sized tuber yield, compared to the non-treated control (40 MT ha^{-1} in 2019 and 56 MT ha^{-1} in 2020). The urea and ESN treatments resulted in an average total yield of 58 MT ha^{-1} in 2019 and 62 MT ha^{-1} in 2020. There was no difference between TMC, ESN, and urea treatments for total and marketable total yields in 2020. Tuber quality was not affected by N treatment in 2020, but specific gravity (SG) was lower (< 1.080) than desired for the processing market, although the SG was >1.080 in 2019. French fry colors were averaging number 1 in 2019 and number 2 in 2020 across all treatments based on the USDA Munsell color scale. These fry colors were acceptable for French fry processing. Banding fertilizer did not prove a placement benefit versus broadcasting for marketable yield. Turkey manure compost was a good source of nitrogen that is readily available and provides a good

sustainable option for potato production. Further work should examine what benefits conventional fertilizer can have when used in combination with TMC.

Introduction

Potato (*Solanum tuberosum* L.) can be grown under many different climatic conditions as a good source of energy for humans (Sieczka and Thornthon, 1993). In potato production, environmental conditions and cultural practices affect yield and tuber quality.

Fertilizer applications play a key role in tuber yield and tuber quality (Westermann, 2005). Potato has a high nitrogen (N) requirement, and organic or inorganic fertilizer treatments may affect tuber size and yield, specific gravity, and tuber N concentration, especially in sandy and nutrient-deficient soils (Harris, 1992; Errebhi et al., 1998; Trehan and Sharma, 2003). In addition to environmental conditions and cultural practices, the N requirement can vary by cultivar, growth stage, yield potential, soil type, and utilization (frozen processing, fresh consumption, and chip processing) (Vandendriessche et al., 1996; Stark and Westermann, 2003).

Nitrogen rate, application method, application timing, and N source also need to be considered in potato production (Rosen and Bierman,2008). The use of synthetic fertilizers improves yield; however, due to leaching, excessive or incorrect N applications may have a negative impact on the environment and public health and may result in economic and tuber quality losses (Rosen and Bierman, 2008; Wang et al., 2002).

Slow-release organic (animal manure) or inorganic (sulfur or polymer-coated urea) N sources can be used as an alternative method to prevent the application of excessive N and to increase tuber yield. These forms of fertilizers may delay or extend N release for plant uptake and use (Liegel and Walsh, 1976; Trenkel, 2010; Waddell et al., 1999). Additionally, organic fertilizers improve the soil organic matter, increasing the water holding capacity and soil aeration, and influence pH changes (reductions or increases) and essential nutrient supply (Fenton et al., 2008).

The use of animal manure, such as poultry litter (chicken (*Gallus gallus*) or turkey (*Meleagris gallopavo*) manure and their bedding materials), is a good source of slow-release organic fertilizer. Manure used as fertilizer has been deemed an acceptable waste management strategy for the environment (Tewolde et al., 2011). Poultry litter has shown favorable results on yield for numerous vegetable crops (Neilsen et al., 1998) and small fruits (Dean et al., 2000). It has been reported that the use of poultry litter in cotton increased lint yield compared to the use of the single-nutrient synthetic fertilizer in Mississippi (Endale et al., 2002). In potato production, poultry manure improved marketable tuber yield and tuber size but decreased specific gravity for the cultivar Shepody in Canada (Rees et al., 2014). As slow-release poultry manure, turkey manure is a good N, P, and K source; these may be varied due to not equally made and mixed with inert ingredients. Turkey manure may contain 55 to 80% dry matter, 10 to 25 kg ton^{-1} N, 19 to 29 kg ton^{-1} P_2O_5, 8 to 18 kg ton^{-1} K_2O, and 3 to 4 kg ton^{-1} S, and these widely different nutrient contents are due to turkey breed and feed used (Chastain et al., 1999). In one experiment, marketable tuber yield was 60% higher with turkey manure (applied at 31.4 Mg ha^{-1} turkey manure, with a nitrogen content of 18.7 kg Mg^{-1}) than the non-treated Russet Burbank potatoes in Minnesota (Waddell et al., 1999). Turkey manure may also reduce N leaching and improve soil N concentration. Waddell et al. (2000) reported that N leaching decreased with turkey manure treatment (0.1 kg N ha^{-1}) compared with the conventional N treatment (0.8 kg N ha^{-1}). Additionally, turkey manure had total N in the range of 51 to 57 g kg^{-1} and organic N in the range of 37 to 43g kg^{-1} in a two-year poultry manure experiment conducted in Iowa. Turkey manure was applied in spring, fall, and winter. The highest NO_3-N concentration resulted from spring application, while the winter application timing was intermediate, and fall application resulted in the lowest soil NO_3-N concentration (Ruiz Diaz and Sawyer 2008).

Turkey manure is easily accessible, as Minnesota is the leading producer of turkey in the USA (USDA, 2019). It is readily available as an inexpensive N source for Minnesota potato producers. However, its use is not a common practice, and little information is available for its use as an alternative N fertilizer (Waddell et al. 1999). Moore et al. (2011) reported that long-term manure applications in potato fields could cause the accumulation of some nutrients that are absent or existing in small amounts in soil, causing negative effects on crop growth, tuber yield, and tuber quality. Manganese toxicity has been found following long-term cattle (*Bos taurus*) manure application; however, this was observed on soils with a pH level < 4.8 (Lee and MacDonald, 1977). Potato solids were reduced following the use of liquid dairy manure compared to conventionally fertilized plots because of the increased salt accumulations (Dawson and Kelling, 2002). Some diseases have increased following manure treatments because they contain living organisms. The use of dairy manure resulted in fecal coliform bacteria, *Enterococcus* spp., and *Escherichia coli* (E. coli), on the skin of potato and in the root rhizosphere when plots were fertilized (297 days from treatment to harvest) with dairy compost (Entry et al., 2005). Additionally, Dawson and Kelling (2002) reported that using liquid dairy manure increased common scab incidence on tubers compared to synthetic fertilizers.

Integrating turkey manure as a source of N into commercial potato production can be difficult. Turkey manure is utilized as a by-product that is often wasted or does not have a big market in organic potato production. Most potato producers utilize conventional fertilizers such as urea or polymer-coated urea because of historical results and ease of handling. Less is known about the uptake of N from turkey manure compared to conventional fertilizers in Minnesota.

Thus, the objective of this study was to compare the effect of traditional N sources and application methods to turkey manure compost (TMC) on nitrogen uptake and tuber yield and quality of Russet Burbank potato in Minnesota.

Materials and Methods

Russet Burbank was used as the potato cultivar in both 2019 and 2020; it is the most widely grown cultivar in North America. Nitrogen treatments (urea, ESN, and turkey manure) were applied at different timings to represent typical grower practices. The non-treated control had no additional nitrogen applied above the available N conveyed in the pre-plant soil test report. Prior to planting, 7.4 tons of TMC ha^{-1} was broadcast and incorporated in the TMC plots. In 2019, the TMC had 13 kg N ton^{-1}, while in 2020, the concentration was 9 kg N ton^{-1} per nutrient analysis. The urea (46% N) broadcast, ESN (44% N) broadcast, and ESN banded were applied to equal 297 kg N ha^{-1} at hilling. All other nutrients were provided to all plots to ensure adequate nutrition as recommended by soil testing. Field trials were established in a commercial potato field on May 10, 2019, near Park Rapids, Minnesota, and April 30, 2020, near Perham, Minnesota. The soil at the Park Rapids site was a Verndale loamy sand (course-loamy, mixed, superactive, frigid Typic Argiudolls) with 80% sand, 16% silt, 4% clay, a pH of 6.1, 1.8 %organic matter (OM), and with residual NO_3^- of 54 kg ha^{-1}. At Perham, the soil type was also Verndale sandy loam (course-loamy, mixed, superactive, frigid Typic Argiudolls) with 74% sand, 12% silt, 14% clay, a pH of 6.9, 2.0% OM, and residual NO_3^- of 12 kg ha^{-1}. The previous crop was yellow peas in 2019 and soybean in 2020. The trials were randomized in a complete block with a split-plot arrangement with four replicates.

Four-row plots measuring 3.7 m wide x 34 m long were established, and the two center rows were used for plant, soil, and tuber sampling during the growing season and harvested at the end of the growing season. Eight, 1.5 m long by 0.9 m wide, sub-plots were established within each plot for sampling every two weeks during each growing season. An area, 1.8 m by 6 m area was measured for harvest at the end of the growing season. All four rows received the same fertility treatment, allowing the outside two rows to function as border rows.

Whole certified seed tubers of Russet Burbank weighing approximately 57-71 g each were planted with a two-row custom research plot planter at 30.5 cm within-row spacing and row spacing of 91cm (36 inches). Pesticides, irrigation, and all other management practices were applied according to recommended practices (Bissonnette,1993).

Sampling and Nitrogen Qualification

Sampling consisted of the petiole, whole plant, soil, and tuber samples. Throughout the growing season, samples from the randomized 1.5 m (5 feet) row were taken approximately every two weeks (from the vegetative stage to harvest).

Petiole samples were collected from the 1.5 m sub-plot at each two-week interval. Fifteen leaves (the first fully expanded leaf equal to the fourth petiole) were sampled from each treatment every two weeks during the growing season, beginning at the vegetative stage through harvest (Table 1). Leaflets were stripped from the leaf, and the petioles were stored in a refridgator at 3°C (38°F) and sent within a week to AgVise Laboratory in Northwood, ND, to be analyzed for NO_3-N concentration. At AgVise, petiole samples were dried in a dryer overnight at 78 °C and analyzed using the method described by Gelderman and Beegle (2015).

Table 1. Production information for the study in 2019 and 2020.

Action	2019	DAP [z]	2020	DAP
Planting	May 10	-	April 30	-
Fertilizer Application	June 11	-	May 13	-
Sampling [y]				
1	June 28	49	June 11	42
2	July 12	63	June 24	55
3	July 26	77	July 10	71
4	August 7	89	July 23	84
5	August 21	103	August 5	97
6	September 5	117	August 19	111
7	-	-	September 3	126
Harvest	September 19	132	September 8	131

[y] Samplings were done on the same days for petiole, whole plant, tuber, and soil.
[z] Days after planting.

Whole plants (4-5 plants in 1.5 m section) were cut at the soil level, and these whole plants were weighed (Weight 1) beginning at the vegetative growth stage through harvest every two weeks (Table 1). A sub-sample of whole plant leaves (included stems and leaves), approximately 1 kg (Weight 2), was cut into small (approximately 10 cm) to facilitate drying. Plant material was dried at 70 to 77 °C for five days. Dried tissue samples were weighed (Weight 5) and sent to AgVise Laboratories for plant NO_3-N (%S-nitrogen) analysis. The NO_3-N analysis process for the whole plant was completed as described by Gelderman and Beegle (2015).

Following whole-plant sampling, tubers from the corresponding plants were dug beginning at the tuber initiation, stage corresponding to 63 and 55 DAP in 2019 and 2020, respectively, through harvest at each two-week interval (Table 1). Tubers were collected, counted, weighed (Weight 3), and saved for further analysis. Approximately 1 kg of arbitrarily selected tubers (from weighed tubers) were washed and cut into quarter sections (Weight 4) within 2-3 hours after digging the tubers and dried (Weight 6) at 70 to 77 °C for five days. After drying, samples were sent to AgVise Laboratory in Northwood, ND, to determine the level of NO_3-N in tubers (%T- nitrogen) using the methods described by Gelderman and Beegle (2015).

Plant tissue (petiole, whole-plant, and tuber) N quantification results were reported on a percentage dry weight basis. The following equations were used to determine N uptake in kg ha^{-1}. Total N uptake was the sum of the values of N in whole plants and tubers. The uptake of nitrogen was calculated as

$$\frac{\text{Weight 1} \times \text{Weight 5}}{\text{Weight 2}} = \text{Dry weight of stems in 1.5 m (a)}$$

$$\frac{\text{Weight 3} \times \text{Weight 6}}{\text{Weight 4}} = \text{Dry weight of tubers in 1.5 m (b)}$$

$$\text{a} \times \%S + \text{b} \times \%\text{T} = \text{Total N uptake}$$

Soil samples were collected from each sub-plot utilizing a soil probe to a depth of 30 cm (12 inches) every two weeks (Table 1). Five soil cores were collected, dried, and mixed to obtain a representative composite sample for each plot. Soil samples were submitted to the NDSU Soil Testing Laboratory for NO_3-N quantification, using the methods described by Vendrell and Zupanic (1990).

