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Annotated Bibliography on the Impacts of Size and Scale of Silvopasture in the Southeastern U.S.A.

Gregory E. Frey and Marcus M. Comer

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Abstract

Silvopasture, the integration of trees and pasture for livestock, has numerous potential benefits for producers. However, size or scale of the operation may affect those benefits. A review of relevant research on the scale and size economies of silvopasture, general forestry, and livestock agriculture was undertaken to better understand potential silvopasture production in the U.S. Southeast. This information was synthesized into a discussion of the factors that might affect production differently at different scales, and adaptations smaller scale producers might use with silvopasture to mitigate problems and enhance benefits tied to scale.

Keywords: Agroforestry, economics, management, production, silvopasture, size and scale.

Introduction and Methods

Silvopasture, the integration of trees and pasture for livestock, has numerous potential benefits for farmland managers. Many of the purported benefits, such as risk mitigation through diversification, could be appealing to smaller and more limited-resource producers. However, costs per unit of output could be higher at smaller scale or size, which would put these smaller scale producers at a disadvantage. That is, there may be economies of size or scale that create barriers to adoption for smaller scale systems. On the other hand, diseconomies may exist which would actually tend to favor those same smaller scale systems.

In a technical sense, economies of scale and size are closely related and can be defined as follows:

- "The concept of economies of size means that the average cost per unit of production decreases as the size of the farm increases…. [E]conomies of scale… measure what happens if all inputs are increased by the same proportion." (Duffy 2009)
- "Pure scale relationships occur only if all the resources that go into production are increased in the same proportion. Economies of size refer to moving along the firm's long-run expansion path; inputs are combined in that particular ratio which minimizes costs for a given output." (Cubbage 1983)

This annotated bibliography explores the state of knowledge of the size and scale economic characteristics of silvopasture. In exploring that topic, we also review literature related to the size and scale economics of silvopasture's components: livestock-raising and forestry. The purpose of this annotated bibliography is not to discuss the theory and concepts of economies of scale and size in detail (or the differences between economies of scale and economies of size), but rather, to identify and summarize literature that helps explain the origin and relevance of those economies or diseconomies in silvopasture. This bibliography helps to understand and compare the findings of past literature by consolidating it in one place, so that it can be utilized as an input for future researchers and practitioners.

The bibliography consists of research-based materials from a variety of sources, including journal articles, books, Extension publications, conference proceeding

papers, Internet publications, and academic theses and dissertations. Additional weight was given to peer-reviewed sources and findings that were not reported elsewhere. Sources were identified using databases of scientific literature; additional resources were also located in the reference sections of articles identified in the initial searches. We generally restricted our search to English-language literature; however, in some cases cross-referenced literature from other languages seemed valuable. We restricted our search to manuscripts on applied research related to empirical economic findings, and did not include manuscripts related to theoretical constructs. Furthermore, we did not typically include most outreach publications or "popular" magazines, except to the extent that they reported research findings or presented a new perspective that were not otherwise noted.

A comprehensive bibliography of all theoretical and applied literature about economies of scale and size in all agricultural and natural resource production activities would be several orders of magnitude larger, and would be practically impossible to consolidate. We used the following criteria to determine whether or not to include a particular citation in this annotated bibliography:

(a) Directly discusses economies of scale and/or size of rural land uses related to silvopasture (forage, livestock, forestry, agroforestry),

(b) Discusses economics of silvopasture, and

(c) Analysis includes the Southeastern U.S.A., or location in which silvopasture might be practiced in a similar manner (e.g., similar climate, species utilized, markets and market access).

Due to the lack of literature directly related to all three criteria, we decided to include references that met at least two of the three criteria. Therefore, each of the articles in the Annotated Bibliography section has some information relevant to the scale characteristics of silvopasture, as it could be practiced in the Southeastern United States, which include topographic regions such as coastal plains, the Appalachian Mountains, and the Lower Mississippi River Alluvial Valley; and native ecological regions that include both hardwood and softwood forests. We included research that empirically tests the hypothesis of economies of scale or size, as well as research that discusses and tests the underlying factors that drive those economies.

The annotations for each reference were not written to describe the entire manuscript; rather, the annotation was restricted to results that strictly relate to economies of size or scale. Some references contained substantial information on size/scale issues and thus have lengthy annotations. Other references may only include size or scale issues as one small part of a larger research topic.

There are a vast number of tangentially related manuscripts that may be of interest. Many of these touch on at least one of the three criteria above, and may in some way touch on economies of size/scale (although usually not stating so directly). Therefore, we include supplemental citations (see App. A) of literature that falls within criteria (a) or (b), but not both; reports preliminary findings that were reported in more final form elsewhere; or otherwise seemed tangentially related. This approach is somewhat unconventional for an annotated bibliography, but we felt it to be the best approach given the way economies of size/scale are usually treated (i.e., usually left implicit with little direct mention or evidence) in the literature. Some sources that were extremely similar to existing citations were either not included or were listed in Appendix A: Supplemental Citations (e.g., a conference proceedings paper or project report that reported preliminary results of a project that was later published in a peer-reviewed journal). We did not put limits on the dates of scientific material we reviewed; however, practically, we found agricultural literature on this issue starting in the 1960s, forestry literature starting in the 1970s, and agroforestry literature starting in the 1990s.

Annotated Bibliography

Silvopasture

1. **Alavalapati, J.R.R.; Shrestha, R.K.; Stainback, G.A.; Matta, J.R. 2004.** Agroforestry development: An environmental economic perspective. Agroforestry Systems. 61(1-3): 299-310. DOI: 10.1023/B:AGFO.0000029006.64395.72.

These authors tested landowners' willingness to adopt silvopasture. One of the covariates used to understand the drivers of adoption was plot size. However, the authors found no statistically significant relationship between plot size and willingness to adopt at the 0.10 or 0.05 alpha-level.

2. **Ares, A.; Reid, W.; Brauer, D.K. 2006.** Production and economics of native pecan silvopastures in central United States. Agroforestry Systems. 66(3): 205-215. DOI: 10.1007/s10457-005-8302-0.

The authors examined silvopasture under a pecan orchard, which is a possibility in some parts of the Southern United States. While the authors did not consider tract scale or size factors, they found that profitability was largely driven by nut prices and livestock and timber returns did not play as large a role.

3. **Barlow, B. 2010.** Silvopasture: an opportunity for additional income from your forestland. Alabama's TREASURED Forest Magazine. Fall 2010: 13-15. http://www.forestry.alabama.gov/TREASUREDForests2010.aspx. [Date accessed: August 29, 2017].

This outreach article notes that silvopasture can be applicable for small-scale private landowners, which includes those with less than 100 acres (40 ha). The author notes that silvopasture creates a diversified income stream, beyond just timber, potentially including wildlife habitat, pine straw, and livestock production. By diversifying the income stream, and potentially generating sawtimber that is of higher quality, small-scale producers can take advantage of incentives that are less prone to economies of size.

4. **Burner, D.; Campbell, L.; Meier, S. 2003.** The Christmas tree plantation—a silvopasture opportunity. The Temperate Agroforester. 11(3): 6-7, 11. http://www.aftaweb.org/latest-newsletter/temporate-agroforester/55-2003-vol-11/july-no-3/31-christmas-tree-plantation.html. [Date accessed: August 29, 2017].

This outreach article cites some general conclusions based on two cases of small-scale silvopasture systems, one of which was 6 acres (2.4 ha), and the other case does not state land area. The article includes adaptations to make them friendlier for small land areas, such as using sheep rather than goats or cattle, and using portable electric fencing. The authors suggest that diversification is a major benefit of silvopasture. Presumably, this would be a more important benefit for smaller scale producers. Christmas trees operate on shorter time scales than timber trees, so would limit the time that producers have their capital "locked up" in trees.

5. **Calle, A.; Montagnini, F.; Zuluaga, A.F. 2009.** Farmers' perceptions of silvopastoral system promotion in Quindío, Colombia. Bois et Forets des Tropiques. 300(2): 79-94.

