Final Technical Report

DOE/ER/60575--T1

Grant No. DE-FG-87ER60575

September 15, 1987 through September 14, 1997

by

Boyd R. Strain and Richard B. *Thomas

Department of Botany

Duke University

Durham, NC 27708

(919) 660-7408

March 10, 1997

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

*Current Address

Department of Biology

University of West Virginia

Morgantown, WV 26506

(304) 293 5201

RECEIVED

MAR 23 1998

OSTI

MASTER

DISCLAIMER

Portions of this document may be illegible electronic image products. Images are produced from the best available original document.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Project Title: Forest Response to CO₂ Enrichment: Physiology and Ecology of Loblolly Pine

Objective:

To examine the direct physiological effects of CO₂ on plants with emphasis on the long-term effects on loblolly pine.

Abstract:

This report covers the results of a long-term project with the primary objective of developing and testing hypotheses on the environmental and physiological controls of loblolly pine response to atmospheric CO₂ enrichment. Earlier research under DOE funding had provided information from loblolly pine and other plant species which allowed the development of specific hypotheses. Phase 1 of this research was a two year pot study of loblolly seedlings to determine the interaction of CO₂ enrichment with soil nutrition. Phase 2 began with the enrichment of loblolly seedlings being grown in the ground, rather than pots, and continued through December 1995. Phase 3 began in April 1994 with the enrichment of undisturbed Piedmont North Carolina old field undergoing succession, including herbaceous annual plants, perennial grasses, and loblolly pine tree seedlings. Phase 3 was designed to gather preliminary information on a regenerating loblolly forest to be used for the development of hypotheses and measurement techniques for a long-term Free Air CO₂ Enrichment (FACE) study of regenerating forest in Duke Forest.

Summary Research Results

Our hypothesis was that elevated atmospheric CO₂ concentrations would act to enhance the growth, productivity and carbon sequestration of loblolly pine trees when soil nutrients and other environmental factors are in non-limiting ranges. When the environment is severely limiting, the enhancement response of loblolly to CO₂ would not be sustained.

Measurements of total growth of two-year old loblolly pine seedlings showed that well fertilized trees produced more dry mass at elevated CO_2 levels. A doubling of CO_2 at high levels of N and P resulted in a 60% increase at the end of year 1 but only a 9% increase in final total biomass at the end of two years treatment. Stringent reduction in available soil phosphorus or nitrogen greatly reduced overall plant growth and eliminated any CO_2 response. Long-term effects of elevated CO_2 and nutrient supply on photosynthesis and the photosynthetic enzyme, ribulose biphosphate carboxylase, demonstrated that photosynthetic rates were higher for plants grown at elevated CO_2 only when they received supplemental N in the soil. Stomatal conductance was reduced at high CO_2 reducing instantaneous water loss in transpiration under conditions of atmospheric CO_2 enrichment independent of soil N or P fertility.

A second two year experiment confirmed that CO_2 enrichment of 150 ppm and 300 ppm above ambient with fertile soil would produce 2-year old loblolly pine seedlings with 20% and 50% greater total biomass respectively. Plants grown at elevated CO_2 were also taller, had greater photosynthetic leaf area, and more frequent flushes of growth. Net photosynthesis was higher for plants grown in elevated CO_2 , but this difference was much greater in spring and summer. Rubisco content, activity, and activation state were unaffected by growth at elevated CO_2 . Results from both Phase 1 and 2 indicate the importance of soil fertility in determining the magnitude of the CO_2 response in terms of total carbon sequestration.

Although field studies have not shown a CO_2 enhancement of growth when soil N or P are stringently limited, we examined several possible mechanisms whereby long-term CO_2 enrichment might alleviate moderate nutrient limitations to growth, leading to greater carbon storage than predicted from existing information and models. We found that:

1. Root growth is stimulated by CO_2 enrichment more than shoot growth. In addition to greater root surface area, greater allocation to root biomass increased the potential of loblolly pine to obtain nutrients. Increased organic matter also feeds back on the mineral substrate thereby increasing soil fertility by increasing mineralization rates.

2. Reallocation of nutrients within the plant or increased efficiency of metabolic processes occasionally occurs lowering nutrient stress.