Yield and Quality Determination

At the end of the growing season, the trials were harvested utilizing a custom single-row harvester on September 19, 2019, and September 8, 2020. Tubers were sized at the USDA-ARS Potato Worksite in East Grand Forks, MN, by separating tubers into the following size categories; <85, 85-170, 171-283, 284-397, and >397g. The percent of tubers >170 and >283 g were calculated by dividing the weight of tubers >170g by the total yield or dividing the tubers >283g by the total yield. Tubers >85g were considered marketable tubers.

Specific gravity was determined using the weight in air minus the weight in water method after harvest by the following formula described by Stark and Love (2003).

Specific gravity = (weight in air (kg)) / (weight in air (kg)-weight in water (kg))

French fry quality for each plot was determined using ten tubers (85 to 283 g tuber size category) per plot shortly after harvest and following three months storage at 9˚C. Tubers were stored at the USDA-ARS Potato Worksite in East Grand Forks, MN, in temperature-controlled research potato storage with 95% relative humidity. After harvest (0-month), tubers were stored at 13 ºC until processing, while tubers were stored for 3-months had the temperature gradually reduced after a three-week healing period from 13 ºCto 9 ºC. The fry color was determined by the Photovolt Reflection Meter. Photovolt % reflectance values correspond to the USDA Munsell color scale (from number 1 to 4) where 1 corresponds to ≥ 43% reflectance, 2 is equal 35.3-43% reflectance, 3 is equal 25.8-35.3% reflectance, and 4 is < 25.8% reflectance. French fry colors of 1 and 2 are acceptable, while 3 and 4 are unacceptably dark. (USDA, 1972; Moore et al., 2011).

Statistical Analysis

Statistical analyses were performed using the Statistical Analysis Software (SAS) (SAS Institute, Cary, NC; release 9.4 for Windows). The sampling data sets were analyzed using the MIXED procedure with the REPEATED option, considering fertilization treatment and sampling date as fixed effects. For the final yield data, the combined analysis of variance was performed using the MIXED procedure in which year was a main plot; fertilization treatment was a subplot, and replicates were nested within a year. The year and fertilization treatment were considered as a fixed effect. The least significant difference (LSD) was used to compare treatment means. Correlation coefficients were estimated using the CORR procedure in SAS. Regression analyses were performed using the REG procedure in SAS to obtain the quadratic polynomial models, and figures were created using Windows (Excel). For the data sampled during the growing season (every two weeks), analysis of variance was performed separately for individual years because the sampling times were not consistent between the two growing years.

Results and Discussion

In-Season Nitrogen Results

Petiole Nitrogen

Petiole analysis is the most common approach to determine N levels in potato production (Zebarth and Rosen, 2007). Current potato production in the United States relies on sampling petioles of the first fully expanded leaves (petiole of the fourth-youngest leaf) to determine nutrient status and are used because petioles reflect the plant's nutrient status (Rosen, 2018). As expected, petiole NO_3-N levels generally declined throughout the growing season in each year (Table 2). Initially, petiole NO_3-N concentrations were not different for N treatments, although they were statistically different from the untreated control. Following sampling at subsequent dates, the NO_3-N concentrations declined rapidly and statistically for both the TMC and untreated control treatments. Petiole NO_3-N concentrations did not differ statistically in 2020 for treatments within sampling date, but concentrations generally declined throughout the growing season as in 2019.

In 2019, there were some reductions in petiole NO_3-N concentration between synthetic fertilizers during the sampling dates; they were not different when assessing the mean for the season. The level of petiole NO_3-N started about 2.7% at 49 DAP (tuber initiation stage), they decreased steadily during tuber bulking stage (63-89 DAP), and this concentration declined to approximately 1.1% at the final sampling dates of 103 and 117 DAP (maturation stage). In comparison, turkey manure compost nitrate-nitrogen concentration had greater decreases from 2.4% at the tuber initiation stage to about 0.8% at tuber bulking, and the final concentration was in the range of 0.3% (maturation) in petioles in the same time interval (Table 2).

Stark and Westermann (2003) reported that the recommended petiole NO_3-N concentration was 2.0-2.5 % in the tuber initiation stage (Table 3). For all treatments, petiole NO_3-N resulted in sufficient levels apart from the non-treated control in 2019. During tuber bulking (approximately 55-90 DAP), the petiole nitrate level should be >1.5% to meet plant N requirements for Russet Burbank (Table 3).In 2019, urea and ESN treated potato plots' petioles with adequate petiole nitrate-N during tuber bulking, the non-treated control and TMC petiole N levels had stayed under the recommended values and were 0.5 and 1.0%, respectively. A recent study indicates that potatoes fertilized with organic fertilizers may contain lower petiole nitrate-nitrogen levels (0.1-0.5%) than conventionally fertilized potatoes, and these plants produced acceptable total yields ranging from 39 to 43 MT ha^{-1} (Moore et al., 2011; Moore et al., 2013).

Table 2. Petiole NO_3-N (%) concentration for nitrogen fertilizer treatment for each sampling date and the season mean for Russet Burbank in 2019 near Park Rapids and 2020 near Perham, MN.

Sampling (DAP)[z]	49	63	77	89	103	117	--	Mean of season
2019				%				
Treatment								
Non-treated control	1.6b[y]	0.5c	0.1b	0.1b	0.06c	0.1b	--	0.4c
ESN broadcast	2.7a	2.3a	2.2a	1.9a	1.3ab	1.1a	--	1.9a
ESN banded	2.5a	2.1a	2.1a	1.8a	1.0a	1.1a	--	1.9a
Turkey manure compost	2.4a	1.0b	0.2b	0.1b	0.06c	0.3b	--	0.7b
Urea	2.9a	2.4a	2.2a	2.1a	0.9b	1.1a	--	1.9a

Sampling (DAP)	42	55	71	84	97	111	126	Mean of season
2020				%				
Treatment								
Non-treated control	2.3	1.0	1.1	0.5	0.2	0.04	0.1	0.8
ESN broadcast	2.5	1.5	1.4	0.5	0.2	0.4	0.4	1.0
ESN banded	2.4	1.1	1.3	0.7	0.1	0.2	0.5	0.9
Turkey manure compost	2.4	1.1	1.1	0.2	0.1	0.1	0.1	0.7
Urea	2.5	1.3	1.2	0.3	0.1	0.1	0.04	0.8

[y] Within each year and sampling date, columns with the same letter or no letter are not significantly different according to the LSD mean comparison procedure (P> 0.05).

[z] Days after planting.

Table 3. Recommended petiole NO_3-N (%) concentrations for Russet Burbank potatoes during different growth stages.

Growth Stage	Petiole NO_3-N (%) [z]
Vegetative	--
Tuber initiation	2.0-2.5
Tuber bulking	1.5-2.0
Maturation	1.0-1.5

[z] Modified from Stark and Westermann (2003).

In 2020, there were no statistical differences between treatments at each sampling date for petiole samples. Petiole NO_3-N levels average 2.4% at 42 DAP (tuber initiation) across all treatments; this level sharply declined from approximately 1.2 to 0.1% between 55 and 97 DAP (tuber bulking) while at maturation (at 111 and 126 DAP) petiole N concentrations generally remained the same (Table 2). Petiole nitrate concentrations were below recommendations throughout the 2020 growing season (excluding 42 DAP) (Table 2 and 3). The average max /min temperature was 24/12ºC in 2019 and 23/10ºC in 2020 (Figures 1 and 2). The total precipitation (rainfall + irrigation) was 455 mm in 2019 and 655 mm in 2020 (Figures 1 and 2). In 2020, potato plants received more water due to rainfalls between 60 to 100 DAP (Figure 2) that was after the tuber initiation stage; however, low petiole nitrate-N levels (approximately 1.2%) were already evident before the increased precipitation. Thus, while leaching due to excessive rainfall is a common problem, there was perhaps another factor limiting N availability uptake, although several rainfall events between 60 and 80 DAP and at 97 DAP may have attributed to losses due to leaching. We did not measure leaching in our study.

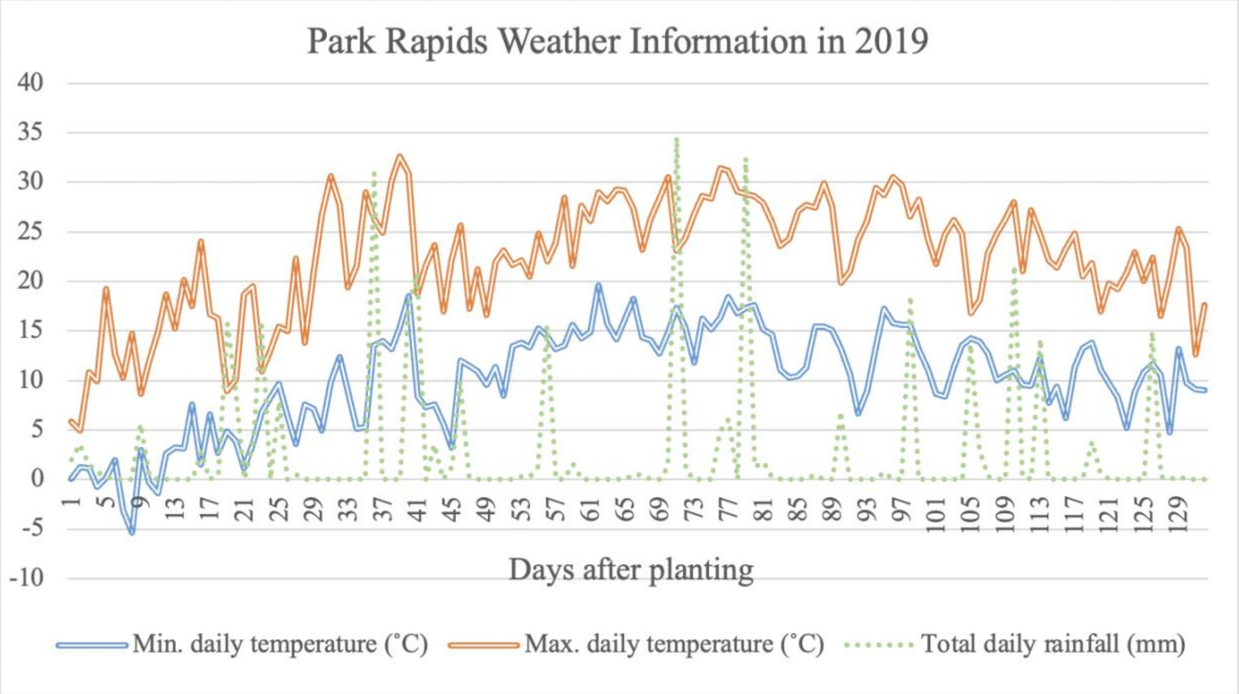

Figure 1. Total daily rainfall (mm) and mean daily air temperature (ºC) from planting to harvest in 2019 near Park Rapids (data source: Minnesota Department of Agriculture, 2021).