The authors describe motivations of farmers that drove adoption of silvopasture in Colombia, and their perceptions of benefits and barriers of the system. The farms in question were mostly small to medium scale (average 89 acres/36 ha, and 57 cattle head), and do not appear to be highly mechanized. Among motivations for adoption, none directly point to concepts explicitly related to scale of farm or parcel. Among perceptions of benefits, numerous respondents (approximately 40 percent) indicated that silvopasture reduced the need for certain capital inputs such as chemical inputs, conventional fences (replaced with live fences), etc., which could otherwise be a burden to low-income/small farmers. However, approximately 20 percent still indicated that other necessary investments were too high for them to pay on their own. Also, about 15 percent of respondents indicated that the time lag between planting trees and the silvopasture becoming

available to graze reduced farm productivity temporarily, which could be challenging to small-scale farms that lack land to shift cattle to other areas. Also, information and knowledge was seen as a barrier to 15–20 percent of farmers, which could be a scale issue if information/social networks are correlated to size of landholding.

6. **Chedzoy, B.J.; Smallidge, P.J. 2011.** Silvopasturing in the Northeast: an introduction to opportunities and strategies for integrating livestock in private woodlands. Ithaca, NY: Cornell University Cooperative Extension. 28 p.

This outreach publication is based on observation of numerous case studies. The authors assert that different strategies at different spatial scales can result in efficiencies, although they do not state explicit levels of land areas. For example, smaller scale (the article uses "small" and "large" in a qualitative sense and does not state a precise, quantifiable definition) operations can establish trees using "single continuous recruitment"—a process that may favor better quality trees (especially for tree species that are shade tolerant), but too laborious for large-scale operation. Silvopasture is flexible enough in establishment and management that a variety of types of equipment and machinery can be utilized. However, it does not discuss whether one type may be more profitable. The authors note that diversified income sources are a benefit, which is presumably more important for smaller scale operators.

7. **Clason, T.R. 1995.** Economic implications of silvipastures on southern pine plantations. Agroforestry Systems. 29(3): 227-238. DOI: 10.1007/BF00704870.

This article is based on research that established an experimental silvopasture plot from a thinned loblolly pine plantation. The author does not directly discuss economies of size. However, the marketable product from the trees is pine timber, likely to have economies of size in the harvesting component.

8. **Cubbage, F.W.; Balmelli, G.; Bussoni, A.; Noellemeyer, E.; Pachas, A.N.; Fassola, H.E.; Colcombet, L.; Rossner, B.; Frey, G.E.; Dubè, F.; Lopes da Silva, M.; Stevenson, H.; Hamilton, J.; Hubbard, W.G. 2012.** Comparing silvopastoral systems and prospects in eight regions of the world. Agroforestry Systems. 86(3): 303-314. DOI: 10.1007/s10457-012-9482-z.

The authors conducted a qualitative comparison of silvopasture systems across countries based on their own knowledge. The article does not specifically discuss economies of size or scale, but does mention countries and system types where adopters of silvopasture tend towards one or the other end of the scale dimension. In the United States, silvopasture adopters have tended to be larger scale innovators who have "larger tracts of both timber and pastureland (total [> 124 acres /] > 50 ha)," which would be required to obtain economies of size, and typical silvopastures would be expected to have at least 40 acres (16 ha). "Limited-resource farmers ([< 50 acres /] < 20 ha) are less common," and might use different livestock, such as goats rather than cattle. Among other countries, most note that silvopasture adopters tend to be either "of various scales" or are large scale.

9. **Current, D.; Lutz, E.; Scherr, S.J. 1995.** The costs and benefits of agroforestry to farmers. The World Bank Research Observer. 10(2): 151-180. DOI: 10.1093/wbro/10.2.151.

This study examined 21 agroforestry case studies in 8 Central American counties and 2 Caribbean countries. The purpose of the study was to focus on the profitability of agroforestry for farmers, focusing on small farms with an average size under 50 acres (20 ha), and under 2 acres (5 ha) in most projects. The study compared the economic and technical performance of agroforestry systems. The study found that agroforestry is comparable to traditional farming systems in terms of profitability across multiple economic conditions. While agroforestry is applicable on these small farms, the authors did find that larger farms within their sample adopted the systems to a greater extent than smaller farms. When they did adopt the practices, smaller farms utilized more intensive systems.

10. **Dangerfield, C.W., Jr.; Harwell, R.L. 1990.** An analysis of a silvopastoral system for the marginal land in the Southeast United States. Agroforestry Systems. 10(3): 187-197. DOI: 10.1007/BF00122911.

This study uses a timber yield simulator with forage budgeting to model the financial returns from a loblolly pine plantation silvopasture with Bahia and coastal Bermuda grasses in the Southeastern United States. The results showed that silvopasture yielded approximately 71-percent higher net present value (at 8-percent discount rate) than conventional monoculture pine plantations ($948 per acre / $2,342/ha for silvopasture vs. $554 per acre / $1,367/ha for pine plantation) due to the addition of income from livestock and increased timber value that resulted from excess fertilization of the pasture. Scale and size issues were not directly addressed.

11. **Frey, G.E.; Fassola, H.E.; Pachas, A.N.; Colcombet, L.; Lacorte, S.M.; Cubbage, F.W.; Pérez, O. 2007.** Adoption and economics of silvopasture systems by farm size in northeastern Argentina. In: Olivier, A.; Campeau, S., eds. When trees and crops get together: 10th North American agroforestry conference. Quebec City, Canada: Association for Temperate Agroforestry: 219-229.

The authors note that silvopasture adoption in Misiones, Argentina, has occurred among producers of all scales. The article discusses the perceptions of those adopters, how perceptions vary by scale, and estimates of economic returns by scale. The economic estimates, based on farmers' stated inputs and outputs at the official national wage plus benefits, showed that large-scale farms (> 2,718 acres / 1100 ha) had much higher annual profits per unit land area. However, if one assumed a lower wage rate, which is common for ad hoc day laborers in the countryside, silvopasture on small-scale farms (< 124 acres / 50 ha) is more profitable. This demonstrates a potential difference in technology depending on size—higher labor inputs per unit land area at small scale, higher mechanization at large scale.

12. **Frey, G.E.; Fassola, H.E.; Pachas, A.N.; Colcombet, L.; Lacorte, S.M.; Pérez, O.; Renkow, M.; Warren, S.T.; Cubbage, F.W. 2012a.** Perceptions of silvopasture systems among adopters in northeast Argentina. Agricultural Systems. 105(1): 21-32. DOI: 10.1016/j.agsy.2011.09.001.

The authors report on a regression model to determine explanatory factors of perceptions of silvopasture among adopters in Misiones and Corrientes provinces, Argentina. As an explanatory factor, farm scale was correlated with the perception of cash flow as an important benefit, with smaller scale farmers (< 124 acres / < 50 ha) more likely to see it as positive and important.

13. **Frey, G.E.; Fassola, H.E.; Pachas, A.N.; Colcombet, L.; Lacorte, S.M.; Renkow, M.; Pérez, O.; Cubbage, F.W. 2012b.** A within-farm efficiency comparison of silvopasture systems with conventional pasture and forestry in northeast Argentina. Land Economics. 88(4): 639-657. DOI: 10.3368/le.88.4.639.

The authors used data envelopment analysis to analyze efficiency and returns to scale of silvopasture in Misiones and Corrientes provinces, Argentina. Silvopasture tracts on small-scale farms (< 124 acres / < 50 ha) seemed to generate higher levels of outputs per unit land area, particularly timber and milk, although medium-scale farms (124–2,470 acres / 50–1000 ha) seemed to generate more beef per unit land area. However, this was obtained at substantially higher cost per unit land area, particularly for labor and field crops, although medium-scale farms invested more capital per unit land area. In sum, silvopasture did show increasing returns to scale among small- and medium-scale farms. However, this effect was less strong for silvopasture than for conventional plantation forestry parcels.