3. Symbiotic root associations with mycorrhizal fungi were also stimulated by CO₂ enrichment and resulted in increased nutrient supply to the plant.

4. We also found that there is a relationship between atmospheric CO₂ concentration, plant growth stage, and carbon acquisition, allocation and storage. Reduced growth and net photosynthesis in plants grown in long-term elevated CO₂ is apparently related to inadequate sink strength in the growing points of the plant. We also found that there is a seasonal component to the response of loblolly pine to CO₂ due to seasonal pulses of nutrients into the system, as well as seasonal changes in light and temperature. Seasonal pulses of nitrogen (a warm week in January, for example) will induce short-term enhancement of the response to CO₂. Because growth rates and carbon allocation patterns of loblolly change seasonally, the degree of CO₂ response will change seasonally. Shoots of loblolly, for example, grow mostly in the early spring and summer, but roots continue to grow for most of the winter. In addition, loblolly maintains its needles for two growing seasons and depending on site quality and latitude, it may produce from one to seven distinct flushes of growth during a growing season. For this reason, we conducted long-term experiments and analyzed seasonal events and responses. By the time the experimental work was terminated following the 1995 growing season, we had 4-year old loblolly pine trees that were continuously exposed to high CO₂ and soil nutrient fertility.

In the 4-year study we found that:

1. Total plant biomass increased in response to elevated CO₂. The absolute difference in tree mass between ambient and elevated CO₂ grown trees was 0.024 kg, 0.63 kg, 4.37 kg, 11.39 kg after one, two, three, and four growing seasons respectively.

2. After four growing season elevated CO₂ trees were 10% taller, had 39% more leaf area and had 90% more biomass than ambient CO₂ trees.

3. Growth related analyses of biomass allocation patterns demonstrated size dependent shifts in carbon allocation.

4. No direct effects of CO₂ concentration on partitioning of biomass.

5. Leaf photosynthetic rates were always higher in trees grown in elevated CO₂, but these differences were greater in the summer months (60-130% increase) than in the winter months (14-44% increase) reflecting a strong temperature effect on photosynthesis.

6. Seasonal photoperiodic changes in daylength, interacting with temperature controlled leaf photosynthesis rates will induce seasonal variation in tree biomass and size growth.

7. Measurements of total nonstructural carbohydrates (sugars and starch) demonstrated that seasonal differences in growth were not always explained by sugars and starch concentrations as originally hypothesized.

8. Reductions in leaf stomatal conductance of water vapor were sufficient to induce decreases in transpirational water loss per leaf. Increasing leaf area on trees grown for four years under enhanced CO₂ levels, however, indicate that whole tree water use will be higher in future loblolly pine forests.

9. Although some photosynthetic down-regulation (acclimation) occurred, net photosynthetic increase was still sufficient to support enhanced tree growth during the four years of this study.

10. The overall conclusion of this ten-year study is that loblolly pine stands and forests will be significant temporary sinks for atmospheric CO₂ in the future. Permanent sequestration of the carbon will, of course, require that pine products be permanently used or stored.

Our study of the effects of increased CO₂ on the early stages of old field succession (Phase 3) is incomplete. Analyses are underway that will provide information on a successional loblolly ecosystem. We are still in the process of measuring a fairly detailed carbon balance of this system which will provide valuable information on whether regenerating pine

forests of the southeastern United States represent a major carbon sink for sequestering excess atmospheric CO₂.

Transition to whole ecosystem studies utilizing FACE technology

This ten-year study in open-top chambers provided essential background information and hypotheses for the important work currently underway at the Duke University free air CO₂ experiment (FACE). Further studies at the FACE research site are focusing on changes in species composition in this diverse system, changes in soil properties such as nitrogen mineralization and soil carbon sequestration, and changes in insect composition. The importance of the contribution of this study to the establishment of the FACE research facility at Duke University was underscored in November 18, 1996 when the Duke FACE research facility was formally dedicated to Boyd R. Strain.

Publications

Fetcher, N. C.H. Jaeger, B.R. Strain and N. Sionit. 1988. Long-term elevation of atmospheric CO₂ concentrations and carbon exchange rate on carbon dioxide exchange rates of saplings of *Pinus taeda* L. and *Liquidambar styraciflua* L. Tree Physiology 4: 255-262.