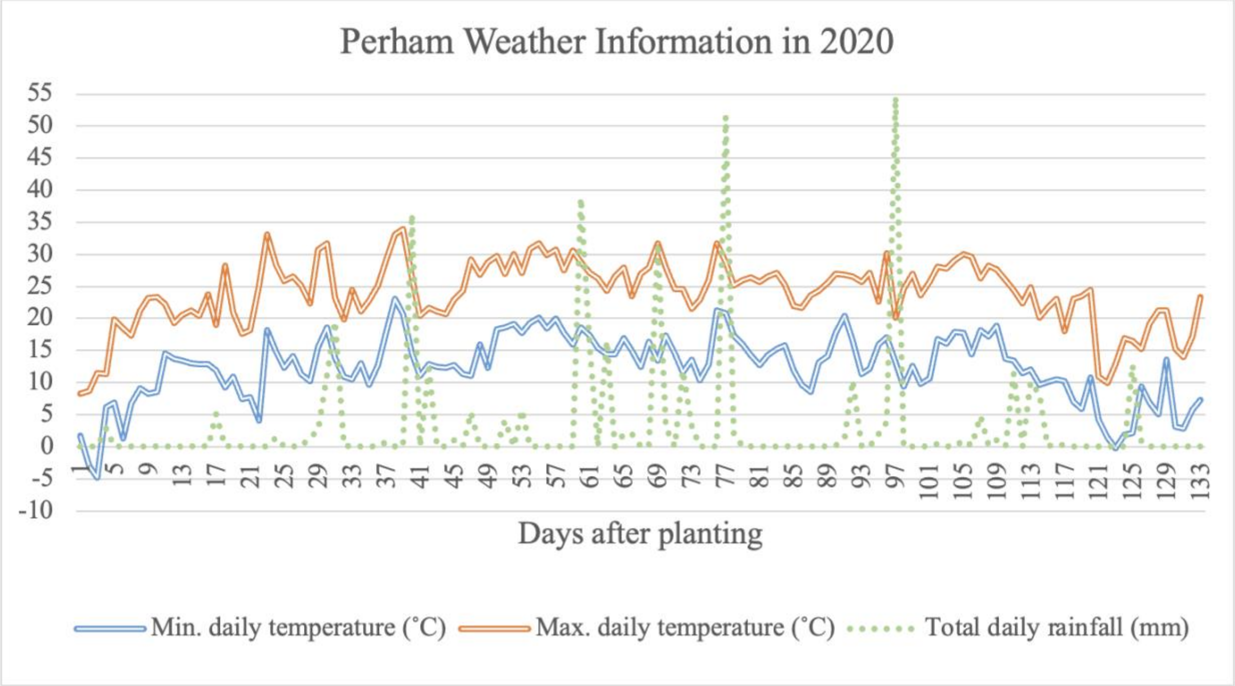

Figure 2. Total daily rainfall (mm) and mean daily air temperature (ºC) from planting to harvest in 2020 near Perham (data source: Minnesota Department of Agriculture, 2021).

Whole Plant Nitrogen

Plant NO_3-N concentration was affected by N treatment and declined throughout the growing season (Table 4). In 2019, even though, for plants, there were some reductions between synthetic fertilizers during the sampling dates. However, plant NO_3-N concentrations were not different when the season of average was assessed, and the level of NO_3-N from about 5.6% to approximately 2.9%. In comparison, the N concentration for the turkey manure treatment had a greater decrease, from 5.2% to 1.55%, for whole plant samples (Table 4). This significant decrease may be associated with having less total N applied than the ESN and urea treatments in 2019. The manure treatment improved the plant parts' NO_3-N level 5% than the non-treated control, and ESN and urea had no differences in the season of average (Table 4). In 2020, no differences were found between treatments for each sampling date for whole plant samples. Whole-plant nitrate concentrations were started with about 5.8% at the first sampling date and declined through harvest for all treatments(Table 4). Plant development may influence temperature and light conditions; therefore, these impact the concentration of plant nutrients (Gianquinto and Bona, 2000). Nitrogen uptake, for instance, can decline under high temperatures due to the ease of nutrient dilution. Cold temperatures can also cause slow plant growth, increasing petiole nutrient concentration (Gianquinto and Bona, 2000). In 2020, this whole plant N level might be affected by rainfall events like petioles.

Table 4. Plant NO_3-N (%) concentration for nitrogen fertilizer treatment for each sampling date and the season mean for Russet Burbank in 2019 near Park Rapids and 2020 near Perham, MN.

Sampling (DAP)[z]	49	63	77	89	103	117	--	Mean of season
2019 Treatment				%				
Non-treated control	5.1b[y]	4.0c	2.7c	2.2c	1.7b	1.1b	--	2.8c
ESN broadcast	5.7a	5.4a	4.6a	3.6b	3.6a	2.8a	--	4.3a
ESN banded	5.5ab	4.7b	4.1a	4.3a	3.4a	2.7a	--	4.1a
Turkey manure compost	5.2ab	4.0c	3.4b	2.0c	2.0b	1.5b	--	3.0b
Urea	5.7a	4.9ab	4.5a	4.0ab	3.6a	2.9a	--	4.3a

Sampling (DAP)	42	55	71	84	97	111	126	Mean of season
2020 Treatment				%				
Non-treated control	5.8	4.7	3.5	2.8	2.5	1.8	1.9	3.3
ESN broadcast	5.8	4.9	4.2	3.7	2.6	2.6	1.8	3.3
ESN banded	5.8	4.6	3.7	2.6	2.5	2.3	1.8	3.7
Turkey manure compost	6.0	4.7	3.4	2.7	2.7	1.7	1.7	3.3
Urea	5.8	4.9	3.7	2.4	2.2	1.9	1.6	3.2

[y] Within each year and sampling date, columns with the same letter or no letter are not significantly different according to the LSD mean comparison procedure (P> 0.05).

[z] Days after planting.

Soil Nitrogen

Soil NO_3-N declined during two growing seasons. In 2019, soil NO_3-N level decreased from 0.002-0.022% N range to 0.001-0.003% N range between 49-117 DAP for all treatments.

When the whole season was assessed, the TMC samples had a lower N level than urea and ESN treatments in 2019; however, TMC improved the soil NO_3-N level by 25% more than the non-treated control at the beginning of the season in 2019 (Table 5).

In 2020, no difference was found between treatments for soil NO_3-N level that concentration decreased from approximately 0.05 to 0.001% soil NO_3-N (Table 5). Decreasing levels can be expected since soil N concentration can differ in response to variation in the preceding crop, N source, climatic conditions, and site (Zebarth et al., 2004). Leguminous crops can provide additional nitrogen in the soil for the following year's crops. (Gianquinto and Bona, 2000). In 2019, having higher soil residual N might influence the soil N concentration; however, each year's previous crops were from the leguminous crops. Yellow peas might leave more N in the soil than soybean in 2019.

Nitrogen placement could influence the soil N concentrations that were significantly different between treatments. The soil N found from ESN banded plots was higher (0.010%) during the 2019 growing season (Table 5); this could happen because of the placement method or ESN structure that is slow-release fertilizer; there was no evidence for it. Kelling et al. (2015) agree with our findings and reported that in a 3-year N rate and placement experiment, the broadcasted treatment soil NO_3-N was lower than the banded treatment results only in the second year of the study. However, in the other years of the study, these treatments had no differences for soil NO_3-N in Russet Burbank potatoes in WI.

Table 5. Soil NO_3-N (%) concentration for nitrogen fertilizer treatment for each sampling date and the season mean for Russet Burbank in 2019 near Park Rapids and 2020 near Perham, MN.

Sampling (DAP)[z]	49	63	77	89	103	117	--	Mean of season
2019 Treatment				%				
Non-treated control	0.002c[y]	0.001d	0.001b	0.001b	0.001b	0.001a	--	0.001c
ESN broadcast	0.007c	0.008b	0.004ab	0.007a	0.002b	0.001a	--	0.005b
ESN banded	0.022a	0.009ab	0.009a	0.006a	0.010a	0.003a	--	0.010a
Turkey manure compost	0.006c	0.002c	0.001b	0.001b	0.001b	0.001a	--	0.002c
Urea	0.017b	0.014a	0.004b	0.002ab	0.001b	0.002a	--	0.007b

Sampling (DAP)	42	55	71	84	97	111	126	Mean of season
2020 Treatment				%				
Non-treated control	0.003	0.002	0.003	0.001	0.001	0.001	0.001	0.002
ESN broadcast	0.008	0.004	0.004	0.001	0.001	0.001	0.002	0.003
ESN banded	0.007	0.005	0.004	0.001	0.001	0.001	0.002	0.003
Turkey manure compost	0.005	0.001	0.004	0.001	0.001	0.001	0.001	0.002
Urea	0.006	0.003	0.004	0.001	0.001	0.001	0.001	0.002

[y] Within each year and sampling date, columns with the same letter or no letter are not significantly different according to the LSD mean comparison procedure (P> 0.05).

[z] Days after planting.

Tuber Nitrogen

Tuber N concentration was influenced by fertilization in 2019 (Table 6). The NO_3-N concentration of tubers decreased for each sampling date, from 63 to 117 DAP, in 2019. Tuber

NO_3-N concentration was higher in the urea and ESN treatments with a range of 1.5- 2.0% range in comparison to the TMC and the non-treated control with a range of 1.0-1.6% NO_3-N concentration in tuber bulking (63 -89 DAP), and during maturation (103 and 117 DAP). Turkey manure compost applications resulted in similar tuber N concentrations as far tubers from the ESN treated plots at the last sampling date (maturation). Further, TMC improved the tuber nitrate-nitrogen when the whole season was assessed compared to the non-treated control (Table 6).

In 2020, there were no statistical differences in tuber N between treatments. The NO_3-N concentration of tubers decreased for each sampling date, from 55 to 126 DAP, in 2020. The concentration of tuber NO_3-N was from approximately 1.2 to 1.9% through the growing season (Table 6).

Young et al. (1993) indicated that tuber N concentration should be between 0.5 to 3.5% during the growing season. The N concentration decreases during tuber initiation; these declines stabilize or increase slightly during tuber bulking (Ifenkwe and Allen, 1983). Also, Gianquinto and Bona (2000) indicated, total N in tubers was, in general, 1.81%, 1.55%, and 1.48% for tuber initiation, tuber bulking, and maturity, respectively. Therefore, tubers had mostly sufficient N for all treatments through the growing season in 2019 and 2020.

Table 6. Tuber NO_3-N (%) concentration for nitrogen fertilizer treatment for each sampling date and the season mean for Russet Burbank in 2019 near Park Rapids and 2020 near Perham, MN.

Sampling (DAP)[z]	63	77	89	103	117	--	Mean of season
2019 Treatment				%			
Non-treated control	1.6b[y]	1.1bc	1.0b	1.1c	0.9c	--	1.1c
ESN broadcast	2.0a	1.5a	1.5a	1.5a	1.3ab	--	1.6a
ESN banded	2.0a	1.3ab	1.5a	1.4ab	1.3ab	--	1.5a
Turkey manure compost	1.6b	1.2b	1.2b	1.1b	1.2b	--	1.3b
Urea	2.1a	1.5a	1.5a	1.2bc	1.4a	--	1.6a
Sampling (DAP)	55	71	84	97	111	126	Mean of season
2020 Treatment				%			
Non-treated control	1.8	1.3	1.3	1.2	1.3	1.2	1.3
ESN broadcast	1.9	1.6	1.5	1.3	1.5	1.3	1.5
ESN banded	1.9	1.4	1.2	1.2	1.4	1.3	1.4
Turkey manure compost	1.9	1.4	1.3	1.3	1.3	1.3	1.4
Urea	2.0	1.4	1.1	1.2	1.2	1.3	1.4

[y] Within each year and sampling date, columns with the same letter or no letter are not significantly different according to the LSD mean comparison procedure ($P > 0.05$).

[z] Days after planting.

Total Nitrogen Uptake

Total nitrogen uptake was influenced by N treatments, and total N uptake primarily increased for each sampling date in 2019 (Table 7). In 2019, the total N uptake was lower for the non-treated control (108 kg ha^{-1}), whereas TMC application increased the total N uptake by 13%

compared to the non-treated check. Turkey manure that had 144 kg ha^{-1} N uptake followed the urea and ESN treatments’ N uptake (188 to 217 kg ha^{-1}), which were not different from each other, in a close manner.

In 2020, there were no differences between treatments, and total N uptake resulted in some fluctuations for each sampling date; however, it was not significant for each treatment, and total N uptake was between 176 to 206 kg ha^{-1} (Table 7).

Stark et al. (2004) indicated total N uptake at tuber bulking was 110-240 kg ha^{-1}, and this stabilized at maturation (Figure 3); our results had similar and adequate N uptake at this growth stage both years (Table 7). Also, the improvement of total N uptake with turkey manure could be expected. Waddell et al. (1999) reported that turkey manure total N uptake was 15% higher than the S-coated urea. For the next year of that experiment, the TMC treatment resulted in a 4% decline in total N uptake, but these differences were not significant.

Table 7. Total nitrogen uptake (kg ha^{-1}) for nitrogen fertilizer treatment for each sampling date and the season mean for Russet Burbank in 2019 near Park Rapids and 2020 near Perham, MN.

Sampling (DAP)[z]	63	77	89	103	117	--	Mean of season
2019 **Treatment**			%				
Non-treated control	81[y]	89c	117b	128b	126c	--	108c
ESN broadcast	120	179a	211a	212a	234a	--	191a
ESN banded	129	160ab	195a	232a	224ab	--	188a
Turkey manure compost	100	134b	140b	153b	193b	--	144b
Urea	144	199a	222a	244a	275a	--	217a
Sampling (DAP)	55	71	84	97	111	126	Mean of season
2020 **Treatment**			%				
Non-treated control	110	168	171	175	239	246	185
ESN broadcast	120	219	211	190	248	251	206
ESN banded	94	181	163	206	233	201	180
Turkey manure compost	101	144	160	255	209	189	176
Urea	106	185	156	221	216	208	182

[y] Within each sampling date and the whole season, columns with the same letter or no letter are not significantly different according to the LSD mean comparison procedure (P> 0.05).