14. **Frey, G.E.; Mercer, D.E.; Cubbage, F.W.; Abt, R.C. 2010.** Economic potential of agroforestry and forestry in the Lower Mississippi Alluvial Valley with incentive programs and carbon payments. Southern Journal of Applied Forestry. 34(4): 176-185.

The authors report on a financial model of hypothetical forestry and agroforestry systems in the Lower Mississippi Alluvial Valley, U.S.A. They found that alley cropping and silvopasture were not financially competitive with traditional row agriculture on anything except the worst agricultural soils. Adding hypothetical carbon payments does improve the calculus for the agroforestry systems, but the authors note that carbon projects have high fixed costs, making them infeasible at small scales.

15. **Frey, G.E.; Mercer, D.E.; Cubbage, F.W.; Abt, R.C. 2013.** A real options model to assess the role of flexibility in forestry and agroforestry adoption and disadoption in the Lower Mississippi Alluvial Valley. Agricultural Economics. 44(1): 73-91. DOI: 10.1111/j.1574-0862.2012.00633.x.

The authors took the deterministic approach in Frey and others (2010) one step further by simulating stochastic financial returns in a real options model. The model indicated that uncertainty would make agroforestry systems even less likely to be adopted than the deterministic models would suggest. Size and scale issues were not directly discussed.

16. **Garrett, H.E.; Kurtz, W.B. 1983.** Silvicultural and economic relationships of integrated forestry farming with black walnut. Agroforestry Systems. 1(3): 245-256. DOI: 10.1007/BF00130610.

The authors modeled economic returns from various black walnut intercropping systems in Missouri, U.S.A. They did not consider scale or size factors, but found that the concept is economically viable, and higher returns can be expected from more intensive regimes. These returns included net present values (at 7.5-percent discount rate) of up to $962 per acre ($2,377/ha) for an alley cropping system and up to $529 per acre ($1,303/ha).

17. **Godsey, L.D.; Mercer, D.E.; Grala, R.K.; Grado, S.C.; Alavalapati, J.R.R. 2009.** Agroforestry economics and policy. In: Garrett, H.E., ed. North American agroforestry: an integrated science and practice. 2nd edition. Madison, WI: American Society of Agronomy: 315-338.

The authors do not discuss scale issues in detail, but they mention that investment levels can be a constraint on adoption for limited-resource producers.

18. **Godsey, L.D.; Walter, W.D.; Dwyer, J.P.; Garrett, H.E. 2006.** A preliminary economic analysis of silvopasture in Missouri's Ozark forests. In: Buckley, D.S.; Clatterbuck, W.K., eds. Proceedings of the 15th central hardwoods forest conference. February 27-March 1, 2006; Knoxville, TN. Gen. Tech. Rep. SRS-101. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 418-424. http://srs.fs.usda.gov/pubs/27398. [Date accessed: August 29, 2017].

This study presents the detailed data of one case study. The purpose of the study was to quantify the economics of hardwood silvopasture, and it did not discuss size or scale issues directly. The authors estimated the establishment costs and the potential revenue using the TWIGS model (The Woodsman's Ideal Growth Projection System). They estimated a net present value (at 4-percent discount rate) of $354 per acre ($875/ha).

19. **Gold, M.A.; Godsey, L.D.; Josiah, S.J. 2004.** Markets and marketing strategies for agroforestry specialty products in North America. Agroforestry Systems. 61(1-3): 371-384. DOI: 10.1023/B:AGFO.0000029011.42829.83.

This article discusses markets for various products from agroforestry systems. Commodity markets, including timber, beef, and dairy, operate at large scales with established infrastructure that reduces transaction and other costs. However, specialty products with niche markets are "small, volatile, specialized, and with relatively few buyers," creating higher informational needs and transaction costs. Still, small markets can be an opportunity for small-scale producers if they are able to satisfy buyers' wants.

20. **Grado, S.C.; Hovermale, C.H.; St. Louis, D.G. 2001.** A financial analysis of a silvopasture system in southern Mississippi. Agroforestry Systems. 53(3): 313-322. DOI: 10.1023/A:1013375426677.

This study focuses on loblolly silvopasture in southern Mississippi, based on a research plot. The economic analysis did not consider differences based on scale or size, and used the cost of establishing practice, revenue from cattle, thinning, and hunting fees. The results indicate a favorable potential for silvopasture applications in the Southern United States. In this study, fees from hunting provide added value. Other income opportunities such as pine straw were not included in this study.

21. **Harwell, R.L.; Dangerfield, C.W., Jr. 1991.** Multiple use on marginal land: a case for cattle and loblolly pine. The Forestry Chronicle. 67: 249-253.

The authors note that as marginal agricultural land reverts to forest land, some smaller scale (the article uses "small" and "large" in a qualitative sense and does not state a precise, quantifiable definition) operators may benefit from the combination of cattle and timber together. The authors used a timber growth and yield model to generate estimated financial returns of conventional pine plantations with silvopasture, showing that net present value can be increased from $554 per acre ($1,367/ha) for conventional pine to $948 per acre ($2,342/ha) for silvopasture on marginal lands.

22. **Hilimire, K. 2011.** Integrated crop/livestock agriculture in the United States: a review. Journal of Sustainable Agriculture. 35(4): 376-393. DOI: 10.1080/10440046.2011.562042.

This study reviews research, policy, and theory as it relates to integrated agriculture. The authors introduce the argument that integrated agriculture is not a new concept: before the onset of industrial agriculture, integrated agriculture was the norm. However, over the past century, there has been a disconnection between the knowledge of how to manage integrated operations. The food industry has been based on specialization, cheap labor, and economies of scale. Ranchers that want to integrate face challenges such as policies designed for specialization, lack of processing plants for small-scale operations (the article uses "small" and "large" in a qualitative sense and does not state a precise, quantifiable definition), and an erosion of animal genetic diversity. A review of the research suggests that integrated operations improve soil quality, decrease the need of external inputs, improve pest management, and strengthen rural economies overall.

23. **Husak, A.L.; Grado, S.C. 2002.** Monetary benefits in a southern silvopastoral system. Southern Journal of Applied Forestry. 26(3): 159-164.

This study compares financial returns from silvopasture, with and without the inclusion of hunting leases, to conventional monocultural systems. Silvopasture is financially competitive with alternative land uses. The estimates were per unit of land area, based on a hypothetical 215-acre (87-ha) farm, and did not include differences per unit of land area for larger or smaller scales.

24. **Lundgren, G.K.; Connor, J.R.; Pearson, H.A. 1983.** An economic analysis of forest grazing on four timber management situations. Southern Journal of Applied Forestry. 7(3): 119-124.

The authors estimated financial returns to forest grazing operations, based on data from Louisiana. The results show positive financial returns. The authors assumed large tract sizes of 3,000 acres (1214 ha) because of their assumptions about practically managing cattle herds. The authors assert economies of size—"larger tracts should improve economies while smaller tracts would diminish economies."

25. **Mercer, D.E. 2004.** Adoption of agroforestry innovations in the tropics: a review. Agroforestry Systems. 20441: 311-328.

This review of research from the tropics has potential implications in the Southeast United States. The past research notes variable impacts of size of farm and scale of system (the article uses "small" and "large" in a qualitative sense and does not state a precise, quantifiable definition) on adoption (Feder and others 1985, Feder and Umali 1993). Some research does indicate that adoption of agroforestry is more difficult for small farms because of budgetary constraints, high investment costs, and longer payback period (Shively 1997, 1999a, 1999b, 2001). On the other hand, small farm size (Scherr 1992) would lead to more intensification of production systems, and agroforestry can be highly intensive. So the adoption potential by farm size depends on numerous, potentially conflicting factors.

26. **Orefice, J.N.; Carroll, J.; Conroy, D.; Ketner, L. 2017.** Silvopasture practices and perspectives in the Northeastern United States. Agroforestry Systems. 91(1): 149-160. DOI: 10.1007/s10457-016-9916-0.