Strain, B.R. 1991. Possible genetic effects of continually increasing atmospheric CO₂. IN: Ecological Genetics and Air Pollution. GE. Taylor, Jr., L. F. Pitelka, and M.T. Clegg (Eds.). Academic Press, New York. Pp.237-244.

Thomas, R.B. and Strain, B. R. 1991. Root restriction as a factor in photosynthetic acclimation of cotton seedlings grown in elevated carbon dioxide. Plant Physiology 96: 627-634.

Thomas, R.B., D.D. Richter, H.Ye, P.R. Heine, and B.R.Strain. 1991. Nitrogen dynamics and growth of seedlings of an N-fixing tree *Gliricidia sepium* (Jacq.) Walp.) exposed to elevated atmospheric carbon dioxide. Oecologia 88: 415-421.

Strain, B.R. (Ed.). 1991. Available technologies for field experimentation with elevated CO₂ in global change research. In:

Mooney, H.A. et al. (Eds.). Ecosystem Experiments. SCOPE 45, John Wiley & Sons, New York. pp 245-261.

Strain, B.R. 1992. Atmospheric CO₂: A plant fertilizer? The New Biologist 14:1-3.

Harley, P.C., R.B. Thomas, J.F. Reynolds and B.R. Strain. 1992. Modeling photosynthesis of cotton grown in elevated CO₂. Plant Cell Environment 15:271-282.

Strain, B.R. and R.B. Thomas. 1992. Field measurements of CO₂ Enhancement and climate change in natural vegetation. Water, Air, and Soil Pollution. 64: 45-60.

Griffin, K.L., R.B. Thomas and B.R. Strain. 1993. Effects of nitrogen supply and elevated carbon dioxide on construction cost in leaves of *Pinus taeda* (L.) seedlings. Oecologia 95:575-580.

Thomas, R.B., C.D. Reid, R. Ybema and B.R. Strain. 1993. Growth and maintenance components of leaf respiration of cotton grown in elevated carbon dioxide partial pressure. Plant. Cell and Environ. 16:539-546.

Tissue, D.T., R.B. Thomas and B.R. Strain. 1993. Long-term effects of elevated CO₂ and nutrients on photosynthesis and rubisco in loblolly pine seedlings. Plant, Cell and Environ. 16:859-865.

Reid, C.D. and B.R. Strain. 1994. Effects of CO₂ enrichment on whole-plant carbon budget of seedlings of *Fagus grandifolia* and *Acer saccharum* in low irradiance. Oecologia 98:31-39.

Thomas, R.B., J.D. Lewis and B.R. Strain. 1994. Effects of leaf nutrient status on photosynthetic capacity in loblolly pine (*Pinus taeda* L.) seedlings grown in elevated atmospheric CO₂. Tree Physiology 14:947-960.

Lewis, J.D., K.L. Griffin, R.B. Thomas and B.R. Strain. 1994. Phosphorus supply affects the photosynthetic capacity of loblolly pine grown in elevated carbon dioxide. Tree Physiology 14:1229-1244.

Lewis, J.D., R.B. Thomas and B.R. Strain. 1994. Effect of elevated CO₂ on mycorrhizal colonization of loblolly pine (*Pinus taeda* L) seedlings. Plant and Soil 165:81-88.

Larigauderie, A., J.F. Reynolds, and B.R. Strain. 1994. Root response to CO₂ enrichment and nitrogen availability in loblolly pine. Plant and Soil 165:21-32.

Williams, R.S., D.E. Lincoln and R.B. Thomas. 1994. Loblolly grown under elevated CO₂ affects early instar pine sawfly performance. Oecologia 98:64-71.

Strain, BR and JD Cure. 1994 Direct effects of atmospheric CO₂ on plants and ecosystems: An updated bibliographic data base. ORNL/CCDIAC-70, Nat. Tech. Info.Ser. , U.S. Dept. of Commerce, Springfield VA 22161. 287 pp.

Telewski, FW and BR Strain. 1994. The response of trees to global change. Journ. Korean Forestry Energy 14:35-54.