[z] Days after planting.

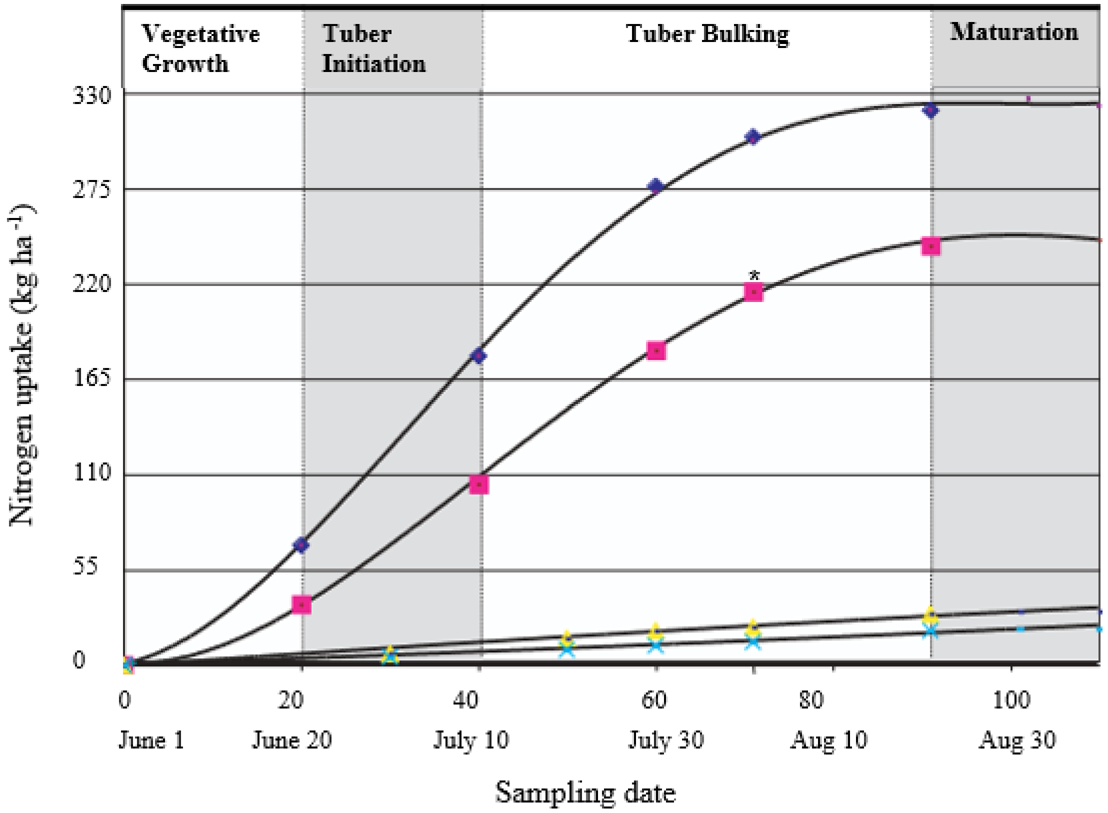

Figure 3. Total nitrogen uptake for Russet Burbank potato plants during three years of field trials at Aberdeen.

* Figure modified from Stark et al. (2004) and pink squares are total N uptake by growth stages.

Tuber Yields and Numbers

Tuber Yields

In 2019, all nitrogen added treatments had similar total (about 61 MT ha^{-1}) and marketable yield (51-59 MT ha^{-1}), while the non-treated control had a reduced yield of 47 MT ha^{-1} for total and 40 MT ha^{-1} for marketable yield compared to the N added treatments (Table 8).

Data from 2020 indicated no differences in total yield (62-70 MT ha^{-1}) between treatments; however, ESN broadcast had a higher marketable yield (65 MT ha^{-1}) than the non-treated control (56 MT ha^{-1}). It was expected that the conventional fertilizers (ESN and urea) would provide the highest yield (Table 8).

Banding ESN was thought to improve nitrogen uptake because of placement, but this was not found in this study. Each year, turkey manure had a similar yield to ESN and/or urea treatments, although the total added nitrogen was less for TMC. Waddell et al. (1999) found similar results with TMC providing a similar or higher total and marketable yield than urea and sulfur-coated urea for Russet Burbank potatoes in Minnesota. Manures have additional micro and macro elements, and external factors such as the content of carbon, the activity of the microbial community, and the structure of soil may affect plant uptake and resulting yield (Moore et al., 2011). These data indicate the benefit that turkey manure can provide to potato production.

Differences in total yield and marketable yield could be explained by the size distribution of tubers. Differences between the tuber sizing groups were found (Table 8). In general, the non-treated control had smaller tubers (<85 g) and fewer larger tubers (>170) than the ESN or urea treatments. This helps explain why the total marketable yield for the non-treated control was less each year. The TMC treatment also improved the overall tuber size, and the tuber size was increased 26% more than the non-treated control for the 171-283 g category in 2019 (Table 8).

Correspondingly, the findings of Moore et al. (2011) indicate an improvement of approximately 37% more tubers in the 170-340 g range than the non-treated control with fresh and composted dairy manure applications in Russet Burbank potatoes in Idaho. These findings indicate that tuber yield and tuber size distribution did not change with the placement of N for ESN and urea treatments. Similarly, a nitrogen experiment showed no difference between broadcast and banding methods for Russet Burbank potatoes for total yield, U.S. No. 1, and >170 g (%) in Wisconsin (Kelling et al., 2015).

Table 8. Mean total tuber yield (Total), marketable tuber yield (Market), tuber yield categories as (<85, 85-170, 171-283, 284-397, >397 gram and >170 and >283 %), affected by nitrogen treatment and year for Russet Burbank in 2019 and 2020, near Park Rapids and Perham, MN respectively.

Effect	Total	Market	<85 g	85-170 g	171-283 g	284-397 g	>397 g	>170 g	>283 g
2019 Treatment	MT/ ha*							%	
Non-treated control	47b[z]	40b	7a	27a	12b	2c	0c	28c	4c
ESN broadcast	61a	57a	5bc	20b	21a	12a	4b	61a	27ab
ESN banded	61a	57a	4c	21b	24a	9ab	3bc	59a	20b
Turkey manure compost	58a	51a	6ab	28a	18a	4bc	1bc	41b	9c
Urea	62a	59a	3c	17b	22a	12a	8a	68a	33a
2020 Treatment									
Non-treated control	62	56b	7a	29a	19b	5b	3a	43b	13b
ESN broadcast	70	65a	5b	23b	26a	11a	5a	61a	23a
ESN banded	62	57ab	6ab	21b	23ab	11a	2a	56a	20ab
Turkey manure compost	67	60ab	7a	26ab	24ab	5b	5a	51ab	15ab
Urea	67	60ab	7a	24ab	24ab	9ab	2a	54ab	17ab

[z] Yields (metric tons ha^{-1*}) affected by nitrogen treatments in 2019 and 2020. Within each year, columns with the same letter or no letter are not significantly different according to the LSD mean comparison procedure (P> 0.05).

Tuber Numbers

Total tuber numbers were not affected by fertilizer treatment or application method, apart from urea having lower tuber numbers than the turkey manure treated potatoes in 2019 (Table 9).

Similarly, marketable total tuber numbers were not statistically different for N treatment within each year. Differences were found for tuber numbers within tuber size categories within each year (Table 9).

In 2019, the TMC treatment had a higher tuber number for the < 171g size category than the urea and ESN treatments (Table 9). Additionally, tuber numbers in the 284-397 g size range were less for TMC than for the urea treatment. Therefore, the tuber size profile was much smaller for TMC than the urea and ESN tuber number profiles. This was most likely due to low N availability. This shift in size distribution is exemplified in the percent of tubers >170 and >283g for the ESN and urea treatments. Both had a higher percentage of larger tubers than the turkey manure treatment. In 2020, the tuber number was similar and did not differ significantly for total yield, marketable yield, and undersized tubers (<85 g) across treatments (Table 9). Similarly, Moore et al. (2011) reported, dairy manure had equal or higher numbers (for total yield, 110-170g, 170-340 g, and >340g tuber size categories) with the non-treated control in Idaho. The percent of tubers >170 and >283g was similar between the turkey manure, ESN, and urea nitrogen treatments in 2020. All our results were similar to the findings of Sharma and Arora (1987), who found the total number of tubers was not significantly affected by N treatment; however, N treatments influenced the number of tubers in different size categories.

Table 9. Mean total tuber number (Total), marketable tuber number (Market), tuber number categories as (<85, 85-170, 171-283, 284-397, >397 gram and >170 and >283%), affected by nitrogen treatment and year for Russet Burbank in 2019 and 2020 near Park Rapids and Perham, MN, respectively.

Effect	Total	Market	<85 g	85-170 g	171-283 g	284-397 g	>397 g	>170 g	>283 g
2019 Treatment	1000/ha*							%	
Non-treated control	353ab[z]	252	161a	196a	51b	5c	0c	16b	1c
ESN broadcast	317ab	251	105b	130b	82a	32a	8ab	39a	13ab
ESN banded	315ab	254	104b	135b	90a	22ab	6bc	38a	9b
Turkey manure compost	367a	281	156a	194a	74ab	11bc	2bc	24b	4c
Urea	292b	245	88b	114b	86a	31a	14a	45a	16a
2020 Treatment									
Non-treated control	396	298	98	201a	78b	13b	7ab	24b	5b
ESN broadcast	365	297	68	154b	105a	29a	9ab	40a	11a
ESN banded	356	270	86	146b	93ab	28a	3b	35a	9ab
Turkey manure compost	399	306	93	182ab	99ab	14b	11a	31ab	6ab
Urea	387	291	95	165ab	98ab	24ab	4ab	33a	8ab

[z] Tuber numbers (1000/ ha*) affected by nitrogen treatments over both years. Within each year, columns with the same letter or no letter are not significantly different according to the LSD mean comparison procedure (P> 0.05).

Nitrogen and Yield Interaction

Petiole Nitrogen and Yield

This study found an interaction between petiole NO_3-N and yield in 2019 (Figure 4).

Similar to the 2020 results (Figure 5), Kerketta (1976) did not find a relationship between petiole

NO_3-N and yield. Data is inconclusive to support the use of petiole samples as a yield predictor. An association was not found between petiole nitrate and yield in 2020 (Figure 5). Despite having low petiole nitrate levels (0.7-1.0% in season average), total yield was not low (ranged from 62 to 70 MT ha^{-1}); this may explain that potato crops may use N effectively.

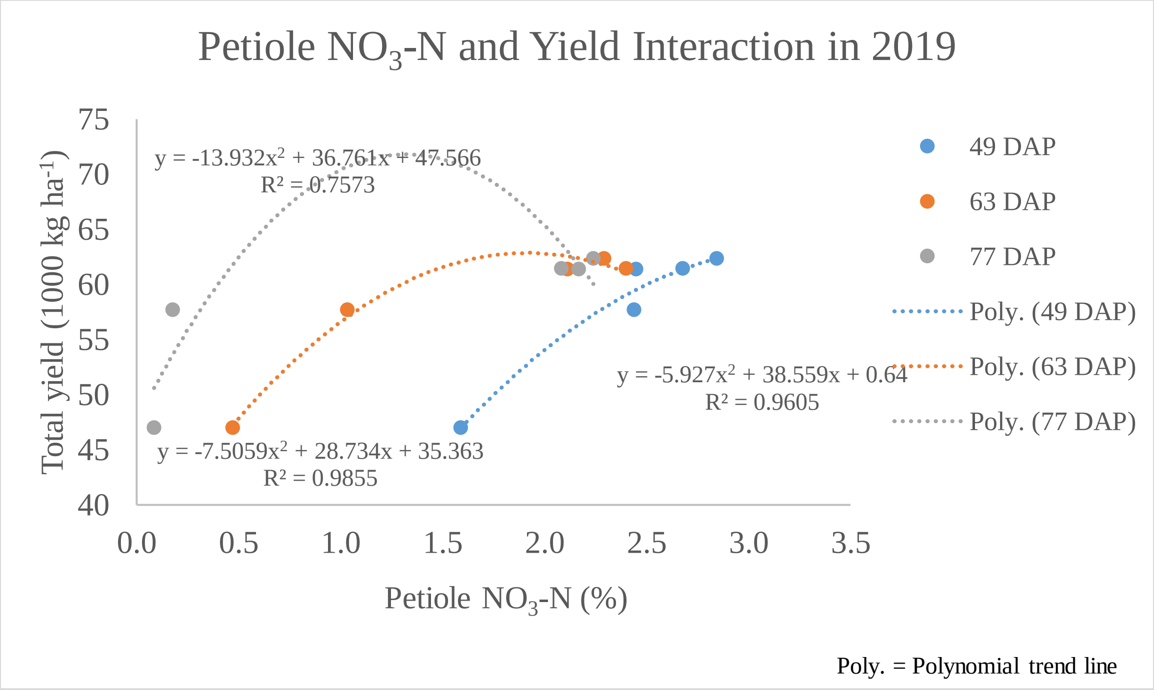

Figure 4. Relationship between petiole NO_3-N concentration (%) and total yield (kg ha^{-1}) at 49, 63, and 77 days after planting (DAP) for Russet Burbank in 2019 near Park Rapids, MN.