The authors interviewed silvopasture practitioners in New York and New England. The amount of silvopastures on farms was relatively small, ranging from 2.5 to 180 acres (1 to 73 ha). Whole farm sizes ranged from 30 to 1,200 acres (12 to 486 ha). Most of the cited benefits of silvopasture were related to livestock production. However, timber production was a goal of some of the respondents (half received no financial benefit from trees). Primary challenges were related to complexity and costs of fencing. There was a wide variety of establishment and management methods, and tree and livestock species.

27. **Pattanayak, S.K.; Mercer, D.E.; Sills, E.O.; Yang, J.C. 2003.** Taking stock of agroforestry adoption studies. Agroforestry Systems. 57(3): 173-186.

The authors conducted a meta-analysis of past research on agroforestry adoption studies, primarily in the tropics. They found that plot size is inconsistently correlated with adoption, suggesting that economies of scale is not a primary driver of adoption.

28. **Pearson, H.A.; Prince, T.E.; Todd, C.M., Jr. 1990.** Virginia pines and cattle grazing—an agroforestry opportunity. Southern Journal of Applied Forestry. 14(2): 55-59.

This article reported on experimentation with a system of planting Virginia pines for Christmas trees into existing pasture. A budget was estimated for a small (4–20 acres / 1.6–8 ha) silvopasture operation, based on a low level of machinery/equipment appropriate at this scale. The research found that trees added $176 per acre ($435/ha) to standard pasture management. These trees were harvested after 3 years.

29. **Prevatt, W.; Yeager, J.; Young, G.; Simpson, G.; Pepper, H. 2005.** An investment analysis of a southern mixed enterprise farm: broilers and silvopasture. Journal of the American Society of Farm Managers and Rural Appraisers. 2005: 60-68.

The authors modeled a hypothetical larger scale (320 acres / 129 ha; capital costs $1.5 M) farm with chickens and silvopasture. They discuss the fact that diversification in this way may increase labor costs. Further, tax benefits, which usually are more beneficial to larger, farm businesses (as opposed to investment property), account for increasing net present value (at 8.15-percent discount rate) from -$102,000 to +$13,000 for the entire operation.

30. **Shrestha, R.K.; Alavalapati, J.R.R.; Kalmbacher, R.S. 2004.** Exploring the potential for silvopasture adoption in south-central Florida: an application of SWOT-AHP method. Agricultural Systems. 81(3): 185-199. DOI: 10.1016/j.agsy.2003.09.004.

This study interviewed three known opinion leaders in Florida, a large landowner, a small landowner, and an extension/research leader. Of these, the small-scale landowner (owns 640 acres / 259 ha and 120–150 head of livestock) was less likely to perceive direct strengths, particularly economic strengths, of silvopasture.

31. **Stainback, G.A.; Alavalapati, J.R.R. 2004.** Restoring longleaf pine through silvopasture practices: an economic analysis. Forest Policy and Economics. 6(3): 371-378. DOI: 10.1016/j.forpol.2004.03.012.

The authors used a modified Hartman model to compare longleaf pine silvopasture to conventional longleaf pine forestry and cattle ranching in the range of longleaf pine in the Southeast United States. They did not directly address size or scale issues. They found silvopasture to be more profitable than either forestry or cattle ranching. Carbon payments increase this profitability and increase the optimal rotation age and plantation density. Restoration of red-cockaded woodpecker habitat is less costly with silvopasture.

32. **Stainback, G.A.; Alavalapati, J.R.R.; Shrestha, R.K.; Larkin, S.; Wong, G. 2004.** Improving environmental quality in south Florida through silvopasture: an economic approach. Journal of Agricultural and Applied Economics. 36(02): 481-489.

As opposed to the research presented in Stainback and Alavalapati (2004), in this study the authors model silvopasture economics with slash pine on native pastures in south Florida. In this case, silvopasture is not competitive with conventional cattle ranching, absent policy incentives that would favor it. Two of these policies are examined: a tax on phosphorous runoff and a payment for carbon sequestered. On its own, a phosphorous tax is not enough to make silvopasture competitive, but a carbon payment at high enough levels or in combination with a phosphorous tax does make silvopasture more profitable.

33. **Workman, S.W.; Bannister, M.E.; Nair, P.K.R. 2003.** Agroforestry potential in the Southeastern United States: perceptions of landowners and extension professionals. Agroforestry Systems. 59(1): 73-83. DOI: 10.1023/A:1026193204801.

The article describes the importance of diversified and integrated production systems in a growing global urbanized market. It further explains how small farmers can utilize agroforestry practices to remain competitive and sustainable. The study conducted surveys of land users and natural resource professionals in Alabama and Florida, to determine their thoughts on the benefits of agroforestry and the obstacles that prevent producers from using agroforestry practices. The survey found that landowners ranked aesthetics as the most important benefit, then shade, wildlife habitat, and soil conservation. Professionals ranked water quality, wildlife habitats, and conservation as most important. Landowners and professionals believed that the greatest barriers were the lack of familiarity and demonstrations of the practices. Lack of markets was also an issue identified, which could cut for or against smaller scale producers (< 10 acres / < 4 ha). Expense of management was also identified.

34. **Zinkhan, F.C.; Mercer, D.E. 1996.** An assessment of agroforestry systems in the Southern USA. Agroforestry Systems. 35(3): 303-321. DOI: 10.1007/BF00044460.

The authors discuss the need for development of agroforestry systems that are suited for small-scale producers (the article uses “small” and “large” in a qualitative sense and does not state a precise, quantifiable definition). In particular, there is a need for systems with specialty outputs, as well as multi-purpose trees such as honeylocust, which can provide seed pods for fodder, or black locust, which produces timber, leaves for forage, and nitrogen fixation.

Tree Component

35. **Barrett, S.M.; Chandler, J.L.; Bolding, M.C.; Munsell, J.F. 2002.** Forest harvesting in Virginia: characteristics of Virginia's logging operations. Publication ANR-5. Blacksburg, VA: Virginia Cooperative Extension. 20 p.

The authors surveyed logging firms in Virginia to determine operation methods and other characteristics. In general, they found that logging in Virginia is often highly mechanized with large equipment such as feller-bunchers, grapple skidders, delimbers, and knuckleboom loaders. This level of mechanization implies certain scale size is necessary for economic returns. However, nearly 50 percent of respondents indicated propensity to use smaller (often hand-held) equipment, particularly chainsaw, for felling and delimbing. Operations using this smaller equipment would likely be less efficient in terms of labor, producing fewer loads per crew per week, but more versatile and able to economically harvest small tracts. Use of large versus small equipment was highly correlated with region, with smaller equipment tending to be used in the mountains, larger equipment in the coastal plain.

About three-quarters of respondents indicated that the average tract size of their harvests is > 20 acres (8 ha), including 15 percent of firms that harvest > 80 acres (32 ha) on average. Still, this leaves some room for smaller harvests, since firms who *on average* harvest large tracts may harvest tracts that are smaller than that much of the time. Further, one-quarter of firms report an average size of < 20 acres (8 ha), and about 10 percent report average harvests of < 10 acres (4 ha). As implied by the equipment use, the smaller scale operations tended to be in the mountains, larger scale operations in the coastal plain.

36. **Bliss, J.C.; Kelly, E.C. 2008.** Comparative advantages of small-scale forestry among emerging forest tenures. Small-scale Forestry. 7(1): 95-104. DOI: 10.1007/s11842-008-9043-5.

The authors hypothesize that large landowners drive markets, government regulations are designed with large landowners in mind, and foresters are less willing or able to deal with large numbers of small tracts with diverse landowner motivations, putting small landowners at a disadvantage. The challenges are manifested in economies of scale that include commodity markets that favor large shipments of uniform product. These challenges notwithstanding, the authors hypothesize that small-scale forest landholdings (the article uses "small" and "large" in a qualitative sense and does not state a precise, quantifiable definition) provide certain benefits to society, including diversity of motivations and management which lead to diverse ecological and market outcomes; local, personal knowledge of their land; love of place; stewardship motivation; long-term focus; and managerial flexibility.