Strain, B.R. and R.B. Thomas. 1995. Anticipated effects of elevated CO₂ and climate change on plants from Mediterranean-type ecosystems utilizing results of studies in other ecosystems. In: J.M. Moreno and W.W. Oechel, eds. Anticipated Effects of a Changing Global Environment on Mediterranean-Type Ecosystems. Springer Verlag, New York. Pp 121-139.

Tissue, D.T., K.L. Griffin, R.B. Thomas, and B.R. Strain. 1995. Effects of low and elevated CO₂ on C3 and C4 annuals. II. Photosynthesis and leaf biochemistry. Oecologia 101:21-28.

Dipperry, J.K., D.T. Tissue, R.B. Thomas, and B.R. Strain. 1995. Effects of low and elevated CO₂ on C3 and C4 annual. I. Growth and biomass allocation. Oecologia 101:13-20.

Griffin, F.L., B.R. Strain and W.E. Winner. 1995. Growth and dry matter partitioning in loblolly and ponderosa pine seedlings in response to carbon and nitrogen availability. New Phytol. 129:547-556.

BassiriRad, H., R.B. Thomas, J.F. Reynolds, and B.R. Strain. 1996. Differential responses of root uptake kinetics of NH_4 and NO_3 to enriched atmospheric CO_2 concentration in field-grown loblolly pine. *Plant, Cell and Environ.* 19:367-371.

Gebauer, R.L.E., J.F. Reynolds and B.R. Strain. Allometric relations and growth in *Pinus taeda*: The effect of elevated CO_2 and changing N availability. *New Phytol.* 134:85-93.

Griffin, K.L., J.T. Ball and B.R. Strain. 1996. Direct and indirect effects of elevated CO_2 on whole-shoot respiration in ponderosa pine seedlings. *Tree Physiology* 16:33-41.

Griffin, K.L., W.E. Winner and B.R. Strain. 1996. Construction cost of loblolly and ponderosa pine leaves grown with varying carbon and nitrogen availability. *Plant, Cell and Environ.* 19:729-738.

King, J.S., R.B. Thomas, and B.R. Strain. 1996. Growth and carbon accumulation in root systems of *Pinus taeda* and *Pinus ponderosa* seedlings as affected by varying CO_2 , temperature and nitrogen. *Tree Physiol.* 16:635-642.

Lewis, J.D., D.T. Tissue, and B.R. Strain. 1996. Seasonal response of photosynthesis to elevated CO_2 in loblolly pine (*Pinus taeda* L.) over two growing seasons. *Global Change Biology* 2:103-114.

Tissue, D.T., R.B. Thomas and B.R. Strain. 1996. Growth and photosynthesis of loblolly pine (*Pinus taeda*) after exposure to elevated CO_2 for 19 months in the field. *Tree Physiology* 16:49-59.

Lewis, J.D. and B.R. Strain. 1996. The role of mycorrhizas in the response of *Pinus taeda* seedlings to elevated CO_2 . *New Phytol* 133:431-443.

Skillman, J.B., B.R. Strain, and C.B. Osmond. 1996. Contrasting patterns of photosynthetic acclimation and photoinhibition in two evergreen herbs from a winter deciduous forest. *Oecologia* 107:446-455.

Ward, J.K. and B.R. Strain. 1997. Effects of low and elevated CO₂ partial pressure on growth and reproduction of *Arabidopsis thaliana* from different elevations. *Plant, Cell and Environment* 20:254-260.

Griffin, K.L., M.A. Bashkin, R.B. Thomas and B.R. Strain. 1997. Interactive effects of soil nitrogen and atmospheric carbon dioxide on root/rhizosphere carbon dioxide efflux from loblolly and ponderosa pine seedlings. *Plant and Soil* 190:11-18.

King, J.S., R.B. Thomas and B.R. Strain. 1997. Morphology and tissue quality of seedling root systems of *Pinus taeda* and *Pinus ponderosa* as affected by varying CO₂, temperature, and nitrogen. *Plant and Soil* 195:107-119.

BassiriRad, H., K.L. Griffin, J.F. Reynolds, and B.R. Strain. 1997. Changes in root NH₄ and NO₃ absorption rates of loblolly and ponderosa pine in response to CO₂ enrichment. *Plant and Soil* 190:1-9.