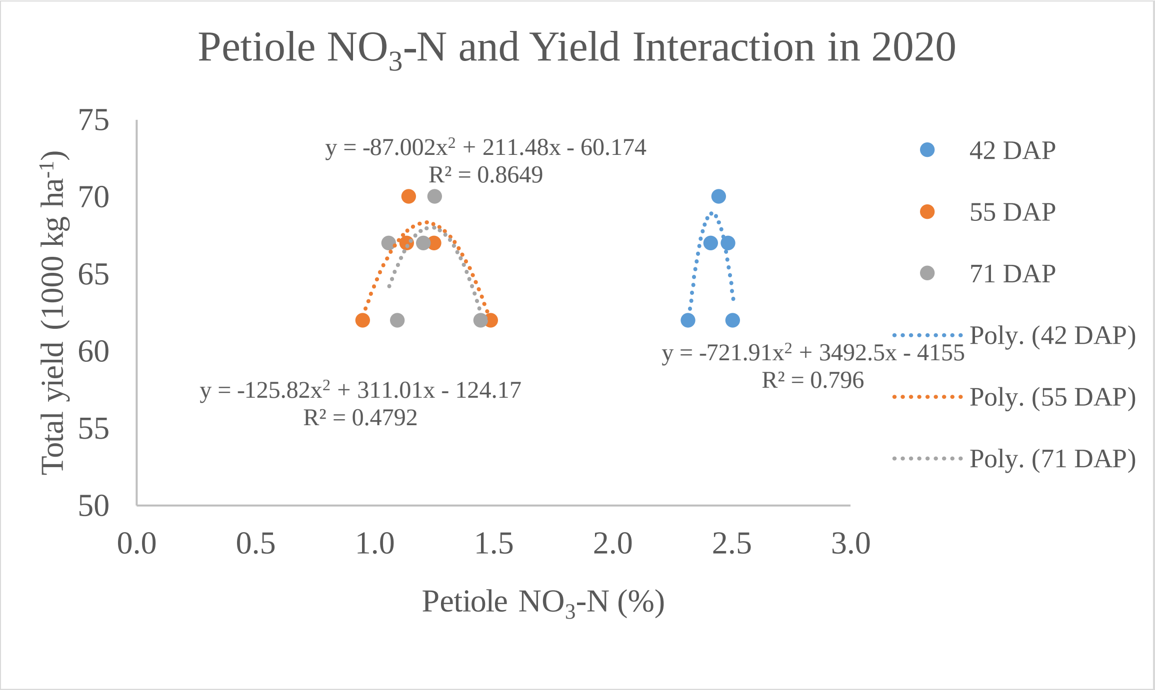

Figure 5. Relationship between petiole NO_3-N concentration (%) and total yield (kg ha^{-1}) at 42, 55, and 70 days after planting (DAP) on Russet Burbank in 2020 near Perham, MN.

Whole Plant Nitrogen and Yield

Yield can be estimated using whole plant N (Zebarthet al., 2004), and a relationship was observed between plant N and yield in 2019 (Figure 6). On the other hand, an association was not seen between plant nitrate and yield in 2020 (Figure 7), and the results indicate the same response as petiole results. While the whole plant nitrate level could be associated with total yield estimation in 2019, there was no relationship between them in 2020.

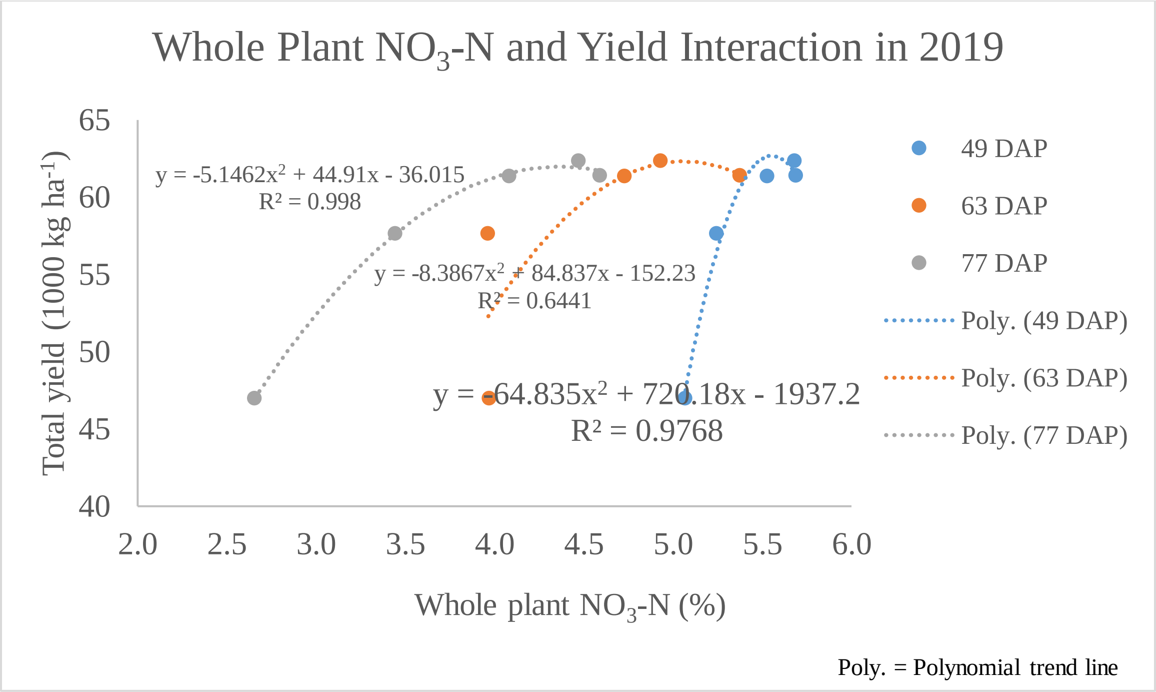

Figure 6. Relationship between whole plant NO_3-N concentration (%) and total yield (kg ha^{-1}) at 49, 63, and 77 days after planting (DAP) on Russet Burbank in 2019 near Park Rapids, MN.

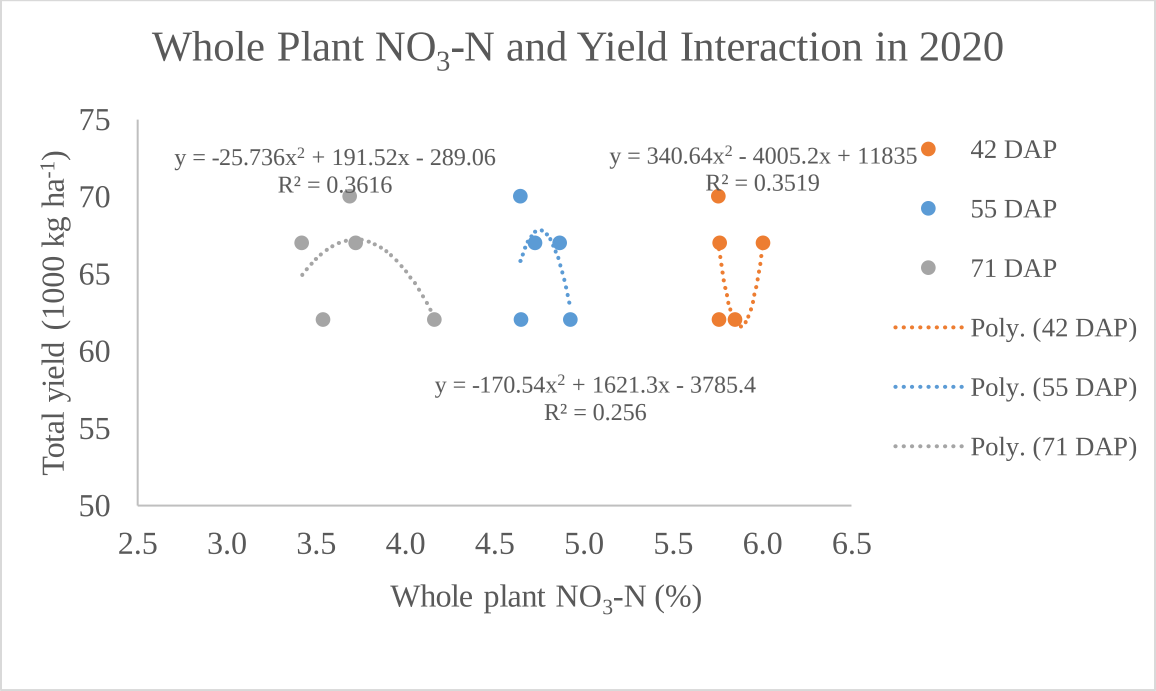

Figure 7. Relationship between whole plant NO_3-N concentration (%) and total yield (kg ha^{-1}) at 42, 55, and 71 days after planting (DAP) on Russet Burbank in 2020 near Perham, MN.

Soil Nitrogen and Yield

A relationship between total yield and soil NO_3-N was found in 2019. In 2020, no statistical differences were found in the relationship between soil NO_3-N concentration and total yield (Figures 8 and 9).

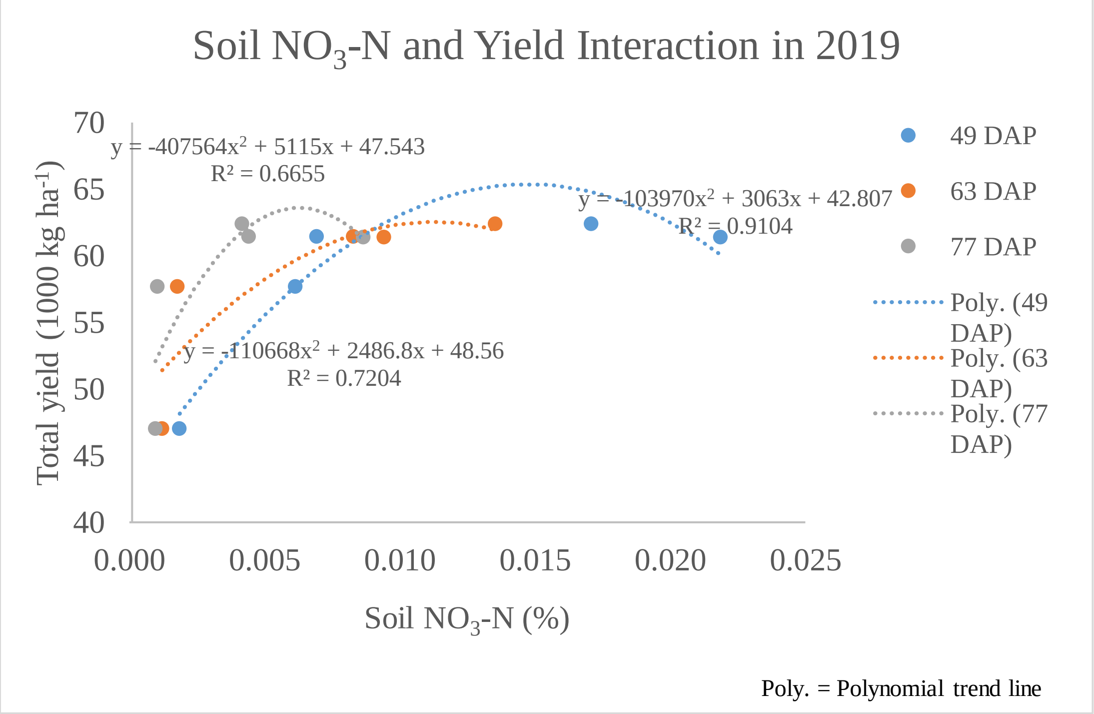

Figure 8. Relationship between soil NO_3-N concentration (%) and total yield (kg ha^{-1}) at 49, 63, and 77 days after planting (DAP) on Russet Burbank in 2019 near Park Rapids, MN.