37. **Cubbage, F.W. 1983a.** Economics of forest tract size: theory and literature. Gen. Tech. Rep. SO-41. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station. 21 p.

This report discusses economies and diseconomies of size and scale, and how they apply to forestry. The author identifies potential causes of economies and diseconomies of forest tract size. Economies can be caused by: utilization of technology and mechanization; specialization of workers and equipment; indivisibilities of inputs; and other factors. Diseconomies could be caused by: strain on individual managers with unique skills; difficulties in communication, coordination, and supervision; less flexibility in large firms; and increased transportation costs if larger parcels are further away on average. However, significant "diseconomies of large forest size are so rare that few have been documented."

38. **Cubbage, F.W. 1983b.** Tract size and harvesting costs in southern pine. Journal of Forestry. 81(7): 430-478.

Economies of tract size in timber harvest are due to the fixed costs of moving and setting up equipment. This study gathered productivity and cost information for several different timber harvest systems prevalent in the Southern United States in the 1980s. The lowest fixed-cost investment systems included mostly chainsaw felling and some limited machinery for skidding and loading. The highest cost investments were highly mechanized systems using feller-bunchers, large grapple skidders, iron-gate delimbers with knuckleboom loaders, or whole-tree chippers. All of the systems except the two lowest investment had downward-sloping or flat short-run average cost curves over the range from 0 to 350 acres (0 to 142 ha).

Highly-mechanized systems' average costs per unit of wood volume harvested began to level off around 50 acres (20 ha) and had mostly exhausted economies of scale around 100 acres (40 ha). Overall, costs per cord decreased from about $41 per cord ($16 per ton) at 0 acres (0 ha) (low mechanization) to about $34 per cord ($13 per ton) (whole tree chipping) or about $38 per cord ($15 per ton) (hauling full-tree) at 100 acres (40 ha).

39. **Cubbage, F.W.; Greene, W.D. 1989.** Conventional and biomass harvesting costs by forest tract size. Biomass. 20(3-4): 219-228. DOI: 10.1016/0144-4565(89)90062-0.

The authors simulated costs for harvests of whole trees to be chipped for biomass. Minimum economical tract size for each system was determined by finding the first section of the cost curve under which average costs leveled out to a decline of "less than US$0.08 [per cubic meter for each change of] 16 ha [40 acres]." The minimum economical tract size varied based on both harvest system and stand type. Bobtail truck was economical on tract sizes as small as 5 acres (2 ha), with costs of about $8.50 per cubic meter across forest types. Whole-tree chipper systems reached minimum economical cost on sites from 100 acres (40 ha) for pines to 200 acres (80 ha) for upland mixed hardwoods. The pine costs were somewhat lower than the bobtail truck, with costs averaging about $7.85 per cubic meter. Still, the differences in cost for pine were not large, and the bobtail truck system was extremely competitive even on small tracts (5 acres / 2 ha) for hardwoods.

40. **Cubbage, F.W.; Greene, W.D.; Lyon, J.P. 1989.** Tree size and species, stand volume, and tract size: effects on southern harvesting costs. Southern Journal of Applied Forestry. 13(3): 145-152.

The authors simulated harvest costs on tracts of various volumes, sizes, and tree characteristics. Economies of tract size were found due to the cost of moving equipment, which ranged from $244 to $1,722 per move for various pieces of equipment.

41. **DeCoster, L.A. 1998.** The boom in forest owners—a bust for forestry. Journal of Forestry. 96 (5): 25-28.

The author cites statistics and trends indicating that forests are being fragmented into more, smaller tracts. The author notes a scale economy of information, what he calls, "the Catch-22 of Occasional Relevance." Basically, this means that because forest activities are so infrequent, small owners do not need to know, and do not seek out information, about forestry most of the time. So when they do need information, they don't know where to find it. Large landowners, on the other hand, use the information more frequently, so they know where to find it. The author also notes that the infrequency may put small owners at other disadvantages, such as tax policies that give better treatment for deductions in cases where there is frequent activity.

42. **Greene, W.D.; Harris, T.G., Jr.; DeForest, C.E.; Wang, J. 1996.** Harvesting cost implications of changes in the size of timber sales in Georgia. Southern Journal of Applied Forestry. 21(4): 193-198.

This article notes that typical timber harvest size is decreasing, especially with fragmentation in the urban area. Highly mechanized systems operate at lowest cost at sizes > 50 acres (20 ha). Smaller land areas are therefore less likely to be harvested frequently, such that when they do harvest, stand composition is less uniform. This requires flexible, labor-intensive systems, which have also increased in cost as the cost of labor and insurance has risen.

43. **Gunter, J.E. 1979.** "Intermediate technology" key to small woodlands productivity. Forest Industries. 106(5): 64-66, 70.

The author notes that high-tech, large harvesting equipment is appropriate for large tracts, while small equipment, such as chainsaw, may be economical for very small tracts. What is left out is intermediate technology, such as tractor-based extensions and small fellers/skidders, which would be appropriate on the many medium scale tracts. The author goes further to discuss, in addition to harvesting, appropriate technologies for silviculture and marketing. For the former, the author suggests more uneven-aged management that allows for the need for income on shorter time intervals, such as every 10 years. For the latter, the author recommends better open timber price data that smaller landowners can access.

44. **Hensyl, C.H. 2005.** Impacts of land and ownership characteristics on the stumpage prices for Virginia's nonindustrial forests. Blacksburg, VA: Virginia Polytechnic Institute and State University. 110 p. M.S. thesis. https://vtechworks.lib.vt.edu/handle/10919/31706. [Date accessed: October 18, 2017].

The objective of this research was to identify how the stumpage price of timber is impacted by the changing characteristics of private forest landownership, from agriculture to absentee, smaller urban tracts. The study analyzed 138 recent Non-Industrial Private Forest timber sales that occurred within central Virginia. Results revealed that sites that were easy for logging crews to access dramatically increased the price paid per ton. Tract size was less important as long as total volume harvested at minimum 500 tons, and/or there were mature hardwood on the site and at least 50 acres (20 ha).

45. **Londo, A.J.; Grebner, D.L. 2004.** Economies of scale and forest management in Mississippi. In: Connor, K.F., ed. Proceedings of the 12th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS-71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 89-91.

The authors used data from cost-share assistance programs on cost of management practices to document economies of size for site preparation and planting. Mechanical and prescribed burn site preparation techniques showed declines in cost per unit land area as area increased, although mechanical was less consistent in decreasing cost as land area increased, and prescribed burning sloped downward through the range (up to 100 acres / 40 ha). Chemical site preparation did not show a strong downward trend in cost. Likewise, hardwood planting costs per unit land area decreased somewhat as land area increased, but pine planting costs were consistent across land areas.

46. **Moss, S.A.; Hedderick, D.B. 2012.** An economic evaluation of a small-scale timber harvesting operation in western Maryland, USA. Small-scale Forestry. 11(1): 101-117. DOI: 10.1007/s11842-011-9171-1.

The authors documented a harvest system with low fixed costs that could be used for small-scale harvests. Overall, the system was not profitable, but potentially could have better returns if there was a large proportion of high-quality timber.

47. **Rasamoelina, M.S.; Johnson, J.E.; Hull, R.B. 2010.** Adoption of woodland management practices by private forest owners in Virginia. Forest Science. 56(5): 444-452.

The researchers surveyed woodland owners about woodland management practices. They found that adopters had significantly larger land areas than non-adopters, potentially because of economies of scale.

48. **Rose, S.K.; Chapman, D. 2003.** Timber harvest adjacency economies, hunting, species protection, and old growth value: seeking the dynamic optimum. Ecological Economics. 44(2): 325-344. DOI: 10.1016/S0921-8009(02)00268-9.