Tissue, D.T., R.B. Thomas and B.R. Strain. 1997. Atmospheric CO₂ enrichment increases growth and photosynthesis of *Pinus taeda* L.: A four year experiment in the field. *Plant, Cell and Environment* 20: 1123-1134.

Johnson, D.W., R.B. Thomas, K.L. Griffin, D.T. Tissue, J.T. Ball, B.R. Strain and R.F. Walker. 1998. Effects of CO₂ and N on growth and N uptake in ponderosa and loblolly pine. *J. Environ. Qual.* (In Press).

Gebauer, R.L.E., B.R. Strain and J.F. Reynolds. 1998. The effect of elevated CO₂ and N availability on tissue concentrations and whole plant pools of carbon-based secondary compounds in loblolly pine (*Pinus taeda*). *Oecologia* 113:29-36.

Additional important loblolly pine papers published from DOE research funding that preceded this grant (DE-AS05-83ER60177).

Tolley, L.C. and B.R. Strain. 1984. Effects of CO₂ enrichment on growth of *Liquidambar styraciflua* and *Pinus taeda* seedlings under

different irradiance levels. Canadian Journal Forest Research 14: 343-350.

Tolley, L.C. and B.R. Strain.. 1984. Effects of atmospheric CO₂ enrichment and water stress on growth of *Liquidambar styraciflua* L. and *Pinus taeda* L. seedlings. Canadian Journal Botany 62: 2135-2139.

Tolley, L.C. and B.R. Strain. 1985 Effects of CO₂ enrichment and water stress on gas exchange of *Liquidambar styraciflua* and *Pinus taeda* seedlings grown under different irradiance levels. Oecologia 65: 166-172.

Strain, B.R. 1986. The biosphere and links to climate. In: Rosenzweig, C. and R. Dickinson (Eds.). Climate-Vegetation Interactions, Report OIES-2. University Corporation for Atmospheric Research. Boulder, CO. 156 pp.

Telewski, F. and B.R. Strain. 1987. Densiometric and ring width analysis of 3-year old *Pinus taeda* and *Liquidambar styraciflua* grown under three levels of CO₂ and two water regimes. IN: Jacoby, G.C. and J.W. Hornbeck (Eds.). Proc. Inter. Symp. on Ecol. Aspects of Tree-Ring Anal. DOE/Conf-86-08144. National Technical Information Service Springfield VA 726 pp.

Strain, B.R. 1987. Direct effects of increasing atmospheric CO₂ on plants and ecosystems. Trends Ecology Evolution. 2: 18-21.

Wray, S.M. and B.R. Strain. 1987. Interaction of age and competition under CO₂ enrichment. Functional Ecology. 1: 145-149.

Wray, S.M. and B.R. Strain. 1987. Competition in old-field perennials under CO₂ enrichment. Ecology 68: 1116-1120.

Marks, S. and B.R. Strain. 1989. Effects of drought and CO₂ enrichment on competition between two old-field perennials. New Phytologist. 111: 181-186.

Graduate students trained during the duration of this grant

DUKE UNIVERSITY
GRADUATE TRAINING IN GLOBAL CHANGE
SUPPORTED BY THE DEPARTMENT OF ENERGY
1985-1997

Physiological Ecology Laboratory of Boyd R. Strain
DOE Grants (DEA101-81ER60012, DE-AS05-83ER60177,
DE-FG05-87ER60575)

Name: Susan Marks Wray
Year: 1985
Title: "Comparative physiological ecology of two old field
perennials, *Aster pilosus* and *Andropogon virginicus*,
under CO₂ enrichment and drought stress"
Degree: MS.
Univ.: Duke University
No pp: 52
Maj. Prof: Boyd R. Strain
Maj. Dept: Botany
PI: Boyd R. Strain
Grant #: DE-AS05-83ER60177

Name: Catherine Jeanne Potvin
Year: 1985
Title: "Responses of two C₄ grasses to CO₂ enrichment and
temperature: Implication on biogeographical distribution
of C₄ plants"
Degree: Ph. D.
Univ.: Duke University
No pp: 156
Maj. Prof: Boyd R. Strain
Maj. Dept: Botany
PI: Boyd R. Strain
Grant #: DEA101-81ER60012, DE-AS05-83ER60177