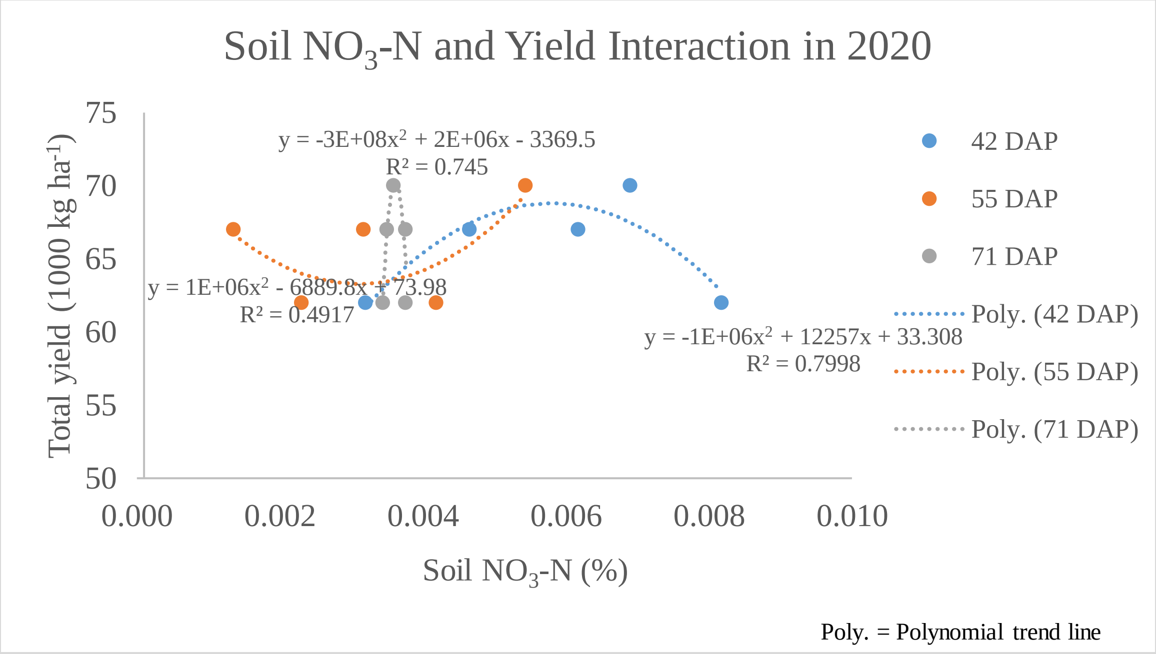

Figure 9. Relationship between soil NO_3-N concentration (%) and total yield (kg ha^{-1}) at 42, 55, and 71 days after planting (DAP) on Russet Burbank in 2020 near Perham, MN.

Tuber Nitrogen and Yield

Tuber NO_3-N concentration was in the 1.6-2.1% range at the beginning of the season, and it ended in the range 0.9-1.4% (Table 6). According to Ifenkwe and Allen (1983), potato crops with high yield are associated with tuber N accumulation, but not necessarily the results of considerable N accumulation. Based on this information, our 2019 data had similar results to Ifenkwe and Allen (1983). Tuber N concentrations and yield resulted in an increasing pattern at the 63 and 77 DAP during the whole growing season in 2019 (Figure 10). Turkey manure had less N than urea and ESN during the tuber initiation (about 63 DAP) (Table 6). However, there was no difference in total yield for the TMC treatment compared to urea and ESN treatments (Figure 10).

Conversely, the N content of tubers was not influenced by treatments in 2020, and N-treated plots were not different from the non-treated control. Yield and tuber N relationship was not observed in 2020 (Figure 11). Biemond and Vos (1992) found similar results, and our 2020 findings agree with their indications. Tubers were not influenced by N treatment even though tuber N concentrations were statistically different during the growing season. There is no evidence to explain the similarities for 2020. Perhaps they are variable because of environmental conditions.

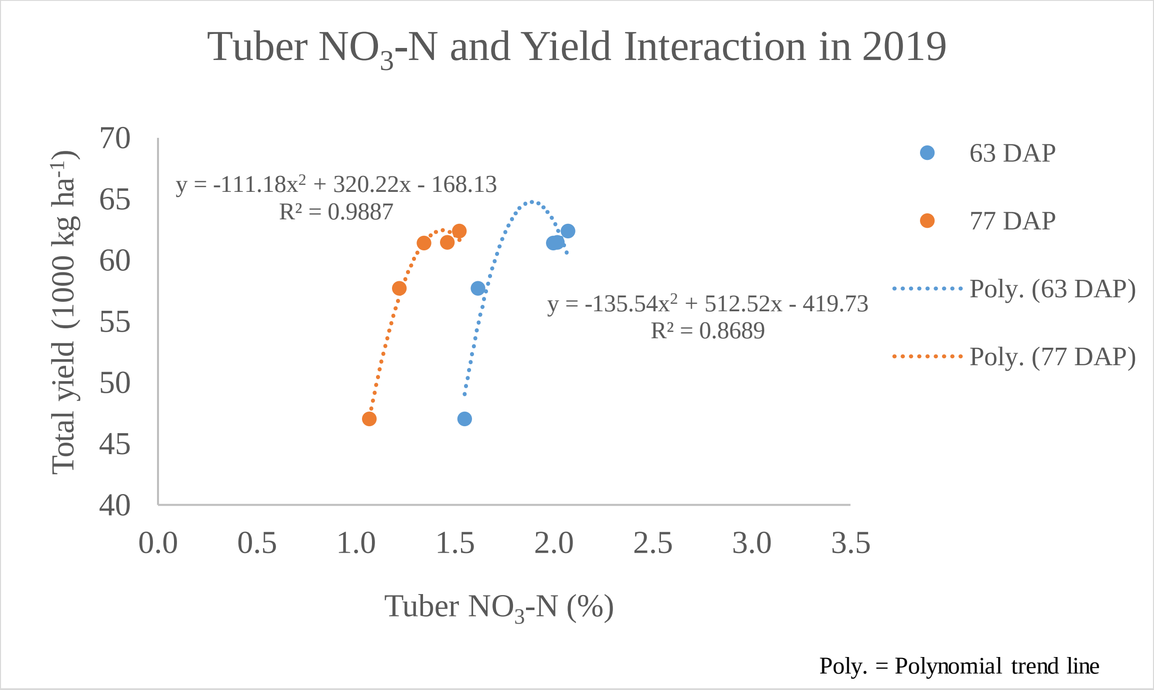

Figure 10. Relationship between tuber NO_3-N concentration (%) and total yield (kg ha^{-1}) at 63 and 77 days after planting (DAP) on Russet Burbank in 2019 near Park Rapids, MN.

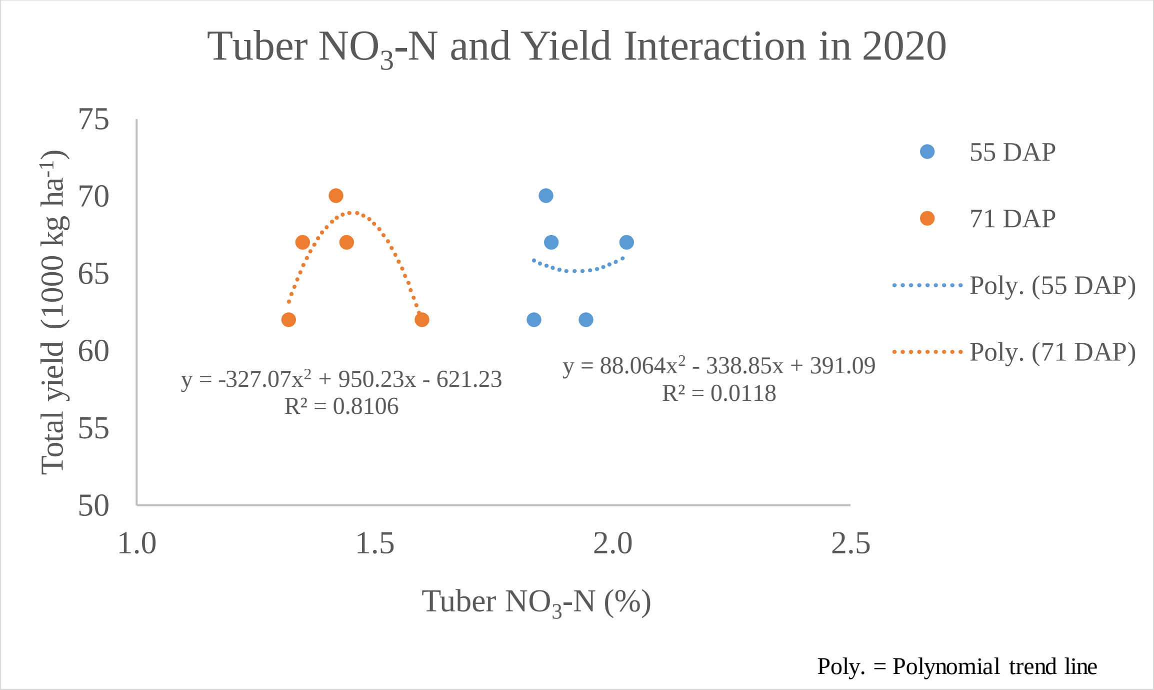

Figure 11. Relationship between tuber NO_3-N concentration (%) and total yield (kg ha^{-1}) at 55 and 71 days after planting (DAP) on Russet Burbank in 2020 near Perham, MN.

Total Nitrogen Uptake and Yield

An interaction occurred between the total yield and total N uptake in 2019. (Figure 12). Total yield was influenced by the total N uptake at 63 and 77 DAP, but the higher value was at 77 DAP to evaluate their interactions (Figure 12). In 2020, the total yield and total N uptake relationship were negative, and an association was not found between them (Figure 13). Total N uptake can range from 220 to 270 kg ha^{-1} for a yield of 50- 63 MT ha^{-1} yield of Russet Burbank potatoes (Stark et al., 2004). In our study, yield resulted in similar for each treatment (exclude non-treated control in 2019) even if total N (between 144- 217 kg ha-1 in 2019 and 180- 206 kg ha^{-1} in 2020) was lower than the stated value (220 to 270 kg ha^{-1}) by Stark et al. (2004).

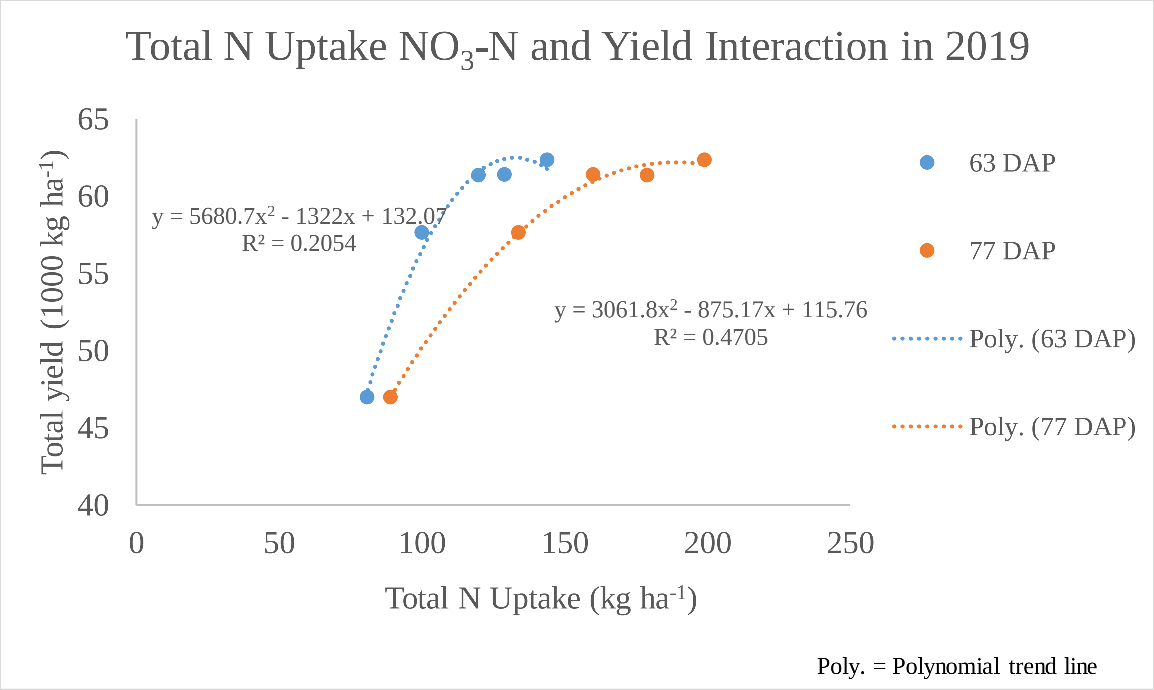

Figure 12. Relationship between total nitrogen uptake (1000 kg ha^{-1}) and total yield (kg ha^{-1}) at 63 and 77 days after planting (DAP) on Russet Burbank in 2019 near Park Rapids, MN.