This article notes trade-offs between timber production and ecosystem services, and that these trade-offs may be affected by economies of scale in timber production. For example, managing large tracts to maximize timber income diminishes edge (variability of habitat) and older growth areas, reducing hunting by 11 percent. Managing to maximize hunting reduces timber income by 7 percent. On the other hand, managing to maximize mature growth or endangered species is incompatible with both timber and hunting, reducing them both to zero or near zero. Including the possibility of economies of scale by harvesting multiple contiguous tracts at the same time has the effect of reducing the optimal rotation age of harvest from 50-53 years to 48 years.

49. **Row, C. 1978.** Economies of tract size in timber growing. Journal of Forestry. 76(9): 576-582.

This article discusses the theory of economies of scale and of size, and how they could apply in the case of forestry. The author discusses interaction of tract size with qualitative objectives: incompatibilities with objectives, lack of funds, lack of information, etc., may not be difficult hurdles when there is prospect of large cash income for the owner. Assuming a single owner and variable tract size, the larger tract is likely to be better managed because there is stronger incentive to do so.

There are economies of costs from scale due to fixed costs that are averaged over a greater area. For this reason, too, revenues per unit land area increase as size increases because the buyer also has fixed costs.

Other factors influencing economies of tract size are: lower exposure to forest fire, storm, and pest risks; and proximity to higher value land leading to higher taxes. There may be fixed transaction costs associated with paying taxes, applying for cost-share programs, and other administrative tasks. On the other hand, certain programs may only serve up to a maximum tract size.

The author suggests that groups or cooperatives of small landowners could help balance these economies of tract size, but still face barriers. Consultants can help pool their clients to get better deals.

50. **Straka, T.J.; Wisdom, H.W.; Moak, J.E. 1984.** Size of forest holding and investment behavior of nonindustrial private owners. Journal of Forestry. 82(8): 495-496.

Lower investment levels of nonindustrial private forest landowners can be explained by economies of tract size, diminishing marginal utility of forest land for recreational or aesthetic purposes, or higher alternative rates of return. The authors find that "(1) size of forest holding is positively related to income and asset position, (2) income and asset position are positively related to management intensity, and (3) size of holding is positively related to forest management intensity."

51. **Stuart, W.B.; Grace, L.A.; Grala, R.K. 2010.** Returns to scale in the Eastern United States logging industry. Forest Policy and Economics. 12(6): 451-456. DOI: 10.1016/j.forpol.2010.04.004.

The authors analyzed logging firm economies of scale using a statistical production function approach. A Cobb-Douglas production function was estimated using panel data in terms of labor and capital. Statistically, the approach found that the logging firms operate under constant returns to scale. However, it is important to note that this applies to the size of the firm, not the size of the timber tract.

52. **Thompson, R.P.; Jones, J.G. 1981.** Classifying nonindustrial private forestland by tract size. Journal of Forestry. 79(5): 288-291.

The authors separated forest landowners into land area groups that created the most consistent significant difference between groups based on present primary use and probability of future commercial management. Using this criteria, groups were created: small—10 to 50 acres (4 to 20 ha); medium—51 to 700 acres (21 to 283 ha); and large—700+ acres (284+ ha). One percent of small owners indicated timber production was primary use, compared to 15 percent of medium and 47 percent of large. Eighty-seven percent of small owners indicated < 25 percent chance of future timber management, compared to 69 percent of medium and 40 percent of large.

53. **Zhang, Y.; Zhang, D.; Schelhas, J. 2005.** Small-scale non-industrial private forest ownership in the United States: rationale and implications for forest management. Silva Fennica. 39(3): 443.

The authors explain parcelization of forest land using a novel theory that incorporates economies of scale. Timber production and harvest has economies of scale; however, many nontimber values do not, or at least the economies happen at smaller scales, then level out. As nontimber amenities become more valuable relative to timber, the incentive for large tracts is lessened.

Livestock and Forage Components

54. **Alvarez, A.; Arias, C. 2003.** Diseconomies of size with fixed managerial ability. American Journal of Agricultural Economics. 85(1): 134-142. DOI: 10.1111/1467-8276.00108.

Input indivisibilities can cause economies of size. Conversely, fixed managerial ability as inputs increase can cause diseconomies of size. This study uses a proxy for managerial efficiency to verify that increasing farm size while holding managerial ability constant can cause these diseconomies. However, this can be overcome by increasing managerial ability.

55. **Bailey, K.W.; Hardin, D.K.; Spain, J.N.; Garrett, J.; Hoehne, J.; Randle, R.; Ricketts, R.; Stevens, B.; Zulovich, J. 1997.** An economic simulation study of large-scale dairy units in the Midwest. Journal of Diary Science. 80(1): 205-214. DOI: 10.3168/jds.S0022-0302(97)75929-0.

The authors used an economic simulation in conjunction with production plans to model profitability of dairy farms of various sizes. They determined that only the largest examples (i.e., 500 to 1,000 head) would be viable as startups including all up-front fixed costs. Existing small farms would not be able to meet cash demands.

56. **Duffy, M. 2009.** Economies of size in production agriculture. Journal of Hunger & Environmental Nutrition. 4(3-4): 375-392.

This article discusses economies of size as it relates to Midwestern agriculture, with limited discussions on other regions. The study finds that although economies of size exist, the average cost curve is L-shaped. This means that the cost per unit decreases to a certain size and then flattens. The authors give an explanation of why farms are increasing in size. In many cases, farmers invest in technology which increases cost, requiring more land area to increase profits. This has led to farms substituting capital for labor. There are also cases of substituting capital for management, as in the case of herbicide-resistant crops where one does not need to hire a specialist to manage weeds.

57. **Feder, G.; O'Mara, G.T. 1981.** Farm size and the diffusion of green revolution technology. Economic Development and Cultural Change. 30(1): 59-76.

Although this article does not specifically discuss livestock or forage technologies, it does discuss the impact of scale on adoption of agricultural technologies in a way not discussed in other articles here, so it was deemed relevant to include. Some agricultural technologies, such as those used in the "Green Revolution" in developing countries, may have divisible inputs and programs that provide inputs free or cheaply on credit, so large investments are not a barrier. Past literature has suggested risk aversion could be a barrier, but when this is tested, the case is not clear-cut. The authors argue that various factors that are not usually considered as part of the investment costs can be substantial for small farmers, and these factors can interact with risk aversion to prevent adoption. First, there are costs of time involved to learn and understand a new technology. Second, there are costs involved with applying for program participation, loans, etc. Finally, there may be a time cost of obtaining necessary inputs.

58. **Gwin, L. 2009.** Scaling-up sustainable livestock production: innovation and challenges for grass-fed beef in the U.S. Journal of Sustainable Agriculture. 33(2): 189-209. DOI: 10.1080/10440040802660095.

This study examines the growth of grass-fed beef production in the United States. Findings indicate that grass-fed producers that desire to scale-up face several obstacles, such as breed selection and adequate land base. The market that is largely shaped around conventional beef production presents yet another challenge: the grass-fed market is driven by consumers' perceptions, so one must consider how to maintain integrity with the end client and become more mainstream. The authors offer several suggestions, such as direct sales to restaurants and retailers, producers collaborating and selling as one multicounty brand, or buying clubs. As consumer demand continues to grow, producers will have to explore new marketing opportunities.

59. **Haden, K.L.; Johnson, L.A. 1989.** Factors which contribute to financial performance of selected Tennessee dairies. Southern Journal of Agricultural Economics. 21(1): 105-112.

This study regressed various indicators of financial performance on 10 explanatory variables. Herd size was positively correlated with one measure of financial performance, cash farm income (which is "total farm receipts less cash operating expenses"), and was negatively correlated with another, returns to operator labor and management (which is "net farm income adjusted for interest paid, less opportunity cost on total capital and the return to non-operator labor").

60. **Lund, P.J.; Hill, P.G. 1979.** Farm size, efficiency and economies of size. Journal of Agricultural Economics. 30(2): 145-158.

The authors used survey data to estimate technical efficiency of farms by size in the United Kingdom. They found that efficiencies tended to increase as farms approached the 2–4 full-time worker size [equivalent to about 124 acres (50 ha) for dairy farms], then stayed relatively flat after that point.