Name: Thomas William Sasek
Year: 1985
Title: "The implications of atmospheric carbon dioxide enrichment for the physiological ecology and distribution of two introduced woody vines, *Pueraria lobata* Ohwi (Kudzu) and *Lonicera japonica* Thunb. (Japanese honeysuckle)"

Degree: Ph. D.
Univ.: Duke University
No pp: 203
Maj. Prof: Boyd R. Strain
Maj. Dept: Botany
PI: Boyd R. Strain
Grant #: DEA101-81ER60012, DE-AS05-83ER60177

Name: Susan Marks Wray
Year: 1987
Title: "Competitive interactions of two old-field perennials, *Aster pilosus* and *Andropogon virginicus* under CO₂ enrichment".

Degree: Ph. D.
Univ.: Duke University
No pp: 167
Maj. Prof: Boyd R. Strain
Maj. Dept: Botany
PI: Boyd R. Strain
Grant #: DE-AS05-83ER60177, DE-FG05-87ER60575

Name: YaoHua Luo
Year: 1989
Title: "Responses of well-watered and water-stressed *Abutilon theophrasti* (C3) and *Amaranthus hybridus* (C4) to long-term differences to CO₂ and humidity"

Degree: Ph. D.
Univ.: Duke University
No pp: 192
Maj. Prof: Boyd R. Strain
Maj. Dept: Botany
PI: Boyd R. Strain
Grant #: DE-AS05-83ER60177, DE-FG05-87ER60575

Name: Chantal Danielle Reid
Year: 1990
Title: "The carbon balance of shade-tolerant seedlings of *Fagus grandifolia* and *Acer saccharum* under low irradiance and CO₂ enrichment"
Degree: Ph. D.
Univ.: Duke University
No pp: 180
Maj. Prof: Boyd R. Strain
Maj. Dept: Botany
PI: Boyd R. Strain
Grant #: DE-AS05-83ER60177, DE-FG05-87ER60575

Name: Joy Kirsten Dippery
Year: 1993
Title: "Effects of reduced and elevated CO₂ partial pressure on C3 and C4 plant growth"
Degree: MS.
Univ.: Duke University
No pp: 52
Maj. Prof: Boyd R. Strain
Maj. Dept: Botany
PI: Boyd R. Strain
Grant #: DE-FG05-87ER60575

Name: Kevin Lee Griffin
Year: 1994
Title: "Effects of resource availability on carbon utilization in *Pinus taeda* L. and *Pinus ponderosa* Dougl. ex Laws. seedlings"
Degree: Ph. D.
Univ.: Duke University
No pp: 169
Maj. Prof: Boyd R. Strain
Maj. Dept: Botany
PI: Boyd R. Strain
Grant #: DE-AS05-83ER60177, DE-FG05-87ER60575

Name: James D. Lewis
Year: 1994
Title: "Effectsof mycorrhizae and phosphorus supply on
response of *Pinus taeda* L. seedlings to elevated CO₂"
Degree: Ph. D.
Univ.: Duke University
No pp: 180
Maj. Prof: Boyd R. Strain
Maj. Dept: Botany
PI: Boyd R. Strain
Grant #: DE-AS05-83ER60177, DE-FG05-87ER60575

Name: Joy Kirsten Dipperry
Year: 1997
Title: "The evolution of *Arabidopsis thaliana* in response to low
and elevated CO₂ partial pressure /
Degree: Ph.D.
Univ.: Duke University
No pp: 155
Maj. Prof: Boyd R. Strain
Maj. Dept: Botany
PI: Boyd R. Strain
Grant #: DE-FG05-87ER60575

Name: John Stephen King
Year: 1997
Title: "Carbon and nutrient cycling in *Pinus taeda* L. and *Pinus
ponderosa* Dougl. ex Laws. as affected by the belowground
response to altered environmental contitions"
Degree: Ph.D.
Univ.: Duke University
No pp: 189
Maj. Prof: Boyd R. Strain
Maj. Dept: Botany
PI: Boyd R. Strain
Grant #: DE-FG05-87ER60575