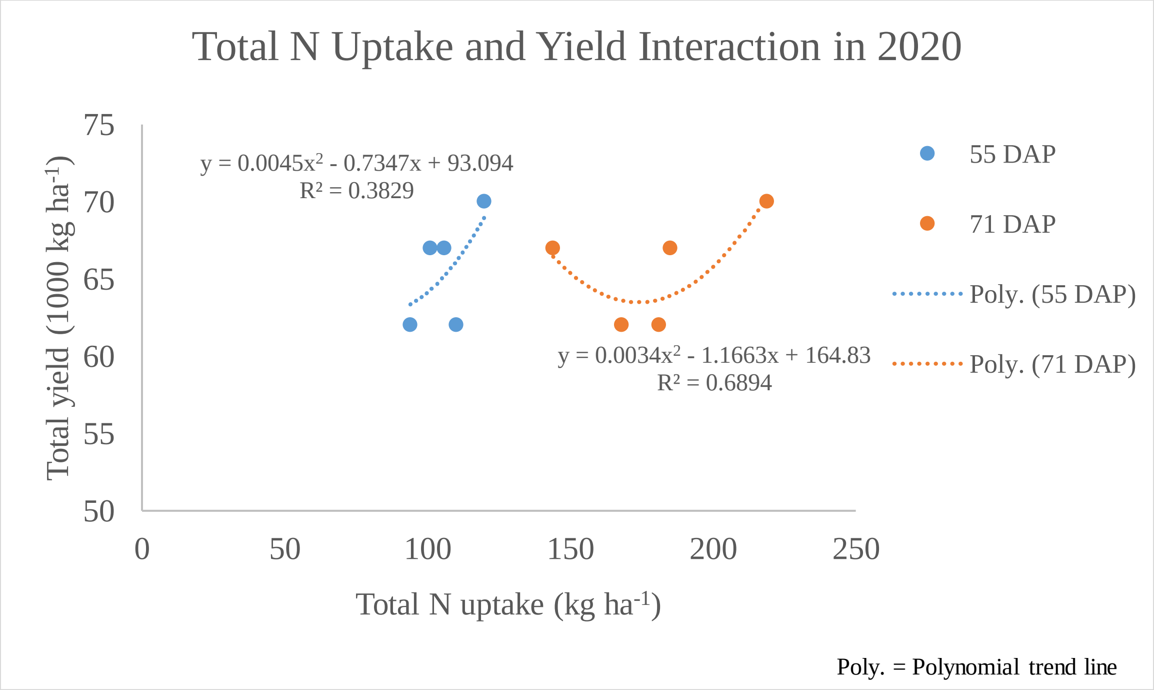

Figure 13. Relationship between total nitrogen uptake (kg ha^{-1}) and total yield (kg ha^{-1}) at 42, 55, and 70 days after planting (DAP) on Russet Burbank in 2020 near Perham, MN.

Tuber Quality

Specific Gravity

Nitrogen treatment impacted specific gravity (SG) significantly in 2019 (Figure 14). Urea and ESN treatments had reduced specific gravity compared to the non-treated control, while TMC resulted in similar SG as the urea and the non-treated control. The highest tuber specific gravity was the non-treated control at 1.095, as expected. The turkey manure treatment resulted in tubers with an average specific gravity of 1.090. Waddel et al. (1999) reported that turkey manure had lower SG (1.091) than urea and S-coated urea (1.098) treatments; however, in the second year of that study, differences were not observed between turkey manure, urea, and S-coated urea, with a mean SG (approximately 1.086) in MN. The preferred SG is between 1.080-1.089 for frozen French fries (Sun et al., 2017), and the specific gravity of synthetically fertilized potatoes ranged from 1.085 to 1.89 (Figure 14). Based on tuber SG in 2019, potatoes from urea and ESN treatments were the acceptable ranges for French fry processing, per processing specifications, while TMC and the non-treated control group were above the recommended SG, but still useable. Further, tuber SG in 2020, across treatments (Figure 14) ranged from 1.075 to 1.079, making them less suitable for processing; SG did not differ significantly across treatments. According to Stark and Love (2003), potatoes with low SG (<1.080), such as many red cultivars, tend to be more suited for boiling and canning.

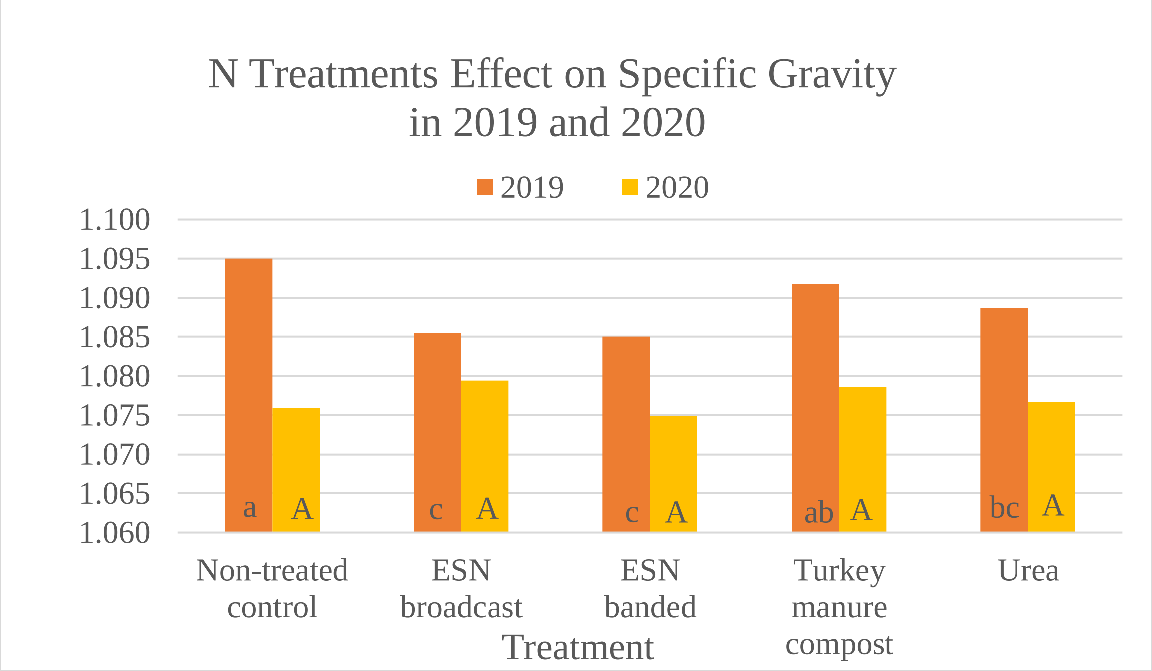

Figure 14. The effects of nitrogen treatments on the specific gravity of Russet Burbank in 2019 and 2020 near Park Rapids and Perham, respectively. For a year, columns with the same letter are not significantly different according to the LSD mean comparison procedure (P> 0.05).

French Fry Quality

Fertilizer application type and amount can influence processing quality (Iritani and Weller, 1978). Processing quality attributes summarize for the each N treatment for 2019 and 2020 (Table 10). In 2019, the non-treated control treatment resulted in a higher glucose level (2.4 mg g^{-1}) than the synthetic fertilized potatoes' glucose levels (1.6-1.9 mg g^{-1} range). However, the non-treated control glucose level was similar to the TMC glucose level (2.2 mg g^{-1}) at harvest (0 (zero) time). Tuber glucose levels decreased to the range of 1.0 to 1.5 mg g^{-1} range following three months of storage at 9˚C (Table 10). At zero time, while the sucrose concentration was similar for each treatment in 2019, potatoes stored for three months had an increasing sucrose level. These were significantly different for the nitrogen-treated potatoes (0.9 mg g^{-1}) compared to the non-treated control (1.1 mg g^{-1}) (Table 10). In 2020, a difference was not observed between treatments at zero time (1.0-1.4 mg g^{-1} glucose and 0.6 mg g^{-1} sucrose) and following 3-

months storage (1.0-1.5 mg g^{-1} glucose and 0.7 mg g^{-1} sucrose) (Table 10). The desired glucose and sucrose concentrations are 1.2 mg g^{-1} (or 0.12 %) and 1.5 mg g^{-1} (or 0.15 %), respectively, at harvest or during storage for French fry processing (Stark and Love, 2003). In 2019, glucose levels for each treatment were greater than recommended values at zero time, but after three months storage, the glucose level was acceptable for tubers from urea and ESN treatments. The glucose concentration was suitable in 2020. The sucrose level for both years and all timings was within acceptable levels. Glucose is important for potato processing since having high glucose concentration causes browning during the frying process (170-190 ˚C) (Maillard reaction), and this darkening is undesired (Pavlista, 1997; Chen et al., 2010).

Bud and stem end French fry colors were not influenced by N treatments during the two years of study for the 0- and 3- month processing timings (Table 10). Bud end fry color was a measure of the main fry color, with a mean of ~33% and 37% reflectance for the 0-month and 3-month processing times, respectively, in 2019. In 2020, fry color reflectance ranged from 41-43% at the 0-months, while these increased to 43-45% after three months storage. When the stem end fry colors were examined, they were between 27-33% reflectance for both years and timings (Table 10). Fry colors were determined by Photovolt % reflectance values that correspond to the USDA Munsell color scale (from number 1 to 4) where 1 corresponds to ≥ 44%, 2 is equal 35.3-43%, 3 is equal 25.8-35.3%, and 4 is < 25.8% reflectance rating. French fry colors of 1 and 2 are acceptable, while 3 and 4 are unacceptably dark. (USDA, 1972; Moore et al., 2011). French fry colors were much lighter following 3-month storage for both years; however, the stem end French fry colors were dark, indicating tuber stress and sugar accumulation. French fry main colors were within the acceptable ranges from 36 to 45% reflectance at 3-month processing time in 2019 and in 0- and 3-month processing times in 2020. These values were number 1 and 2 by the USDA Munsell scale for fry color determination. Fry color by this scale was number 3 that means having darker fry colors (Table 10). Moore et al. (2011) indicate that having the lower stem end reflectance values and the higher glucose level caused darker fry color in unfertilized Russet Burbank potatoes at harvest. However, the fry color for 0- and 3-month was not affected by glucose level in our study (Table 10). Potatoes that were overly matured can have higher glucose levels in the non-treated control when comparing to manure, compost, and traditional fertilizer treated potatoes (Iritani and Weller, 1978; Moore et al., 2011). Inadequately fertilized or non-fertilized treatment can result in different maturities and high glucose concentrations (Moore et al., 2011); therefore, for the non-treated control, this high glucose might be explained by this.

Table 10. Processing quality attributes including sugar concentration, bud end fry color, and stem end fry color for Russet Burbank produced using five nitrogen fertilizer sources/application methods, near Park Rapids in 2019 and near Perham, MN in 2020, at harvest and following three months storage at 9˚C.