61. **MacDonald, J.M.; McBride, W.D. 2009.** The transformation of U.S. livestock agriculture scale, efficiency, and risks. Economic Information Bulletin Number 43. Washington, DC: U.S. Department of Agriculture, Economic Research Service. 40 p.

Financial pressures have driven family livestock farms to grow into industrialized farms. Larger operations are able to realize lower costs and higher returns, and they are more efficient. This study found that while most large livestock and poultry farms are still family owned, they are closely linked to input providers and processors through formal contracts and joint ownership of animals. Waste from these large farms is harmful to the environment, along with the heavy use of antibiotics. Individual producers often do not have the ability to install the costly systems to mitigate these issues.

62. **Matulich, S.C. 1978.** Efficiencies in large-scale dairying: incentives for future structural change. American Journal of Agricultural Economics. 60(4): 642-647.

The author notes that dairy operations have shown significant consolidation over time, likely due to technological advances. This study modeled large-scale (375–1,200 head) dairy operations to estimate a long-run average cost curve. The model does show economies of size up to about 750 head. These economies depend mainly on milking and other technologies.

63. **McBride, W.D.; Mathews, K., Jr. 2011.** The diverse structure and organization of U.S. beef cow-calf farms. Economic Information Bulletin Number 73. Washington, DC: U.S. Department of Agriculture, Economic Research Service. 42 p.

The authors discuss the nature of small, beef cow-calf operations in the United States. The study found that the majority of U.S. beef cow operations are located in the South. Many of them are small, family-owned farms that generate most of their income from off-farm sources, and although economies of size suggest that such operations have incentives to become larger, many do not due to access to land. Most operations do not specialize in beef cow-calf production but are diversified. The study also found that 80 percent of the operations used some type of identification system, with many reporting that lack of familiarity and costs prevented them from participating in the program.

64. **Melhim, A.; O'Donoghue, E.J.; Shumway, C.R. 2009.** Do the largest firms grow and diversify the fastest? The case of U.S. dairies. Applied Economic Perspectives and Policy. 31(2): 284-302. DOI: 10.1111/j.1467-9353.2009.01438.x.

The authors grouped U.S. dairy farms into size cohorts, as determined by total agricultural sales. Small farms were considered those with annual sales < \$92,000, medium farms \$92,000–\$339,000, and large farms > \$339,000. They compared the farms using a panel data set with three points in time. They found that the smallest and largest farms grew the fastest, but smallest farms diversified the fastest while large farms diversified at the same rate as medium-sized farms. Overall, there was evidence of economies of both scale and scope. However, the authors did not estimate a minimum efficient size.

65. **Mishra, A.K.; El-Osta, H.S.; Steele, C.J. 1999.** Factors affecting the profitability of limited resource and other small farms. Agricultural Finance Review. 59: 77-91.

For limited resource farms, profitability is negatively correlated with debt-to-asset ratio, possibly indicating high interest rates and constraints on further investment. Limited resource and other small farms (annual gross sales < $250,000) that can control costs tend to be more profitable. Also, other small farms that were more diversified and had basic crop insurance were more profitable.

66. **Mosheim, R.; Lovell, C.A.K. 2009.** Scale economies and inefficiency of U.S. dairy farms. American Journal of Agricultural Economics. 91(3): 777-794. DOI: 10.1111/j.1467-8276.2009.01269.x.

Using a dataset from the 2000 Agricultural Resource Management Survey, this study details estimation of scale relationships of dairy farms of differing sizes across various regions in the United States. Using a multi-output shadow cost function system, this study analyzed scale economies and decomposed economic efficiency of the dairy sector. Findings resulted in identifying five characteristics that affect technical inefficiency and four affecting allocative inefficiency. The results suggest that scale economies exist, potentially even for the largest cohort of farms.

67. **Short, S.D. 2001.** Characteristics and production costs of U.S. cow-calf operations. Statistical Bulletin Number 974-3. Washington, DC: U.S. Department of Agriculture, Economics Research Service. 26 p.

Cow-calf operations in the Southeast tend to be smaller (100 head) on average than those in the West (278 head) and Plains (139-150 head). Southeast farms also had smaller acreages (318 acres / 129 ha) than all other regions and were less likely to have cow-calf production as the primary enterprise. “Operations with 250 or more bred cows had significantly lower total operating and ownership costs; indicative of the economies of scale experienced as the enterprise size increased.” Costs that declined per head with size included feed and supplements, health, equipment and machinery, fuel, repairs, taxes, and insurance. Part of this correlation may be due to the fact that larger herds are found in Western and Southern States that have longer growing seasons.

68. **Sumner, D.A. 2014.** American farms keep growing: size, productivity, and policy. The Journal of Economic Perspectives. 28(1): 147-166. DOI: 10.1257/jep.28.1.147.

The author examined data on farm size and production in the United States. Data show that the average farm size increased from 1987 to 2007, and the distribution became more skewed such that the largest few farms produced a larger proportion of the total output in 2007 than in 1987. This shift included farms of all types. Median herd size of dairy farms increased from 80 in 1987 to 570 in 2007. Dairy farm production is concentrated in the largest farms, with 20 percent of the farms producing 80 percent of the output. This was more concentrated than some farm types, such as corn, but less concentrated than others, such as grape and egg layer farms.

69. **Sumner, D.A.; Leiby, J.B. 1987.** An econometric analysis of the effects of human capital on size and growth among dairy farms. American Journal of Agricultural Economics. 69(2): 465-470.

This study examined the relationship of human capital and growth patterns of dairy farms. The model suggests that human capital’s effect on herd size and growth is based on experience and age of the principal operator, education of the workers, and management techniques. In essence, an older, experienced operator takes less risk.

70. **Tauer, L.W. 2001.** Efficiency and competitiveness of small New York dairy farms. Journal of Dairy Science. 84(11): 2573-2576. DOI:10.3168/jds.S0022-0302(01)74710-8.

The authors measured total costs of production on dairy farms in New York, and estimated an efficient frontier assuming variable returns to scale. An efficient, smaller scale farm (such as 50 head) would have higher costs of production than efficient, large-scale farms (such as 500 head) ($0.299 per kilogram for a 50-head farm vs. $0.287 per kilogram for a 500-head farm). The smaller farms also tended to have a larger share of costs due to inefficiencies.

71. **Tauer, L.W.; Mishra, A.K. 2006.** Can the small dairy farm remain competitive in U.S. agriculture? Food Policy. 31(5): 458-468. DOI: 10.1016/j.foodpol.2005.12.005.

The authors measured the component of fixed cost due to inefficiency and size. Most of the increased cost for smaller scale farms (those with 50, 100, 150 head) is due to inefficiency, and a smaller amount due to the size or scale of the farm. This suggests that education could help small farms use existing technology more effectively. Still, some economies of scale do apparently exist.

72. **Tew, B.V.; Spurlock, S.R.; Musser, W.N.; Miller, B.R. 1980.** Some evidence on pecuniary economies of size for farm firms. Southern Journal of Agricultural Economics. 12(1): 151-154.

When comparing purchase of variable inputs for peanut farms of 50–500 acres (20–202 ha), authors found that farms can obtain units of about half of variable inputs cheaper at a larger scale. However, the “price impact only had very small effects on unit costs per [unit land area],” changing variable costs from $139.04 per acre ($343.58/ha) for 50-acre (20-ha) farms to $138.49 per acre ($342.22/ha) for 500-acre (202-ha) farms.

73. **U.S. Department of Agriculture, National Animal Health Monitoring System. 1996.** Management practices associated with profitable cow-calf herds. APHIS Info Sheet, Veterinary Services. Fort Collins, CO: U.S. Department of Agriculture, Animal and Plant Health Inspection Service, Centers for Epidemiology and Animal Health. 2 p. https://www.aphis.usda.gov/animal_health/nahms/beefcowcalf/downloads/chapa/CHAPA_is_MgmtPrac.pdf. [Date last accessed: December 2017].

The paper discusses what factors drive profitability in cow-calf operations. The average size of herds for profitable vs. unprofitable operations was similar (167 head for profitable vs. 162 head for unprofitable), suggesting that size is not the main driver of determining profitability.

Discussion and Conclusions

Silvopasture presents possibilities for economics to be influenced by or correlated to the size or scale of the operation. First, there are several factors that are well known to cause economies and diseconomies of size or scale. In general, economies can be caused by: utilization of large indivisible inputs such as equipment and machines; high fixed costs of mobilization; specialized labor and capital; investment in technological advancements; and other factors. Diseconomies can be caused by: strain on individuals with unique skills; difficulties in communication, coordination, and supervision; less flexibility in large firms; and increased transportation costs if larger parcels are further away on average (Cubbage 1983a).

Second, there are other factors that influence economies which may be correlated with tract size or scale of operation, but not directly due to size/scale. For example, owners of small tracts may have certain characteristics that affect their management which are not due to owning small tracts, but still set them apart from large landowners. Also, smaller tracts may be clustered in different types of geographical locations than larger tracts. These factors may include: differing aversion to risk; constraints on capital; different exposure levels to risks such as fires and pests; and proximity to higher value land leading to higher taxes.

Finally, there may be economies or diseconomies of size/scale that are created by policy. There may be fixed transaction costs associated with paying taxes, applying for cost-share programs, and other administrative tasks. Some provisions that reduce taxes owed may only apply if income, costs, or management intensity are above a certain level. On the other hand, certain incentive programs may only serve up to a maximum tract size, or some tax deductions may phase out above certain income levels.

Specifically, for the case of silvopasture, we interpret the literature to suggest that the following size/scale related factors may affect the economics. Given the lack of empirical evidence that identifies scale factors specific to silvopasture in the U.S. South, the existence of these factors is relatively theoretical and unproven. Some of these potential factors may contradict or counteract each other. More research would be needed to test empirically for the existence and relative impacts of these potential factors:

- **Large-scale mechanization**, which is common in the industry. This includes both high investment costs and costs of mobilizing large equipment. This is most obvious with timber harvest equipment, but may also be true of certain livestock-oriented investments such as tractors, milking parlors (for dairy operations), and others.
- **Specialization of labor and equipment** could also create some barriers on small tracts. In an extreme case, a very large producer may have on staff technicians individually specialized in forestry, livestock, and forage, whereas a small producer may rely solely on him/herself. This can be difficult for one-time activities, also. For example, a controlled burn is often a cost-effective way to eliminate undesired competition and prepare a site for planting. However, it requires trained personnel and appropriate equipment, regardless of whether the plot is 1 or 100 acres (0.4 or 40 ha). Even if it is economical for them to work on small tracts, these and other technical service providers may not want to engage myriad small landowners with diverse goals and aspirations.
- On the other hand, smaller scale producers may have **access to a particular type of high-quality knowledge and labor** that is difficult for larger scale producers to replicate. Knowledge of an individual parcel of land, animal, etc., may be a type of specialization of knowledge that favors

smaller scale producers. Smaller scale producers may be able to more closely monitor animals, trees, and forage.

- Even when the level of inputs is not considered extraordinarily expensive, difficult to mobilize, or specialized, other **inputs that are indivisible may create difficulties for small-size adopters**. For example, a large producer might plan one waterer per 50 acres (20 ha); however, a small-scale operator who plans only 1 acre (0.4 ha) still needs one waterer. Similarly, there may be herd-level "indivisibilities," in the sense that only one bull may be needed for multiple cows.
- **Access to information** can be a significant barrier for small-scale producers. This can in some ways be connected to specialization of labor, but can also be an independent concern. Small-scale producers would more infrequently carry out certain activities. Therefore, they may not have fully developed networks of people or resources they can consult, and would have to spend significant time finding reliable information. Further, for information that may only be needed once, smaller and larger scale producers may need to spend the same amount of time learning—a fixed cost which creates a lower cost per unit land area for larger scale producers.
- Similarly, there could be **other fixed costs of participation** related to the time of the producer. For example, they might have to fill out paperwork related to cost-share program participation. For the most part, this time cost is the same regardless of whether the tract is 1 or 100 acres (0.4 or 40 ha).
- Apart from these fixed costs of participation, various **policies and programs may be designed in ways that benefit either larger scale or smaller scale owners**. For example, more advantageous tax treatments may be reserved for producers that are more active in management and have more frequent receipt of income from their tract. On the other hand, other programs may specifically target smaller scale producers by setting upper limits (in terms of land area, head of livestock, income, etc.) for whom may participate.
- **Smaller scale farmers are more land-constrained**. Some silvopasture establishment methods involve planting trees into pasture and excluding livestock. Effectively then, in the short run, silvopasture could aggravate the land constraint. In the long run, however, silvopasture may be a way to intensify land usage.
- **Smaller scale farmers may also be capital constrained**. That is, they may be less wealthy and less able to self-finance or access credit for these costs. This is not necessarily an economy of scale or size, but it is a demographic factor that may be correlated with scale or size. If this is the case, then high levels of up-front investment, which are often reported for silvopasture, may be particularly difficult for smaller scale producers. Also, a waiting period for returns, as is the case with timber, would be seen as a disadvantage.
- **Lack of wealth can also generate relative risk aversion**, as there is less wealth to fall back on if the investment goes wrong. In one sense, risk aversion could lead to lower adoption of silvopasture because it is not widely practiced and producers would see it as uncertain. On the other hand, silvopasture specifically has some financial benefits that may be seen as beneficial for the risk averse, including diversifying sources of income and diversifying cash flows in time (annual pasture-related cash flows vs. long-term/periodic timber-related cash flows). Also, silvopasture may be able to reduce the need of certain capital inputs such as herbicides, effectively using the livestock as weed-control agents.
- **Markets generally favor larger scale producers**. Commodity markets are simple and streamlined but typically demand large quantities of uniform product. On the other hand, specialty/niche/novelty markets accept smaller quantities of product but require substantial transactional information and marketing costs. Furthermore, lending institutions may have streamlined processes for financing commodity-crop production, whereas niche product producers may have more difficulty obtaining financing. This could create negative interactions if the smaller scale farms are also more cash-constrained.

While these potential factors of scale or size may exist, there also are opportunities to adapt practices to size. The following adaptations may address some of the issues outlined above and make them easier to implement on a smaller scale:

- Utilize lower cost infrastructure (e.g., portable fencing);
- Utilize smaller, more versatile livestock (e.g., goats, sheep);
- Use short-rotation trees;
- Use multi-purpose/multi-product trees;
- Use single continuous recruitment of trees in hardwood silvopasture;
- Substitute labor for capital, using more labor-intensive systems;
- Combine silvopasture activities with activities on rest of farm (silvopasture may only be a small part of farm);
- Monitor the system closely; and
- Produce specialty products and domestic consumption products.

Past research and literature provide a starting point for understanding how scale and size factors could affect silvopasture production opportunities. More direct research into this area will be needed to provide the best knowledge and guidance for producers, technical service providers, and social scientists.

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Appendix A: Supplemental Citations

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Appendix B: Index of Authors

Numbers refer to page numbers; authors may appear multiple times on a single page.

Frey, Gregory E.; Comer, Marcus M. 2018. Annotated bibliography on the impacts of size and scale of silvopasture in the Southeastern U.S.A. e-Gen. Tech. Rep. SRS-230. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 35 p.

Silvopasture, the integration of trees and pasture for livestock, has numerous potential benefits for producers. However, size or scale of the operation may affect those benefits. A review of relevant research on the scale and size economies of silvopasture, general forestry, and livestock agriculture was undertaken to better understand potential silvopasture production in the U.S. Southeast. This information was synthesized into a discussion of the factors that might affect production differently at different scales, and adaptations smaller scale producers might use with silvopasture to mitigate problems and enhance benefits tied to scale.

Keywords: Agroforestry, economics, management, production, silvopasture, size and scale.

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