Effect	Glucose (mg/g)	Sucrose (mg/g)	Bud end fry color (%)[z]	Stem end fry color (%)	Glucose (mg/g)	Sucrose (mg/g)	Bud end fry color (%)	Stem end fry color (%)
2019 Treatment		0 Month				3 Month		
Non-treated control	2.4a[y]	0.7	33	31	1.5a	1.1a	37	30
ESN broadcast	1.9b	0.6	33	31	1.1bc	0.9b	37	31
ESN banded	1.6b	0.6	34	33	1.0c	0.9b	38	33
Turkey manure compost	2.2ab	0.5	34	30	1.3ab	0.9b	36	31
Urea	1.8b	0.6	32	32	1.2abc	0.9b	36	32
2020 Treatment								
Non-treated control	1.4	0.6	41	30	1.5	0.7	43	28
ESN broadcast	1.0	0.6	43	29	1.1	0.7	44	32
ESN banded	1.0	0.6	43	29	1.0	0.7	44	31
Turkey manure compost	1.4	0.6	41	29	1.2	0.7	45	30
Urea	1.0	0.6	43	27	1.2	0.7	43	30

[y] Within each year, quality attributes with the same letter or no letter are not significantly different by the LSD mean comparison procedure (P> 0.05).

[z] Fry color was determined using a Photovolt, which reports color as percent reflectance. The fry color rating was determined based on the evaluated by USDA Munsell color scale (number 1 to 4), where 1 corresponds to > 44%, 2 is equal to 35-44%, 3 is equal to 26-35%, and 4 is <26% reflectance. French fry colors of 1 and 2 are acceptable, while 3 and 4 are unacceptably dark.

Conclusion

This experiment compared the effects of organic and inorganic N treatments and placement methods. Yield results varied by treatment within years and between years ESN, urea, and turkey manure treatments (TMC) did not differ statistically from one another for total or marketable yield, although they differed from the non-treated control. Turkey manure compost increased tuber yield for some tuber size categories, including undersized tuber yield (<85 g), and the 85-170 g category yield, while tuber yield in the 171-283 g and oversized categories were reduced. The tuber size profile was smaller with the TMC treatment and had a higher tuber count than the urea and ESN treatments. This might be due to inadequate available N throughout the growing season when compared to synthetic fertilizers. Urea performed similar or better compared to ESN and ESN-banded, while the placement method did not influence the yield, total nitrogen uptake, and most other factors measured. Only the soil N residual amount (only the first year of the study) resulted higher than others; however, this is not adequate information to determine the best placement of ESN fertilizer. Specific gravity was influenced, while French fry color quality was not affected by N treatments.

This study suggests that potato yield and quality may vary between years under the same N treatments, perhaps because of environmental conditions or other cultural practices. Turkey manure was a good nitrogen source for a local, sustainable fertilizer for potato since total yield was not different compared to inorganic N sources. Turkey manure compost improves soil organic matter, water retention and provides adequate nutrition for the plant. Further research should be examined what benefits conventional fertilizer can have when used in combination with TMC.

Literature Cited

Biemond, H., and J. Vos. 1992. Effects of nitrogen on the development and growth of the potato plant. The partitioning of dry matter, nitrogen, and nitrate. *Annals of Botany* 70:37-45.

Bissonnette, H.L., D. Preston, and H. A. Lamey. 1993. Potato Production and Pest Management in North Dakota and Minnesota. North Dakota State University Extension Bulletin 26 AG-BU-6109-S.

Chastain, J. P., James J. Camberato, and Peter Skewes. 1999. Poultry manure production and nutrient content. Chapter 3b, 1-17.

Chen, J. Y., Z. Han, M. Yelian and A. Mitsunaka. 2010. Nondestructive determination of sugar content in potato tubers using visible and near infrared spectroscopy. *Japan Journal of Food Engineering*. 11: 59 - 64.

Dawson, M.A., and K.A. Kelling. 2002. Use of manure in potato production. Proceedings of Wisconsin’s Annual Potato Meeting 15:17–27.

Dean, D. M., B. J. Zebarth, C. G. Kowalenko, J. W. Paul, and K. 2000. Chipperfield. Poultry manure effects on soil nitrogen processes and nitrogen accumulation in red raspberry. *Canadian Journal of Soil Science* 80:849-860.

Endale, D.M., M.L. Cabrera, J.L. Steiner, D.E. Radcliffe, W.K. Vencill, H.H. Schomberg, and L. Lohr. 2002. Impact of conservation tillage and nutrient management on soil water and yield of cotton fertilized with poultry litter or ammonium nitrate in the Georgia Piedmont. *Soil Tillage Research* 66:55–68.

Entry, J.A., A.B. Leytem, and S. Verwey. 2005. Influence of solid dairy manure and compost with and without alum on survival of indicator bacteria in soil and on potato. *Environmental Pollution* 138:212–218.

Errebhi, M., C.J. Rosen, S.C. Gupta, D.E. Birong 1998. Potato yield response and nitrate leaching as influenced by nitrogen management. *Agronomy Journal* 90:10-15.

Fenton, M., C. Albers, and Q. Ketterings. 2008. Soil Organic Matter. Cornell University Cooperative Extension. http://franklin.cce.cornell.edu/resources/soil-organic-matter-fact-sheet. Accessed May 1, 2021.

Gelderman, R., and D. Beegle. 2015. Nitrate-nitrogen. In *Recommended Chemical Soil Testing Procedures for the North Central Region*, eds. Nathan, M.V., and R. Gelderman, 17-20. North Central Reg. Res. Publ. no. 221 (revised). Missouri Agric. Exp. Stn. SB 1001. Columbia, MO.

Gianquinto, G. and S. Bona. 2000. Plant nitrogen status. In *Management of nitrogen and water in potato production,* eds. A.J. Haverkort and D. MacKerron, 35-47. Wangeningen: Wangeningen Academic Press.

Harris, P.M. 1992. Mineral nutrition. In *The Potato Crop*, ed. P.M. Harris, 162-213. London: Chapman and Hall.

Ifenkwe, O., and E. Allen. 1982. Nitrogen and potassium uptake by high-yielding potato crops. *The Journal of Agricultural Science* 101:103-111.

Iritani, W.M., and L. Weller. 1978. Influence of low fertility and vine killing on sugar development in apical and basal portions of Russet Burbank potatoes. *American Potato Journal* 55:239-246.

Kelling, K., R. Hensler, and P. Speth. 2015. Importance of early-season nitrogen rate and placement to Russet Burbank potatoes. *American Journal of Potato Research* 92:502-510.

Kerketta, R. (1976). Growth, nitrogen nutrition, and leaf senescence in the potato. Ph.D. Thesis, Reading University.

Lee, C.R., and M.L. MacDonald. 1977. Influence of soil amendments on potato growth, mineral nutrition, and tuber yield and quality on very strongly acid soils. *Soil Science of America Journal* 41:573–577.

Liegel, E.A., and L.M. Walsh. 1976. Evaluation of sulfur coated urea (SCU) applied to irrigated potatoes and corn. *Agronomy Journal* 68:457-463.

Moore, A., N. Olsen, A. Carey, and A. Leytem. 2011. Residual effects of fresh and composted dairy manure applications on potato production. *American Journal of Potato Research* 88:324-332.

Moore, A., N. Olsen, M. Satterwhite, and M.J. Frazier. 2013. Organic potato production in Idaho: Nutrient management and variety selection. Universtiy of Idaho. https://www.extension.uidaho.edu/publishing/pdf/BUL/BUL885.pdf.

Neilsen G. H., E. J. Hogue, D. Neilsen, and B. J. Zebarth. 1998. Evaluation of organic wastes as soil amendments for cultivation of carrot and chard on irrigated sandy soil. *Canadian Journal of Soil Science* 78:217-225.

Pavlista, A., 1997. Potato types and characteristics: Laboratory exercises. *The American Biology Teacher* 59:30-34.

Porter, G.A. and J.A. Sisson. 1991. Petiole nitrate content of Maine-grown Russet Burbank and Shepody potatoes in response to varying nitrogen rate. *American Potato Journal* 68:493–505.

Rees, H., T. Chow, B. Zebarth, Z. Xing, P. Toner, J. Lavoie, and J. Daigle. 2014. Impact of supplemental poultry manure application on potato yield and soil properties on a loam soil in north-western New Brunswick. *Canadian Journal of Soil Science* 94:49-65.

Rosen, C., and P. Bierman. 2008. Best management practices for nitrogen use: Irrigated potatoes. https://conservancy.umn.edu/handle/11299/198232.

Rosen, C. 2018. Potato fertilization on irrigated soils. Extension.umn.edu. https://extension.umn.edu/crop-specific-needs/potato-fertilization-irrigated-soils. Accessed May 2, 2021.

Ruiz Diaz, D., and J. Sawyer. 2008. Plant-available nitrogen from poultry manure as affected by time of application. *Agronomy Journal* 100:1318-1326.

Sharma, U., and B. Arora. 1987. Effect of nitrogen, phosphorus, and potassium application on yield of potato tubers (*Solanum tuberosum* L.). *The Journal of Agricultural Science* 108:321-329.

Sieczka, J.B. and R.E. Thornton. 1993. Commercial potato production in North America: Potato Association Of America Handbook. Orono, Maine: Potato Association of America.

Stark, J. and S. Love. 2003. Tuber quality. In Potato Production Systems, eds. J. Stark and S. Love, 329-342. The USA: University of Idaho Agricultural Communications.

Stark, J. and D.T. Westermann. 2003. Nutrient management. In Potato Production Systems, eds. J. Stark and S. Love, 115-130. USA: University of Idaho Agricultural Communications.

Stark, J., D. Westermann, and B. Hopkins, 2004. Nutrient management guidelines for Russet Burbank potatoes. Extension.uidaho.edu. Available at: https://www.extension.uidaho.edu/publishing/pdf/BUL/BUL0840.pdf. Accessed May 10, 2021.

Sun, N., C. Rosen, and A. Thompson. 2017. Nitrogen response of french fry and chip cultivars selected for low tuber reducing sugars. *American Journal of Potato Research* 94:606-616.

Tewolde, H., A. Adeli, K. Sistani, and D. Rowe. 2011. Mineral nutrition of cotton fertilized with poultry litter or ammonium nitrate. *Agronomy Journal* 103:1704-1711.

Trehan, S.P., and R.C. Sharma. 2003. External phosphorus requirement of different potato (*Solanum tuberosum*) cultivars resulting from different internal requirements and uptake efficiencies. *Indian Journal of Agricultural Sciences* 73:54–56.

Trenkel, M. E. 2010. Slow- and controlled-release and stabilized fertilizers. An option for enhancing nutrient use efficiency in agriculture. International Fertilizer Industry Association. Paris, France.

United States Department of Agriculture (USDA). 1972. USDA's color standard for frozen French-fried potatoes. 3rd ed. Munsell Colour Co., Baltimore, MD.

United States Department of Agriculture (USDA). 2019. Turkey Sector: Background and Statistics. https://www.ers.usda.gov/newsroom/trending-topics/turkey-sector-background-statistics/.

Vandendriessche, H., J. Bries, and M. Geypens. 1996. Experience with fertilizer expert systems for balanced fertilizer recommendations. *Communications in Soil Science and Plant Analysis* 27:1199-1209.

Vendrell, P., and J. Zupancic. 1990. Determination of soil nitrate by transnitration of salicylic acid. *Communications in Soil Science and Plant Analysis* 21:1705-1713.

Waddell, J., S. Gupta, J. Moncrief, C. Rosen, and D. Steele. 1999. Irrigation and nitrogen management effects on potato yield, tuber quality, and nitrogen uptake. *Agronomy Journal* 91:991-997.

Waddell, J., S. Gupta, J. Moncrief, C. Rosen, and D. Steele. 2000. Irrigation- and Nitrogen-Management Impacts on Nitrate Leaching under Potato. *Journal of Environmental Quality* 29:251-261.

Wang, Z.H., Z.Q Zong, S.X. Li, and B.M. Chen. 2002. Nitrate accumulation in vegetables and its residual in vegetable fields. *Environmental Sciences* 23:79 83.

Westermann D.T. 1993. Fertility management. In Potato health management, ed. R.C. Rowe, 77-86. St. Paul: APS Press.

Westermann, D.T. 2005. Nutritional requirements of potatoes. *American Journal of Potato Research* 82:301 307.

Young M., H. Davies, and D. MacKeron. 1993. Basic concepts of the management of supply of nitrogen and water in potato production. In *Management of Nitrogen and Water in Potato Production*, eds. A.J. Haverkort and D. MacKerron, 16. Wangeningen: Wangeningen Academic Pers.

Zebarth, B., Y. Leclerc, G. Moreau, and E. Botha. 2004. Rate and timing of nitrogen fertilization of Russet Burbank potato: Yield and processing quality. *Canadian Journal of Plant Science* 84:855-863.

Zebarth, B., and C. Rosen. 2007. Research perspective on nitrogen bmp development for potato. *American Journal of Potato Research* 84:3-18.